Telephone 615/336-4000
Fax no. 615/336-4505

Olin CHEMICALS

P. O. Box 248, Charleston, TN 37310

RECEIVED
AUG 29 1989
Bureau of Hazardous Waste Facility Permitting
Division of Hazardous Substances Regulation

LETTER OF TRANSMITTAL

TO Jean Dubois, PE
NYSDEC
Albany - NY

DATE 8/25/89

RE: Olin NF Groundwater Assessment

GENTLEMEN:

WE ARE SENDING YOU ☐ Attached ☐ Under separate cover via ____________ the following items:

☐ Prel. drawings ☐ Prints ☐ Draft report ____________

☐ Analytical data ☐ Specifications ☒ Final report

Copies	Prepared by	Description
1	Woodward Clyde	Groundwater Assessment & Attachments (3 vols)

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ Approved as submitted ☐ Revise and resubmit

☒ For your information ☐ Approved as corrected ☐ Copies for distribution

☒ As requested ☐ Returned for corrections ☐ Corrected prints

☐ For review and comment ☐ ____________

REMARKS As agreed to in our meeting of 8/89

COPY TO DCC

SIGNED [signature]

OLIN CORPORATION
ENVIRONMENTAL AFFAIRS DEPARTMENT

GROUND WATER ASSESSMENT

OLIN CHEMICALS
BUFFALO AVENUE PLANTS
NIAGARA FALLS, NEW YORK

for:

Olin Corporation
Charleston, Tennessee

October 1988

Woodward-Clyde Consultants

Consulting Engineers, Geologists, and Environmental Scientists
2822 O'Neal Lane, Baton Rouge, LA 70896

GROUND WATER ASSESSMENT

OLIN CHEMICALS
BUFFALO AVENUE PLANTS
NIAGARA FALLS, NEW YORK

for:

Olin Corporation
Charleston, Tennessee

October 1988

Woodward-Clyde Consultants

Consulting Engineers, Geologists, and Environmental Scientists
2822 O'Neal Lane, Baton Rouge, LA 70896

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

LIST OF PLATES

LIST OF APPENDICES

EXECUTIVE SUMMARY

This report presents findings on the condition of ground water quality, and on the potential for offsite transport of chemicals in ground water at the two Buffalo Avenue plants in Niagara Falls, New York. Archived historical, hydrogeological, and analytical data have been synthesized into a base for this assessment.

Olin's operations have qualitatively changed little over the century-long history of these facilities, centering around the electrolytic production of caustic soda and chlorine from rock salt using various modifications of the mercury-cell/chlor-alkali process. Several organic chemicals, including benzene, chlorobenzene, trichlorobenzene, trichlorophenol, and BHC (hexachlorocyclohexane) were used or manufactured in a small part of the Plant 2 facility between 1950 and 1956.

The Olin plants lie on or near the crest of an isolated bedrock ridge. Unconsolidated soils overlying the bedrock range in thickness from 4 to 13 feet across the two plants. Although most of the overburden has been modified by excavation and fill, fine-grained glacial lake sediments and more recent marsh deposits characterize undisturbed remnants of the original soil sequence. Ground water occurs at 5 to 10 feet below the surface in the overburden and flows radially from the bedrock crest toward Gill Creek on the east and the Upper Niagara River to the south (See Sections 3.1, 4.2, and 4.4).

The overburden is underlain by more than 150 feet of the Lockport dolomite. Four significant water-bearing horizontal bedding plane fracture zones have been identified on adjacent DuPont properties within the upper 100 feet of the Lockport, and can be expected beneath the Olin plants. These zones are identified as the B-, CD-, D- and F-Zones (See Sections 3.2 and 4.3).

A system of ten monitoring wells was installed in the Alundum Road-Gill Creek (ARGC) section in 1978. Five wells were installed in the unconsolidated overburden and five in the upper 10 feet of the bedrock (See Section 4.1). Mercury, organic compounds used in BHC production, and BHC are detected at cumulative concentrations averaging less than 10 parts per million (ppm) in both

overburden and shallow bedrock ground water beneath the ARGC section of Plant 2. Mean concentrations in the overburden are about half of those in samples from the shallow bedrock (See Section 5.3).

Analytical data from shallow soil borings show that with the exception of BHC, potentially Olin derived organic compounds were not detected in plant site soils outside of the ARGC section. Elevated concentrations of mercury were found inside and outside of the ARGC section, as were lower levels of the coal derivatives flouranthene, phenanthrene and pyrene (See Section 5.2).

Chlorinated phenolics, benzene, chlorobenzene, and BHC, all potentially Olin-derived compounds found in ground water beneath the ARGC section, are also present at very low concentrations in untreated ground water produced by the cooling water wells on Plant 1.

The primary factor influencing ground water flow west of Gill Creek in the bedrock aquifers is the rate of pumping from the Olin cooling water supply wells. Ground water withdrawal from these wells currently averages a minimum of 500 gpm and is sufficient to create cones of depression within each of the principal water-bearing bedrock bedding planes which extend to the vicinity of Gill Creek.

The Olin production wells and treatment system have formed a part of the DuPont ground water remediation program since February 1985. Approximately 50 lbs per day of organic compounds are removed from the discharge of these wells using an activated carbon treatment system. Removal rates for potentially Olin-derived organic compounds from the production well capture zone are calculated to be as high as 0.13 lbs/day for benzene, chlorobenzene, and BHC, and up to 0.20 lbs/day for the phenolics. Non-Olin sources for these compounds exist in the Buffalo Avenue industrial corridor, but offsite data indicate that, regardless of source, these compounds locally have a limited vertical distribution, being largely confined to the overburden and uppermost bedrock B-Zone (See Sections 6.0 and 6.1).

It is not possible to precisely define the extent of hydraulic influence of the Olin production wells on the Olin plants with the existing data base. It is likely, however, that both Olin plants probably fall within the CD-Zone cone of depression. The cone is believed to be less extensive in the B-Zone and may not include all of the ARGC section (See Section 5.4).

The relatively low concentrations of organic compounds present in the ARGC combined with the influence of Olin ground water withdrawal suggest that migration of Olin-derived chemicals from the Olin plants is not significantly affecting ground water quality on a regional scale. Although a regional ground water gradient exists for transport from the area east of Gill Creek toward the NYPA conduits, the principal potential ARGC Olin compounds, with the exception of BHC, do not appear in U. S. Geological Survey (USGS) monitoring well data from the Olin side of the conduits (See Section 6.2).

Potential loadings of organic compounds to Gill Creek from the overburden were calculated using the mean concentration levels from the ARGC deeper well data, and ground water flow estimates obtained from a simple water budget model. A loadings range of between 0.56 and 0.24 lbs/day has been calculated, which is similar to earlier estimates developed using hydrogeological methods. Such a loading is on the same order as the estimated rate of removal by the Olin production wells (See Section 6.3).

1.0 INTRODUCTION

The Olin Corporation (Olin), under its present name, and earlier as the Olin-Mathieson Chemical Corporation, the Mathieson Chemical Company, and the Castner Electrolytic Company, has manufactured chemical products in Niagara Falls, New York, since 1897. Production has occurred at two plant sites located south of Buffalo Avenue approximately 1000 feet north of the Upper Niagara River (see Figure 1).

A map showing the two plants in more detail is given in Figure 2. The smaller (6 acre) western Plant 1 site is separated from Plant 2 by Chemical Road and by 300 feet of property owned by E. I. DuPont de Nemours and Company (DuPont). Plant 2 (16 acres) is divided into two sections by Alundum Road (private). This operating plant is bounded by Adams Avenue and DuPont to the south and, on the east, by the bed of Gill Creek, a small channelized stream flowing into the Upper Niagara River.

Olin's principal business in Niagara Falls has always centered around the electrolytic production of chlorine and caustic soda from rock salt (sodium chloride) using various modifications of the mercury-cell/chlor-alkali process. Mercury cells were once operated on both plant sites, but have been confined to Plant 2 for the past 30 years. Plant 1 has been largely inactive since the shutdown of calcium hypochlorite (HTH™) production in September 1982 and is presently used only for warehousing and ground water treatment.

Despite the historical predominance of inorganic chemical production at Olin's Niagara Falls locations, several organic chemicals, including trichlorobenzene, trichlorophenol, and BHC (hexachlorocyclohexane), were manufactured in the section of Plant 2 between Alundum Road and Gill Creek between 1950 and 1956.

Olin investigations conducted since 1978 have documented the presence of mercury and a variety of organic chemicals at parts-per-billion (ppb) to parts-per-million (ppm) concentrations in soils and shallow ground water at Plant 2, and in cooling water produced from deeper wells at Plant 1. Since May 1984, Olin has treated ground water withdrawn from the bedrock production wells using activated carbon. DuPont entered into an agreement with Olin in February 1985 under which Olin's production wells and treatment system are operated as part of DuPont's ground water remediation program.

DuPont has conducted ground water studies since 1983, and has made this information available to public agencies. DuPont data form the basis for much of this report and are gratefully acknowledged.

In the early 1980's, the EPA commissioned an effort to estimate individual facility chemical contributions to the Niagara River directly, and via ground water infiltration to the Fall Street Tunnel (Koszalka, et. al., 1985). These two routes are described in more detail later. Both this study and a more recent one conducted for the City of Niagara Falls (O'Brien and Gere, 1987) have claimed a potential for offsite chemical migration in ground water from the Olin Buffalo Avenue plants.

1.1 Assessment Objectives

The purpose of this assessment was to evaluate Olin's impact on ground water and surface water quality based on currently available data. The objectives are, first, to apply existing information effectively to narrow offsite loading estimates to a useful range and, second, to identify any necessary investigatory steps which Olin might take to resolve remaining questions about the nature of migration.

This report focuses on these objectives by comprehensively documenting current ground water conditions at the two Olin plant sites, and by clearly defining the limitations of existing baseline information. Specifically, the information summarized and evaluated falls into the following six categories.

1. Present knowledge of the extent of plant soils conditions.
2. Present knowledge of the extent of shallow ground water quality.
3. Present knowledge of the extent of deeper ground water quality.

4. An evaluation of the potential for lateral offsite migration of chemicals.
5. An evaluation of the effects of the Olin production well on ground water quality beneath Olin plants.
6. Identification of data gaps.

1.2 Assessment Strategy

Much information about chemicals in soils and ground water at the Olin locations has been amassed over the past decade. Additional work on the dynamics of the local and regional ground water systems has been done by Olin, DuPont, and various government agencies, including the U. S. Geological Survey (USGS). Most of this information can be found in public reports and open files. Relevant data collected by Olin have now been systematically collated and evaluated by Woodward-Clyde Consultants (WCC), and are presented here in a form which permits an assessment of onsite conditions and offsite loadings.

This assessment has been based, wherever possible, on primary sources and independent analytical approaches. These are summarized below.

- Archived aerial photographs dating back to 1938 have been analyzed to provide location information for activities which may be linked to observed chemical distributions.

- Analytical information has been extracted, along with relevant QA/QC data, from original laboratory reports. These data have been placed in a relational computer data base (HAZWASTE) which allows reference and permits data retrieval in a variety of formats. A description of the analytical data base, followed by a complete listing of the data, is included in Appendix A. All samples included in the data base include a report reference code. This reference code can be used to identify the original laboratory report from which any analytical result is derived. A complete collection of the original laboratory reports with matching reference codes, is provided in Appendix D.

- Geological and hydrologic information developed during earlier investigations have been evaluated. Complete copies of pertinent Olin reports, including well logs, are collated in Appendix B.

- The locations and elevations of all available sewer system and catchment basin manways and stubs have been placed on a computer data base in order to permit ready access to information on possible man-made contaminant migration routes. A description of this data base and a listing are provided in Appendix C.

- The two plant sites have been remapped using low-altitude, high-resolution, black and white controlled stereo imagery. This permits discrimination of surface drainage patterns, as well as present building and pavement boundaries.

- The new map base has been utilized to organize all existing geologic, chemical and subsurface utility information according to location. This approach facilitates coherent presentation of information contained in the various data bases in a range of map overlay formats.

- The most current USGS and DuPont geological and hydrological data have been combined with information developed by Olin to provide a more comprehensive understanding of subsurface flow regimes.

- Subsurface flow estimates in the upper water-bearing zone have been independently assessed using a simple water balance model developed by the USDA Soil Conservation Service (SCS 1975).

- Investigative strategies are suggested to close specific data gaps identified as part of the assessment process.

Some preliminary information is required before the primary objectives can be directly addressed. Specifically, the next section starts with a review of past and present operations at the two Olin plants. Then, the aquifer systems in the

Niagara Falls region, and the various large-scale influences which affect them are described from the regional hydrogeological literature.

The main body of the report is directed toward what Olin, DuPont and USGS investigations have shown with respect to ground water dynamics and contaminant levels in the immediate vicinity of the Olin plant sites. The organization follows the six objectives outlined previously, covering sequentially the condition of the soil, shallow ground water, and deeper (bedrock) ground water for specific contaminant classes. Subsequent sections contain an analysis of the potential for offsite contaminant migration and an evaluation of the effectiveness of existing remediation efforts.

The report concludes with a synthesis of the state of existing knowledge and the identification of key subjects requiring further investigation.

2.0 PLANT HISTORY

Apart from the Saltville, Virginia, works, Olin's Niagara Falls plants are the oldest Olin facilities presently in operation. Thomas Mathieson, the founder of Olin Corporation, came to Niagara Falls along with many other industrialists in the 1890's to take advantage of the abundant electrical power available from the first commercial alternating current hydroelectric plant built in North America. He constructed a mercury cell room on the Plant 1 site and initiated production of chlorine and caustic soda under the name of the Castner Electrolytic Company in November 1897. The first cell room was built on the northern part of the site just south of Buffalo Avenue as the remainder of the property consisted of low-lying marshlands.

The Plant 2 site was acquired incrementally between 1901 and 1942, although parts were leased before this from Niagara Mohawk. The part of Plant 2 from the present cell room east to Gill Creek was the last section incorporated and was previously the location of Norton and Star Electrode.

The demand for land south of Buffalo Avenue led to large-scale reclamation efforts by DuPont and others. This resulted in filling of the former marshes and a gradual southward extension of the shoreline out into what was once the river bed. As a result, the river bank now lies nearly 1000 feet south of Adams Avenue, the southern boundary of the Olin properties. The last 50 years of this filling process, which ended with the construction of the Robert Moses Parkway, are documented in a series of aerial photographs taken in 1938, 1963, 1970, 1972, and 1988, and reproduced in this report as Plates 1, 2, 3, 4, and 5, respectively.

