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HYDROGEOLOGICAL REVIEW
AND
PROPOSED GROUNDWATER INVESTIGATION
NIAGARA FALLS PLANT

NIAGARA FALLS NEW YORK

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

return to Mary McIntosh

Golder Associates

CONSULTING GEOTECHNICAL AND MINING ENGINEERS

REPORT TO

FRONTIER CHEMICAL WASTE PROCESS, INC.

HYDROGEOLOGICAL REVIEW AND PROPOSED GROUNDWATER INVESTIGATION NIAGARA FALLS PLANT

NIAGARA FALLS NEW YORK

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EXECUTIVE SUMMARY

Groundwater contamination has been detected beneath Frontier Chemical Waste Process, Inc.'s Niagara Falls Plant during a recent hydrogeological investigation (Thomsen Associates, 1985). The major contaminants were high phenols, high chloride and sodium concentrations in wells near an old settler and a number of organic chemicals, the principal ones being chlorotoluene, chlorobenzene, benzene, tetrachloroethene, toluene, trichloroethene and dichlorobenzene. The levels of many of these contaminants are highest in the three downgradient wells (MW-9, MW-11 and MW-12) along the south side of the site along Royal Avenue.

Downward hydraulic gradients exist at the site, with a shallow perched water table in fill and piezometric elevations in the shallow bedrock at 11 to 18 ft. beneath ground surface generally close to the top of the rock. Groundwater flow in the shallow bedrock is predominantly from north to south, but the piezometric elevation decreases significantly close to the unlined sewer tunnels along 47th Street and Royal Avenue.

The three wells along Royal Avenue are screened in the bedrock at and slightly below the elevation of the Falls Street Tunnel. It is reported that the Falls Street Tunnel was blocked in 1982 opposite the Frontier plant so that there was effectively no flow. The extent of any groundwater flow reversal in the shallow bedrock as a consequence of the blockage in the Falls Street Tunnel is unknown, but, if present, would probably have occurred up the beddings of utility lines and/or around footings of buildings.

Since Frontier is located at the focus of groundwater flow in the shallow bedrock (uppermost part of the Lockport formation) from the surrounding area, chemical data available from several neighboring sites was also reviewed.

A four stage groundwater investigation program is proposed prior to any groundwater remediation plan in order to define the source(s) of the groundwater contamination. This program will comprise:

(1) an on-site historical review

(2) a regional review

(3) ongoing routine monitoring

(4) additional boreholes and monitoring wells

Both the on-site historical review and the regional review should be completed prior to any drilling or monitoring well installations at the site. The historical review will compile information relating to chemicals treated, stored or spilled on-site as well as details concerning utilities and preferential pathways of potential migration.

The purpose of the regional review will be to ascertain characteristic groundwater contamination parameters, reasons for apparent groundwater contamination in Frontier's upgradient wells and details regarding connections to the Falls Street Tunnel, as well as data from the period when the tunnel was blocked.

Quarterly monitoring of bedrock wells for three successive quarters for pH, specific conductance, phenols and volatile organics with the addition of chlorotoluene and dichlorobenzene is recommended to establish a basis for the evaluation of groundwater quality at the site.

A four stage approach to the drilling of additional boreholes and monitoring wells is proposed, comprising: 1) testing of manholes and basements, 2) soil drilling and OVA testing, 3) drilling of boreholes and installation of bedrock monitoring wells, and 4) water sampling and analytical testing.

It is envisaged that the on-site and regional reviews would proceed during the Winter with borehole drilling and the installation of monitoring wells in Spring 1986.

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1. INTRODUCTION

Golder Associates has been retained by Frontier Chemical Waste Process, Inc. (Frontier) to conduct a hydrogeological review of data available at, and around, their Niagara Falls Plant and to recommend a process for the investigation of the source(s) and remediation of groundwater contamination at the site.

This report refers to two existing hydrogeological investigations at Frontier's site, namely:

(1) Wehran Engineering
Hydrogeologic Investigation
Frontier Chemical Waste Process, Inc.
October 15, 1982, WE Project No. 01332120

(2) Thomsen Associates
Hydrogeologic Investigation
Evaluation of Groundwater Quality
June, 1985, Job No. BD-84-142

Background information on the site and the above hydrogeological investigations are summarized in Sections 2.1 to 2.3, followed by a discussion of other information from surrounding areas relevant to the Frontier site in Section 2.4. This section makes particular reference to the Falls Street Tunnel which is located along Royal Avenue, immediately south of Frontier's site.

The plan to define the nature, extent and source of contamination at Frontier's site is presented in Section 3; the schedule for the work in the proposed plan is set out in Section 4.

2. BACKGROUND

2.1 Location

Frontier's Niagara Falls Plant is located on the northwest corner of the intersection of 47th Street and Royal Avenue in the City of Niagara Falls, New York. The plant is approximately 1 mile north of the Niagara River and 1 mile west of U.S. Interstate 190 (see Figure 1). The plant is about one-third of a mile east of the NYPA (New York Power Authority) tunnels. Ground surface at the site is at approximately elevation 570 ft.

2.2 Site History

From conversations with Frontier personnel, it is understood that the site has been in active use since at least 1911. The first plant at the site was an old caustic chlorine manufacturing plant.

A 1959 drawing of the site supplied by Frontier indicates that the site belonged to the Agricultural Chemicals Division of International Minerals & Chemical Corporation. Many of the buildings on the 1959 drawing are similar to those in place today, with the exception of the easternmost 120 ft. of the site. The southern half of this part of the site adjacent to 47th Street contained buildings while the northern third of this part of the site contained two sludge ponds - Sludge Pond No. 1, about 60 ft. square and a larger Liquid Bleach Sludge Pond No. 2, about 120 ft. square. This latter pond is located immediately west of the present truck scale in the northeast part of the present site.

The 1959 drawing appears to show the settler, although the individual buildings and facilities are not named. It is understood that the plant produced caustic soda and caustic potash.

It is understood that the site was purchased by Frontier in 1975, although it only really became open for the treatment of wastes in 1977. Initially, treatment concentrated on wastes such as pickle liquors but this subsequently diversified to solvent reclamation and treatment of a wider variety of wastes.

It is understood that historically, the only serious spill at the site was a sulphuric acid and nitric acid spill near the truck scale. The settler was used as a settling pond for sludges for two years from 1977, before being shut down in 1980.

The approximate present layout of the site is shown on Figure 2, although modifications are currently in progress at the site. The main process area and drum storage areas are located towards the north of the site, while the extreme eastern and western parts of the site are reserved for truck or office parking. The largest buildings at the site are Buildings 8 (Offices), 9 (Drum Storage), 12 (Storage Area), 50 (Process Area), 21 (Storage Area) and 27 (Process Area).

Three tanks located between Buildings 14 and 16 were demolished between 1983 and 1985. Three tanks located immediately west of the settler in 1983 were removed during 1985, with two (Tanks 1 & 2) removed to the new tank farm south of Monitoring Well 15. The five tanks north of the former settler are currently being demolished.

Drainage and treated process water leave the south side of the site at five locations (see Figure 2). The main location is the 12 in. line which leaves the site between Buildings 16 and 25. This line passes through a new monitoring station.

2.3 Previous Hydrogeological Studies

2.3.1 Wehran (1982)

In December, 1981, Wehran Engineering installed 8 PVC monitoring wells at the site (for locations, see Figure 2). Four of these wells (MW-1 to MW-4) were installed as "top of rock" wells, while the remaining four (MW-5 to MW-8) were installed as "top of clay" or "top of silt" wells.

The boreholes put down for the above monitoring wells indicated the general strata at the site. No groundwater samples were taken during this specific investigation.

2.3.2 Thomsen Associates (1985)

Thomsen Associates was retained by Frontier in November 1984 to carry out the following:

(a) install additional monitoring wells,

(b) prepare a hydrogeologic report describing groundwater flow conditions beneath the site,

(c) prepare a groundwater assessment report based on an analysis of water quality data from the monitoring wells.

Thomsen installed nine surficial bedrock 2 in. I.D. PVC monitoring wells (MW-9 to MW-17) around the periphery of the site and in the vicinity of the inactive sludge settler. Initially all wells were drilled so that the well screens could be placed 3.4 to 5.8 ft. below the top of rock. However, the three wells along the southern side and the one well on the eastern side of the site (MW-9, MW-11, MW-12 and MW-13) were all found to be dry or to have less than 1 ft. of water in them. These four wells were therefore redrilled and new wells advanced to depths of 15 to 17.7 ft. below the top of the bedrock.

2.3.3 Subsurface Conditions

Both the Wehran and Thomsen investigations found similar subsurface conditions across the site. Four main overburden strata were detected at the various borehole locations overlying bedrock (see representative north-south cross section, Figure 3). These were:

Between 2 and as much as 5 ft. of fill, which was typically cohesionless and generally water-saturated at a depth of approximately 2 ft. below ground surface

6 ft. (average) of soft to very stiff lacustrine silt, although the thickness at individual boreholes varied from as little as 3.5 ft. at MW-9 to as much as 10 ft. at MW-10

A relatively thin layer of soft to very stiff lacustrine clay, with thicknesses at borehole locations generally varying from zero to as much as 6.5 ft. but averaging around 3 ft.

A thin (1 to 6 ft. thick) layer of red brown silt and clay till, with some sand and gravel.

From the borehole logs, it would appear that at times it may be difficult to distinguish between the middle two strata. Relatively pervious fill was apparently encountered at MW-14 down to the top of the till, while 4 ft. of white lime was encountered immediately below the topsoil at MW-17.

A chemical odour was noted at a depth of about 10 ft. during the drilling of MW-10, while a chemical odour was noted to the full depth during drilling of MW-15, but especially from 6.1 to 6.3 ft. below ground surface.

Bedrock was encountered beneath ground surface at depths ranging from 11.0 to 18.2 ft. Both investigations reported encountering Lockport dolomite as the upper bedrock stratum beneath the site. The elevations of the top of bedrock at the different monitoring well locations are plotted on Figure 4, where it will be seen that bedrock falls in a southeasterly direction from a high of 559.9 at MW-3 near the northwest corner of the site to a low of 553.4 at MW-12 in the southeast corner of the site.

2.3.4 Water Levels

Wehran monitored the water levels in wells MW-1 to MW-8 at monthly intervals after installation at the end of 1981. Thomsen Associates monitored water level elevations in wells MW-9 to MW-17 for approximately 4 months after their installation in January 1985. It is understood that water levels are now measured by Frontier every two months when groundwater samples are obtained.

A plan of the site showing water levels in all bedrock monitoring wells across the site in June 1985* is shown on Figure 5. The water levels in most interior wells across the site vary between a high of elevation 559.3 at MW-3 in the northwestern corner of the site and 554.5 at MW-10 downgradient of the settler. In all these wells, the water

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* June 1985 was selected because at other times some wells went dry.

level is between 1.0 and 3.4 ft. below the top of the bedrock. The water levels in MW-9, MW-11, MW-12 and MW-13 are all significantly lower than the water levels in the above monitoring wells. In these four monitoring wells, the water levels vary between elevations 544.2 and 546.3, or between 8.8 and 11.5 ft. below the top of bedrock at the monitoring locations.

Thomsen attributed the steeper horizontal gradients along the eastern and southern property boundaries to the deep sewers beneath 47th Street and Royal Avenue. They therefore concluded that monitoring wells MW-14, MW-15 and MW-17 are upgradient of the facility while monitoring wells MW-9, MW-11, MW-12 and MW-13 are downgradient of the facility.

While small variations in water level of plus or minus 1 foot can be detected from both the Wehran and Thomsen water level measurements, it should be noted that there was a substantial decrease in the water level in MW-12 when it was redrilled and deepened (see Table 1, Thomsen 1985). When MW-12 was first installed (5 ft. below the top of bedrock at that location) the water level elevation varied between elevation 549.7 and 550.0 during January 1985. The well was redrilled on January 29, 1985 and a new well installed with its base 13 ft. below the top of bedrock. The water level in this new well varied between elevation 543.8 and 544.6 during the period February to April, 1985. This water level was therefore some 5 ft. lower than that measured in the first well installed at this location. It is also pertinent to note that during redrilling of MW-12, coring water was lost at elevation 544.7.

The water level contours on Figure 5 do suggest that general groundwater flow is predominantly north to south, with a southeasterly deviation near 47th Street. These contours are substantially different from those shown on Drawing No. 2 of the Thomsen 1985 report, which had a much more easterly component. The main reason for the lack of resolution of water level conditions is the absence of monitoring wells in the interior of the eastern part of the site.

2.3.5 Groundwater Quality Monitoring

No water samples were taken or analyzed by Wehran. Thomsen carried out a detailed groundwater quality investigation at the site in the first half of 1985. Water samples were taken weekly for one month and then monthly for two months at the nine monitoring wells installed into bedrock (MW-9 to MW-17) and were analyzed for pH, specific conductance, total organic carbon (TOC) and phenol. The samples taken at the end of each month were also analyzed for iron, nickel, chromium, cadmium, copper and zinc. Water samples were also taken monthly from four shallow wells (MW-5 to MW-8) and three wells installed at the soil rock interface (MW-2 to MW-4)*. In addition to the above parameters, these more shallow samples were also analyzed for total organic halogens, cyanide, thiocyanate, chloride, sulfate, manganese and sodium. In addition, water samples were taken on two occasions (February 28, 1985 and April 25, 1985) from the bedrock wells (MW-9 to MW-17) and analyzed for volatile organic priority pollutants by two different laboratories, Ecology and Environment and ZENON Environmental, respectively.

As noted in Thomsen (1985), the analytical methods were not identical. Ecology and Environment appear to have carried out a basic volatile scan (EPA Method 624) with the addition of chlorotoluene. The detection limit used by E & E was 50 ppb. ZENON have a reported detection limit of 0.1 ppb but scanned the GC/MS output from the volatile scan for

* MW-1 has been found to be consistently dry and has now been formally abandoned.

other consitutents present at significant levels. ZENON therefore also reported results for methyl toluene, dichlorotoluene, bromobenzene, dichlorobenzene, trichlorobenzene and dichlorofluoroethane. The summaries of groundwater sampling results from Thomsen (1985) are included for ease of reference in Appendix 1.

Substantial discrepancies were found between the results of the volatile organic analyses for the different laboratories, although some of the differences could be attributed to the different sampling dates and different detection limits. However, the very high concentrations of chlorotoluene and toluene apparently measured by one laboratory (E & E) on water samples from some wells was questioned by Frontier and errors in the analyses by this laboratory were later confirmed. Also, as discussed in Thomsen's 1985 report, concentrations of at least 6 parameters were 2 to 3000 times higher in one laboratory compared to the other as well as other discrepancies and inconsistencies. Thomsen did suggest, however, that when the data was (subjectively) ranked, concentrations of volatile organics were highest at MW-11, followed by MW-16, MW-9, MW-12 and then MW-10 and MW-15.

Thomsen Associates concluded that the concentrations of many parameters were elevated in the downgradient wells compared to the upgradient wells MW-14 and MW-17. However, it was concluded that the sludge settler did not appear to be the source of the elevated concentrations of most parameters in the downgradient wells but probably only the elevated concentrations of phenols in MW-10.

The distributions of chemical concentrations and parameters across the site in Spring 1985 are shown on the following figures:

Specific Conductance	Figure 6
TOC	Figure 7
Phenols	Figure 8
Benzene	Figure 9
Chlorobenzene	Figure 10
1,1-Dichloroethene	Figure 11
Toluene	Figure 12
Chlorotoluene	Figure 13
Dichlorobenzene	Figure 14

The volatile and semi-volatile organic data plotted on Figures 9 to 14 are based on ZENON's data.

There is no way of reconciling satisfactorily at present the substantial differences encountered between the results from the two laboratories. However, the fact that discrepancies were subsequently discovered in the E & E data leads to less confidence in those results. It is understood that both sets of samples were collected by Frontier personnel using the same procedure, as is used now, namely:

(a) all except deep wells 9, 11, 12 and 13 are purged using a peristaltic pump with dedicated tubing in each well

(b) MW-10 and MW-16, with a low recharge rate, are pumped till dry. About 10 liters of water (3 volumes of standing water in the well) are removed from the other wells*

(c) MW-9, 11, 12 and 13 are too deep and are purged using a plastic bailer which is rinsed in tap water between wells

* Calculations show that, for 5 ft. of standing water in the wells, 10 liters actually corresponds to only 2 well volumes when the volume of water in the surrounding sandpack is included.

(d) all samples are taken the following day, using dedicated aluminum bailers for each well, with a new nylon line and cork each time

The specific conductances at the various wells (Figure 6) appear to fall into 5 categories:

1,400 to 2,600 μmhos/cm	Shallow monitoring wells
2,500 to 3,500 μmhos/cm	Bedrock wells to north and east of the site
14,000 to 17,000 μmhos/cm	Bedrock wells MW-15, MW-16 and MW-17
26,000 μmhos/cm	Bedrock wells MW-11 and MW-12 along the south side of the site
63,000 to 77,000 μmhos/cm	Bedrock wells MW-2, MW-9, MW-10, all located downgradient of the former settler

The phenol concentrations in many wells were less than 0.1 mg/L (Figure 8). The highest concentrations were found at MW-10, MW-2 and MW-16. Although these are screened at different depths, this again suggests a source at, or close to, the former settler.

Based on ZENON's data, the concentrations of the 6 volatile organic parameters plotted on Figures 9 to 14, inclusive, do not follow the above pattern.