Three other important developments can be seen in this photographic time sequence. First, attention is drawn to the area of the Plant 2 site between Gill Creek and Alundum Road which is vacant in the 1938 photograph, but shows at least five buildings in the 1963 image. Two of these buildings were tied to Olin's brief venture into organic chemical production in the 1950's. The cluster of tanks which first appear in the northeastern corner of this area in the 1963 photograph are settling tanks associated with the chlor-alkali operation.

The rest of the two plant sites were heavily developed by 1938. In fact, the second most obvious change in the 1938-63 sequence, which is also apparent in the 1963-70 interval, is the removal of large buildings in the northwestern quadrant of Plant 2. These changes were a consequence of the early 1960's conversion of chlor-alkali processing from rocking cells to more efficient stationary amalgam cells.

The third major change visible in the photo time-series is the appearance of track sidings and a large tank between 1972 and 1988 in the previously cleared area west of Alundum Road at Plant 2. These facilities were constructed in 1986 as part of the joint Olin/DuPont Niachlor Chloralkali project.

2.1 Operations

2.1.1 Chlor-Alkali Process and Products. Olin's principal Niagara operations have qualitatively changed little since start-up nearly a century ago. Caustic soda (sodium hydroxide) and chlorine continue to be produced from sodium chloride brine by electrolysis in mercury cells. In the modern chlor/alkali cells located in the one remaining cell room at Plant 2 (see Figure 3), mercury flows by gravity in a thin layer along the bottom of a steel electrolyzer trough and serves as the cathode in the electrolytic cell. The brine flows on top of the mercury. The sodium/mercury amalgam formed is removed at the end of the cell. It then goes to a decomposer where it is reacted with water to form caustic soda. The denuded mercury is then collected in a sump from which it is returned to the top of the electrolyzer to begin the cycle again. Chlorine gas collects in the cell chamber above the anodes and goes from there to the cooling, drying, and liquefaction part of the plant.

Insoluble brine impurities collect to form a "brine mud" at the bottom of settling tanks. This mud, which may contain up to 50 ppm mercury, must be periodically removed and constitutes the primary waste product of the chlor-alkali process. Mud is accumulated in a concrete tank east of Alundum Road (see Figure 3) until it has dewatered sufficiently to be loaded onto trucks for offsite disposal. Water decanted from the waste is collected and recycled to the production process.

Waste handling occurs under the provisions of Resource Conservation and Recovery Act (RCRA) Permit No. NYD002123461.

Several products have been developed as side-streams of the chlor-alkali process at the Plant 2 location. Sodium methylate has been produced since 1941 in reactors combining sodium and methyl alcohol, and, since October 1986, potassium hydroxide has been added to the product line.

Sodium chlorite production was initiated in 1941 using recycled sulfuric acid from the chlorine drying towers. The Olin Niagara plant is currently the only commercial sodium chlorite facility in the United States.

2.1.2 Calcium Hypochlorite (HTH™ Dry Chlorinator). Calcium hypochlorite was produced between 1927 and 1982. Shut-down of this operation marked the end of active chemical production at Plant 1.

2.1.3 Synthetic Ammonia. Synthetic ammonia was produced for the first time in North America at the Olin Plant 1 location in 1922, but was discontinued in 1962.

2.1.4 Pesticide Organics. Olin began producing organic pesticides in the eastern section of Plant 2 lying between Alundum Road and Gill Creek in 1950. Specific chemicals produced were benzene hexachloride (BHC), trichlorobenzene, and trichlorophenol.

BHC operations were begun 1950. In 1955, efforts were undertaken to upgrade the gamma isomer of the saleable product. Building No. 75, located in the southern part of the Alundum Road-Gill Creek area (ARGC), was the center for this work (see Figure 3). An explosion on August 6, 1956, destroyed most of the building, and resulted in termination of BHC production. The eastern part of No. 75 has since been rebuilt, but a concrete slab extending west of the existing structure still marks the location of the section destroyed.

Trichlorobenzene was produced from 1950 to 1956, and trichlorophenol from 1954 to 1956, in Building No. 97 located adjacent to Alundum Road in the eastern portion of the ARGC area (see Figure 3). These operations were linked to the BHC project and were discontinued shortly after the explosion.

2.1.5 Other Discontinued Products. Other Olin Niagara products that have been discontinued include bleaching powder (1897-1945), tin tetrachloride (1906), sulfur monochloride (1908), diglycolic dihydrizide (GX, 1957-1959), and OMSET (1957-1959).

2.2 Water Supply

From the beginning, Olin's Buffalo Avenue chlor-alkali works required an abundant supply of fresh water for cooling and liquefying the chlorine gas produced. Initially, this demand was met solely by pumping from the river. It was found, however, that cooling efficiency was compromised by the wide seasonal temperature range of the river water. A search for a water supply with a more constant year-round temperature led to the drilling of several wells on the Plant 1 and Plant 2 properties in the 1930's. No information other than location is available for the wells drilled at Plant 2, however, installation and testing of the Plant 1 wells are described in some detail in a 1947 report included with the geologic data in Appendix B. The Plant 2 wells did not produce in sufficient quantity and were not used extensively.

The two wells presently in use are 24-inch diameter wells drilled in 1947 to a depth of 125 feet. They are spaced approximately 15 feet apart along a north-south line. They are located in a pump house on the eastern margin of the Plant 1 site (see Figure 3) and have been successfully pumped at a combined rate in excess of 2500 gallons/minute (gpm). They currently produce water at an average rate of 750 gpm because of reduced demand and provide approximately 25% of the cooling water used at Plant 2.

Due to the large concentrations of organics contained in ground water withdrawn by the production wells and discharged from the cooling towers, Olin initiated activated carbon treatment in 1984 as a condition for permitting under the State Pollution Discharge Elimination System (SPDES). In 1985, DuPont entered into an agreement with Olin such that Olin now operates its production wells and treatment facility as a part of DuPont's ground water remediation program. Approximately 50 lbs of organic compounds are removed each day from ground water by the Olin water treatment system.

2.3 Areas of Concern

Plant areas likely to be most affected by the activities described above are expected to be linked to present or past building locations identified on Figure 3. The locations of former organics production facilities in the ARGC makes this entire area one of particular importance.

Mercury cell operations have been widely distributed across the northern parts of both plant sites for nearly a century (see Figure 3). The "brine mud" handling operations in the northeastern part of the ARGC section constitute an additional possible source of mercury.

Since 1978, regulatory attention has been directed at several other areas. Olin reviewed its past waste disposal practices at that time, in response to a questionnaire circulated by the Interagency Task Force. Olin reported that in September 1957 and July 1958 approximately 264 cubic yards of brine mud containing up to 50 ppm mercury were used as fill in two locations at Plant 2, and in one location at Plant 1. These sites are identified in Figure 4 as the Building No. 13 and Building No. 46 sites, both on Plant 2, and the Gas Holder site on Plant 1.

On the basis of this information, the New York Department of Environmental Conservation (NYDEC) designated the entire Plant 2 facility in December 1985 as an "Inactive Hazardous Waste Disposal Site" (DEC Site No. 932051-b). The plant was alleged by NYDEC to pose a "significant threat to the public health or environment." Olin has since supplied NYDEC with information showing that the Building No. 13 location was excavated to a foot or more in 1978, and to greater depths in 1986. The boundaries and depths of these excavations are shown in Figure 5. The Building No. 46 and Gas Holder locations have been paved with asphalt.

Two additional Plant 2 locations, also shown on Figure 4, designated the Pond and Disposal Well, were placed on the list pending development of additional information (DEC Site Nos. 932038 and 932037, respectively).

The location designated as the Pond was a temporary earthen impoundment reportedly used for two to three months in 1970 to receive recycled overflow water from the cell room during upgrading of the waste water treatment equipment. This overflow water is presumed to have contained mercury at concentrations between 0.5 and 1.0 ppm. Very little is known about this impoundment except its approximate location adjacent to the cell room. No evidence of such a pond is visible in aerial photographs from late June 1970 (Plate 3) or from May 1972 (Plate 4). Much of the area thought to have been occupied by this pond was excavated to bedrock during construction of the Niachlor caustic storage facility in 1986 (see Figure 5).

The Disposal Well site (DEC Site No. 932037) is an abandoned Plant 2 water well which was used during the period between 1963 and 1977 to dispose of an estimated 130,000 tons of an end liquor consisting of water (60-65%), sulfuric acid (30%), and sodium chlorite (5-10%). The liquor was discharged to the well with a gravity feed. No information exists concerning the construction of this well, but it is presumed to have been drilled in the 1930's or 40's, and to be similar to other Olin exploratory water wells (125 feet deep). This well has been covered with a concrete pad. The site is presently a Class 4 site properly closed; requires continued management on the NYDEC site registry.

Coal was used in the past at the Olin plants along with coal tars, at adjacent plants (Great Lakes Carbon and Carborundum), and at companies which preceded Olin at the Plant 2 location (Star Electrode, Norton). Coal tar derivatives or polynuclear aromatic hydrocarbons (PAH) are found, both in the vicinity of former stockpiles and loading areas, and are ubiquitous in the Niagara Falls area. Coal piles and handling areas are thought to have been located at various times in the ARGC section, around the two obsolete plant boilerhouses shown in Figure 4, and along adjacent railroad sidings.

3.0 REGIONAL HYDROGEOLOGY

Ground water recharge, movement, and discharge in the Niagara Falls area is affected by both natural and man-made factors. The characteristics of the soils and rock underlying the plant sites affect the rate at which chemicals introduced at the surface are mobilized in the uppermost water bearing zone. The degree to which this zone is connected with lower-lying permeable layers governs the potential for vertical migration. Excavation and filling activities affect soil properties in the upper 10 feet. At greater depths, the horizontal and vertical transmissivity of the strata are determined by the depositional and diagenetic history.

A complex sequence of geologic events has resulted in the placement of two sedimentary units of very different ages, origins, and characteristics in direct contact in the Niagara Falls area. A veneer of unconsolidated Pleistocene glacial till and fine-grained lake bottom sediments less than 20,000 years old overlie 80 to 158 feet of dolomite bedrock deposited as limestone in the Middle Silurian period (350 million years before present (BP)). Water moves through the glacial deposits at rates determined by the local texture of the unconsolidated sediment matrix. The dolomite, however, is essentially impermeable except where dissolution channels have developed along horizontal bedding planes or through vertical fractures and joints. A 60-foot thick sequence of impermeable calcareous shale, the Rochester Formation, underlies the Lockport, and separates lower-lying aquifers from those connected with the surface. Exclusive of man-emplaced fill, the Pleistocene glacial deposits and the Lockport bedrock are the only two units of interest here. The thickness, lithology, and hydraulic characteristics of the deposits underlying the Niagara Falls area have been extensively studied by the USGS (Maslia and Johnston, 1982) and are summarized in Figure 6.

3.1 Glacial Deposits

Prior to excavation and filling activities associated with development of the Plant 1 and 2 sites, glacial deposits occurred beneath both locations. Remnants of these deposits may still be found in some undisturbed areas, particularly where the overburden sequence is thicker, as at Plant 1.

Continental ice masses moved south across the Niagara Falls region during the most recent Wisconsin glacial advance. The ice sheet plucked loose and weathered rock from the bedrock surface and removed unconsolidated deposits remaining from earlier glacial and inter-glacial periods. During the retreat of the ice approximately 12,000 years BP, these glacially transported materials, or till, collected in unstratified, unsorted deposits. In some places, these materials have been reworked into better sorted alluvial deposits by glacial outwash streams. Elsewhere, they remain as originally deposited and may contain the full suite of sediment sizes, from boulders to clay. The permeability of the unsorted deposits is typically low, with hydraulic conductivities of less than 0.5 feet/day. Gravel or sand-rich alluvial deposits are more permeable and may exhibit higher conductivities.

The retreating ice left large accumulations of till blocking northward drainage from the ancestral Lake Erie. Lowlands south of the Niagara escarpment, including the Niagara Falls area, were inundated by a large water body which has been named Lake Tonawanda. Sandy beach deposits associated with the margins of this lake are found at places to the north of the Olin location where the bedrock protrudes above the present 585-foot MSL contour line (Calkin and Brett, 1978). Relatively fine-grained sediments were deposited in deeper waters at places with lower bedrock elevations, as at the Olin location (560 feet MSL).

Calkin and Brett (1978) describe the glacial sedimentary sequence which was exposed during excavations for a new sewage treatment plant approximately 1000 feet west of the Olin Plant 1 site. They found a basal till unit of stony, silty sand in contact with the striated bedrock surface. The till was overlain by a red, varved silt and clay deposit which is believed to have formed in a glacial outwash lake predating Lake Tonawanda. A mottled, silty, fine-sand and silt unit found above this deposit is ascribed to the period of Lake Tonawanda. This unit fined upward to a woody peat with sand stringers. This peat is believed to have formed in the same marsh environment which characterized the northern bank of the Upper Niagara River prior to reclamation in the last century.

Undisturbed overburden soils on the Olin plant sites can be expected to exhibit the same textural diversity encountered at the sewage treatment plant location. The thickness of the overburden, however, is largely governed by the topography of the top of the bedrock surface. It thickens up to 48 feet over bedrock swales and valleys, and thins to just a few feet on the crests of bedrock ridges (Miller and Kappel, 1986). This topography is shown in Figure 7. It should be noted that the Olin plants are located above an isolated local bedrock high situated on the western flank of a north-south trending bedrock valley.

3.2 Bedrock

The Lockport Dolomite provides most of the ground water used in the Niagara Falls area and is the source of the cooling water pumped by Olin. The upper 15 feet of the bedrock has been repeatedly exposed to weathering, and to flexure associated with tectonic processes and glacial rebound. This zone is characterized by an abundance of vertical joints and passageways for water along bedding planes. Water-bearing bedding planes and vertical fractures are also found less frequently at greater depths.

Bedding planes follow the 23 to 29 feet/mile slope of the top of the bedrock surface south from a high at the Niagara escarpment (Figure 7). Johnston (1962) examined the bedding planes exposed in the upper 100 feet of the Lockport during excavation for the conduits of the New York Power Authority (NYPA) Niagara Power Project. Twin conduits placed in these excavations now conduct water northward from the river for four miles to a pumped-storage hydroelectric facility. The conduit intakes are located 2000 feet east of the Plant 2 site.

Johnston (1962) noted water seeping from seven thinly-bedded zones interspersed through the generally massive dolomite. These zones are shown in a stratigraphic cross-section reproduced in Figure 8. Johnston (1962) also observed numerous vertical joints exposed on the rock face. He found that while some had been widened by solution, most were tight and incapable of transmitting water. Joints in the upper 15 feet of the bedrock had been widened by solution but were filled with fine-grained mud.