The highest benzene concentrations were detected in MW-9, 11 and 12 along the south side of the property and MW-16, upgradient of the settler (see Figure 9). Similar contaminant distributions were also true for chlorobenzene (although high levels were also detected at MW-15 and MW-17, (see Figure 10), toluene (with high levels also at MW-10 and MW-15, see Figure 12) and dichlorobenzene (although the level at MW-15 was considerably higher than that measured at MW-16, see Figure 14). Chlorotoluene levels appeared to be elevated at MW-11, MW-10, MW-16, MW-17 and MW-9 (see Figure 15). The distribution of elevated levels of 1,1-Dichloroethene (see Figure 11) was different to those noted above, with the highest concentrations in MW-13 along the eastern side of the site.

The chemical analyses of water samples from the shallow overburden ("top of clay") wells (MW-5, 6, 7 and 8) all indicated levels close to background and generally below applicable drinking water criteria. Wells MW-3 and MW-4 installed at the very top of the bedrock at the north of the site were also relatively clean, whereas MW-2 west of the former settler exhibited high chloride, sulfate, sodium, iron and nickel levels.

The above results lead to the conclusion that the wells which are most contaminated with organic chemicals at the site are MW-9, 11 and 12 followed by MW-10, 15, 16 and sometimes 17. This is similar to Thomsen's assessment. However, MW-2 also exhibits high levels of several contaminants.

Thomsen Associates recommended that groundwater monitoring of the bedrock wells continue every two months for one year, with analysis of the following parameters:

pH	Chromium
Specific Conductance	Nickel
TOC	Benzene
Phenol	Tetrachloroethene
Iron	

Tetrachloroethene and benzene were chosen to provide an indication of differences in migration between halogenated hydrocarbons and non-halogenated hydrocarbons, respectively. Semi-annual sampling of the remaining shallow wells was also recommended.

2.4 Utilities and Other Sites

2.4.1 Utilities

Approximate piezometric contours in the upper Lockport formation in the vicinity of the Frontier site are shown on Figure 15. These contours are derived from the Report of the Niagara River Toxics Committee. As shown on Figure 15, the contours are influenced by:

(a) the external drain system of the NYPA conduits, which extends to an elevation of 488 ft., or approximately one-third of the thickness of the Lockport dolomite

(b) the Falls Street Tunnel, an unlined tunnel in the bedrock but relatively close to the surface of the bedrock near the site

From a draft report on an inspection of the Falls Street Tunnel in 1982 (Camp, Dresser & McKee, 1982) it is understood that along the south side of Frontier's site, the Falls Street Tunnel, which was constructed in the early 1900's, is a 6 ft. high by 7 ft. wide unlined tunnel, with its invert approximately 30 ft. below ground surface (approx. elevation 539). The Falls Street Tunnel at 47th Street is fed by both the John Avenue sewer from the east and the New Road Tunnel, another unlined tunnel in bedrock but slightly smaller (6 ft. x 5 ft.), which comes down 47th Street from Packard and Pine Avenue.

In the vicinity of the Frontier site, the Falls Street Tunnel includes (see Figure 16):

- Shaft 15 at the intersection of Royal Avenue and 47th Street
- Shaft 14B, some 375 ft. west of Shaft 15 and therefore about half way along the south side of Frontier's site
- Shaft 14A, some 530 ft. west of Shaft 15
- Shaft 14, some 910 ft. west of Shaft 15 and therefore about 150 ft. west of the western boundary of the Frontier site

Close to Shaft 14B, there is a dam to elevation 542.15 within the tunnel to promote low flow diversion to the Southside Interceptor through a 2 ft. x 4 ft. connection. However, the inspection in late 1982 found an additional dam of hard material in the tunnel 185 ft. downstream of Shaft 14A which had formed in such a manner as to effectively block all flow.

Samples of sediment were obtained from the tunnel at the base of Shafts 14B and 14A and 185 ft. downstream of Shaft 14A. Both the samples from Shaft 14B and Shaft 14A indicated the presence of a range of volatile organics and base-neutral extractable organics, although the concentration levels in the sample from the base of Shaft 14A, which would be just downstream of the diversion dam rather than upstream of it, were far more elevated, see Table 1. The reasons for this are not clear; however, the elevated levels of chlorobenzene, toluene, benzene, dichlorobenzene and trichlorobenzene are particularly interesting in view of the presence of these contaminants in the wells along Frontier's southern property. Since the water levels in these wells are only slightly above the Falls Street Tunnel, it is conceivable that contaminants could have migrated out of the tunnel, particularly since it

TABLE 1

PRELIMINARY RESULTS OF CHEMICAL ANALYSES OF SEDIMENT SAMPLES

FALLS STREET TUNNEL (1982)

	Base of Shaft 14B mg/kg (ppm)	Base of Shaft 14A mg/kg (ppm)
Volatile Organics		
Benzene	9.2	120
Chlorobenzene	12	630
Chloroform	-	0.36
1,1-Dichloroethane	0.56	1.2
Ethylbenzene	1.0	3.3
Methylene Chloride	9.7	33
1,1,2,2-Tetrachloroethane	-	-
Tetrachlorethylene	2.0	36
Toluene	37	150
1,2-Trans-Dichloroethylene	-	0.44
1,1,1-Trichloroethane	1.5	59
Trichloroethylene	1.8	51
Trichlorofluoromethane	-	-
Vinyl Chloride	0.35	0.71
Base-Neutral Extractable Organics		
Anthracene	-	3700
Benzo(A)Anthracene	-	3500
Benzo(A)Pyrene	-	1900
3,4-Benzofluoranthene	-	1900
Benzo(K)Fluoranthene	-	1900
Chrysene	-	3500
1,2-Dichlorobenzene	56	2300
1,3-Dichlorobenzene	40	800
1,4-Dichlorobenzene	-	1300
Fluoranthene	48	5500
Phenanthrene	-	3700
Pyrene	40	4200
1,2,4-Trichlorobenzene	810	1700

was noted as being blocked downstream of Shaft 14A in late 1982. This could have backed up the tunnel, thereby promoting the flow of contaminants out of the tunnel. If this were the case, the southerly monitoring wells on Frontier's site (MW-9, MW-11 and MW-12) would not be downgradient wells measuring contamination from Frontier's site.

At the present time the exact disposition of sewers in the area feeding into the Falls Street Tunnel has not been ascertained. However, it appears that a combined sewer opposite Frontier extends in a southerly direction at least half way towards the Conrail tracks. A recent review of the Occidental Plant site shows drainage from the north side of the site northwards up 47th Street beneath the Conrail tracks (GTC, 1984). High chlorotoluene concentrations (50 to 7,600 ppb) were measured in overburden wells in this area (47th Street south of the Conrail tracks) but it is believed that the wastewater sewer from Occidental does not extend up 47th Street to Royal Avenue but rather turns westward along 'A' Street. In the opposite direction, the New Road Tunnel could bring contaminants to the Falls Street Tunnel from the area north and east of the site.

2.4.2 Other Sites

Since the Frontier site is located so close to the Falls Street Tunnel and the NYPA conduits, it is the potential focus of groundwater flow and contamination from a number of upgradient sites. The possibility of contamination from other sites to Frontier's property needs to be evaluated and separated from on-site contamination from any past spills or leaks on the property. Based on the Niagara River Toxics Committee Report of 1984, the following sites might conceivably be upgradient of Frontier:

Buffalo Avenue - Site 83
DuPont-Necco Park - Site 14
Reichhold-Varcum Chemical Division - Site 66
Occidental Chemical, S-Area - Site 41A
Occidental Chemical, Plant Site - Sites 41B to 49

The sites are briefly reviewed below. For complete details, the reader is referred to the report of the Niagara River Toxics Committee.

Buffalo Avenue

This site is located in the City of Niagara Falls between Buffalo Avenue and the Robert Moses Parkway along the Niagara River at mile point 17.9.

The area was formerly a wetland on which the City of Niagara Falls disposed of an unknown quantity of non-combustibles and incinerator residue from 1930 to 1950.

Nine soil samples were collected by the USGS and analyzed for mercury and organic compounds. Mercury was not observed above the detection limit. The results at one boring which was 8.1 m (26.5 ft.) deep are shown on Table 2.

DuPont (Necco Park)

The Necco Park landfill is located in the City of Niagara Falls and Town of Niagara less than 1 mile northeast of Frontier (see Figure 15).

According to the Niagara River Toxics Committee report, the chemical data collected at the site and the adjacent areas indicated a definite leachate plume which has migrated south-southeast from the landfill. The plume has migrated into at least the top 6.1 m (20 ft.) of the Lockport Dolomite. It has been estimated that the plume is advancing at the rate of 30.5 m/year (100 ft/year) in the dolomite.

TABLE 2

CHEMICAL RESULTS - BUFFALO AVENUE

Parameter	Concentration (ug/g)
Phenanthrene[1/]	4,750
Fluoranthene[1/]	4,750
Pyrene[1/]	4,700
Benz(a)anthracene[1/]	2,000
Chrysene[1/]	3,100
Benzo(b)fluoranthene[1/]	1,325
Benzo(k)fluoranthene[1/]	1,100
Benzo(a)pyrene[1/]	2,700

1/ EPA priority pollutant

TABLE 3

CHEMICAL RESULTS - DUPONT-NECCO PARK

Parameter	Concentration (ug/L) Maximum	Mean
Methylene chloride[1/]	3,000	1,967
Chloroform[1/]	26,000	18,333
Carbon tetrachloride[1/]	63,000	25,703
1,1,2-Trichloroethane[1/]	12,000	6,433
Tetrachloroethane[1/]	19,000	11,333
1,1-Dichloroethylene[1/]	530	243
Trans-1,2-dichloroethylene[1/]	5,400	2,730
Tetrachloroethylene[1/]	34,000	12,733
Trichloroethylene[1/]	45,000	25,667
Hexachloro-1,3-butadiene[1/]	42,000	14,600
Benzene[1/]	800	267
Toluene[1/]	590	245

1/ EPA priority pollutant

Samples taken from three wells in June 1982 by the owner indicated high levels of organic priority pollutants, as shown on Table 3.

Recent work has suggested that elevated chloride concentrations are present in groundwater and to the south of Necco Park, while elevated VHO concentrations in the groundwater are a result of several to tens of parts per million concentrations of:

carbon tetrachloride
chloroform
trans-1,2-dichloroethylene
methylene chloride
1,1,2,2-tetrachloroethane
tetrachloroethylene
1,1,1-trichloroethane
trichloroethylene

Phenol and hexachlorobutadiene appear to be the only other priority pollutants which occur in the groundwater downgradient of Necco Park at significant parts per million concentrations.

Reichhold-Varcum Chemical Division

The Reichhold-Varcum site is located in the eastern portion of the City of Niagara Falls some 3,000 ft. north of the Frontier site.

Until 1979, a settling pond was used on the site for the removal of phenolic waste sludge from plant wastewater. The pond was removed from service in 1979 and all excavated materials were placed in a secure landfill. Monitoring wells were subsequently installed on the plant site in 1981 and 1982 to determine the impact the lagoon and phenol storage area had on the groundwater beneath the plant site.

Data collected by the owner from monitoring wells screened above and below the clay layer show elevated levels of phenols. The maximum and mean values from monitoring wells screened below the clay layer and located near the perimeter of the plant site were as follows:

Parameter	Concentration ug/L (ppb) Maximum	Mean
Phenol	330,000	64,000
Total organic halogens	73.2	39.4

Occidental Chemical, Buffalo Avenue, S-Area

The S-Area is located in the southeast corner of the Occidental Chemical, Buffalo Avenue plant in the City of Niagara Falls, adjacent to the Robert Moses Parkway.

The 6.4 hectare (16 acre) landfill was used to dispose of 63,100 tons of organic phosphates, acid chlorides, phenol tars, thionyl chloride, HET acid, TCP, benzoyl chloride, liquid disulphides/monochlorotoluene, metal chlorides, thiodan, and chlorobenzenes.

Chemical data from samples collected by the owner from a well located south of the Robert Moses Parkway along the Niagara River and wells along the southern portion of the S-Area indicate highly elevated levels of organic contaminants as shown on Table 4.

Occidental Chemical, Buffalo Avenue Plant

These sites are located on the Occidental Chemical (Buffalo Avenue Plant) site in the City of Niagara Falls, between 2,000 and 5,000 ft. south of Frontier's site. The disposal sites contain mostly unknown quantities of organic chemicals, metals, chlorides, sulfides and phosphorus compounds.

TABLE 4

CHEMICAL ANALYSES - S-AREA

Parameter	Concentration (ug/L) Maximum	Mean
Trans-1,2-dichloroethylene1/	261	162
Chloroform1/	1,750	530
Trichloroethylene1/	6,870	1,774
Benzene	3,860	1,799
1,1,2,2-Tetrachloroethylene	15,400	5,621
Toluene1/	1,420	588
Chlorobenzene1/	4,160	1,781
Phenol1/	2,990	1,184
Dichlorobenzenes	2,980	758
Hexachloroethane1/	4,450	912
Hexachlorobutadiene1/	22,800	4,995
Hexachlorocyclopentadiene1/	12,000	2,400
Hexachlorobenzene1/	25,200	5,319
Trichlorobenzenes	50,400	11,318
Tetrachlorobenzenes	223,000	45,521
Monochlorotoluenes	9,300	2,264
Dichlorotoluenes	5,840	1,271
Octachlorocyclopentene	15,000	3,000
Trichlorophenols	1,280	257
Hexachlorocyclohexanes	789	253
Mirex	1,610	463
Carbon tetrachloride1/	7,400	1,496
Pentachlorobenzene	1,200	255

1/ EPA priority pollutant

Water levels in wells installed in the Lockport Dolomite indicate groundwater moving northwest, away from the Niagara River. At the site, groundwater in the Lockport Dolomite is recharged by the Niagara River.

According to the Niagara River Toxics Committee, 11 plant site wells installed in the unconsolidated deposits along the Robert Moses Parkway were sampled from May to July 1980 by the owner. Results indicated highly elevated levels of organic contaminants in the water, as shown on Table 5.

Although there is not sufficient data currently to reach any interpretation regarding the possible influence of any of the above sites on the Falls Street Tunnel in front of Frontier, the following may be noted:

- Buffalo Avenue: presence of several base-neutral extractables similar to those found in the Falls Street Tunnel
- DuPont (Necco Park): no chlorotoluenes and only low levels of benzene and toluene as opposed to high values at Frontier
- Reichhold-Varcum: very high phenol levels, but flow would probably occur westwards towards the NYPA conduits
- Occidental Chemical: extremely high levels of chlorotoluenes, trichloroethylene, tetrachloroethylene and dichlorobenzenes

TABLE 5

CHEMICAL ANALYSES - BUFFALO AVENUE PLANT

Parameter	Concentration (ug/L) Maximum	Mean
Trichloroethylene1/	400,000	71,790
Tetrachloroethylene1/	32,000	7,120
Toluene1/	2,940	435
Chlorobenzotrifluorides	400	112
Monochlorobenzene1/	1,025	255
Dichlorobenzenes	31,000	5,830
Chlorotoluenes	79,000	10,500
Dichlorotoluenes	14	12
Trichlorobenzenes	150	44
Tetrachlorobenzenes	240	125

1/ EPA priority pollutant

3. PROPOSED GROUNDWATER INVESTIGATION

3.1 Introduction

Review of site specific and regional data in Section 2 of this report indicates that:

(1) Downward gradients exist at the site with a difference in piezometric elevation between the shallow overburden and top of bedrock of approximately 7 to 14 ft. The piezometric elevation in the top of the bedrock declines significantly close to the unlined sewer tunnels along 47th Street and Royal Avenue, but flow across the site in the shallow bedrock is predominantly north to south. It also appears that based on the drilling of MW-12, downward gradients exist in the bedrock, and that a fracture zone (defined as 100% water loss during drilling) exists within the Falls Street Tunnel (elevation 544.7).

(2) The Frontier site has been in use for a considerable period of time and it is probable that some spills or leaks have occurred. At present, information relating to the history of the site operations, wastes handled and the location of utilities has not been well documented. However, the three downgradient wells at the site (MW-9, 11 and 12) are actually screened in the bedrock at and slightly below the Falls Street Tunnel which is located along Royal Avenue south of Frontier. These three wells are the most highly contaminated at the site, although precise levels of contamination are not known at this time due to vastly different analytical results on water samples from the same wells sent to two different laboratories.

(3) Although the contamination in the above three wells could indeed have come from Frontier's site due to past operations, it is understood that the handling of chlorotoluenes and chlorobenzenes is not at all common at Frontier. In addition, the highest volatile organic contaminants found in sediments in the tunnel in front of Frontier were chlorobenzene, toluene and benzene.

(4) Extremely high specific conductances and high phenol concentrations were found in wells downgradient of or around the former settler. It is understood that Frontier has submitted a closure plan for the former settler.

(5) It is reported that the Falls Street Tunnel was blocked opposite the Frontier plant (opposite Building 16 or just west of MW-11) so that there was effectively no flow. The level to which flow backed up upstream is unknown, but if the tunnel were full, gradients would have been reversed out of the tunnel to MW-11 and 12. The tunnel would have had to backup even more before northward flow would occur further across the Frontier site (for example, as far as Frontier's upgradient wells, which show signs of some contaminants) but if such were to occur, any flow would probably have preferentially occurred through fracture planes in the bedrock and along major utility lines (e.g. the main sewer outfall which leaves the site between Buildings 16 and 25).

(6) It is understood that excessive blasting for the deep sewer along Royal Avenue in about 1977 ruptured some lines and caused damage on the site. It is believed that bedrock in the immediate area might have been cracked or fractured.

In light of the above considerations, a further limited but well defined program of drilling, instrumentation and monitoring is required in conjunction with a more detailed review of the history of the site and nearby utilities and sites in order to define the source(s) and methods of groundwater remediation. The program is divided into four components. However, as discussed in succeeding paragraphs, several of these components may be carried out concurrently.

(1) On-site historical review
(2) Regional review
(3) Ongoing routine monitoring
(4) Additional boreholes and monitoring wells
  - testing of manholes, basements etc.
  - soil sampling and OVA testing
  - drilling of boreholes and installation of monitoring wells
  - water sampling and analytical testing

3.2 On-site Historical Review

Frontier have collected significant information relevant to the past operation of the site. This will be continued by Frontier in the early stages of this groundwater investigation program in an effort to document all types of contaminants which could have been stored, spilled or treated on the site. In addition, details concerning the utilities at the site (depth, backfill, any historical monitoring or data) and any other pertinent data regarding preferential pathways of potential migration (e.g. footings of buildings) will be reviewed and assessed. The results of all on-site monitoring data will also be reviewed.

3.3 Regional Review

The existence of the Falls Street Tunnel and some results from the monitoring of it were reviewed in Section 2.4.1, while data from other sites in the area were briefly reviewed in Section 2.4.2. There are a large number of unanswered questions. As an early part of the proposed groundwater investigation, the data compiled in this report will be reviewed with NYDEC and any additional data available reviewed.

The purpose of this review will be to:

(a) ascertain any characteristic parameters (including, for example, the use of base-neutral extractable organics) which can be used subsequently to determine the source(s) of groundwater contamination at Frontier, whether on-site or off-site.

(b) ascertain reasons for apparent groundwater contamination at Frontier's upgradient wells.

(c) ascertain details regarding the Falls Street Tunnel, connections into it from Frontier and elsewhere and historical data regarding water levels in it when it was blocked and when the blockage was cleared.

3.4 Ongoing Routine Monitoring

As noted in Section 2.3.5, Thomsen Associates (1985) recommended that groundwater monitoring of bedrock wells continue every two months for one year and shallow wells on a semi-annual basis, with analysis of the following parameters:

pH	Chromium
Specific Conductance	Nickel
TOC	Benzene
Phenol	Tetrachloroethene
Iron	

Nevertheless, at present many of the bedrock wells at Frontier show elevated levels of organic chemicals, although the levels are in doubt. Golder Associates therefore recommends that an Interim Groundwater Monitoring Plan be adopted which can be used in the groundwater assessment and investigation program. Golder Associates proposes that the Interim Groundwater Monitoring Plan include quarterly sampling and analyses for three quarters for volatile organic compounds (EPA Method 624), phenol, TOX and field determination of pH and specific conductance on all bedrock wells (i.e. MW-2 to 4 and 9 to 17). However, since past monitoring has shown high levels of chlorotoluene and dichlorobenzene at a number of monitoring wells at the site, it is recommended that these also be added to the list of volatile contaminants included on EPA Method 624.

Since the major problem of concern and uncertainty at the site is the source of organic contaminants, Golder Associates does not recommend for the Interim Groundwater Monitoring Plan routine sampling for drinking water or groundwater quality parameters or TOC although it is acknowledged that high chloride, sulfate, sodium, iron and nickel levels were determined in MW-2. However, once additional monitoring wells have been installed it is proposed that one complete GC/MS scan be carried out on a sample from each well at the site (see Section 3.5).

624 & 625 volatiles & base neutrals inc. almost all priority pollutants

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3.5 Additional Boreholes and Monitoring Wells

Golder Associates is of the opinion that some additional boreholes and monitoring wells are required at the site. However, the installation of monitoring wells and subsequent water sampling and chemical analyses is a slow and expensive operation at a site where contaminant migration may be controlled by utilities and building foundations. In addition, past groundwater flow directions could have been different from those today. For this reason a four stage approach to the drilling of additional boreholes and monitoring wells is proposed, comprising:

(1) Testing of manholes, basements etc.
(2) Soil drilling and OVA testing
(3) Drilling of boreholes and installation of monitoring wells
(4) Water sampling and analytical testing

Testing of Manholes and Basements

Depending on the results of the on-site review, it is envisaged that testing of various manholes and/or basement sumps might assist in the delineation of potential source(s) of groundwater contamination without the drilling of boreholes. This possibility will be verified prior to the drilling of any boreholes at the site.

Soil Drilling and OVA Testing

At present, the source(s) of contamination are unclear. If contamination of the bedrock under Frontier's site originated in the plant, it is reasonable to infer that the overburden beneath the site would be highly contaminated. However, if the contamination originated from an external source in the bedrock, the overburden will not demonstrate signs of similar contaminants.

Once the previous components of the groundwater investigation have been completed, it is recommended that boreholes be drilled at various locations across the site prior to siting any additional monitoring wells. Continuous soil samples would be taken using specially cleaned standard split spoon samplers. The samples would be placed in glass jars, agitated and the head space analyzed using a portable organic vapor analyzer (OVA) with a GC attachment.

This would provide a fast delineation of the occurrence and extent of any plumes in the area as well as delineating what strata the contaminants are present in. At present, it is estimated that about 15 holes will be drilled.

These holes could be located close to, or on alternate sides of, utilities which could have acted as conduits for contaminant migration. Some holes would be located close to existing monitoring wells. The holes would be backfilled with a bentonite grout immediately after the completion of drilling, although consideration will be given to installing a simple standpipe piezometer in the overburden in some of these holes. This would increase the number of wells to determine piezometric heads in the overburden and better define overburden flow directions.

At present, the installation of additional overburden monitoring wells is not considered required, but it is recognized that the results of the soil sampling and OVA testing could suggest that some wells are indeed required.

Drilling of Boreholes and Installation of Bedrock Monitoring Wells

The source and extent of contaminant migration in the underlying bedrock is not well defined. Golder Associates is of the opinion that additional bedrock monitoring wells are required at Frontier's site to resolve this. The locations of proposed wells are shown on Figure 17.

At four locations (18-21), a single bedrock well would be installed in the uppermost 6 to 7 ft. of the bedrock. The purpose of these wells is to expand the existing network to provide better definition of piezometric head, flow directions and background chemistry.

At six locations (22 to 27), twin bedrock monitoring wells would be installed, with the upper well installed in the shallow bedrock similar to the above wells and other existing wells. The lower well would ideally be installed to intersect both the first fracture zone (100% loss of core water)* and/or be screened at the same elevation or slightly below the Falls Street Tunnel. Three of these installations are located about 100 ft. north of Frontier's southern property line, while the other three are located inside the plant and northwest, north and east of the former settler.

Three initial holes in this group would be core drilled in order to provide a rock core which can be photographed and logged. These holes will be used to confirm the elevation to which the deeper monitoring wells will be installed. However, it is presently envisaged that they will be installed using telescoping casing of a smaller diameter than the casing used to drill into the upper 6 to 7 ft.

* Three fracture zones were found in the uppermost 30 ft. of bedrock at Necco Park, the uppermost being at about elevation 560. Formations in the Niagara Falls area dip to the south at about 30 ft/mile (Johnston, 1964). If there were no east-west dip, the first fracture zone at Frontier would be at about elevation 545. Although this is only very approximate, it actually agrees well with the loss of coring water at elevation 544.7 in MW-12.

of bedrock; this larger casing would be grouted in prior to reaching the first fracture zone or the elevation of the Falls Street Tunnel.

Golder Associates is of the opinion that deeper drilling of the bedrock is not warranted at the present time and any decision in this regard should be deferred until after the source(s) and extent of the groundwater contamination are determined.

Water Sampling and Analytical Testing

After installation, the new wells would be purged and rising head permeability tests carried out on representative wells. The piezometric level in each well would also be measured every 2 months.

The new wells would be sampled and analyzed once for both volatile and base-neutral organics (EPA Methods 624 and 625), phenol, TOX together with the field determination of pH and specific conductance. This sampling would be carried out at the same time as a quarterly sampling of the other bedrock wells at the site (see Section 3.4). At this time, extra samples of all other bedrock wells (MW-2 to 4 and 9 to 17) would also be obtained and analyzed for base-neutral organics (EPA Method 625). The analytical laboratory carrying out this testing would be instructed to review the GC/MS output and to identify any other peaks present, particularly those of semi-volatile halogenated organics. overburden wells?

In summary, water sampling of wells at the Frontier site will therefore comprise:

- 3 quarterly samples on existing bedrock wells MW-2 to 4 and 9 to 17 for phenol, TOX, pH, specific conductance, volatile organics (and chlorotoluene and dichlorobenzene for two quarterly samples).

- 1 sampling to coincide with a quarterly sampling above, of all new wells for phenol, TOX, pH, specific conductance, volatile and base-neutral organics, together with an additional sample from existing bedrock wells for base-neutral organics.

4. SCHEDULE

This document has presented a conceptual groundwater investigation plan. Specifications for the soil sampling and OVA testing and bedrock drilling will be submitted prior to the initiation of drilling, together with a sampling and analysis plan, QA/QC plan and health and safety plan.

It is understood that this groundwater investigation plan may form part of a consent order. The date at which work can be started is therefore not defined at present. However, it is envisaged that the on-site historical review and regional review could take 8 to 10 weeks and be completed prior to Spring 1986. It is recommended that a meeting take place with NYDEC at the conclusion of this phase of the groundwater investigation and prior to the drilling of any boreholes/monitoring wells at the site.

The soil sampling and OVA testing and boreholes/installation of monitoring wells would proceed in Spring 1986 and be completed by the end of June 1986.

A possible schedule for the work is set out on Table 6. The actual schedule which will be followed will be influenced by the availability of drillrigs and the weather conditions in Niagara Falls. Work which increases the risk of downhole contamination due to it being carried out during wet or cold winter conditions would be deferred.

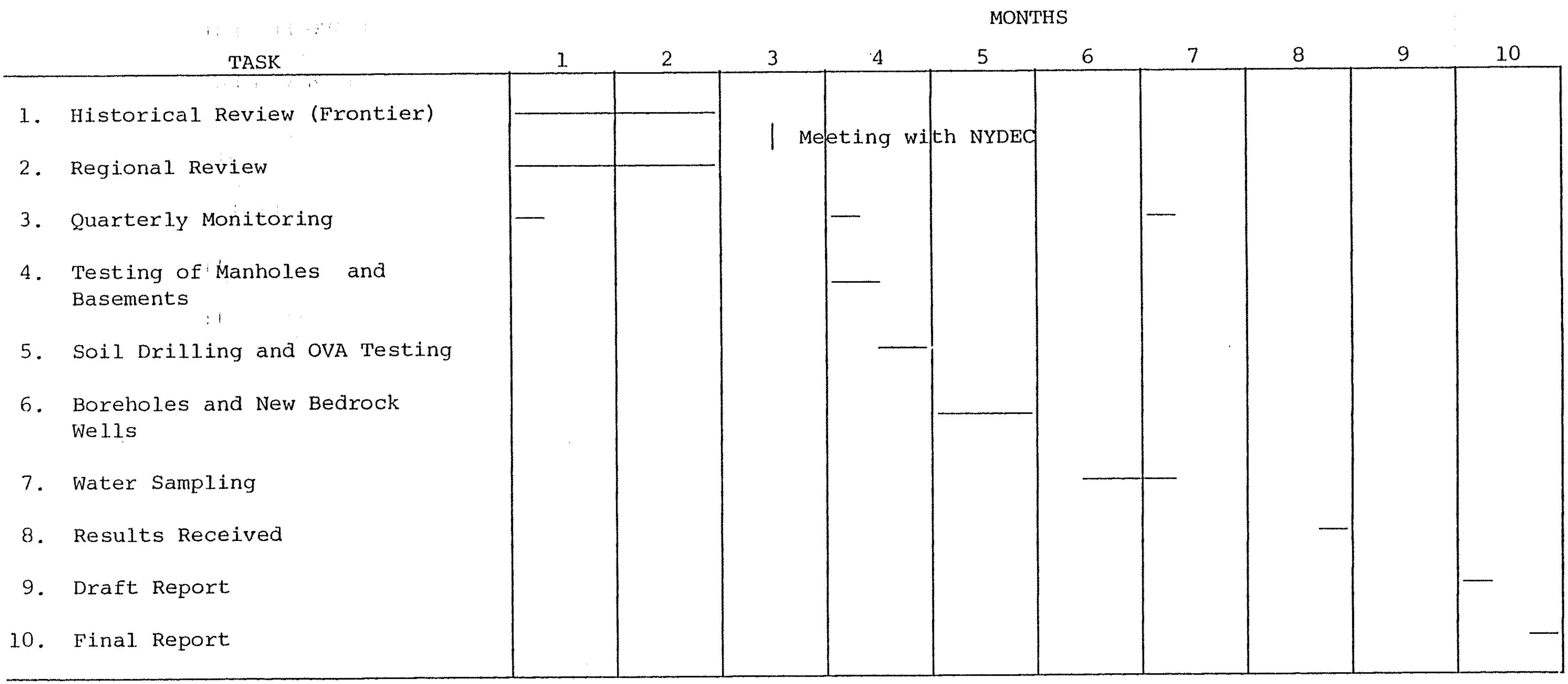
The Groundwater Investigation Report will include the following:

(a) Results of site historical review of relevant data including a list of chemicals which could have been stored or used in these areas and location plans and

TABLE 6

SCHEDULE

NOTE: This schedule is to be read in conjunction with the text.



information on underground site utilities in these areas.

(b) Results of review of regional hydrogeology including geologic stratigraphy descriptions and anticipated regional groundwater flow directions and anticipated impact of other neighbouring sites and outside utilities including the Falls Street Tunnel on groundwater quality at Frontier.

(c) Description of the site hydrogeology from existing borehole data and data obtained during this study. This description will indicate the hydrostratigraphic units investigated, the direction of groundwater flow, and the estimated rate of groundwater flow. Information obtained during the investigation will be fully documented in the report. This will include boring, well and piezometer logs; site plan showing boring, well and piezometer locations; groundwater level data; and descriptions of the methods used to perform this field work.

(d) Results of organic vapor analyses (OVA) performed on overburden samples from boreholes. Results of groundwater analytical tests obtained during the course of the investigation from the existing shallow wells and any new site overburden wells installed during this investigation. Determination of the lateral extent of any contaminant plume(s) from the OVA and analytical data and their source(s).

(e) Analytical results of tests on groundwater samples from both the existing and new bedrock holes and wells. Determination of the lateral and vertical extents of the contaminant plume(s) from these data and their source(s).

(f) Estimate of the rate and direction of migration of groundwater contamination from the existing data and data obtained during the investigation.

(g) Recommendations for additional work or studies which are deemed necessary to better define the site hydro-stratigraphy and/or to better define the extent, rate, and direction of groundwater contaminant migration.

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APPENDIX 1

SUMMARIES OF GROUNDWATER SAMPLING RESULTS

TABLES 2 & 3

FROM THOMSEN (1985)