Despite the presence of vertical connections between distinct Lockport aquifers, piezometric levels measured in adjacent wells screened in progressively lower water-bearing zones show a step-wise decrease in elevation. Johnston (1962) found that when a well was drilled through the uppermost water-bearing zone, the water level measured in the well initially rose, but then remained roughly constant until a second water-bearing zone was encountered. Then the water level abruptly declined to the piezometric level more representative of the lower zone. Each water bearing zone may, therefore, be considered a separate confined aquifer, in that vertical permeability through joints and fractures is greatly exceeded by horizontal permeability along bedding planes. Ground water has the potential to move downward from upper to lower zones wherever vertical connections exist as the hydraulic head decreases with the depth of the water-bearing zone.

Well yields in the Lockport, though higher than in the overburden, are typically quite low, ranging from 10 to 100 gpm (Johnston, 1964). Hydraulic conductivities range from 1 to 1,000 feet/day (WCC, 1986). Near the river, however, induced infiltration augments well yields. The USGS (Yager and Kappel, 1987) suggest that deep basin faulting associated with tectonic plate movements (Sanford, et. al., 1985) may be responsible for a band of high yielding wells which starts at Olin and appears to trend northeast away from the river. Yager and Kappel (1987) note that this trend follows the orientation of the predominant joint set. (N70°E to N80°E). Such a feature might locally affect infiltration and recharge by increasing fracture density and the width of joint openings along its strike. The nature of this structure has not been confirmed.

3.3 Regional Influences on Ground Water Flow

Man-made and natural factors affect the rate and direction of ground water movement through the overburden soils and bedrock. Some of these influences have been mentioned earlier, but are described more fully here.

3.3.1 Natural Factors. The USGS (Miller and Kappel, 1986) has attempted to reconstruct the probable pattern of regional ground water flow in the overburden and upper weathered section of the Lockport prior to major human alteration. This interpretation is depicted on the map shown in Figure 9 and should be compared with the bedrock topography shown in Figure 7. The basic pattern is one of flow away from recharge zones located on bedrock highs to discharge boundaries at the Upper Niagara River on the south, and the Niagara River Gorge to the west. Flow in the vicinity of the plant site is thought to have originally been from north to south, toward the river.

This interpretation differs substantially from an earlier reconstruction proposed by Johnston (1964) which suggested that flow in the southern part of the city moved north and west across the Olin location from the Upper Niagara River around the falls to discharge into the Niagara Gorge. It is now known that the Niagara Gorge influences flow only locally in a 1 to 2 mile wide band in the western part of the city.

The rate of regional ground water flow through the Niagara Falls region prior to significant human influences was determined primarily by rainfall and snowmelt recharge through the soil to the water table. Precipitation in Niagara Falls averages 30 inches/year and is fairly evenly distributed throughout the year. USGS well records indicate, however, that ground water levels exhibit a more seasonal fluctuation. Most infiltration and recharge occurs between November and April, when evaporation from the soil surface and uptake by vegetation is reduced (Miller and Kappel, 1986). This recharge occurs despite the accumulation of snow between December and March. It appears that the occurrence of rapid thaws during this interval may actually contribute to recharge.

3.3.2 Human Influences. Several major projects undertaken since the onset of industrialization have altered ground water flow regimes in the overburden and upper Lockport. Some of the effects of these modifications can be seen in a recent potentiometric surface and flow map constructed by the USGS (Yager and Kappel, 1987), and reproduced in Figure 10.

The single factor which outweighs all others in the vicinity of the plant sites, but which is hardly discernable on the regional flow map (Figure 10), is the cone of depression developed under the Buffalo Avenue plants by the withdrawal of industrial cooling water at Plant 1. Today, Olin pumps at a rate of between 500 and 1000 gpm from one of the two closely spaced supply wells. For most of the forty years since these wells were installed, however, cooling water demand was higher and both of these wells were used simultaneously to deliver water at combined rates up to 5,000 gpm.

Olin's Plant 1 wells are the only industrial supply wells currently active south of Buffalo Avenue and west of the NYPA conduits. Other wells on both the Olin and DuPont properties are known, however, to have been used at least through the 1940's. A DuPont report given in Appendix B describes the effects of interferences between Olin and DuPont wells active during the late 1940's.

A comparison of Figure 10 with Figure 9 indicates that flow directions have changed relatively little over the past century in the western part of the city between the gorge and the bedrock ridge. The position of the ground water divide associated with this ridge is also relatively unchanged. East from this divide, however, the flow regime has been altered profoundly.

Where ground water previously flowed down the east flank of the ridge, and then south toward the river, it now moves westward toward a discharge point located one mile northeast of the Olin location along the NYPA Niagara River Power Project corridor. Ground water flow also converges on this corridor from the east. The map depicts flow in the area of the Olin plants as being north and east, away from the river. It might be incorrectly concluded on the basis of this generalized depiction (Figure 10), which does not show the Olin cone of depression that construction of the NYPA facility has reversed regional ground water flow across the plant location.

This regional flow is reported to be directed toward the intersection of the NYPA conduit excavations and the Falls Street Tunnel (FST) (O'Brien and Gere, 1987). The FST is a 3.5 mile long, unlined tunnel which was bored east-west through the upper part of the Lockport in the early 1900's to carry sewage and storm water to a treatment plant in the Niagara River Gorge below the falls (see Figure 10). A vertical section showing the path of this tunnel through the Lockport, and its relationship to the NYPA conduit excavation is shown in Figure 11a. The cross-section shows that the FST rises into the uppermost weathered zone of the Lockport at approximately the same location that it crosses the buried NYPA conduits.

Sewage and industrial flows were diverted from the FST in 1985, leaving the tunnel to carry only "clear" storm water flow directly to the Niagara River. Recent studies have shown, however, that approximately 9 million-gallons-per-day (mgd) of ground water, in addition to storm runoff, enters the FST. Most of this infiltration is believed to occur through failed gaskets between the concrete pipe sections installed above the NYPA conduits (O'Brien and Gere, 1987). A diagram showing the crossing and the points of infiltration in more detail is given in Figure 11b.

Because the ground water entering the FST is contaminated with volatile organic pollutants, the FST now constitutes a source of contamination to the lower Niagara River. According to USEPA and NYDEC, it must be treated by the city. The total volatile organic pollutant loading from the FST has been estimated at 20 to 50 lbs/day (O'Brien and Gere, 1987).

The subsurface area drained by the NYPA conduits is not precisely known. O'Brien and Gere (1987) concluded that the organic pollutants entering the FST might be derived from as many as 23 chemical plants and waste disposal facilities located within an 11 square mile area surrounding the NYPA corridor, the FST, and associated feeder tunnels (Figure 12). All of the sites indicated, with the exception of three, are located east of the NYPA corridor. Olin's Plant 2 is one of the three potential sources identified to the west. DuPont is a second, and Solvent Chemical, a former chlorinated benzene production facility located east of Gill Creek, is the third.

The creation of a major new discharge point in the vicinity of the FST crossing is the most important influence of the NYPA project on ground water flow in the Niagara Falls area. Another change associated with this project is the creation of a significant recharge area northeast of the city. Recharge occurs there through the unlined bottom of the large pumped-storage reservoir west of the northern terminus of the conduits. It is unlikely, however, that this recharge significantly influences the Olin plant area as it appears that little ground water crosses the NYPA corridor (Koszalka, et. al., 1985).

Other effects of the NYPA project on the Upper Niagara River are not apparent on potentiometric maps. A gated structure which partially crosses the river downstream of the Olin location can be seen in Figure 12. The gates in this structure are closed on a regular schedule to raise water levels upstream and thereby increase the rate at which water is diverted to the NYPA power plants. During the tourist season, between April 1 and October 31, it is mandated that at least 100,000 cubic-feet-per-second (cfs) out of a total peak river flow of 204,000 cfs must be allowed to pass over the falls during daylight hours. At night, and during the rest of the year, flow over the falls can be reduced to 50,000 cfs. At these times, as much as 75% of the total flow of the river may be diverted through conduits to hydroelectric plants. This diversion schedule results in 2-foot daily and seasonal fluctuations in river stage adjacent to the Olin plants. These "tides" are transmitted to the bedrock ground water system. Investigations conducted by Woodward-Clyde Consultants (WCC) on the DuPont plant have shown that water levels in bedrock wells located as much as 1500 feet from the river rise and fall in phase with the river, but with damped excursion amplitudes (WCC, 1983).

4.0 LOCAL HYDROGEOLOGY

Hydrogeological information specific to the Olin plants has been developed by drilling and testing wells installed on or near the Olin property. The combined Olin and DuPont well network is shown in Figure 13.

4.1 Monitoring Wells

Approximately 70 ground water monitoring wells have been installed by DuPont in clusters located on several DuPont properties surrounding the Olin plants. The DuPont clusters include overburden wells with the bottom of the screened interval screened at the interface between the unconsolidated soils and the top of bedrock. This uppermost ground water-bearing stratum is DuPont's "A" Zone. Additional wells in each cluster monitor the bedrock and are open to successively deeper bedding plane water-bearing zones in the upper 100 feet of the Lockport formation. A diagram showing typical construction of the DuPont wells is presented in Figure 14.

Olin has installed ten monitoring wells in the eastern part of Plant 2 between Alundum Road and Gill Creek. The installation and testing of these wells is described in a report by Harza Engineering (1979a) which is included in Appendix B. The Olin wells are of two types, as is also shown in Figure 14, and appear to monitor somewhat different strata than do the A-Zone DuPont wells. Five of the borings (BH-2, BH-5, BH-6, BH-8, BH-9) were advanced to the top of the bedrock. Well points were then installed with the bottom of the screened interval perched on the bedrock. The remaining five Olin monitoring wells (BH-1, BH-3, BH-4, BH-7, BH-10) were drilled between 6 and 10 feet into the bedrock and installed as shown in Figure 14.

The fracture zone classification of bedrock wells in the Niagara Falls area must be established with care. The Olin wells have generally been assumed to be A-Zone or regolith wells. However, it appears from the log of BH-1, which is shown in Figure 15, that this well may actually monitor DuPont's B fracture zone rather than the overburden. The B-Zone of the bedrock is operationally picked by

DuPont's geologists as the first bedrock fracture zone encountered in which fluid circulation is lost. A significant fracture zone was penetrated by the bit approximately 3 feet into the bedrock during drilling for BH-1, and fluid circulation was lost at this point. No mention of similar fracture zones appears in any of the other Olin logs.

The local topography of the bedrock surface developed from the logs of Olin and DuPont wells, and from those of shallow borings, is shown in Figure 16. The geological characteristics of the plant site overburden and bedrock are considered separately below.

4.2 Overburden

A comparison of the local bedrock topography with the regional bedrock surface depicted in Figure 7 shows that the Olin plant lies on or close to the crest of an isolated bedrock high which trends northwest-southeast across Plant 2. Maximum bedrock elevation on the Olin property is approximately 566 feet above MSL and is found close to Buffalo Avenue in the north-central part of Plant 2 just west of the active cell room. The top of the bedrock drops in all directions from this point, except possibly to the northwest, at a slope of approximately 1 ft/100 ft. The ground surface across the two plants is essentially without relief, and, as is shown in Figure 2, lies at a uniform elevation of approximately 571 feet MSL. Consequently, the thickness of the overburden ranges from 4 to 13 feet across the two plant sites.

Harza Engineering (1979a, 1979b) describe the stratigraphy exposed in an 8-foot deep trench excavated at Plant 1, and in cores obtained during the drilling for the wells in the ARGC section. Locations of the trench and wells are shown in Figure 13.

The stratigraphic sequence exposed in the Plant 1 trench is shown in Figure 17 and appears to correspond to the upper part of the section described by Calkin and Brett (1978) from the sewage treatment plant excavation 1000 feet to the west. The major difference is that no till was encountered in the Plant 1 trench.

Instead, approximately 4 feet of mottled clayey silt deposits directly overlie the bedrock. These are lake deposits which may be correlated to the Lake Tonawanda unit identified by Calkin and Brett (1978). As was observed at the treatment plant site, the lake deposits become more organic toward the top of the unit indicating a transition to a marshy depositional environment. Harza Engineering (1979b) interpret the abundance of plant roots at the top of the marsh deposit as the position of the original ground surface prior to industrial development. The rooted surface was overlain by 3 feet of coarse-grained rubble placed to bring the surface up to its present grade.

Geologic information from the drilling of wells at the Plant 2 site is less extensive. A log from BH-3, located at the southeastern corner of the plant, shows that bedrock was encountered at close to 8 feet below grade (see Figure 15). Instead of lake deposits, however, 3.5 feet of poorly-sorted sandy gravel overlies the bedrock at this location. It, in turn, is overlain by 4 feet of clayey silt. One foot of gravel fill brings the section up to grade. Because of the proximity of this well to Gill Creek, it is likely that the sandy gravel in contact with the bedrock is partially reworked till, and that the fine-grained sediment above it is flood deposition from the stream.

The locations of a series of soil borings made in 1985 are shown in Figure 31. These borings were advanced to bedrock and logs were constructed. The logs, reproduced in Appendix B, show that virtually all of the much thinner overburden sequence in the northern and central parts of Plant 2 is either fill or soils reworked by excavation. Sands and silts predominate but gravel and brick fragments were found in most cores.

Ground water occurs in the overburden at 5 to 10 feet below grade. Estimated permeabilities in the Olin wells ranged from 50 to 0.1 gpd/ft^2 (Harza, 1979a). A-Zone permeabilities calculated from slug tests by WCC (1983) on the DuPont wells tend to be much higher, ranging from 1000 to 100 gpd/ft^2. Some of the apparent difference between the Olin and DuPont permeabilities can probably be attributed to the different well construction techniques used (see Figure 14).

Harza Engineering (1979a) constructed a piezometric map for the Olin wells which is shown in Figure 18. This map indicates southeasterly flow toward Gill Creek across the southern portion of the ARGC section of Plant 2. Olin Monitor Wells BH-2, BH-5, and BH-10 were plugged and abandoned in 1986 to permit construction of a railroad siding for the Niachlor project (Figure 5). Monthly piezometric readings for the complete Olin monitor well network were, however, tabulated by Olin (1986) for 1983, 1984, and 1985, and are included in Appendix B. Hydrographs for this period were constructed from mean ground water elevations in all the Olin wells and are plotted in Figure 19. These hydrographs show that overburden ground water elevations generally increase in the colder months. Piezometric plots developed from this data indicate that ground water flow direction throughout the three years of record is well represented by the Harza piezometric surface shown in Figure 18.

The usefulness of the Olin piezometric information is greatly augmented by A-Zone elevations measured in the DuPont wells. A representative map from June 1985 is shown in Figure 20 and indicates that a local ground water high is located in the western section of Plant 2. It can be inferred that A-Zone ground water flows from this recharge point radially toward discharge boundaries at Gill Creek on the east and the Niagara River on the south. This pattern is the reverse of the northeasterly regional flow shown in Figure 10.

Recharge over the bedrock high mapped in Figure 16 influences flow in the overburden over the Olin and west DuPont plant areas. This is true despite significant ground water withdrawal from deeper bedrock aquifers by the Olin production wells. Indeed, analyses of two pump tests by WCC (1983, 1986) suggest that withdrawal from the confined bedrock aquifers has only minor effects on the relatively unconfined overburden ground water regime. It should be noted, however, that this unconfined zone would not be expected to respond to short-term changes in pumping. A response in an unconfined unit requires dewatering, which is a slow process compared to the pressure responses measured in the confined bedrock zones.

The relationship between bedrock topography and overburden ground water elevations is shown by two plots in Figure 21. The first of these (Figure 21a) shows the relationship in DuPont's A-Zone wells monitored on a single date. It can be seen that ground water elevations generally track the top of the bedrock surface. A similar plot generated using ground water elevations averaged over the three years of monthly records for the Olin wells shows the same general trend but with marked departures for the two northernmost wells, BH-1 and BH-4. It has been suggested earlier that BH-4 may monitor a lower bedrock aquifer, but the anomalously low ground water elevations found in BH-1 cannot be similarly explained. Harza Engineering (1979a) suggested that the low elevations observed in these two wells may be due to the proximity of a large city sewer main which is excavated into the bedrock just north of the plant boundary and runs down Buffalo Avenue. Indeed, the departure from predicted ground water elevation shown in Figure 21b could well be due to the presence of such a line drain. The potential influences of man-made passageways such as the Buffalo Avenue sewer, is discussed in more detail in Section 4.4 below.

4.3 Bedrock

The two Olin production wells at Plant 1 are the only true bedrock wells on the Olin property. These are 24-inch diameter wells cased from 25 to 28 feet below grade (536 feet MSL), and open to the bedrock down to a 110-foot total depth. The design of both wells is similar and is shown in logs developed from down-hole television inspections carried out in 1978. The report and logs from these inspections are included in Appendix B.

A large number of bedrock wells designed to monitor specific bedding plane fracture zones have been installed at the DuPont locations shown in Figure 13. Much can be inferred about bedrock ground water flow beneath the Olin plant by examining DuPont information developed during drilling and testing of these wells.

Detailed logs of fracture frequency were maintained during the drilling of all the DuPont wells and were plotted for each well cluster (WCC, 1983). As bedding planes dip with approximately the same slope as the bedrock, major laterally continuous bedding plane fracture zones tend to occur at similar spacings from the top of the Lockport, and, in some cases, may be carried between wells.

Fracture frequencies averaged over 5-foot intervals from the top of bedrock were computed for each of the 15 well clusters from which detailed information is available. The mean fracture frequency for all clusters at each interval has been reduced to the histogram shown in Figure 22. Standard deviations are also shown for each interval and provide a measure of the variability in fracture frequency between well clusters. Fracture zones with a high degree of lateral continuity exhibit similar fracture densities at similar depth intervals in all clusters and are indicated by relatively low standard deviations.

Examination of this diagram leads to two important observations. First, while it is clear that the highest fracture frequency occurs in the upper 5 feet of the bedrock, some fractures are found in all intervals within the 100-foot section analyzed. Second, zones with a very high fracture frequency occur at depth, as in the intervals between 50 and 65 feet, but tend to be characterized by high standard deviations. This implies that the locations of these fracture zones are less predictable from well to well. Higher standard deviations are, therefore, indicative of a lower degree of lateral continuity. Such zones may be of lesser importance in conducting ground water than the magnitude of the fracture frequency would suggest.

DuPont's investigations have led to the identification of four important water-bearing fracture zones beneath the overburden A-Zone discussed. These have been designated B, CD, D, and F, respectively on Figure 22. These zones are indicated in Figure 23 on north-south (C-C') and east-west (B-B') geologic cross-sections constructed from the DuPont wells by WCC (1983). Though they do not cross the Olin plant locations directly, these cross-sections provide a general indication of the depths at which the various important bedrock zones may be found at Olin. The B-Zone should be present generally within 15 to 20 feet of the ground surface. The CD-, D-, and F-Zones would be expected to occur at depths of 35, 55, and 85 feet, respectively.

The reports of the television inspections from the Olin production wells (Appendix B) show that considerable variability can be expected even in wells located 15 feet apart. Static water level in these wells was observed to be 32 feet below grade. The inspections were made without interrupting pumping by alternating withdrawal from the two wells to permit insertion of the camera in the inactive well. Fractures which showed evidence of significant water flow in the open rock below the casing were observed at 57 and 70 feet below grade in the north well, and at 47 and 70 feet below grade in the south well. These fracture positions would nominally appear to correspond to the D- and F-Zones identified by DuPont.

Piezometric maps produced by WCC (1986) for each of the B-, CD-, D-, and F-Zones from elevation data collected in June 1985 are reproduced as Figures 24, 25, 26, and 27, respectively. Mean ground water elevations for each of these zones decrease with the depth of the zone monitored, as was initially observed in the Lockport by Johnston (1962). A potential, therefore, exists for downward ground water movement from upper to lower zones. Otherwise, these maps are qualitatively similar in two important respects. First, they all show evidence of a cone of depression created by the Olin ground water withdrawal at Plant 1. Ground water moves from the river toward this point of discharge. Second, an apparent ground water divide occurs in the vicinity of Gill Creek. Ground water contours east of the creek indicate a flow to the northeast which probably corresponds to the regional regime. The extent of the cone of depression and the effects of Olin pumpage on the ground water divide arè discussed in more detail in Section 4.5 below.

Meaningful permeability and transmissivity estimates are difficult to develop for the fractured bedrock medium as flow paths through a crevice network bear little relationship to distances between wells. Furthermore, it is difficult to estimate the effective thickness of a bedding plane aquifer. WCC (1983) estimated permeability coefficients from slug test results by assuming that each bedding plane aquifer was confined and 1 foot in thickness. Permeabilities calculated in this way decreased with the depth of the fracture zone from 21,000 gpd/ft^2 in the B-Zone to around 100 gpd/ft^2 in the F-Zone.

WCC (1986) conducted a pump test by analyzing the effects of stepping up production from the Olin wells. Although the locations of the uppermost significant fracture zone identified by the television inspection is at a nominal D-Zone location, study of the effects of a packer installed in the south well at 55 feet below grade show that although all bedrock zones respond to pumping, most fluid withdrawal occurs from the CD-Zone. Modifications in the rate of withdrawal are transmitted virtually instantaneously through all of the fracture zones as a pressure response rather than as a direct consequence of the dewatering of the media.

Hydraulic heads in the B- through F-Zones were found to decrease throughout the west DuPont plant as the rate of withdrawal was increased. A discharge of 500 gpm was found to create a cone of depression which extended east as far as Gill Creek. Greater pumping rates might extend the boundary of this zone of influence farther to the east. The western or northern boundaries of this zone of influence extend unknown distances beyond the limits of the monitor well network. The extent of the cone of depression developed by ground water withdrawal at Plant 1 is discussed in more detail in Section 4.5 below.

Effects of increased pumpage on the A-Zone could not be distinguished from the far greater influences of precipitation recharge and changes in the stage of Gill Creek. It appears likely that the major effect of bedrock withdrawal on the overburden is to increase the rate of leakage to the bedrock, but this has never been measured. It is also likely that this leakage is not uniform across the plant sites as most of the uppermost vertical natural fractures tend to be filled with fine-grained sediments (Johnston, 1962). Excavations like that for the Buffalo Avenue sewer may play an important role as is discussed in the next section.

4.4 Man-Made Passageways

The Olin plant facilities are serviced by a number of subsurface utilities which may act to influence hydrogeologic flow conditions and provide pathways for chemical migration. Most notable of these are the clear water and sanitary sewers located on Olin's Plant 1 and the large municipal sewers which follow the

Buffalo Avenue right-of-way adjacent to the plant sites. All Old Plant 2 sewers are plugged. Existing Plant 2 sewers are now above grade.

A significant body of information is available regarding the existing clear water and sanitary sewers on the two Olin Niagara plant sites. This information originates from a series of design drawings prepared by Hibbard Engineers and is included in Appendix C where it has been collated in a computerized database. Summary reports prepared from this database are also presented in Appendix C.

The computer database of plant site sewer information was designed to aid in the evaluation of these features' impact on the shallow ground water flow regime and identification of surface water drainage routes. As such, specific data which are currently contained in the database (as summarized in Appendix C), or which may be added through field investigation include:

- identification of 13 separate plant site sewer systems and their general location at plant site;
- accesses to these systems classified by type (manhole or catchment basin);
- invert and surface elevations of access points; and,
- the number, diameter, direction, invert elevations, and destination of any stubs leaving these accesses.

The two plant sites are serviced by 13 sanitary and clear water sewer systems identified in Table 1. These systems each drain specific areas of the respective plant sites. When plant site coordinate data and field verification information become available for individual accesses, this information can be added to the database. Subsequent comparisons of topographic drainage areas and flow within specific sewers can help to characterize recharge rates. Comparisons of field verified invert elevations with local top of bedrock elevations and water table elevations will focus the extent of future investigatory efforts on those sewers which could affect the shallow hydrogeologic flow regimes.

Available historical data indicate that the large municipal sewers beneath Buffalo Avenue impact the shallow ground water flow regime. DuPont Monitoring Well Clusters 20 and 22 (Figure 13) are installed on either side of Buffalo Avenue and have been regularly monitored. Both clusters contain wells screened in the overburden (A-Zone) and upper bedrock (B-Zone). A-Zone wells in each of these clusters have been repeatedly reported as dry in previous studies, suggesting the proximity of a significant ground water sink.

Along the path of Buffalo Avenue from Gill Creek to west of Plant 1, top of bedrock elevations range between 558.0 feet and 566.0 feet (Figure 16). Data contained in Appendix C indicate that the inverts of the Buffalo Avenue sewers at places where the plant systems tie-in range from 554.7 to 557.8 as shown in Table 2.

As the invert elevations indicate, these sewers are excavated through the overburden and some distance into rock. These excavations, therefore, have the potential to act both as pathways from the A-Zone to the B-Zone, and as a line drain for lateral transport of water from the system.

Cross-sections provided in the 1979 report by Harza are reconstructed in Figure 28 (Harza, 1979a). These cross-sections show the overburden, top of rock, and bedrock/water level relationship that existed at that time. The cross-sections are oriented north to south approximately paralleling Gill Creek. We have extended these cross-sections northward across Buffalo Avenue to show conceptually the potential influence which these installations can be expected to apply to the shallow flow regime at the site.

The current impact of these sewers is not known, and constitutes a data gap which must be addressed. It is known that portions of the sanitary sewer have been slip-lined in recent years, thus the conceptual relationship shown on Figure 28 may not be an accurate representation of current conditions.

4.5 Olin Ground Water Withdrawal

Olin obtains plant cooling water from two production wells located 15 feet apart in a pumphouse on the eastern margin of the Plant 1 property (Figure 3). Although they have been pumped simultaneously in the past at a combined rate in excess of 5000 gpm, current average production is 750 gpm due to lower demand, and is typically withdrawn from one well at a time. Production water is treated using an activated carbon system prior to use at the Olin plant. Spent treated cooling water is discharged to the sanitary sewer system under an SPDES permit.

DuPont has contracted with Olin to incorporate Olin's ground water production and treatment system into a ground water remediation program for the DuPont Niagara plant south of Olin. On DuPont property, WCC (1986) has mapped cones of depression in the bedrock aquifers occurring in the B- through F-Zones which are attributable to Olin ground water withdrawal. The extent of this cone is dependent on the rate of ground water withdrawal at the time of sampling (WCC, 1986).

The extent of the cones cannot be precisely determined in the piezometric surfaces of the B- through F-Zones shown in Figures 24, 25, 26 and 27. In all cases, the eastern ground water divide on the DuPont property occurs somewhat to the west of Gill Creek, but typically within 500 feet of the stream channel. The most extensive effect of the Olin withdrawal on the DuPont plant is observed in the CD-Zone.

Bedrock monitoring well data do not exist for defining the extent of hydraulic influence of the Olin production wells on the ARGC area. An estimate can be made, however, by assuming simplistically that flow to the production well is radial, that the bedrock aquifers are relatively homogeneous and isotropic, and that they may be characterized by hydraulic properties similar to those estimated from the DuPont investigations.

Recent B- and CD-Zone piezometric data (4th Quarter, 1987) from the DuPont monitoring well network are mapped in Figures 29 and 30, respectively.

Numbered flow zones are delimited by solid lines indicating flow divides. Using the previously stated assumptions, the flow divides developed from the DuPont data have been extended as dashed lines across the Olin property. Based on this interpretation, Flow Zone 1 in the B-Zone, and Flow Zones 1, 2 and 3 in the CD-Zone would appear to lie within the cone of depression produced by the Olin wells.

The CD-Zone extrapolated flow divide which marks the postulated eastern margin of ground water movement toward the production well lies very close to Gill Creek. It is estimated in this way that the cone of depression in the CD-Zone includes virtually all of Plant 2. The cone is somewhat less extensive in the B-Zone, and may have an eastern boundary which falls within the ARGC section, a few hundred feet west of Gill Creek.

It is estimated, using assumed values for gradient and transmissivity of 0.0025 and 10^{-3} ft^2/sec, respectively, that B-Zone flow from Plant 2 to the Plant 1 production wells is on the order of 0.0013 ft^3/sec, or 0.56 gpm. Flow in the CD-Zone is much greater as both gradient and transmissivity are considerably higher, 0.01 and 10^{-2}, respectively. A yield of 0.05 ft^3/sec, or 22.4 gpm, is calculated for this zone. These flow estimates were obtained using Darcy's Law and assuming passage across an imaginary flow plane along Chemical Road between Buffalo and Adams Avenues (500-foot cross-section).

It is possible that most or all of Plant 1 lies within the B- and CD-Zone production well cone, but the extent cannot be determined without onsite well data. DuPont overburden (A-Zone) wells proximal to the production wells and the Buffalo Avenue sewer quite often yield no water for samples. This observation indicates that the water table in this area may be affected by induced leakage to the bedrock or to sewers and other backfilled excavations.

5.0 CHEMICALS PRESENT ON THE OLIN PLANT SITES

Several Olin investigations conducted since 1978, though undertaken for purposes not directly related to ground water assessment, have yielded useful information about the type and extent of organic and inorganic chemicals at the Buffalo Avenue locations. The majority of the analytical data for soils was acquired as a result of testing to determine the suitability of excavated materials for offsite disposal. Shallow ground water samples obtained from the ARGC wells have been analyzed periodically as part of Olin's voluntary monitoring program to evaluate potential loadings to Gill Creek, a surface water conduit to the Niagara River. Organic chemical concentrations have also been monitored before and after treatment in water pumped from the production wells as required by Olin's SPDES permit.