TABLE 2

SUMMARY OF GROUNDWATER SAMPLING RESULTS

		BEDROCK WELLS									SHALLOW WELLS						
		Upgradient		Downgradient							Upgradient		Downgradient				
COMPOUND	WEEK	MW-14	MW-17	MW-9	MW-10	MW-11	MW-12	MW-13	MW-15	MW-16	MW-8	MW-3	MW-5	MW-6	MW-7	MW-2	MW-4
pH	1	7.3	7.3	11.4	9.3	9.5	9.4	7.2	11.7	11.5	7.2	7.5	7.4	9.8	7.7	8.6	-
	2	7.2	7.4	11.3	9.4	9.4	9.5	7.4	11.6	11.5	-	-	-	-	-	-	-
	3	7.1	7.4	11.4	9.3	11.1	10.3	7.1	11.4	11.4	-	-	-	-	-	-	-
	4	7.1	7.2	11.2	9.5	10.3	9.7	7.1	11.1	11.5	7.4	7.8	7.5	9.4	7.7	8.4	7.7
	8	7.5	8.1	11.4	9.7	10.7	9.8	8.0	11.4	11.5	7.9	8.3	8.0	9.5	8.1	8.8	7.9
	12	7.9	8.1	10.5	9.1	10.0	9.3	7.5	10.7	10.3	8.0	8.2	7.7	8.7	8.2	8.4	-
Specific Conductance (umhos/cm)	1	2700	12000	71000	62000	17000	32000	2500	15000	14000	3900	3400	1700	2200	5200	82000	-
	2	2600	12000	70000	61000	15000	32000	2500	15000	14000	-	-	-	-	-	-	-
	3	2400	10000	94000	90000	38000	28000	2300	18000	17000	-	-	-	-	-	-	-
	4	2400	19000	91000	94000	29000	36000	2300	18000	20000	2900	2900	1900	670	2400	82000	3600
	8	3000	14000	71000	77000	29000	26000	2000	42000	16000	2300	3100	1600	1500	3000	83000	3500
	12	2600	14000	63000	67000	26000	26000	3000	17000	16000	2200	2700	1400	1600	2600	77000	-
TOC (mg/l)	1	30	70	650	1500	80	170	30	340	460	70	50	20	80	80	950	-
	2	40	70	620	1500	80	190	40	320	510	-	-	-	-	-	-	-
	3	40	110	620	1700	530	250	50	310	530	-	-	-	-	-	-	-
	4	40	40	480	1500	460	190	30	220	560	80	40	20	20	90	940	40
	8	100	120	500	1800	430	240	60	280	480	50	30	10	10	40	1300	50
	12	20	50	500	2000	260	60	30	200	700	40	30	10	90	30	1800	-
Phenol (mg/l)	1	<0.1	<0.1	50	370	3.6	1.1	<0.1	11	87	<0.1	<0.1	<0.1	<0.1	<0.1	13	-
	2	<0.1	<0.1	56	380	4.5	1.2	<0.1	6.4	91	-	-	-	-	-	-	-
	3	<0.1	<0.1	47	390	28	4.2	<0.1	3.2	82	-	-	-	-	-	-	-
	4	<0.1	<0.1	38	390	14	1.1	0.1	1.5	80	<0.1	<0.1	<0.1	<0.1	<0.1	64	<0.1
	8	<0.1	<0.1	28	420	13	<0.1	<0.1	[illegible]	24	<0.1	<0.1	<0.1	<0.1	<0.1	110	-
	12	<0.1	<0.1	37	367	34	<0.1	<0.1	<0.1	63	<0.1	<0.1	<0.1	<0.1	<0.1	85	-
THO (ug/l)	1	-	-	-	-	-	-	-	-	-	0.06	0.16	0.01	0.20	0.14	0.05	-
	4	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	0.13	0.23	-
	8	-	-	-	-	-	-	-	-	-	1.0	1.8	2.5	0.7	20	83	-
	12	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	0.2	0.8	3.8	-
Cyanide (mg/l)	1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	0.18	-
	4	<0.02	0.04	0.97	0.78	0.40	0.11	0.04	0.78	0.57	<0.02	0.04	<0.02	<0.02	<0.02	0.95	-
	8	<0.1	<0.1	1.9	1.6	1.4	0.1	<0.1	0.8	1.4	<0.1	<0.1	<0.1	<0.1	<0.1	3.3	<0.1
	12	<0.1	<0.1	1.1	1.2	0.5	<0.1	<0.1	0.6	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	1.5	-
Thio-cyanate (mg/l)	1	-	-	-	-	-	-	-	-	-	0.46	0.66	1.6	18	0.98	50	-
	4	-	-	-	-	-	-	-	-	-	0.10	0.14	0.35	3.9	0.22	11.2	-
	8	-	-	-	-	-	-	-	-	-	0.6	0.6	<0.5	4.2	1.9	43	1.0
	12	-	-	-	-	-	-	-	-	-	0.4	0.5	<0.1	15	1.3	43	-
Chloride (mg/l)	1	-	-	-	-	-	-	-	-	-	570	370	270	240	1100	4400	-
	4	-	-	-	-	-	-	-	-	-	480	440	530	70	540	42000	730
	8	-	-	-	-	-	-	-	-	-	190	320	310	130	490	32800	630
	12	-	-	-	-	-	-	-	-	-	130	330	300	980	500	52000	-
Sulfate (mg/l)	1	-	-	-	-	-	-	-	-	-	800	900	100	340	600	4400	-
	4	-	-	-	-	-	-	-	-	-	480	750	1290	33	540	3700	120
	8	-	-	-	-	-	-	-	-	-	650	500	150	80	200	3500	1100
	12	-	-	-	-	-	-	-	-	-	200	580	120	250	880	3800	-
Sodium (mg/l)	1	-	-	-	-	-	-	-	-	-	490	460	220	240	590	6800	-
	4	-	-	-	-	-	-	-	-	-	100	200	190	40	250	10000	180
	8	-	-	-	-	-	-	-	-	-	50	140	90	40	170	850	140
	12	-	-	-	-	-	-	-	-	-	70	200	170	40	280	10700	-

TABLE 2

SUMMARY OF GROUNDWATER SAMPLING RESULTS

COMPOUND	WEEK	BEDROCK WELLS Upgradient		BEDROCK WELLS Downgradient							SHALLOW WELLS Upgradient		SHALLOW WELLS Downgradient				
		MW-14	MW-17	MW-9	MW-10	MW-11	MW-12	MW-13	MW-15	MW-16	MW-8	MW-3	MW-5	MW-6	MW-7	MW-2	MW-4
Arsenic (mg/l)	1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-
	4	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	8	-	-	-	-	-	-	-	-	-	<0.05	<0.1	<0.05	0.1	0.2	0.2	<0.05
	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron (mg/l)	1	-	-	-	-	-	-	-	-	-	0.2	<0.1	0.8	2.2	<0.1	3.9	-
	4	<0.5	<0.5	<0.5	1.4	<0.5	<0.5	<0.5	<0.5	0.67	<0.5	<0.5	<0.5	<0.5	<0.5	2.2	<0.5
	8	<0.1	0.1	3.3	6.7	0.6	0.3	<0.1	0.4	0.4	<0.1	<0.1	0.1	0.2	<0.1	3.6	0.2
	12	0.1	0.1	0.7	3.7	0.2	0.1	0.2	0.2	0.6	<0.1	<0.1	0.2	0.2	<0.1	8.2	-
Manganese (mg/l)	1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	0.4	0.5	-
	4	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	<0.5	<0.5	0.21	<0.5
	8	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	<0.05	0.1	0.7	<0.05
	12	-	-	-	-	-	-	-	-	-	<0.05	<0.05	<0.05	0.11	<0.05	0.42	-
Nickel (mg/l)	1	-	-	-	-	-	-	-	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	-
	4	<0.1	0.14	0.24	0.27	0.18	0.14	<0.1	0.10	0.15	<0.1	<0.1	<0.1	<0.1	<0.1	0.85	<0.1
	8	<0.1	<0.1	0.9	1.2	0.2	0.2	<0.1	0.4	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	2.0	<0.1
	12	<0.1	<0.1	0.6	0.5	0.2	<0.1	<0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	1.3	-
Chromium (mg/l)	4	<0.2	<0.2	<0.2	<0.2	<0.2	<0,2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-
	8	<0.1	<0.1	0.3	0.21	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
	12	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
Cadmium (mg/l)	4	<0.01	<0.01	0.07	0.08	0.03	0.02	<0.1	<0.01	0.02	-	-	-	-	-	-	-
	8	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
	12	<0.1	<0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
Copper (mg/l)	4	<0.05	<0.05	0.05	0.37	<0.05	<0.05	<0.05	0.14	<0.05	-	-	-	-	-	-	-
	8	0.3	<0.05	<0.05	<0.05	0.23	<0.05	<0.05	<0.05	<0.05	-	-	-	-	-	-	-
	12	<0.05	<0.05	0.10	0.19	<0.05	<0.05	<0.05	0.2	0.05	-	-	-	-	-	-	-
Zinc (mg/l)	4	0.16	0.07	0.19	0.46	0.04	0.05	0.08	0.04	0.07	-	-	-	-	-	-	-
	8	<0.1	<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	-	-	-	-	-	-	-
	12	0.05	0.06	0.56	0.77	0.06	<0.05	0.10	0.08	0.06	-	-	-	-	-	-	-

Notes: - Parameter not analyzed

TABLE 3

SUMMARY OF VOLATILE ORGANIC DATA

Volatile Organics (ug/l)	Lab[1]	Upgradient Wells MW-14	Upgradient Wells MW-17	Upgradient Wells MW-9	Downgradient Wells MW-10	Downgradient Wells MW-11	Downgradient Wells MW-12	Downgradient Wells MW-13	Downgradient Wells MW-15	Downgradient Wells MW-16	NYDEC[4] Guidance Criteria	NYDEC[5] Groundwater Standard
Benzene	E	152	290	40,600	690	83,200	88,800	137	11,100	116,000	1.5	N.D.
	Z	23	63	870	124	>1,600	>1,600	6.4	141	725		
Carbon Tetrachloride	E	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	0.3	5
	Z	297	2.4	1,520	187	>24,000	16	343	5.6	157		
Chlorobenzene	E	N.D.[2]	221	10,600	167	42,100	2,900	63.1	7,000	2,140		
	Z	62	500	3,630	388	979	1,230	20	851	806	20	-
1,2-Dichloroethane	E	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]	N.D.[2]		
	Z	6.5	1.4	457	20	701	141	5.3	249	6.6	1.0	-
1,1,1-Trichloroethane	E	835	883	1,350	1,160	22,100	18,000	1,750	359	7,540		
	Z	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	[50][6]	-
1,1-Dichloroethane	E	<50	<50	2,810	<50	722	643	<50	<50	2,890		
	Z	55	5.7	>2,250	107	2.4	515	86	59	702	[50][6]	-
Chloroform	E	197	<50	52.3	59.8	706	98.8	<50	416	489		
	Z	17	6.3	29	15	253	11	107	15	70	0.2	100
1,1-Dichloroethene	E	<50	<50	<50	<50	<50	<50	<50	<50	<50		
	Z	43	12	549	234	230	695	1,100	148	242	0.9	-
Methylene Chloride	E	<50	134	17,400	2,130	6,910	551	73.2	1,060	18,000		
	Z	6.7	2.8	993	294	>1,340	79	3.3	88	200	10	-
Tetrachloroethene	E	50	<50	1,620	<50	6,150	900	78.2	68.3	342		
	Z	47	2.9	1,410	107	>9,300	422	32	46	259	2	-
Toluene	E	182	409	14,700	4,310	26,100	10,200	1,150	5,190	40,500		
	Z	29	128	809	716	>4,300	683	66	526	>3,000	[50][6]	-
Trichloroethene	E	206	<50	4,040	1,020	2,540	17,400	327	455	2,760		
	Z	68	4.5	1,360	241	>5,400	1,410	20	121	572	5	10
Chlorotoluene	E	17500	46,000	9,700	105,000	108,000	3,400	1,270	4,760	33,000		
	Z	233	>4,700	3,340	>11,500	>26,500	1,210	419	2,000	>4,700	-	-
Methyl Toluene	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	4.6	5.6	140	59	414	33	1.7	41	170	-	-
Dichlorotoluene	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	0.7	0.4	8.3	11	92	25	0	35	0	-	-
Bromobenzene	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	0.4	0	38	3	88	23	0	27	19	-	-
Dichlorobenzene	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	64	4.9	1,950	261	>100,000	1,370	20	3,200	484	20	4.7
Trichlorobenzene	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	5.5	1.3	97	26	1,060	157	2.3	241	0	10	-
Dichlorofluoroethane	E	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]	N.A.[3]		
	Z	0	0	2.4	21	71	0	0.2	5.5	18	-	-

[1]Lab E is Ecology and Environment, Lab Z is Zenon Environmental.

[2]N.D. is not detected by laboratory.

[3]N.A. is not analyzed by laboratory.

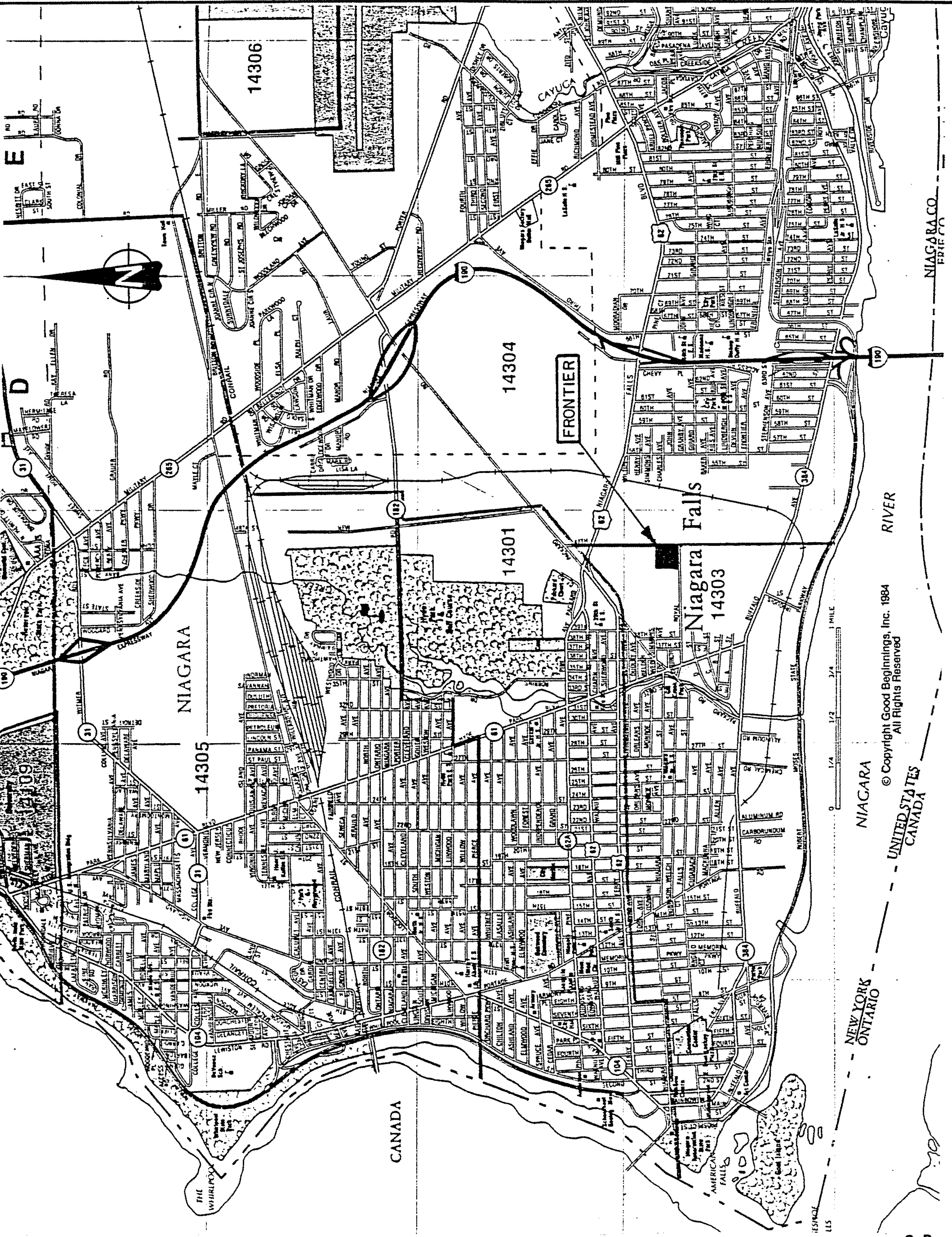
[4]Guidance Criteria are from: New York State Department of Environmental Conservation, 1984,"Ambient Water Quality Criteria", Technical and Operational Guidance Series, Memorandum Number 84-W-38.

[5]Groundwater Standards are from 6NYCRR Part 703.

[6]This limit is a general organic guideline not specific to this parameter

SITE LOCATION MAP

FIGURE 1



Date NOV. 18, 1985
Project No. 851-1275

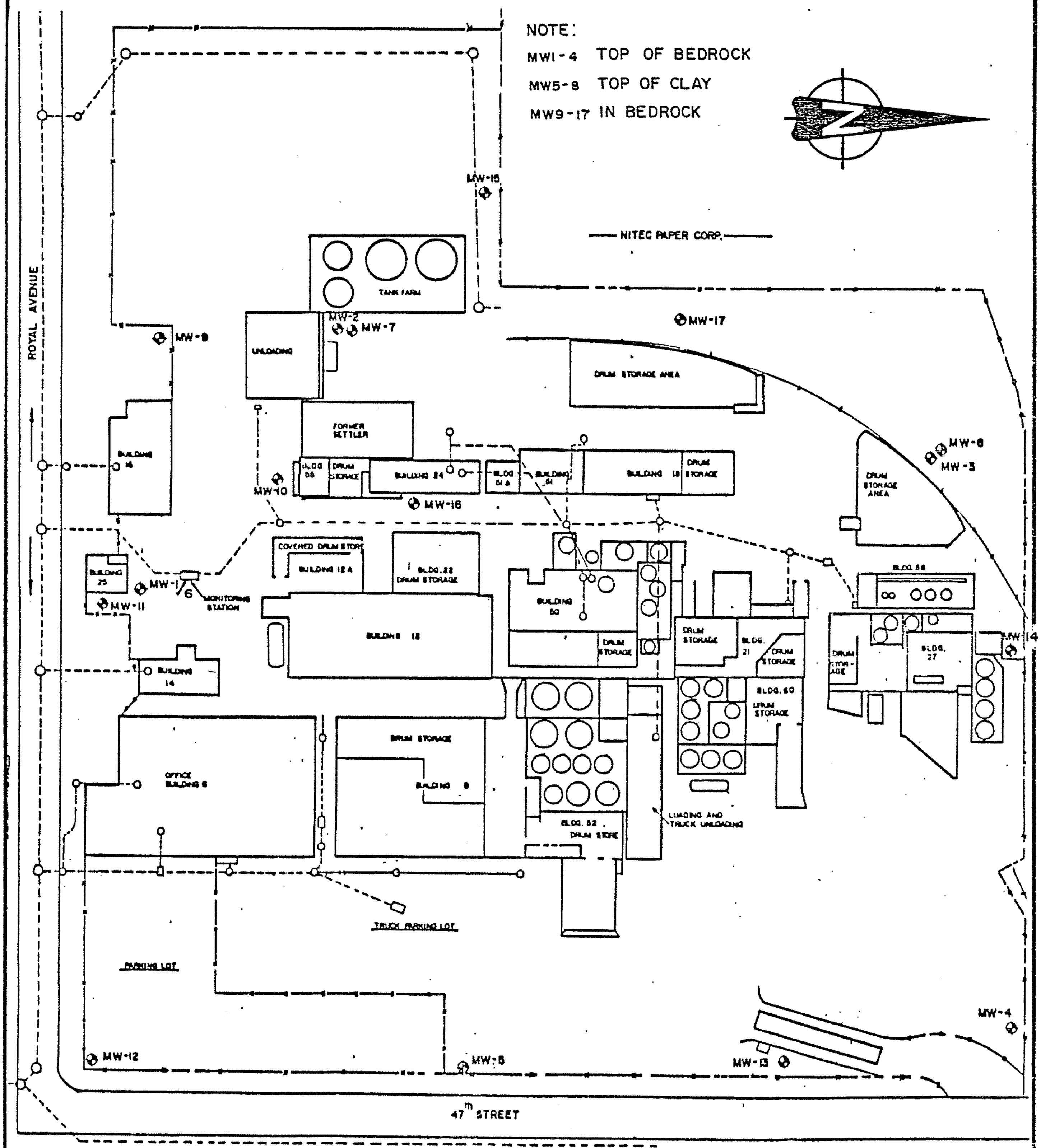
Golder Associates

Drawn G.P.
Chkd. [illegible]