5.1 Data Base

A data base containing all of the soil and shallow ground water analytical results, as well as the appropriate laboratory report references, detection limits, locations and dates was compiled using the WCC HAZWASTE software. This software permits computation of basic statistics and ready translation to other formats for generation of graphics or higher level statistics. The final data base included upwards of 300 parameters for which at least one analysis had been run. Complete listings for soil and ground water samples are included in Appendix A.

A complete set of the original laboratory reports from which these data were collated is provided in Appendix D. While all analyses met every applicable quality control standard applicable to the program under which it was originally run (SPDES, RCRA), these standards varied between programs and over time. As a result, it is not appropriate to subject the wide variety of analytical data used in this report to recently developed ground water QA/QC standards. Instead, a reference code has been provided with every sample report included in the database. This code allows reference to the appropriate laboratory report for assessment of any single value.

The ARGC shallow ground water wells monitor a specific part of the Olin plant sites. Analytical results for soils are available which cover a larger area and most of the priority pollutants. These data are obtained from shallow soil boring programs conducted first in 1982 with the USGS, and then in 1985-86 as part of the Niachlor project. These data have been used to evaluate the representativeness of the ARGC ground water information for the rest of the plant sites. This approach is justified on the basis of the conservative assumption that if chemicals are present in the soils, they may also be present in ground water.

The majority of the soil samples outside of these two boring programs were analyzed using the EP TOX leachate procedure as mandated by Olin policy for all excavated materials scheduled for offsite disposal. These results can be used to assess the relative mobility of mercury compounds present, but cannot be correlated with total mercury concentrations in soils. Results of samples collected from the wall of a trench excavated in Plant 1 (Harza, 1979b) provide an indication of the vertical distribution of mercury in the overburden which cannot be ascertained from the depth composited boring samples.

One to four rounds of shallow ground water samples have been collected from the ARGC wells each year since installation in 1978. A complete GC/MS scan, including the volatile organic fraction, was conducted by Olin on samples obtained from these wells in 1979 (Report 0021 in Appendix D). The results of this set of analyses showed that mercury, BHC, and several compounds associated with the BHC process were present at ppb to ppm concentrations. Volatile organic compounds which could not be related to Olin activities were also found. Calculations of the rate at which compounds originating in the ARGC overburden could seep into Gill Creek indicated that the potential for significant impact to the Niagara River was small (Harza, 1979a; Wendel, 1981).

Subsequent ground water samples were analyzed for a less extensive suite of specific organic compounds. These included the chlorophenols, BHC, and for mercury and some other inorganic chemicals. Halogenated organic and volatile halogenated organic scans employing an electron capture detector (ECD) were run as a substitute for other compound specific analyses. Specific compounds in the suite covered by the ECD scan cannot be identified, and the results are not considered quantitative. ECD results are not evaluated in the following discussion, but are tabulated in the database and summary tables.

The analytical time-series for ARGC ground water is most complete for BHC. The chlorophenol data are also extensive, but are more difficult to interpret as detection limits ranged from 2 to 200 ppb, while the isomeric resolution increased steadily over the decade of record. As a result, isomers initially grouped were later isolated and reported individually.

The most voluminous analytical data are from the Olin production wells. Between 1978 and May 1984, when the activated carbon treatment system came on-line, water samples were collected weekly at the well head and analyzed for volatile organics, and less frequently for non-volatile compounds. Samples are now collected on a quarterly basis to establish the effectiveness of the treatment system under Olin's SPDES program. Analytical sets from 1980 and 1983 which include both volatile and non-volatile priority pollutants are included in Appendix A. The results of this production well analytical program prior to 1983 are included in a report (Olin, 1983) which is attached in Appendix B of this report. More recent results, which include some non-volatile compounds, have been checked for quality control and tabulated by WCC for DuPont on a quarterly basis. Results from the third and fourth quarters of 1987 and the first quarter of 1988 are also provided in Appendix A.

Soil and shallow ground water parameters were separated into three major classes, according to whether they were (1) positively identified as present, (2) possibly present, or (3) positively identified as not present in plant site soils or shallow ground water. The logic used to develop the target parameter list is shown in Table 4. Parameters positively identified in plant site soils and/or ground water constitute the first three of the six parameter classes shown. The last three classes include parameters which have been observed in Olin production well water and/or are of regional extent in the bedrock aquifers. Superscripts indicate which of these potential contaminants are associated with Olin processes, products and operations.

A tailored version of this parameter list was used for this initial assessment and is shown with the soils data in Table 5. This list consists of 33 separate parameters divided into five subdivisions: metals (mercury), base/neutral extractable organics (dichlorobenzenes, trichlorobenzenes and polynuclear aromatics (PAH)), acid extractable organics (phenolics), volatile organics, and pesticide organics (BHC).

Summary statistics were computed for these parameters to discriminate (1) the spatial distribution of contaminants in plant site soils and shallow ground water, (2) temporal concentration trends, and (3) concentration ranges to be used in determining offsite loadings. These statistics were developed using two approaches. The first is a very conservative assumption that once quantified, all subsequent non-detect parameters are actually present at half of the detection limit. A second set of means were calculated assuming the other extreme, that non-detects are not present at all (zero value). With the exceptions of BHC and mercury, which were quantified in most soil and shallow ground water samples, non-detects play an important, and, in many cases, an unrealistic role in the interpretation of Olin data set using the first approach. For several parameters, detection limits decreased over the course of the sampling program, leading to an apparent decrease in mean values with time which may not reflect actual conditions. A comparison of the conservative and zero value statistics provides one indication of the relative importance for different parameters.

5.2 Soils

Analytical results from 19 soil borings obtained at 12 locations in Plant 2 are summarized in Table 4. Target parameter results for each boring extracted from the data base are included in Appendix A. As is shown in Table 4, non-detects constitute in excess of half of all values included in this summary for all parameters except mercury and BHC, suggesting that these are the only contaminants with a widespread distribution in Plant 2 soils. The importance of non-detects varies with the parameter, as can be seen in the differences in the means calculated using the two methods (Figure 4).

The distribution of total mercury in Plant 2 soils is shown in Figure 31. Despite total mercury concentrations averaging 50 ppm, but ranging as high as 204 ppm, EP Tox mercury levels averaged less than 0.01 ppm, indicating that the mercury compounds present have a relatively low solubility or conversely, a high affinity for the soil. Such a conclusion is supported by analytical results developed by Harza (1979b) from the Plant 1 trench excavation discussed earlier (Figure 17). Total mercury concentrations in excess of 1 ppm were found to be confined to the upper 2 feet of fill, and to decrease rapidly with depth. The total mercury distribution shows no coherent spatial pattern and is known to be associated with "hot spots." Two locations are shown in Figure 31 where small quantities of elemental mercury beads were discovered during Niachlor excavation work for the large caustic storage tank west of the active cell room. The soils in these areas have been excavated and disposed of offsite in secure landfills as provided by the long-standing Olin policy.

Total BHC, which is the sum of the alpha, beta, delta, and gamma isomers, averaged 0.1 ppm for the Plant 2 soils for either method of calculation, with the alpha and beta isomers making up approximately 70% of the total. The distribution of total BHC at the Plant 2 soil boring locations is shown in Figure 32. Highest concentrations were found adjacent to the slab formerly occupied by the BHC production facility (SB85-7, 0.2 ppm), and lowest values on the western margin of Plant 2.

Base/neutral extractable organics were considered in two groups, one made up of three dichlorobenzene isomers and 1,2,4-trichlorobenzene, and a second which includes the PAH's flouranthene, phenanthrene, and pyrene. For the di-, trichlorobenzene group, no values were quantified in the 1982 soil boring program at a detection limit of 2 ppm. Totals for this parameter group were, however, found to range up to 0.5 ppm in the 1985-86 sampling program when lower detection limits were attained. The distribution of the sum of the dichlorobenzenes and trichlorobenzenes in the various borings is shown in Figure 33. Concentrations were again highest in SB85-7 at the BHC pad and appear to diminish to the north and west.

Samples were analyzed for the PAH compounds only during the 1982 boring program, and again the detection limit was 2 ppm. A quantifiable value was obtained only at SB82-2 at the end of the rail spur in the far western part of Plant 2, as is shown in Figure 34. No information is available from the ARGC section.

No detections were recorded for the target chlorinated phenolics at any of the soil boring locations. The distribution of detection limits applicable at each sample site is shown in Figure 35.

The volatile organics results from the two soil boring programs are very important to this assessment because shallow ground water samples were analyzed for this fraction on only one occasion. Reference to Table 4 shows that the most commonly encountered volatile organics were methylene chloride, toluene, tetrachloroethene, and trichloroethylene, all compounds which are not linked to specific Olin products, processes or operations. Highest concentrations were observed for trichloroethylene (42 ppm), tetrachloroethene (28 ppm), and chloroform (11 ppm), while 1,1,2,2-tetrachloroethane, 1,1,1-trichloroethane, and vinyl chloride were not detected.

Benzene and chlorobenzene were used or produced in quantity in the ARGC section of Plant 2 during the 1950's, and were found to be present 30 years later in Plant 2 soils. Maximum values recorded for benzene and chlorobenzene were 7 and 9 ppm, respectively. The distribution of the sum of these two potentially Olin-derived compounds is shown in Figure 36, and shows that detectable concentrations are found only in the ARGC section.

It is more difficult to explain the distribution of the remainder of the target volatile organic compounds. These too occur predominantly in the Alundum Road-Gill Creek samples, as is shown in Figure 37, but were also detected in relatively low concentrations at other locations across the Plant 2 site.

5.3 Shallow Ground Water

The shallow ground water data, though based on a larger number of sampling events than the soils data, is less complete with respect to the number of parameters systematically monitored. The best data are available for mercury and BHC. The chlorinated phenolics data are also extensive though subject to a variable detection limit and changes in isomeric resolution.

For the remainder of the target parameters, reliance must be placed on a single set of analytical results from 1979 (Report 0021, Appendix D). Of the 33 parameters in the target list, 20 are represented by a single result from this sampling date (Table 5).

Four shallow overburden wells, and four deeper regolith wells are adequately represented in the sample pool. Shallow well BH-2 was monitored only intermittently as it was normally dry, but BH-5 provides coverage of the shallow zone in this cluster which includes BH-10 as the deeper member. No shallow well is associated with BH-4 or BH-1 on the northern plant boundary, and no deeper well is available at the BH-9 location on the southern boundary. The remaining wells occur in three pairs. BH-2, BH-5, and BH-10 were decommissioned in 1986, and thus monitor a shorter time interval than the others.

Ground water samples were collected from two more or less distinct lithologic zones, thus results from the deep wells and shallow wells are reported separately in the summary provided in Table 5. Means have been calculated using the two alternative methods of dealing with non-detects as was discussed earlier. As these two results differ significantly only for the chlorophenols, a single value is reported below for other parameters.

Mean mercury concentrations in ground water samples from both deep and shallow wells ranged from 0.003 to 0.186 ppm and did not differ significantly with depth. The highest mean concentration was observed in BH-4 along the northern plant margin, as is shown in Figure 38.

Total BHC concentrations averaged 1 ppm in the deep wells and 0.2 ppm in the shallow wells. The difference between the two zones was accentuated by the high values observed in deep well BH-3 located in the southeastern part of the ARGC section (4.6 ppm), as is shown in Figure 39. In contrast, the two deep wells in the northern part of the section, BH-1 and BH-4, were characterized by mean values nearly two orders of magnitude lower.

The BHC data were sufficiently complete and free of non-detects to analyze for temporal trends. Given that BHC production occurred over a relatively short period of time and was abruptly terminated more than 30 years ago in 1956, a decline in values over the nine years of record might be expected. In fact, two different patterns are observed which are illustrated in Figure 40 by records from BH-7 and BH-3. All wells north of the BHC production site show a steady decline similar to that seen in BH-7, while those to the south and east show no distinct trend, as in BH-3.

Dichlorobenzenes were not detected in the 1979 samples analyzed, but the detection limits are not known. The 1,2,4-trichlorobenzene isomer was quantified in samples taken at the same time and was found to average 0.1 ppm in the shallow wells and 1.7 ppm in the deeper wells. The spatial distribution is shown in Figure 41 and shows the highest value, 4.5 ppm, to be associated with deep Monitor Well BH-1 in the northeastern section of the plant.

In contrast to trichlorobenzene, PAH's detected in the 1979 samples were an order of magnitude higher in the shallow wells than in the deeper wells, averaging 0.2 ppm and 0.01 ppm in the two zones, respectively. The highest mean concentrations are found in the shallow wells along Gill Creek, as can be seen in Figure 42.

The majority of the chlorinated phenolics data consist of non-detects which were included in the statistics shown in Table 5, first, at half of the detection limit and, second, at a zero value. The relative importance of non-detects for each of the chlorophenol isomers ranges from 68 to 93 percent in the data from all wells. The 2,4,5-, 2,3,4-trichlorophenol grouping has the lowest incidence of non-detects and is the most commonly quantified group analyzed in both shallow and deep wells. The least commonly quantified chlorophenol isomers are 2,4,6-trichlorophenol (93% ND), 2-chlorophenol (84% ND) and 2,3,5,6-tetrachlorophenol (82%).

Mean concentrations for all chlorinated phenolics calculated using the first method were 0.68 and 1.83 ppm, respectively, for the shallow and deeper wells. Means using the second method were slightly lower, 0.60 and 1.76 ppm, respectively, for the shallow and deeper wells. The most significant effect of including non-detects is observed when the relative contribution of the 2,4,5-, and 2,3,4-trichlorophenol isomers is considered. This single group makes up more than 70 percent of the concentration of all chlorinated phenolics actually quantified (Method 2), but only around 50 percent of the total when non-detects are included at half the detection limit (Method 1).

Concentrations of 2,4,5-, 2,3,4-trichlorophenol isomers in excess of 5 ppm were quantified in both shallow and deeper ground water zones. The remaining chlorophenols, where detected, are present at far lower concentrations. Data for phenol itself are restricted to the 1979 sampling date and indicate concentrations of less than 0.1 ppm

The spatial distribution of total chlorinated phenolics is shown in Figure 43. These compounds do not appear to show any systematic variation with respect to the two depth zones monitored. Concentrations are, however, highest in wells BH-7 and BH-8 which are closest to the former production facility. Lowest concentrations are observed in the northernmost wells.

Volatile organics data for the shallow ground water are available only from the 1979 sampling round. A comparison of Tables 4 and 5 shows that with the exception of methylene chloride, all of the non-Olin compounds which were identified in plant soils are also present in the shallow ground water, though at very low concentrations (0.1 ppm).