Form G.A.-

PLAN SHOWING BOREHOLES AND MONITORING WELL LOCATIONS

FIGURE 2



SCALE: 1 INCH TO 100 FEET

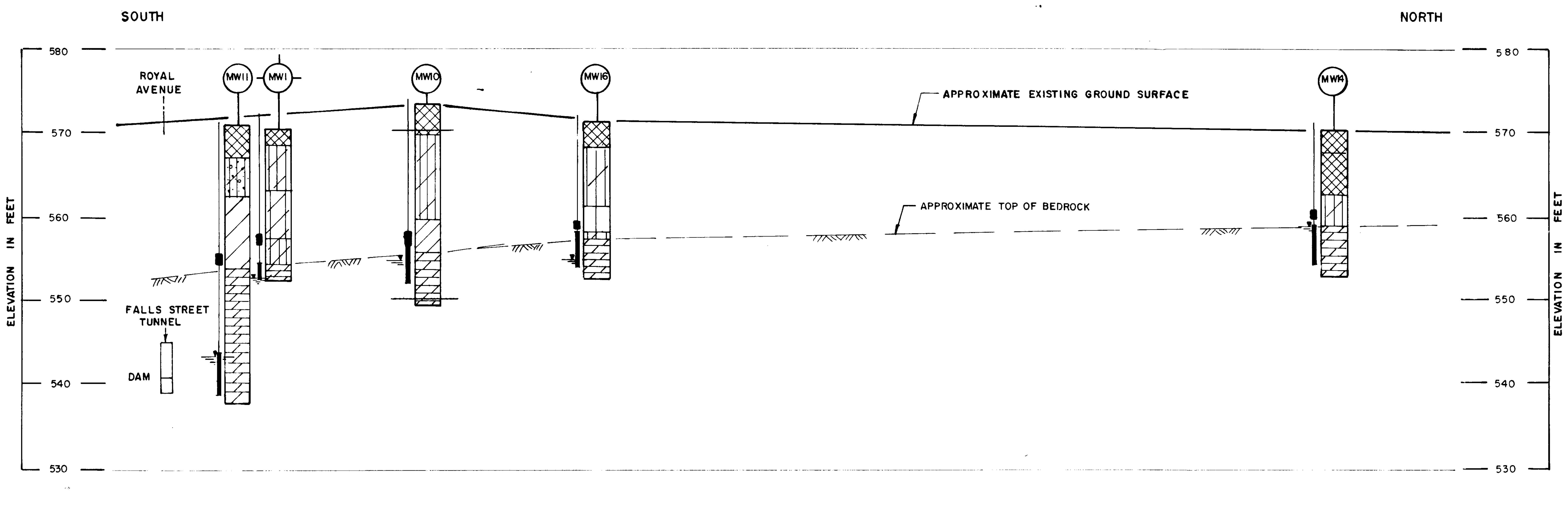
Date NOV. 15, 1985
Project No. 851-1275

Golder Associates

Drawn D. M.
Chkd. [illegible]

SCHEMATIC SECTION (N-S)

FIGURE 3



SECTION A- A

LEGEND

BOREHOLE IN ELEVATION; THOMSEN ASSOCIATES REPORT DATED JUNE 1985

BOREHOLE IN ELEVATION; WEHRAN ENGINEERING REPORT DATED OCT. 1982.

BENTONITE SEAL

WELL INSTALLATION

WATER LEVEL IN WELL; JUNE 1985*

*EXCEPT BOREHOLE MW-1 W.L. TAKEN; JUNE 30, 1982

STRATIGRAPHY

FILL

SOFT TO VERY STIFF LACUSTRINE SILT

SOFT TO VERY STIFF LACUSTRINE CLAY

RED BROWN SILT AND CLAY (TILL)

LIGHT GREY DOLOSTONE BEDROCK (LOCKPORT FORMATION)

SCALES

HORIZONTAL 1 INCH TO 50 FEET
VERTICAL 1 INCH TO 10 FEET

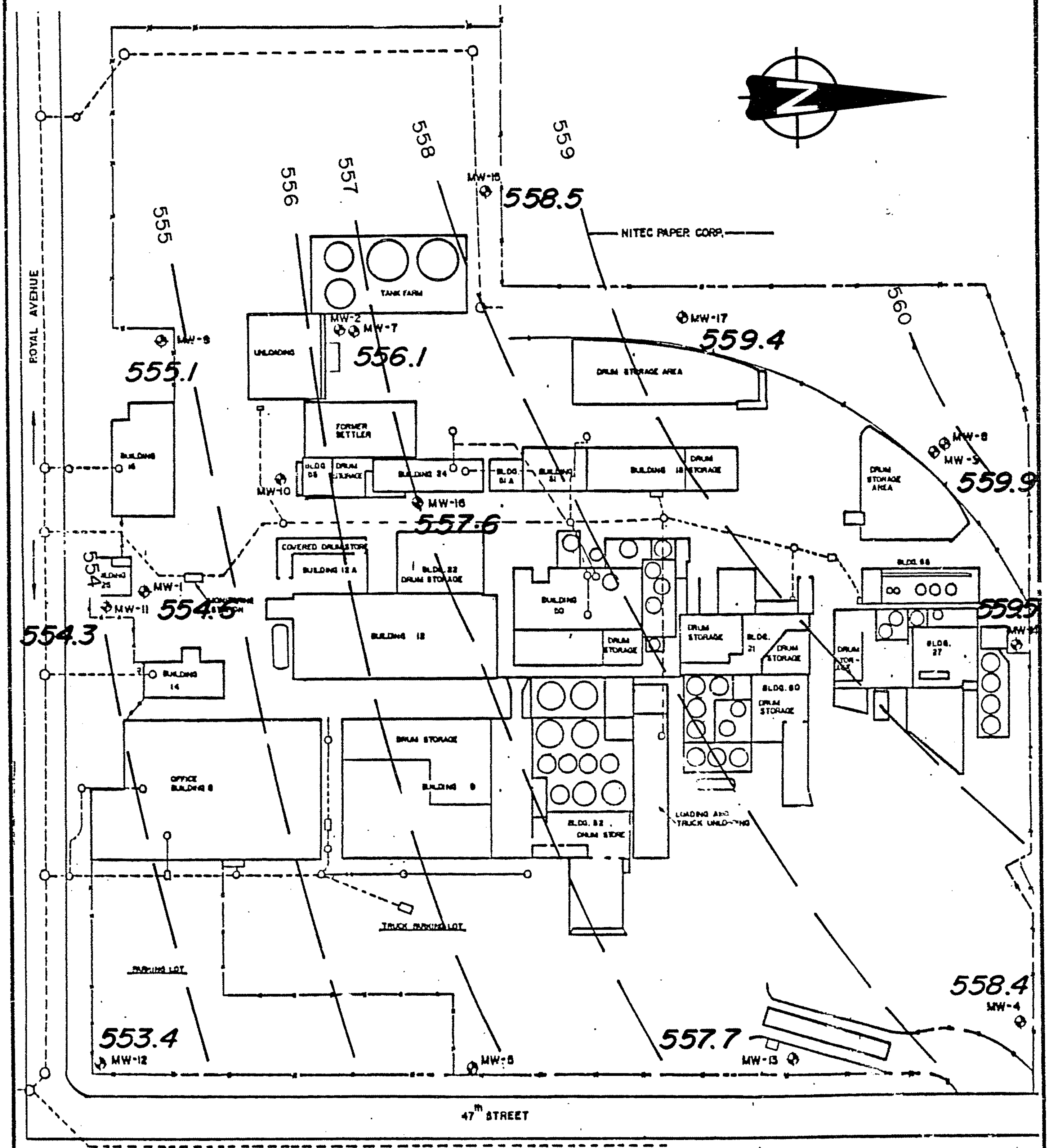
Date NOV. 15, 1985
Project 851-1275

Golder Associates

Drawn D. M.
Chkd [illegible]

ELEVATIONS OF TOP OF BEDROCK

FIGURE 4



SCALE: 1 INCH TO 100 FEET

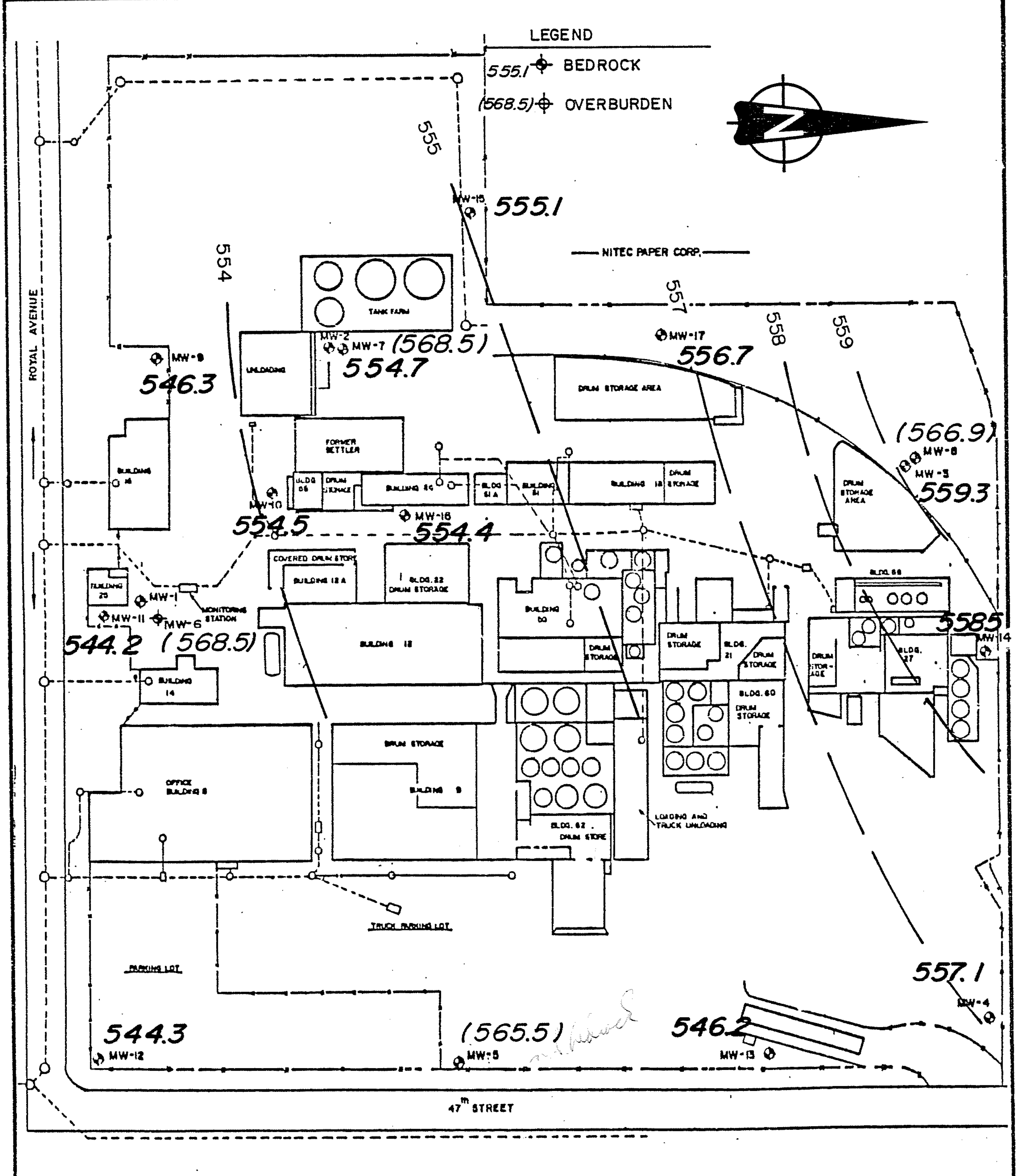
Date NOV. 15, 1985
Project No. 851-1275

Golder Associates

Drawn D. A.
Chkd. L.A.

BEDROCK WATER LEVEL CONTOURS
(JUNE 1985)

FIGURE 5



SCALE: 1 INCH TO 100 FEET

Date NOV. 15, 1985
Project No. 851-1275

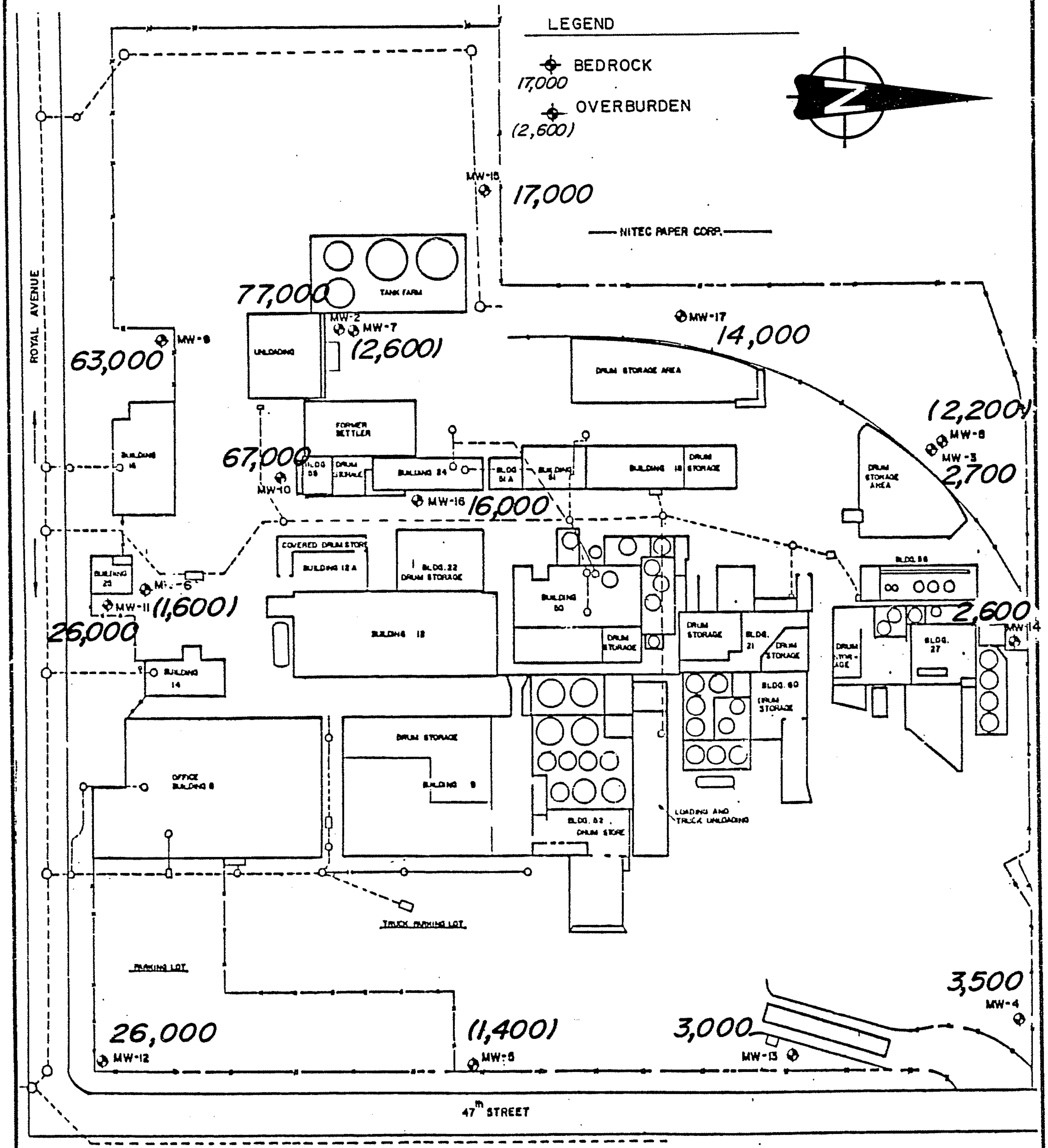
Golder Associates

Drawn D. M.
Chkd. M

Form G.A - D - 4.

SPECIFIC CONDUCTANCE (μ mhos/cm.)
MAY 1985

FIGURE 6



SCALE: 1 INCH TO 100 FEET

Date NOV. 15, 1985
Project No. 851-1275

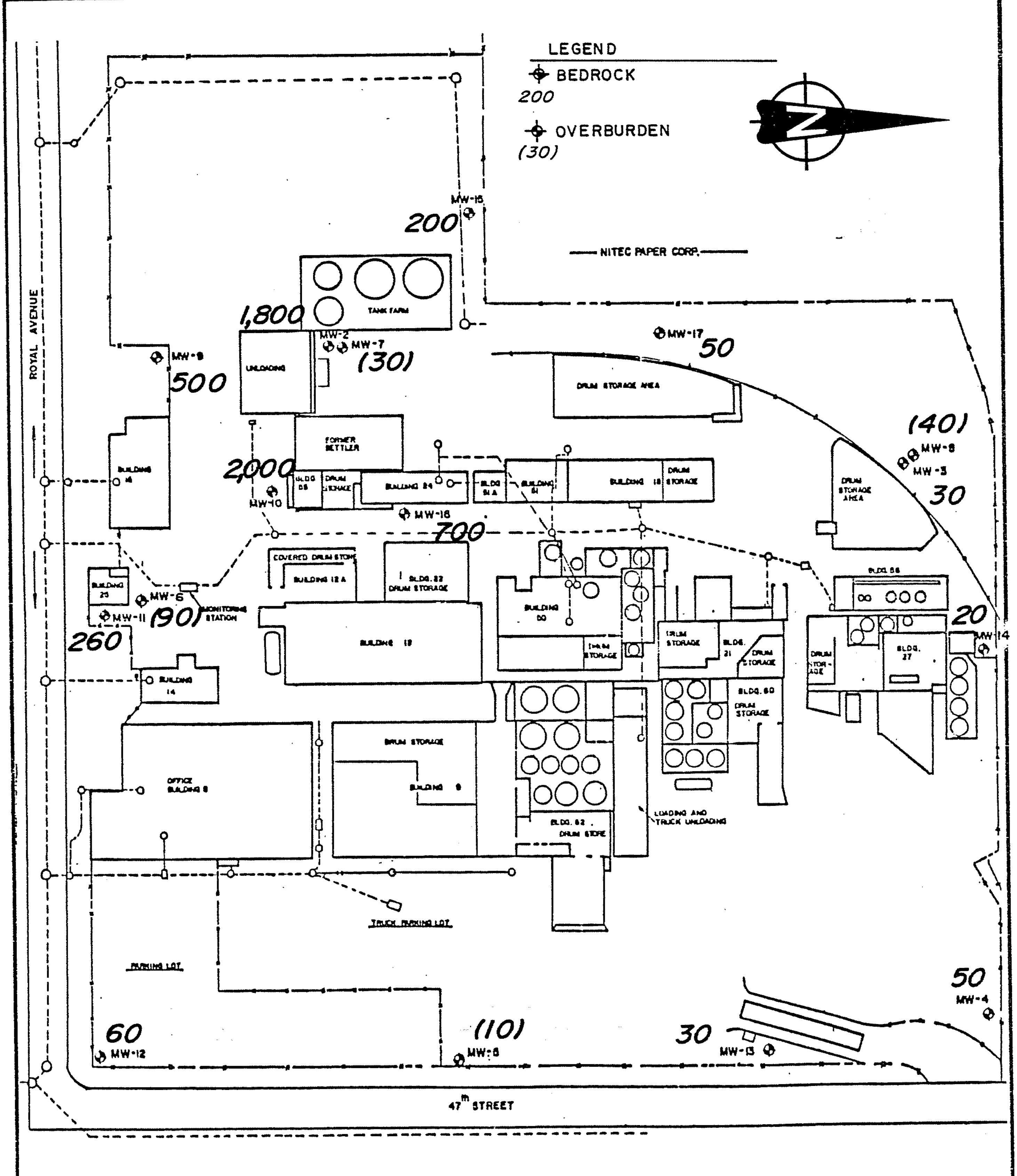
Golder Associates

Drawn D. M.
Chkd. MM

Form G.A - D - 4

TOC (mg/L)
MAY 1985

FIGURE 7



SCALE: 1 INCH TO 100 FEET

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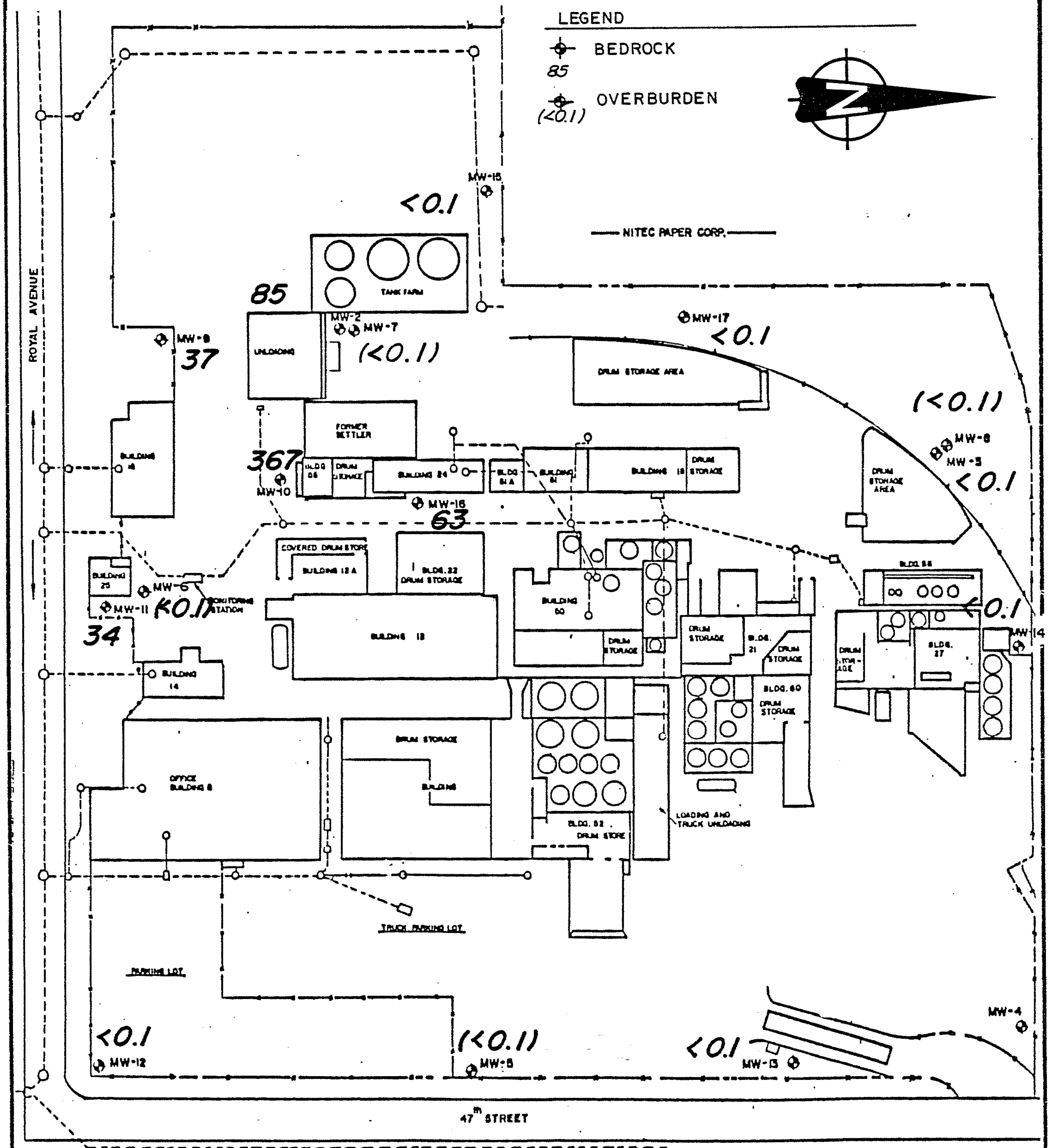
Chkd. [signature]

PHENOL (mg/L)
MAY 1985

FIGURE 8



SCALE: 1 INCH TO 100 FEET

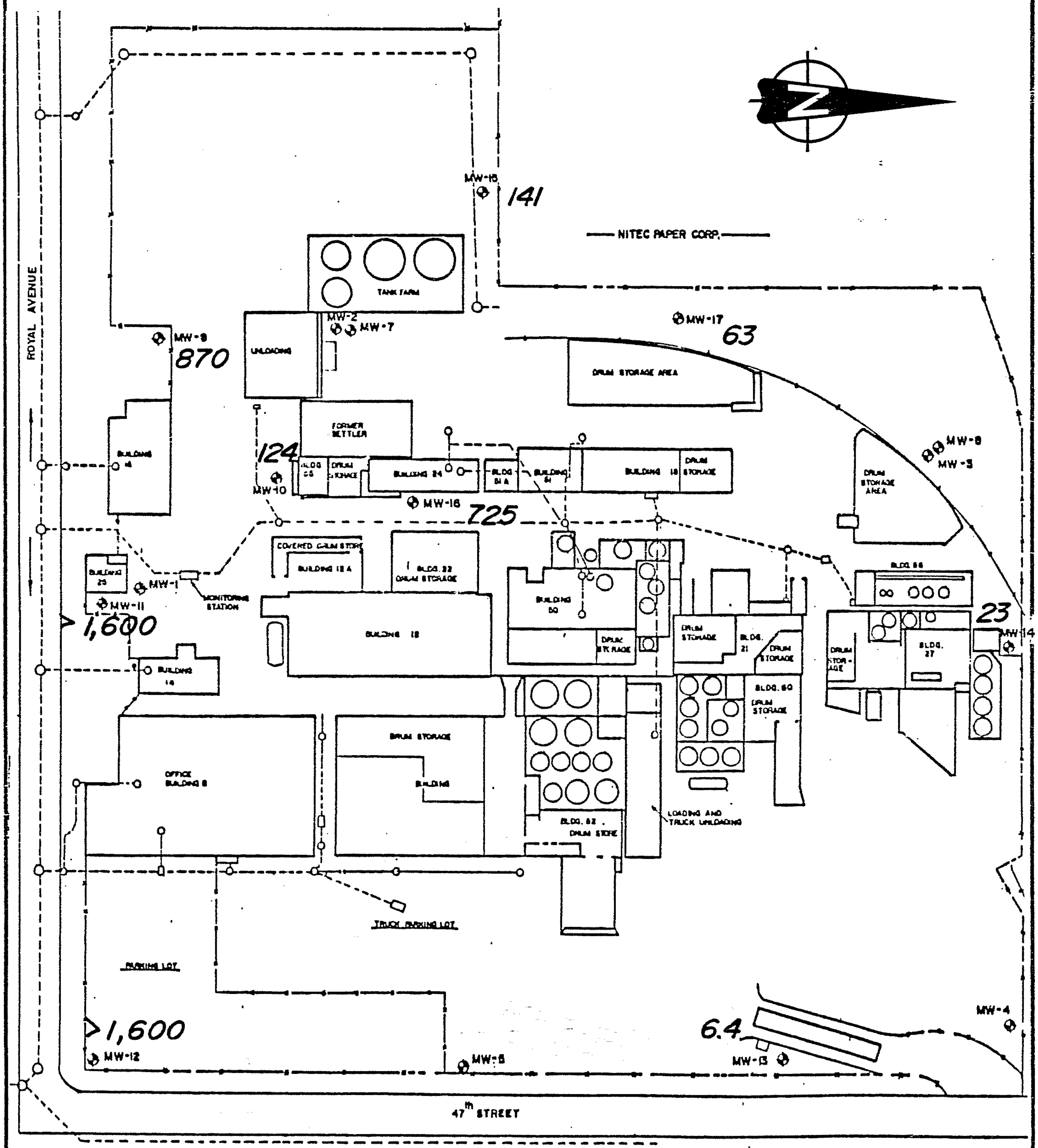
Date NOV. 15, 1985
Project No. 851-1275

Golder Associates

Drawn D. M.
Chkd. [illegible]

BENZENE CONCENTRATION (ppb)
(ZENON DATA)

FIGURE 9



SCALE: I INCH TO 100 FEET

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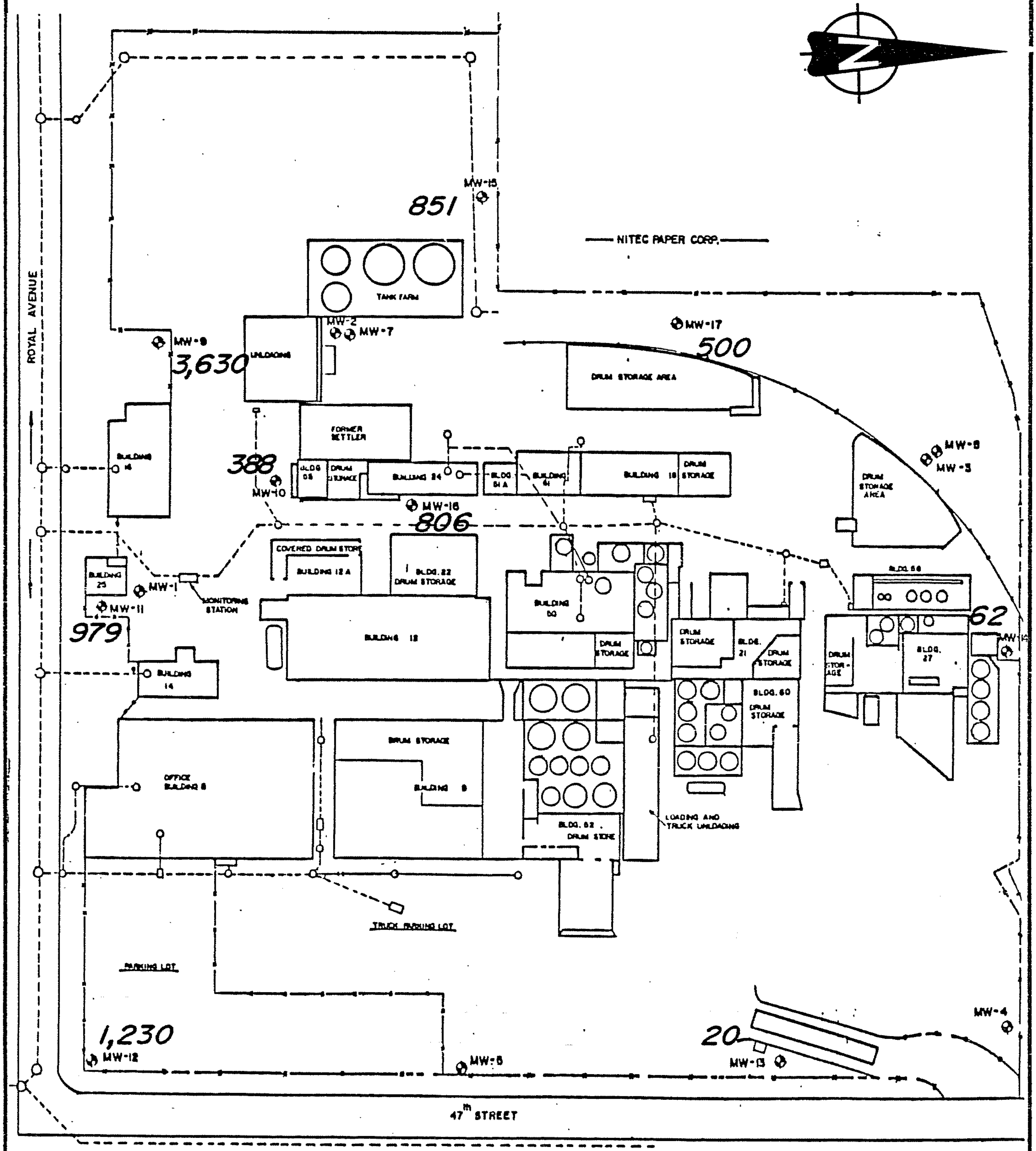
Chkd. M

CHLOROBENZENE CONCENTRATION (ppb) (ZENON DATA)

FIGURE 10



SCALE: 1 INCH TO 100 FEET

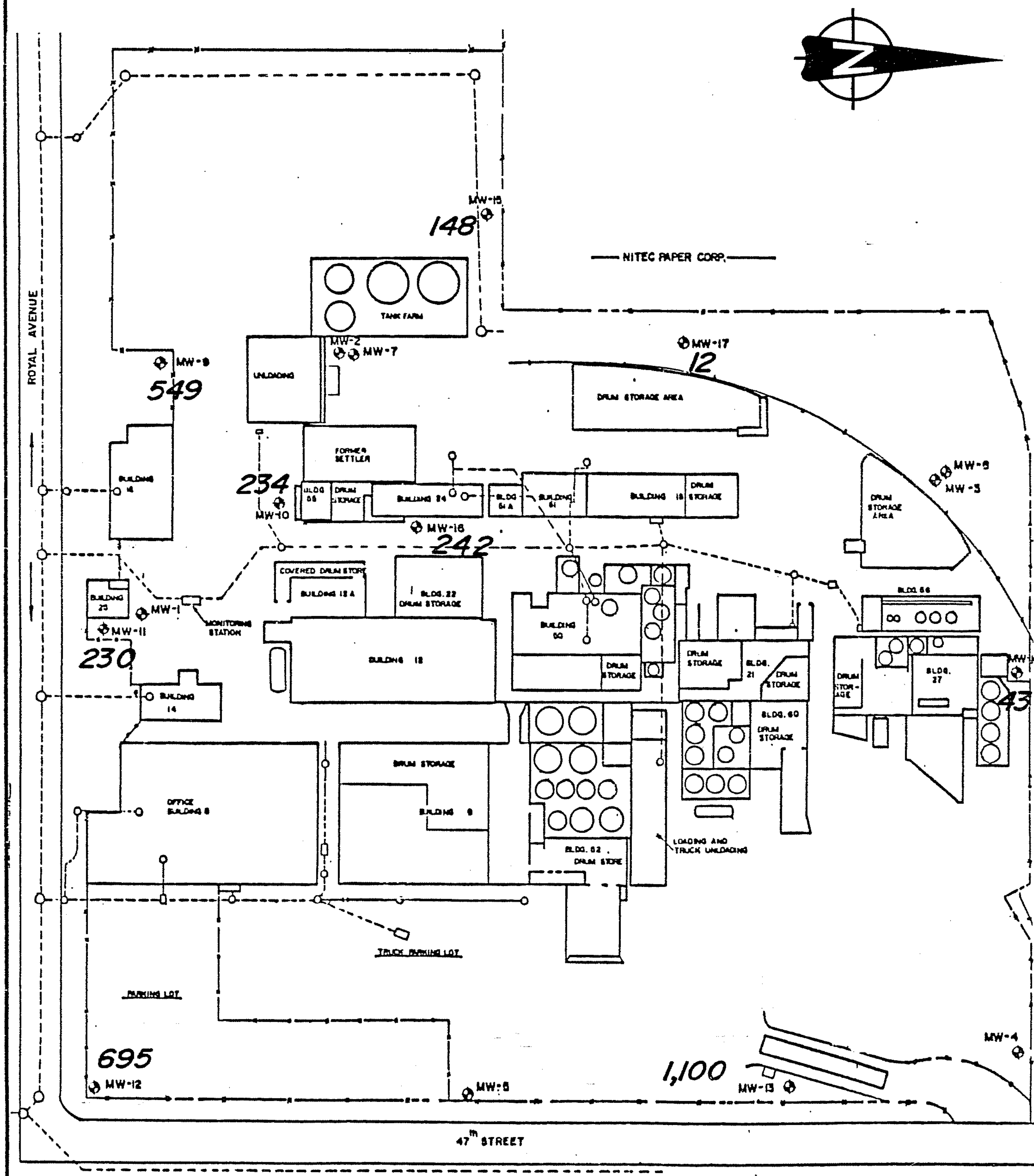
Date NOV. 15, 1985
Project No. 851-1275

Golder Associates

Drawn D. M.
Chkd. [illegible]