Benzene and chlorobenzene were quantified at concentrations in the deeper wells of up to 9 and 2 ppm, respectively. The distribution of the sum of these two potentially Olin-derived compounds is shown in Figure 44. Benzene and chlorobenzene concentrations in excess of 1 ppm were found only in the deeper wells along Gill Creek. Conversely, the remaining non-Olin volatile organics are more important in the interior of the ARGC section, as is shown in Figure 45.

5.4 Production Well Ground Water

The ARGC shallow ground water wells do not monitor the deeper bedrock aquifers which are most affected by the pumping of the Olin production wells. It is known, however, that compounds identified in soils and shallow ground water from the ARGC section, including several of those potentially derived from Olin products, processes and operations, are found at ppb concentrations in untreated well water produced for cooling at the Plant 1 pumphouse. Olin treats this water with activated carbon under an agreement with DuPont in which this system is incorporated in DuPont's ground water remediation program.

A breakdown of the organic compounds detected in untreated production well water between 1979 and 1983, ranked in order of decreasing concentration, is provided in Table 6. No chlorinated phenolics appear on this 32 compound list, but chlorobenzene, benzene, and BHC are ranked 14, 16, and 27, respectively. These chemicals may have entered the upper bedrock water-bearing zones from the overburden in the dissolved phase and migrated to the west along one or more bedding plane fracture systems.

A selection of production well analytical results between 1980 and 1988 is given in Table 7 for the target parameter list. This table should be compared with that generated from the ARGC wells. For all compounds shown except benzene, chlorobenzene, phenolics, and BHC, concentrations are higher in the production well data than in the ARGC data. Benzene, chlorobenzene, phenolics, and BHC, which could have originated in Olin products, processes or operations, are present in untreated ground water at levels below or very close to the analytical detection limit. Mean concentrations for all of the listed target parameters have been calculated from the limited database shown in Table 7. A conservative approach has been taken in that values reported as below minimum detection are included at half the detection limit, if they have ever been quantified.

6.0 SOLUTE TRANSPORT

The data presented in the last section show that mercury and PAH's are present in plant site soils, and to a lesser degree in shallow ground water. These contaminants have a relatively low potential for widespread dispersal, however, as they appear to be retained largely in the upper part of the overburden above the water table (Harza, 1979b). The potential for continuing PAH and mercury introduction to ground and surface waters has been reduced by the excavation, removal and replacement of soils in the central part of Plant 2 and along Gill Creek (Figure 5).

Concern for offsite contaminant migration is therefore focused on the organics produced in the ARGC section of Plant 2 more than 30 years ago. Low levels of benzene, chlorobenzene, trichlorobenzene, trichlorophenol, and BHC are still present in the shallow ground water beneath this area. Because the wells were designed to monitor a limited area along Gill Creek, few conclusions about the potential for offsite contaminant transport can be drawn solely from information developed by the ARGC monitoring well network. Relevant analytical data are, however, also available from the Olin production wells, as was discussed above, and from the DuPont well clusters. This information and the extensive literature on overburden and bedrock hydrogeology greatly augment the usefulness of the ARGC data, and provide a starting point for assessing the transport potential of the compounds of concern.

Direct evidence of the offsite occurrence of benzene, chlorobenzene, phenolics, and BHC is available in analytical results from DuPont well clusters (WCC, 1983). A map of benzene concentrations from samples taken in October 1983 is shown in Figure 46. Benzene was detected in A- and B-Zone wells only in the area east of Gill Creek closest to the Solvent Chemical site. Analytical data from wells on this facility indicate that benzene concentrations beneath this site range from 1.6 to 170 ppm (O'Brien and Gere, 1987). This site may be a source for the benzene distribution noted in the DuPont wells.

Chlorobenzene concentrations in DuPont wells on the same sampling date are shown in Figure 47, and show the same vertical and lateral extent observed for benzene. O'Brien and Gere (1987) report ground water chlorobenzene concentrations from the Solvent Chemical site ranging from 1.2 to 110 ppm.

It is only with respect to phenolics and BHC that DuPont wells both east and west of Gill Creek show detectable levels of possible ARGC compounds. The distribution of total recoverable phenolics in DuPont wells is shown in Figure 48. "Total recoverable phenolics" is a generic grouping which can include many compounds in addition to the chlorinated phenolics potentially associated with Olin's activities in the ARGC section. Here again, other sources may be involved as phenolics were not detected in DuPont well clusters closest to the ARGC, but were instead, highest to the east of Gill Creek. West of Gill Creek, phenolics were present at ppb concentrations in the A- and B-Zones only, except in one well adjacent to Gill Creek, where the contamination appears to extend to the CD-Zone.

The distribution of total BHC in the DuPont wells is provided in Figure 49. It should be noted that the concentration data presented in this figure are in ppb, rather than ppm. Virtually all DuPont wells sampled on the October 1983 date show detectable levels of BHC in the A- and B-Zones, but the highest concentration measured, 499 ppb, was obtained from a CD-Zone sample in one well adjacent to Gill Creek (DuPont Cluster 1). This is the same well that yielded phenolics from the CD-Zone.

BHC is widely distributed in the Buffalo Avenue industrial corridor, and potential sources other than the Olin ARGC sector exist in this area (Koszalka, et. al., 1985; O'Brien and Gere, 1987). The offsite chemical data from the DuPont wells do not suggest any simple transport paths originating in the ARGC section. It does, however, raise a number of questions about the potential for solute dispersion both in the subsurface and via Gill Creek which can only be resolved by analytical data from additional monitoring wells on Olin property.

One very important point which can be drawn from the DuPont data, however, is that the potentially Olin-derived compounds appear to be largely restricted to the overburden and the uppermost water-bearing bedrock zones. This observation suggests that the scope of future investigations will probably be narrowed to the A-, B-, and CD-Zones.

6.1 Effects of Olin Production Wells

Phenolics (including chlorinated phenols), benzene, chlorobenzene and BHC are present at very low levels in untreated production well water, however, the effects of the production wells in removing these compounds from the bedrock ground water system should not be underestimated. Using the mean levels for these compounds shown in Table 5, and assuming a 500 gpm production rate, removal rates from the production well capture zone could be as high as 0.13 lbs/day (49 lbs/yr) for benzene, chlorobenzene and BHC, and up to 0.20 lbs/day (74 lbs/yr) for the chlorinated phenolics.

A removal rate of potential Olin compounds on the order of 0.5 lbs/day represents 1 percent of the approximately 50 lbs of total organic chemicals currently withdrawn each day by the Olin well as part of the DuPont remediation program. The removal of Olin derived chemicals from ground water beneath the ARGC area by the Olin production wells could have been considerably greater in the past, however, when (1) pumping rates were higher, (2) the solute source fresher, and (3) the cone of depression was not limited by the interfering regional influence of the flow toward the NYPA conduits (1950-63).

It is possible that offsite sources contribute to the chlorinated phenolics, benzene, chlorobenzene and BHC reaching the production wells. It is certain, however, that ground water withdrawal from the Olin production wells has served, and continues to serve as a significant factor for the containment and removal of any Olin-derived chemicals from ground water. More precise quantification of the current importance of this factor awaits further investigation.

6.2 Falls Street Tunnel Loadings

Interest has recently focused on the possibility that Olin-derived contaminants may be contributing to the high organics loadings noted in the FST. Analytical data from three USGS wells, NFB-11, 12, and 13, located in the immediate vicinity of the FST-NYPA conduit crossing, are presented in Table 8 (reproduced from O'Brien and Gere, 1987). The positions of these wells are shown in Figure 12 and are very important to the interpretation of the chemical data.

The largest variety and highest concentrations of organic compounds were found in ground water samples from Monitor Wells NFB-11 and NFB-12 which are located on the east side of the NYPA conduits, the side farthest from the Olin plants. The variety and concentrations of compounds found in NFB-13, the well closest to the Olin locations, were far less. Koszalka, et. al. (1985) ascribed this difference in water quality on the two sides of the conduits to the fact that ground water converges on the conduits from east and west, but does not flow across the conduits. This suggests that the solutes being transported toward the NYPA-FST crossing from the west would be prevented from migrating beneath the discharge area east toward wells NFB-11 and NFB-12.

Benzene, chlorobenzene, and trichlorobenzene were not detected in USGS well NFB-13 on the Olin side of the conduits, while they were quantified in USGS wells NFB-11 and NFB-12 on the opposite, eastern side. Chlorophenols were not reported in any of the wells, but BHC was found in all three.

Although a regional ground water gradient exists which suggests the potential for transport from the area west of Gill Creek toward the NYPA conduits, direct evidence that potentially Olin-derived solutes originating in this area are reaching the FST through this route is lacking. Many factors, particularly adsorption and dispersion, typically reduce solute transport velocities below that of an "ideal tracer" moving with the ground water velocity (Mercer, et. al., 1985).

In order for dissolved compounds originating on Olin's Buffalo Avenue plants to reach the FST at the NFB-13 location, two assumptions must be made without supporting data. First, it must be assumed that these solutes have escaped capture by the Olin production wells. Second, these compounds must have crossed the Gill Creek area and migrated a minimum of 0.5 miles to the northeast over the 25 year period since 1963 when the NYPA conduits are presumed to have begun affecting regional ground water flow.

Additional information on solute transport is clearly needed to explain why benzene and chlorobenzene, at least, which are known to have a non-Olin source between Gill Creek and the conduits (O'Brien and Gere, 1987) do not appear in USGS well NFB-13. Such information for the potentially Olin derived compounds can be developed from studies on the Olin properties.

6.3 Gill Creek Loadings

Given the relatively low concentrations of organic compounds present in the ARGC, it seems unlikely that migration of Olin-derived chemicals from the Olin plant impacts ground water quality on a regional scale. Although direct analytical data are lacking, chemicals could move through the overburden in the ARGC section to Gill Creek. Using the mean concentration levels conservatively calculated for ARGC shallow ground water in Table 5, and ground water flow estimates in the overburden, it is possible to estimate offsite loadings to Gill Creek.

Wendel Engineers (1981, included in Appendix B) estimated ARGC loadings to Gill Creek at between 0.05 and 2.4 lbs/day based on the analytical database available at that time, and hydraulic conductivity values developed by Harza (1979a) from single well slug tests. Given the high degree of uncertainty surrounding any hydrogeological characterization of the heterogeneous overburden soils in the ARGC, an effort is made here to generate ground water flow volumes across the ARGC which do not depend on such estimates.

The water budget model used is described in Technical Release No. 55 of the Soil Conservation Service (1975) titled "Urban Hydrology for Small Watersheds." Empirical curves given in this publication permit calculation of infiltration from precipitation data in areas like the Buffalo Avenue plant sites which are largely covered by buildings, roads and other impervious structures. The basic components of the model are shown in Figure 50.

Infiltration was calculated for the area of the bedrock high within the 560 feet MSL contour both on the Olin plants and immediately to the north (Figure 50). As has been shown previously, this area is a local recharge point for the A-Zone ground water system. The boundaries of this recharge area were estimated from the USGS bedrock topography map in Figure 7 and from the more detailed information in Figure 16. The plant sites are estimated to receive recharge from an area north of the Buffalo Avenue boundary of approximately 12 acres (529,254 square feet).

Examination of the most recent aerial photos shows that approximately 54% of the recharge area is paved or covered by impervious structures which drain to storm sewers. It was conservatively assumed that the remainder of the watershed area is characterized by gravel covered soils with the highest possible infiltration potential.

Monthly precipitation data at Buffalo for 1983, 1984, and 1985 were obtained from the National Weather Service. A continuous record of monthly ground water elevations for the ARGC wells is available for these years. Ground water elevation in the ARGC wells rises and falls depending on the rate of recharge from precipitation. It was found that the Buffalo monthly precipitation data could be used to predict mean ground water elevations for the ARGC wells if it was assumed that 50% of precipitation (snowfall) during the winter months of December through February was carried over to the following month.

Infiltration was calculated from the corrected precipitation data and plotted against ARGC ground water elevations for each of the three years of record, as is shown in Figure 51.

The perimeter of the two plant sites was partitioned into sections characterized by net inflow and net outflow based on bedrock topography (Figure 50). Inflow takes place across approximately 55% of the Buffalo Avenue boundary while outflow occurs across the remainder of the perimeter which, for simplicity, includes the DuPont Buffalo Avenue facility north of Adams Avenue. Infiltration directly to the plant area is added to the water volume entering from the north. This total is used to estimate outflow on the assumption that overburden ground water volume remains relatively static on an annual basis, that is, that the sum of inflow and direct recharge is balanced by outflow. It was further conservatively assumed that no losses to lower bedrock zones occur.

The volume of total overburden ground water outflow from the Olin plants was calculated on a yearly and daily basis and is shown in Table 9. To obtain an initial estimate of potential outflow to Gill Creek, outflow volume was divided by the total length of the perimeter across which outflow occurs, and then multiplied by the length of the Gill Creek boundary. A-Zone ground water flow to Gill Creek, assuming uniform flow across all segments of the outflow perimeter, was estimated to be on the order of 830 cubic feet/day.

This model was then refined further to account for the effect of the apparent bedrock crest/ground water divide on the Plant 2 site which can be expected to result in non-uniform flow across the outflow perimeter. The assumed position of this divide is sketched on Figure 50. A divide with this configuration would cause outflow to be partitioned as shown in Table 10 and reduce A-Zone flow to Gill Creek to a value on the order of 350 cubic feet/day.

Total organic concentration for the ARGC deep well ground water over the 1979-1987 period of record was conservatively estimated (Method 1) in Table 5 to be 9.2 ppm. Using the two Gill Creek outflow volume estimates as upper and lower bounds, A-Zone offsite organic loadings to Gill Creek of between 0.24 and 0.56 lbs/day were calculated assuming a specific gravity of 1.2 for the organics. These values fall in the middle of the range of 0.05 to 2.45 lbs/day originally proposed by Wendel Engineers (1981).

Agreement between estimates calculated using two entirely different approaches increases confidence that Gill Creek loadings from the Olin plant are actually known to within an order of magnitude. It should be noted that the water budget calculated here is a first approximation which can be improved with the addition of more exact information concerning land use and the boundaries of the recharge area. It is also a conservative estimate which is more likely to be revised downward than upward.

As shown in Table 10, the water budget model permits calculation of outflow volume across segments of the outflow perimeter other than that adjacent to Gill Creek. No ground water quality data are available for areas outside of the ARGC section, so estimates of offsite loadings for the areas drained by these segments were not attempted. It should be noted, however, that outflow volumes for these areas would be significantly reduced if further investigations establish that the Buffalo Avenue sewer backfill is intercepting flow from the recharge area north of Buffalo Avenue.