1,1 - DICHLOROETHENE CONCENTRATION (ppb) (ZENON DATA)

FIGURE 11



SCALE: 1 INCH TO 100 FEET

Date NOV. 15, 1985
Project No. 851-1275

Golder Associates

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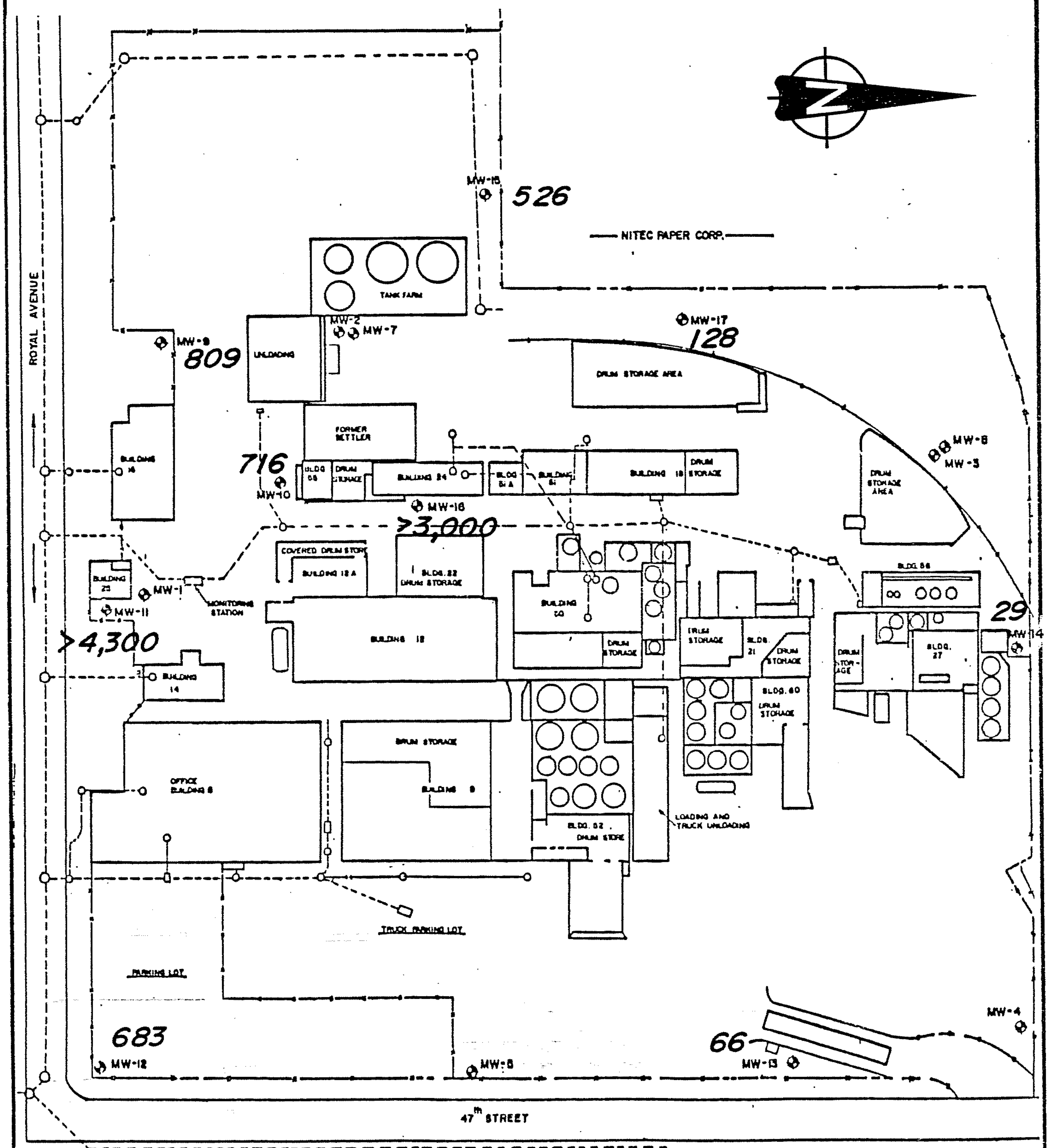
Chkd. M

TOLUENE CONCENTRATION (ppb) (ZENON DATA)

FIGURE 12



SCALE: 1 INCH TO 100 FEET

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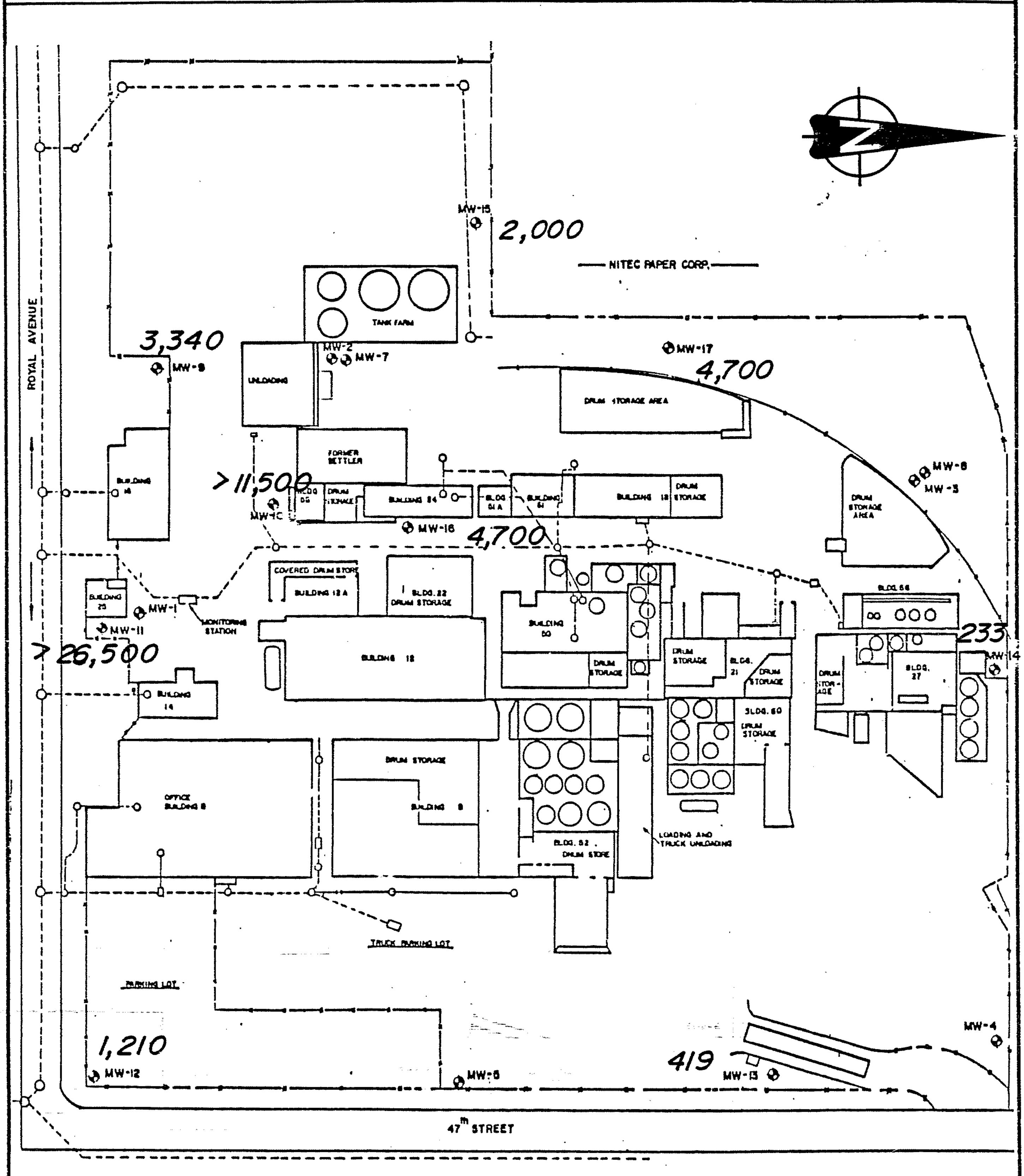
Date NOV. 15, 1985
Project No 851-1275

Drawn D. M.
Chkd.

CHLOROTOLUENE CONCENTRATION (ppb) (ZENON DATA)

FIGURE 13



SCALE: 1 INCH TO 100 FEET

Date NOV. 15, 1985
Project No. 851-1275

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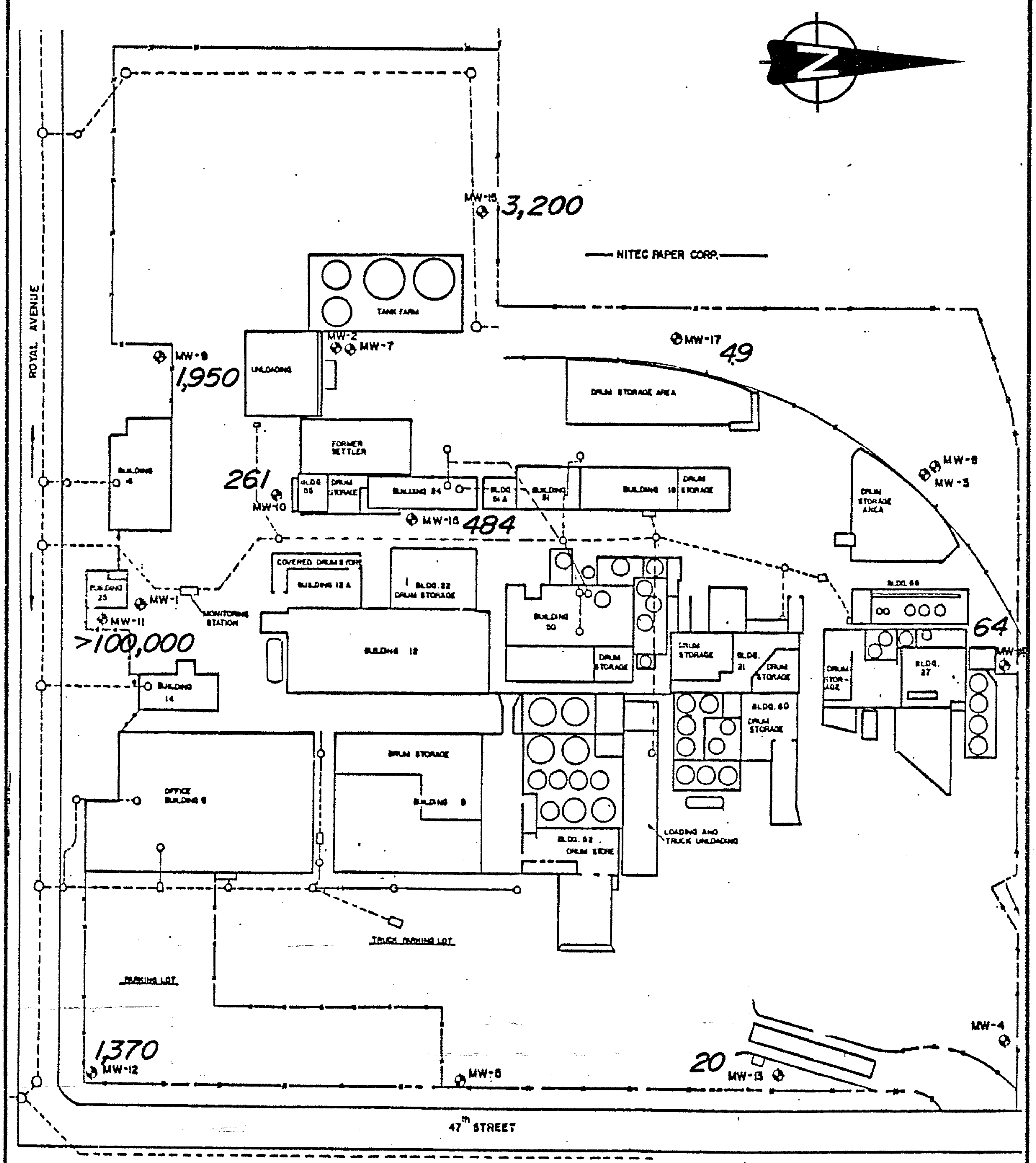
Chkd. M.

DICHLOROBENZENE CONCENTRATION (ppb) (ZENON DATA)

FIGURE 14



SCALE: 1 INCH TO 100 FEET

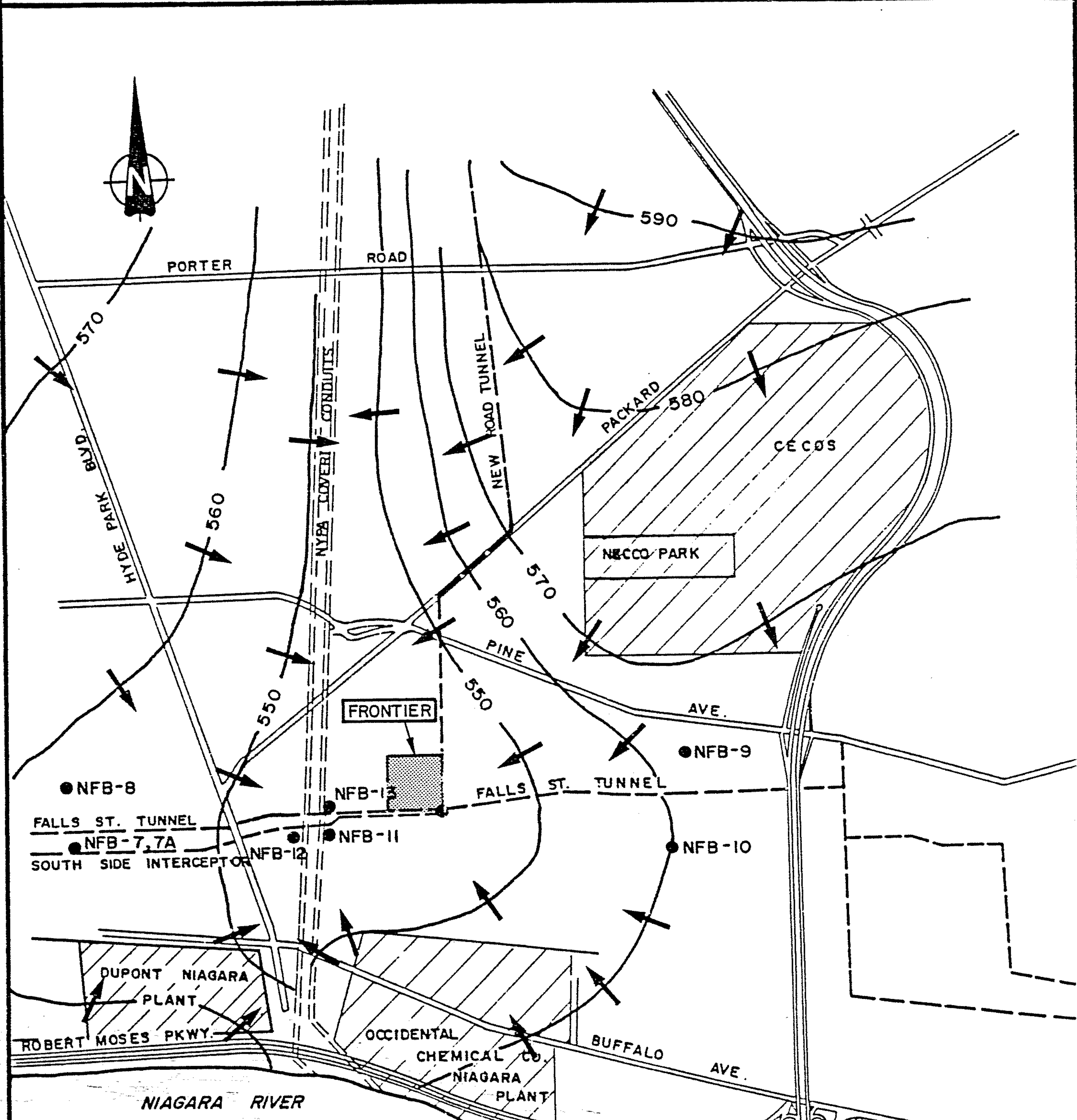
Date NOV. 15, 1985
Project No 851-1275

Golder Associates

Drawn D. M.
Chkd. JM

PLAN SHOWING REGIONAL PIEZOMETRIC LEVELS OF THE UPPER LOCKPORT IN THE VICINITY

FIGURE 2



LEGEND

- ● NFB MONITORING WELL - USGS
- 560 WATER LEVEL CONTOURS (APPROXIMATE)
- ➜ DIRECTION OF GROUNDWATER FLOW

NOTE

ADAPTED FROM REPORT OF NIAGARA TOXICS COMMITTEE, 1985

SCALE: 1 INCH TO 2000 FEET

Date NOV. 14, 1985

Project 851-1275

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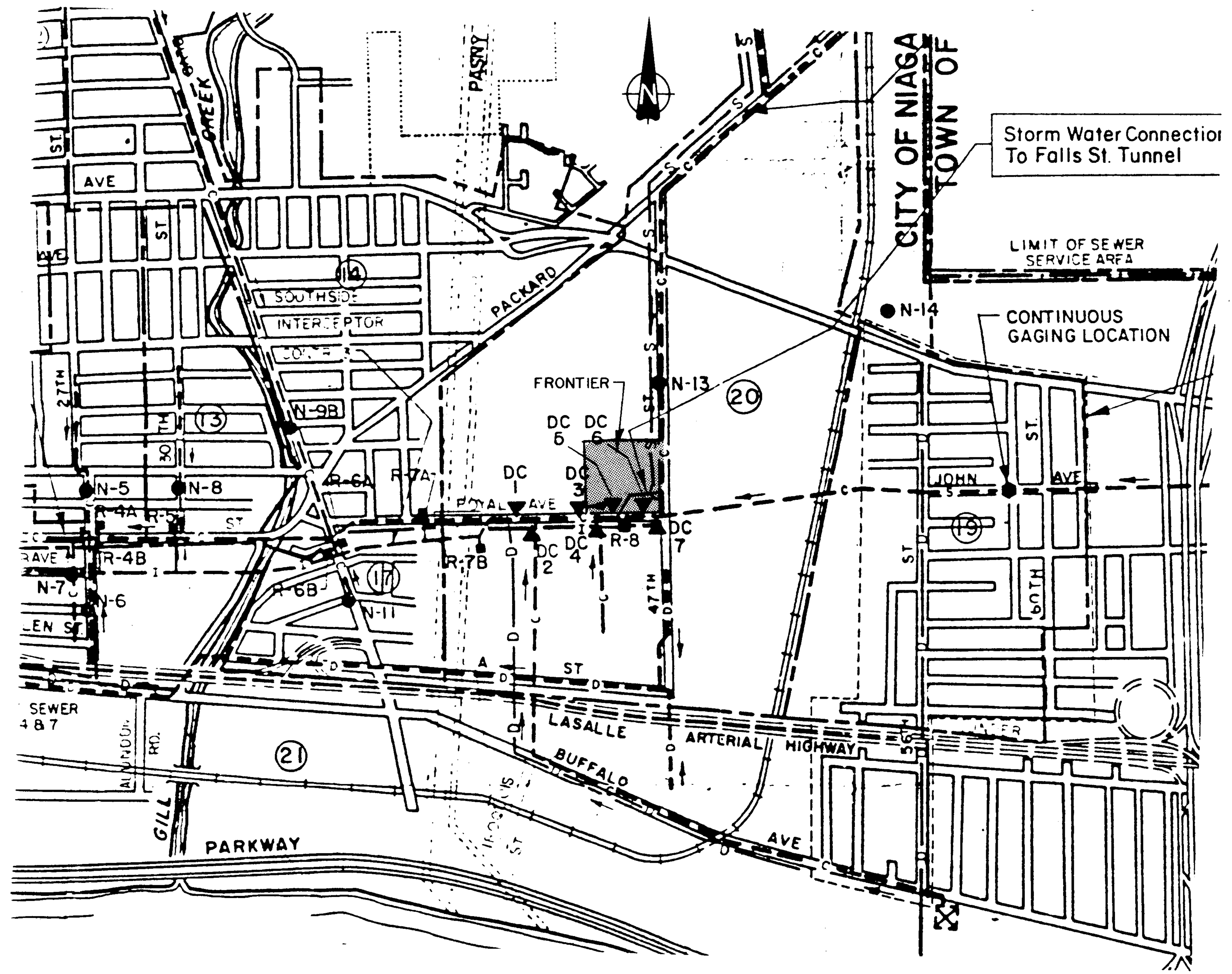
Drawn D.M.

Chkd MA

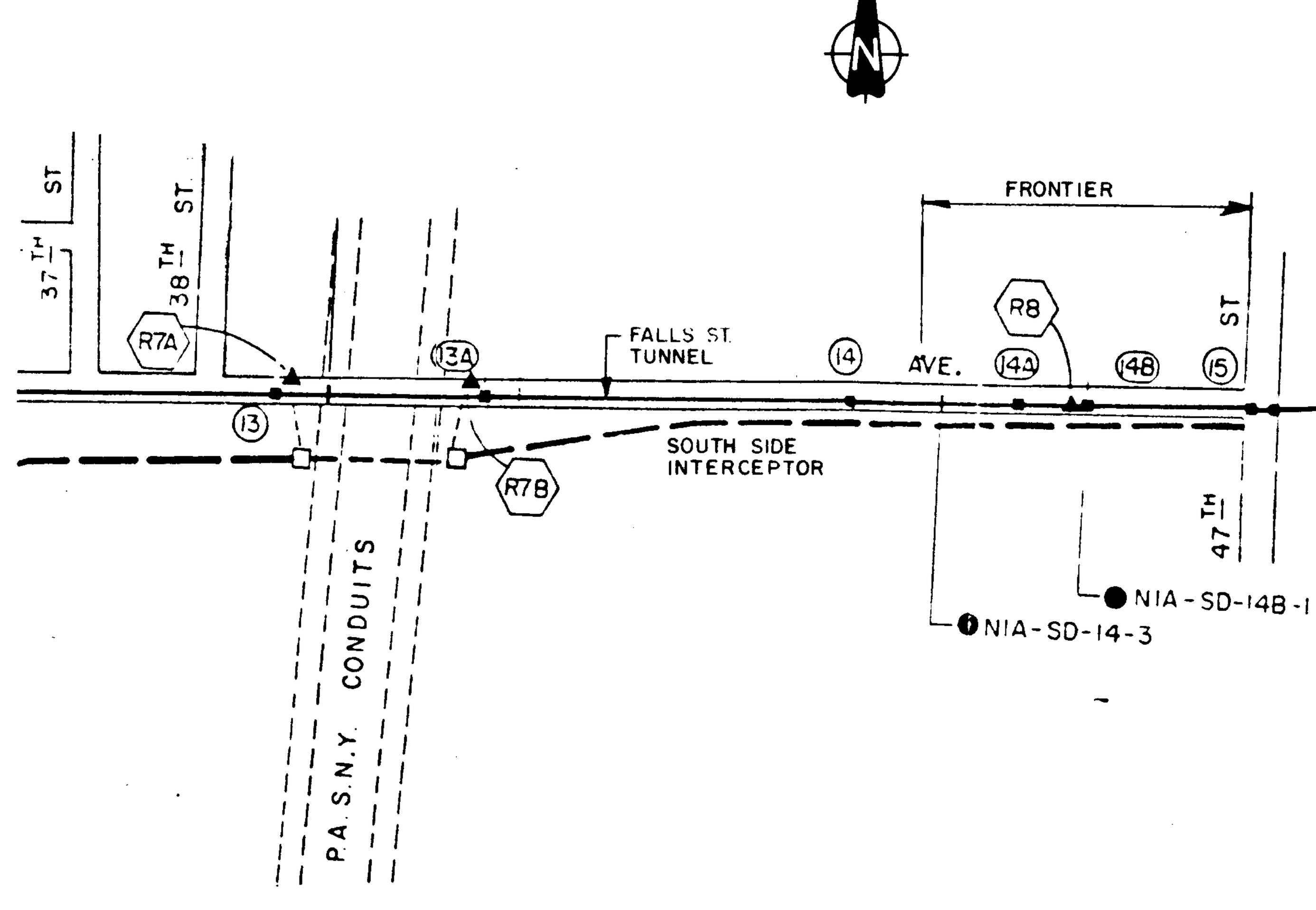
PLAN AND SECTION FALLS STREET TUNNEL

FIGURE 16



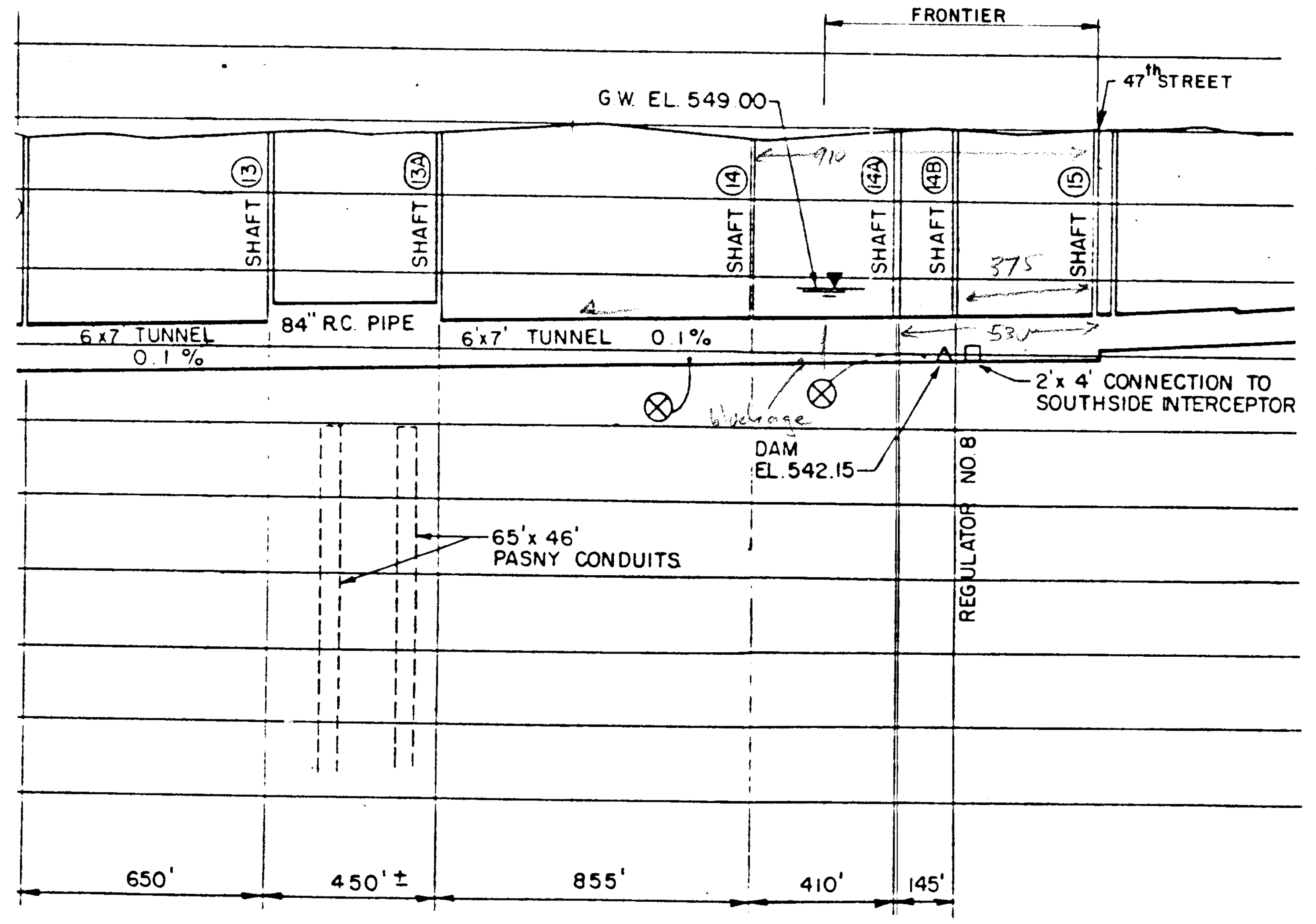
OVERALL PLAN

SCALE: 1" TO 1000'



PLAN NEAR FRONTIER

SCALE: 1" TO 400' (APPROX.)



SECTION ALONG ROYAL AVENUE NEAR FRONTIER

SCALE: HORIZONTAL 1" TO 400' (APPROX.)
VERTICAL 1" TO 20' (APPROX.)

LEGEND

- ● SEDIMENT SAMPLE LOCATION
- ⊗ OBSTRUCTIONS
- (R3A) ▲ OVERFLOW REGULATOR AND REGULATOR NUMBER
- (14A) (14) ■ SHAFT LOCATION AND SHAFT NUMBER

REFERENCE: CAMP, DRESSER AND McKEE (1982) FIGURE A.

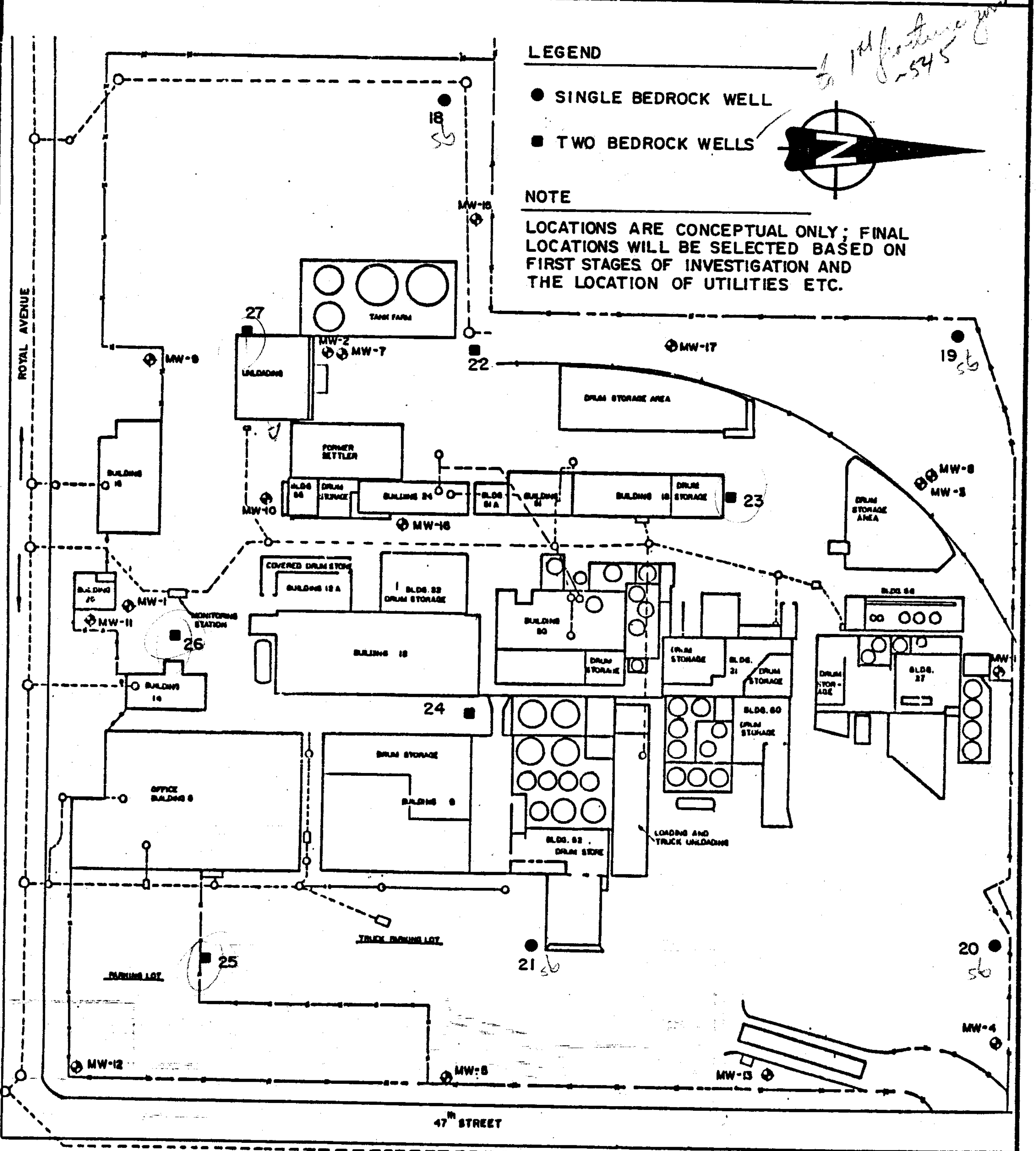
Date: NOV. 18, 1985
Project: 851-1175

Golder Associates

Drawn: G.P.
Chkd: [illegible]

LOCATIONS OF ADDITIONAL BOREHOLES AND BEDROCK MONITORING WELLS

FIGURE 17



SCALE: 1 INCH TO 100 FEET

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Date NOV. 15, 1985
Project No. 851-1275

Drawn D. M.
Chkd. M