7.0 DATA LIMITATIONS AND POSSIBLE INVESTIGATIVE STRATEGIES

One important purpose of this assessment is to serve as a baseline document to guide future investigative work on ground water conditions at the Olin Buffalo Avenue plants. Questions are raised at several points which can only be answered through acquisition of additional onsite data. Here we attempt to identify the most important of these data limitations, and to suggest investigative approaches which are likely to provide answers.

- The full configuration of the cone of depression developed by the Olin production wells in the upper bedrock zones is not known. The need to evaluate the locations of the ground water divide in the ARGC section must assume a high priority and will require installation of a limited number of well clusters extending at least into the CD-Zone in the east part of Plant 2 and perhaps immediately to the east of Gill Creek. Such wells will also serve to define the vertical and lateral eastern limits of potentially Olin-derived compounds in the ARGC section.

- It has been assumed in several parts of this report that hydrogeologic parameters developed from the DuPont investigations can be directly applied to the Olin plant sites. In reality, these properties show considerable variability from fracture zone to fracture zone and from one location to another. It is important that once a monitoring capability is developed that a pump test program be undertaken to provide better estimates of hydrogeologic properties across the Olin plant sites area.

- The importance of the Olin production wells in withdrawing organic compounds from the ARGC section cannot be fully evaluated without some bedrock monitoring capability along the assumed transport path to the production wells. Analytical and hydrogeologic data from well clusters located between the ARGC and the production wells can provide solute transport dynamics information which will also be useful in assessing the potential for migration outside of the production well capture zone.

- Gill Creek serves as a discharge boundary for the A-Zone, as a potential surface water conduit for dispersion of ARGC-derived solutes, and as a potential bedrock recharge boundary. The relative importance of each of these three roles has not been established. Investigation of these questions will probably involve placement of piezometers along both east and west banks, and the simultaneous monitoring of ground water and creek elevations over a time interval of several days.

- Sufficient evidence is available to suggest that the Buffalo Avenue sewer passageway may be an important influence on ground water flow in at least the A- and B-Zones. Further investigation of the role of this large deeply excavated passage as a potential line-drain should assume a high priority. Such work could involve placement of north-south transects consisting of three piezometers or piezometer clusters across the Buffalo Avenue right-of-way. Monitoring of such a piezometer system would help determine whether A-Zone recharge can move across Buffalo Avenue onto the plant sites from the unpaved area to the north.

- A well calibrated water budget for the Olin plant sites could provide better estimates of offsite loadings from the A-Zone, and, combined with additional hydrogeologic information, could form a basis for estimating seepage to the B-Zone. A first step in developing this capability would be to obtain more detailed information on how much of the recharge area is actually covered by impervious surfaces within sewer catchment systems. The April 1988 map created as part of this assessment is a good base which could be further refined with a ground survey. As mentioned above, a Buffalo Avenue sewer investigation would also contribute to this effort.

- Data collated in this report (Figure 5) suggest that most of the areas identified by the NYDEC as brine sludge disposal zones have actually been excavated to depths sufficient to remove any mercury containing material which may have been spread on the surface in the 1950's. A limited soil boring program directed specifically at these areas, the Building 13 location, and the pond site could serve to resolve concerns about continuing mercury contamination in these zones.

8.0 CONCLUSIONS

This report presents findings on the condition of ground water quality, and on the potential for offsite transport of chemicals in ground water at the two Buffalo Avenue plants in Niagara Falls, New York. This assessment has been based on local and regional ground water flow data, supplemented with historical information about plant operations and available analytical results from site soils and ground water samples.

Olin's operations have changed little over the century-long history of these facilities, centering around the electrolytic production of caustic soda and chlorine from rock salt using various modifications of the mercury-cell/chlor-alkali process. A portion of the cooling water for this process is obtained from two ground water supply wells located on Plant 1. Since February 1985, these production wells and Olin's activated carbon system for treating ground water withdrawn have been incorporated in the ground water remediation program being conducted by the adjacent DuPont facility.

Despite the predominance of inorganic chemical production at the Buffalo Avenue plants, several organic chemicals, including benzene, chlorobenzene, trichlorobenzene, and trichlorophenol were used or manufactured between 1950 and 1956 in a small area of the Plant 2 facility. These chemicals were used in the Alundum Road-Gill Creek (ARGC) area as part of a program to manufacture the pesticide hexachlorocyclohexane (BHC).

Ground water monitoring wells were installed in the ARGC section in 1978 to explore the possibility that chemicals associated with the BHC operation were present in ground water. Five wells were installed to monitor the unconsolidated overburden and an additional five to monitor the upper 6 to 10 feet of the bedrock.

Analytical results from samples obtained in 1979 showed several chemicals not attributable to Olin operations at concentrations ranging up to 0.2 ppm. Benzene, one of the chemicals used in the ARGC section, was found at mean concentrations of 0.36 ppm in the shallow wells, and 3.69 ppm in the deeper wells. Similar results for chlorobenzene and trichlorobenzene show concentrations of 0.02 ppm and 0.13 ppm, respectively, in the shallow wells; and 0.72 and 1.65 ppm in the deeper wells using the conservative method of calculating means.

Far more extensive results are available for the chlorophenols and BHC, for which analyses have been run two to four times a year since 1979. More than 75 percent of the results were below analytical limits of detection. The most significant effect of including non-detects is observed when the relative contribution of the 2,4,5- and 2,3,4-trichlorophenol isomers is considered. This single chemical group makes up more than 70 percent of the concentration of all chlorinated phenolics actually quantified (Method 2), but only around 50 percent of the total when non-detects are included at half the detection limit (Method 1). Mean concentrations for all chlorinated phenolics calculated using the first method were 0.68 and 1.83 ppm, respectively, for the shallow and deeper wells. Means using the second method were slightly lower, 0.60 and 1.76 ppm, respectively, for the shallow and deeper wells.

In contrast to the chlorinated phenolics, non-detects play a small role in the BHC data. Total BHC concentrations in the ARGC wells averaged 0.23 and 0.99 ppm, respectively, in the shallow and deeper wells.

In summary, Olin ground water analytical data show that the organic compounds used in the BHC production process, as well as BHC itself, are present in both overburden and shallow bedrock ground water beneath the ARGC section of Plant 2. Mean concentrations in the overburden are about half of those found in the shallow bedrock. In addition to the organics, mercury was also found in samples from these wells at concentrations averaging 0.02 ppm in the shallow wells, and 0.06 ppm in the deeper wells.

Analytical data from shallow soil borings were examined to determine whether areas of the Olin plants other than the ARGC might have been affected by organic chemical production. With the exception of BHC, potentially Olin-derived organic compounds were not found in plant site soils outside of the ARGC section.

Soil mercury concentrations in excess of 10 ppm were found inside and outside of the ARGC, as were lower levels of the coal derivatives flouranthene, phenanthrene and pyrene.

The Olin plants lie on or near the crest of an isolated bedrock high. Unconsolidated soils overlying the bedrock range in thickness from 4 to 13 feet across the two plants. Much of the overburden has been modified by excavation and fill, but fine-grained glacial lake sediments and more recent marsh deposits characterize undisturbed remnants of the original soil sequence. Ground water is found in the overburden soils at depths of 5 to 10 feet below the ground surface.

The overburden is underlain by more than 150 feet of the Lockport dolomite. Examination of the logs of the Plant 1 production wells and those of monitor wells drilled on adjacent DuPont properties indicate the presence of significant water-bearing horizontal bedding plane fracture zones in the otherwise low permeability dolomite. Four of these zones have been identified by DuPont geologists within the upper 100 feet of the Lockport, and can be expected beneath the Olin plants at depths of approximately 15, 35, 55, and 85 feet below the ground surface. Despite the presence of vertical joints and fractures connecting these zones, each exhibits the properties of a separate confined aquifer.

Data from overburden wells such as those in the ARGC section suggest that localized recharge from precipitation over the bedrock crest is the principal source of ground water above the bedrock (A-Zone) on the Olin plant sites. Ground water appears to move radially from the bedrock crest toward discharge boundaries at Gill Creek on the east and the Upper Niagara River to the south. The backfilled sewer excavation which follows Buffalo Avenue is deeply incised into the bedrock and may serve as a line drain receiving discharge from the overburden and perhaps the upper bedrock zone (B-Zone).

The rate of pumping from the Olin cooling water supply wells is the primary factor influencing ground water flow west of Gill Creek in the bedrock water-bearing zone. Ground water withdrawal from these wells currently ranges from 500 to 950 gpm and is sufficient to create cones of depression within each of the principal water-bearing bedding planes which extend to the vicinity of Gill Creek, at least on the DuPont property. Ground water within the radius of the cone of depression tends to flow toward the discharge point at the production wells.

Chemical compounds which are withdrawn with the water from the production well are removed via activated carbon treatment. Outside of the cone of depression formed by production well withdrawal, post-1963 bedrock ground water flow appears to be largely toward the northeast, away from the Niagara River, and toward the intersection of the NYPA conduits and the Falls Street tunnels.

The extent of hydraulic influence of the Olin production wells on the Olin plants cannot be precisely defined on the basis of existing data. Extrapolating from DuPont data, however, it is possible to estimate the approximate limits of the cone of depression in the two uppermost bedrock aquifers, the B- and CD-Zones. It is likely that both Olin plants fall within the CD-Zone cone of depression. The cone is believed to be smaller in the B-Zone, however, and may not include all of the ARGC section of Plant 2.

Non-Olin sources for chemicals used in the ARGC section of Plant 2 are found in the Buffalo Avenue industrial corridor, but offsite data indicate that, regardless of source, these compounds have a limited vertical distribution, being largely confined to the overburden and uppermost bedrock B-Zone.

Phenolics, benzene, chlorobenzene and BHC are also found at very low levels in untreated production well water from Plant 1. Because of the high rate of discharge (greater than 500 gpm), however, removal rates for these compounds from the production well capture zone could be as high as 0.13 lbs/day for benzene, chlorobenzene, and BHC, and up to 0.20 lbs/day for the phenolics. A total removal rate of these potential Olin compounds on the order of 0.5 lbs/day would represent about 1 percent of the approximately 50 lbs of organic chemicals currently removed by the activated carbon treatment system each day as part of the DuPont ground water remediation program. Ground water withdrawal by Olin serves as a significant factor for the containment and removal of compounds of both Olin and non-Olin origins from beneath the Buffalo Avenue plant sites.

Interest has recently focused on the possibility that Olin-derived chemicals may have escaped capture by the Olin production wells and be contributing to organics loadings noted in the Falls Street Tunnel. Although a regional ground water gradient exists which suggests a potential for transport from the area east of Gill Creek toward the NYPA/Falls Street Tunnel intersection, USGS monitoring well data from the Olin side of the conduits do not support the conclusion that chemicals used by Olin in the ARGC section have reached this point of discharge.

The relatively low concentrations of organic compounds present in the ARGC suggest that migration of Olin-derived chemicals from the Olin plants is unlikely to impact ground water quality on a regional scale. Organics moving through the overburden in the ARGC section are, however, expected to locally affect water quality in Gill Creek. Potential loadings of organics to Gill Creek were calculated using the mean concentration levels calculated from the ARGC deeper well data, and ground water flow estimates in the A-Zone overburden from a simple water budget model. A range of between 0.56 and 0.24 lbs/day is proposed, which is similar to earlier estimates developed by hydrogeological methods. Such a loading is on the same order as the estimated rate of removal of chemicals used in the ARGC section by the Olin production wells.

A better understanding of the location of ground water divides in the bedrock zones is necessary to carry further this assessment of Olin's potential impact on regional ground water quality. Similarly, the importance of the Olin production wells in withdrawing organic compounds used by Olin in the ARGC section cannot be precisely evaluated without onsite bedrock monitoring capabilities. Both of these data limitations can be resolved by an investigation which includes installation of a limited number of additional monitoring well clusters at Olin to provide hydrogeologic and analytical data on the A-, B- and CD-Zones.

9.0 REFERENCES

Calkin, P.E., and C.E. Brett, 1978. Ancestral Niagara River drainage: stratigraphic and paleontologic setting. Geol. Soc. Am. Bull. 89: 1140-1154.

Harza Engineering, 1979a. Hydrogeologic field investigation near Gill Creek at Olin Corporation's Plant Number 2, Niagara Falls, New York. June 1979. 14 p.

Harza Engineering, 1979b. Ground water quality investigation at Olin Corporation's Plant Number 1, Niagara Falls, New York. November 1979. 20 p.

Johnston, R.H., 1962. Water-bearing characteristics of the Lockport Dolomite near Niagara Falls, New York. U.S. Geol. Survey Prof. Paper 450-C: C123-C125.

Johnston, R.H., 1964. Ground Water in the Niagara Falls Area, New York. N.Y. State Water Res. Comm. Bull. GW-53. 93 p.

Koszalka, E.J., Paschal, J.E., Jr., Miller, T.S., and P.B. Duran, 1985. Preliminary Evaluation of Chemical Migration to Groundwater and the Niagara River from Selected Waste Disposal Sites. Environmental Protection Agency Report, Great Lakes National Program Office, Chicago. EPA-905/4-85-001. 425 p.

Maslia, M.L. and R.H. Johnston, 1982. Simulation of ground-water flow in the vicinity of the Hyde Park landfill, Niagara Falls, New York. U.S. Geol. Survey Open-File Rept. 82-159. 19p.

Mercer, J.W., Silka, L.R., and C.R. Faust, 1983. Modeling Groundwater Flow at Love Canal, New York. J. Env. Engr. 109(4):924-942.

Miller, T.S., and W. M. Kappel, 1986. Effect of Niagara Power Project on ground-water flow in the upper part of the Lockport Dolomite, Niagara Falls area, New York. U.S. Geol. Survey Water RES. Invest. Rept. 86-4130. 31p.

O'Brien and Gere Engineers, 1987. Phase I Falls Street Tunnel Study. Prepared for the City of Niagara Falls, New York. October 1987.

Sanford, B.V., Thompson, F.J., and G.H. McFall, 1985. Plate tectonics - a possible controlling mechanism in the development of hydrocarbon traps in southwest Ontario. Bull. Can. Petrol. Geol. 33(1): 52-71.

Soil Conservation Service, 1975. Urban hydrology for small watersheds. Tech. REL. No. 55. Eng. Division, U.S. Dept. Agriculture.

Yager, R.M. and W. M. Kappel, 1987. Detection and characterization of fractures and their relation to ground-water movement in the Lockport Dolomite, Niagara County, New York. U.S. Geol. Survey Water Res. Invest. 47p.

Wendel Engineers, 1981. Discussion of questions raised in response to the Harza hydrogeologic field investigation near Gill Creek. June 1979. Olin Corporation's Plant Number 2, Niagara Falls, New York. 14p.

Woodward-Clyde Consultants, 1983. Geohydrologic investigations, Niagara Plant, Niagara Falls, New York. Prepared for E.I. duPont de Nemours & Co., Inc. by the Plymouth Meeting Office. 57p.

Woodward-Clyde Consultants, 1986. The hydraulic impact of the Olin production wells on the Niagara Plant, Niagara Falls, New York. Prepared for E.I. duPont de Nemours & Co., Inc. by the Plymouth Meeting Office. 12p.

TABLE 1

Sanitary and Clear Water Sewer Systems: Olin Buffalo Avenue Plants*

Plant 1	Plant 2
1S	3CW
1CW	4CW
2CW	6S
2CW(OLD)	7S
2S	8S
3S	5S
9S	

TABLE 2

Characteristics of Buffalo Avenue Sewer Connections*

Sewer System	Access No.	Invert Elevation	Connection Type
4CW	MH114	556.62	48in. Storm
7S	MH113	555.42	38in.Sanitary
2CW	MH80	560.72	60in.Sanitary
3S	MH79	557.78	24in.Sanitary
2S	MH97'	557.41	20in.Sanitary
1S	MH95	556.63	20in.Sanitary

* Refer to drawings in Appendix C

Table 3

CLASSIFICATION OF PARAMETERS DETECTED AT THE OLIN PLANT SITE

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Positive	Soil/MW[1]	Soil/MW	Soil/MW	Prod. Well	Prod. Well	-
	Prod. Well[2]	-	-	-	-	-
Negative	-	-	Prod. Well	-	Soil/MW	-
	-	-	-	-	-	-
Possible	-	Prod. Well	-	Soil/MW	-	Prod. Well
	-	-	-	-	-	Soil/MW
METALS						
	Mercury[3]					
BASE/NEUTRAL SEMI-VOLATILES						
	1,2,4-Trichlorobenzene[3]	Hexachlorobenzene[4]		Hexachlorobutadiene[5]		Diethylphthalate
	1,2-Dichlorobenzene[4]			Hexachloroethane		Dioctylphthalate
	1,3-Dichlorobenzene[4]			Flouranthene		Naphthalene
	1,4-Dichlorobenzene[4]			Phenanthrene		Pentachlorobutadiene[5]
				Pyrene		Tetrachlorobutadiene[5]
ACID EXTRACTABLE SEMI-VOLATILES						
		3-,4-Chlorophenol[4]	2-Chlorophenol[4]			Phenol[4]
		2,3-,2,4-,2,5-Dichlorophenol[4]				
		3,4-Dichlorophenol[4]				
		2,4,5-,2,3,4-Trichlorophenol[3]				
		2,3,5-,2,3,6-Trichlorophenol[3]				
		2,3,4,5-,2,3,4,6-Tetrachlorophenol[4]				
		2,3,5,6-Tetrachlorophenol[4]				
PESTICIDES						
	alpha-BHC[3]					
	beta-BHC[3]					
	delta-BHC[3]					
	gamma-BHC[3]					
VOLATILES						
	Benzene[3]		Methylene Chloride[5]	Vinyl Chloride[5]	1,1,2,2-Tetrachloroethane[5,6]	Bromodichloromethane
	Chlorobenzene[3]		Toluene	1,1,1-Trichloroethane[5]	1,1,2-Trichloroethane[5,6]	1,1-Dichloroethene
	Chloroform[5]			Carbon Tetrachloride[3,5]		Pentachloroethane
	1,2-Dichloroethene[5]					
	Tetrachloroethene[5,6]					
	Trichloroethylene[5]					

[1] Soil or Monitor Well (Water) Samples from Olin Plant 2.
[2] Production Well Water Samples from Olin Plant 1.
[3] Used or Produced in Quantity by Olin (mercury at both plants, organics only at Plant 2 site).
[4] Potential By-Product, Olin Plant 2 site.
[5] Products or By-Products of Non-Olin Processes.
[6] Used in Non-Production Quantities at Olin.

TABLE 4

PLANT 2 SOILS ANALYTICAL DATA

Note. Mean (1) includes non-detects (ND) at 0.5 detection limit.
Mean (2) includes non-detects (ND) as zero value (0).

PLANT 2 SOILS (PPM)	MEAN(1)	MEAN(2)	MAX	No. Samples	% N.D.
METALS					
MERCURY (TOTAL)	49.87	49.83	204	12	8
MERCURY (EPTOX)	0.0066	0.0063	0.07	71	14
BASE/NEUTRAL EXTRACT					
1,2-DICHLOROBENZENE	0.513	0.012	0.135	17	88
1,3-DICHLOROBENZENE	0.544	0.043	0.348	17	82
1,4-DICHLOROBENZENE	0.62	0.117	1.8	17	88
FLOURANTHENE	1.433	0.6	3.6	6	83
PHENANTHRENE	1.417	0.583	3.5	6	83
PYRENE	1.383	0.55	3.3	6	83
1,2,4-TRICHLOROBENZENE	0.483	0.116	0.853	17	71
ACID EXTRACT					
2-CHLOROPHENOL	0.727	0	<2.0	11	100
2,3-,2,4-,2,5-DICHLOROPHENOL	0.727	0	<2.0	11	100
3,4-DICHLOROPHENOL					
2,4,5-,2,3,4-TRICHLOROPHENOL					
2,3,5-,2,3,6-TRICHLOROPHENOL					
2,4,6-TRICHLOROPHENOL	0.727	0	<2.0	11	100
2345-,2346-TETRACHLOROPHENOL					
2,3,5,6-TETRACHLOROPHENOL					
PHENOL	1	0	<2.0	6	100
VOLATILES					
BENZENE	1.26	1.115	7.02	14	71
CARBON TETRACHLORIDE	0.157	0.005	0.074	14	93
CHLOROBENZENE	1.426	1.281	8.69	14	71
CHLOROFORM	1.177	1.086	11.3	14	71
1,2-DICHLOROETHENE	0.224	0.114	1.07	14	86
METHYLENE CHLORIDE	0.502	0.094	1.07	14	57
1,1,2,2-TETRACHLOROETHANE	0.145	0	<0.5	14	100
TETRACHLOROETHENE	3.852	4.107	27.9	14	57
TOLUENE	1.113	0.968	5.2	14	64
1,1,1-TRICHLOROETHANE	0.145	0	<0.5	14	100
TRICHLOROETHYLENE	5.51	5.492	41.8	14	57
VINYL CHLORIDE	0.145	0	<0.5	14	100
PESTICIDES					
ALPHA BHC	0.0385	0.0382	0.4	14	7
BETA BHC	0.0493	0.0493	0.2	14	0
DELTA BHC	0.0083	0.0076	0.041	14	57
GAMMA BHC	0.0069	0.006	0.025	14	7
BHC (ALL ISOMERS)	0.103	0.1011			

TABLE 5

Chemicals in Groundwater: Alundum Rd-Gill Creek Section (1979-1987) (Concentrations in ppm)

Parameter	%ND	Deep wells Mean(1)	Deep wells Mean(2)	Deep wells MAX	Shallow Wells Mean(1)	Shallow Wells Mean(2)	Shallow Wells MAX
Mercury		0.0634	0.0634	0.326	0.0185	0.0185	0.560
Phenol*		0.0198	0.0198	0.037	0.0069	0.0069	0.017
1,2-Dichlorobenzene*		ND	ND	ND	ND	ND	ND
Fluoranthene*		0.0037	0.0037	0.008	0.0932	0.0932	0.413
Phenanthrene*		0.0051	0.0050	0.018	0.0706	0.0706	0.304
Pyrene*		0.0022	0.0022	0.004	0.0623	0.0623	0.269
1,2,4-Trichlorobenzene*		1.6524	1.6524	4.518	0.1299	0.1299	0.610
CHLORINATED PHENOLICS:							
2-Chlorophenol	84	0.0140	0.0068	0.230	0.0200	0.0137	0.30
2,3-2,4-2,5-Dichlorophenol	77	0.0275	0.0198	0.320	0.0202	0.0118	0.08
3,4-Dichlorophenol	78	0.1106	0.1019	1.500	0.0545	0.0399	0.67
2,4,5-2,3,4-Trichlorophenol	68	1.3133	1.3026	20.130	0.3802	0.3720	7.30
2,3,5-2,3,6-Trichlorophenol	81	0.0497	0.0389	1.400	0.0630	0.0531	2.90
2,4,6-Trichlorophenol	93	0.0412	0.0339	3.300	0.0169	0.0079	0.10
2,3,4,5-2,3,4,6-Tetrachloro-phenol	79	0.2132	0.2000	2.100	0.0849	0.0699	1.10
2,3,5,6-Tetrachlorophenol	82	0.0653	0.0548	1.600	0.0376	0.0281	1.27
SUB-TOTAL(Chlorophenols)		1.8348	1.7587		0.6773	0.5964	
BENZENE HEXACHLORIDE:							
Alpha BHC		0.4226	0.4226	18.000	0.0719	0.0719	0.44
Beta BHC		0.0593	0.0593	3.070	0.0284	0.0284	0.06
Delta BHC		0.1956	0.1956	4.200	0.0490	0.0489	1.40
Gamma BHC		0.3092	0.3092	17.000	0.0842	0.0841	0.60
SUB-TOTAL(BHC)		0.9867	0.9867		0.2335	0.2333	
Benzene*		3.6892	3.6892	8.869	0.3556	0.3556	1.26
Carbon Tetrachloride*		ND	ND	ND	ND	ND	N
Chlorobenzene*		0.7230	0.7220	1.885	0.0246	0.0246	0.05
Chloroform*		0.1946	0.1946	0.360	0.0742	0.0742	0.21
1,2-Dichloroethene*		0.0086	0.0086	0.160	0.0482	0.0482	0.22
Methylene Chloride*		ND	ND	ND	ND	ND	N
1,1,2,2-Tetrachloroethane*		ND	ND	ND	ND	ND	N
Tetrachloroethene*		0.0191	0.0191	0.039	0.0144	0.0144	0.03
Toluene*		0.0041	0.0041	0.014	0.0022	0.0022	0.00
1,1,1-Trichloroethane*		ND	ND	ND	ND	ND	N
Trichloroethylene*		0.0160	0.0160	0.016	0.0414	0.0414	0.1
Vinyl Chloride		ND	ND	ND	ND	ND	N
Total (Organics + Mercury)		9.2227	9.1450		1.8344	1.7719	

NOTE: Mean(1)-- Mean includes non-detects (ND) at 0.5 detection limit.
Mean(2)-- Mean includes non-detects (ND) at zero concentration.
* Single date - January 1979

TABLE 6

OLIN PRODUCTION WELLS 1978 - 1983

SUMMARY OF ORGANIC CONTAMINANTS
(Total Number of Analyses - 276)
(Total Number of Complete Characterizations - 7)
(Data Through February 1983)

COMPOUND	NUMBER OF TIMES DETECTED/276	NUMBER OF TIMES DETECTED/7	MAXIMUM VALUE (ppb)	CHLORINATED SOLVENT MANUFACTURE(6)	OLIN USAGE
1,1,2,2-Tetrachloroethane	260	--	26887	Known Intermediate	(1)
Tetrachloroethene	285	--	16000	Known Product/By-Product	(1)
Trichloroethene	265	--	14000	Known Product	
Dichloroethenes	269	--	2006	Known Product/By-Product	
Chloroform	283	--	1400	Known Product	
Carbon Tetrachloride	282	--	1200	Known Co-Product	(2)
Methylene Chloride	108	--	670	Known Product/By-Product	
Methanol	1(5)	--	485	Known Product	(3)
Vinyl Chloride	227	--	440	Believed By-Product	
1,1,1-Trichloroethane	202	--	140	Believed By-Product	
1,1,2-Trichloroethane	106	--	53	Believed By-Product	
Hexachloroethane	--	7	29.6	Known to be Present	
Trichlorofluoromethene	4(7)	--	27		
Monochlorobenzene	46	--	24		(2)
Tetrachlorobutadiene	--	2	22.2	Known Intermediate	
Benzene	33	--	19		(2)
Ethylbenzene	2	1	18		
Dioctylphthalate	--	2	18	(5)	
Hexachloro-1,3,-butadiene	--	6	16	Believed By-Product	
Pentachlorobutadiene	--	2	13.4	Known to be Present	
Dichloroethane	8	--	10		
Pentachloroethane	--	3	8.6		
Diisooctylphthalate	--	3	5.9	(5)	
Trichlorobenzene	--	6	5		(2)
Phenanthrene/Anthracene	--	3	4		
Pyrene	--	5	2		
BHC (hexachlorocyclohexane)	--	5	1.21		(2)
Toluene	4	--	1.8		
Dioctyladipate	--	2	1.7	(5)	
Dichlorobenzenes	--	2	1.2		(4)
Fluoranthene	--	5	1		
Hexachlorobenzene	--	1	1	Believed By-Product	(4)

(1) Known to have been used; small, non-production quantity.
(2) Used or produced in quantity at Plant 2 site.
(3) Used in quantity, past and present, at Plant 2 site.
(4) Potential by-product, Plant 2 site.
(5) Presence of both phthalates and adipates at least partially due to contamination in analysis.
(6) Non-Olin processes.
(7) Compound from 4/7/82 sample identified as dichlorodifluoromethane.

NOTE: Compounds detected on one occasion only and not quantitated or quantitated at <1 ppb have been omitted.

DLC/vrp
4/11/83

TABLE 7
Target Compounds In Production Well Samples
(Concentrations in ppm)*

Parameter	North Well 5/16/80	North Well 9/28/83	South Well 7/30/87	South Well 11/5/87	South Well 1/26/88	Mean*
Benzene	<0.010	<0.0044	<0.020	0.0050	0.0032	0.0043
Carbon Tetrachloride	0.030	0.047	<0.010	0.0183	0.0281	0.0181
Chlorobenzene	<0.010	<0.006	<0.020	<0.0020	<0.0020	0.0040
Chloroform	0.351	2.000	0.440	0.2020	0.7500	0.7500
1,2-Dichlorbezene	<0.010	-	<0.020	<0.0020	<0.0020	0.0043
1,4-Dichlorobenzene	<0.010	-	<0.020	<0.0020	<0.0020	0.0043
1,2-Dichloroethene	0.351	0.180	0.120	0.0115	<0.0010	0.1326
Methylene Chloride	0.016	<0.0028	0.130	0.1200	0.0813	0.0697
1,1,2,2-Tetrachloroethane	<0.010	0.120	0.025	0.0714	0.0793	0.0601
Tetrachloroethene	0.764	0.970	0.300	0.4940	0.3700	0.5796
Toluene	<0.010	-	<0.020	0.0026	<0.0020	0.0047
1,1,1-Trichloroethane	<0.010	0.0052	<0.010	0.0174	<0.0010	0.0066
Trichloroethylene	0.670	0.930	0.570	1.3400	0.6410	0.8302
Vinyl Chloride	<0.010	0.029	<0.020	0.0757	0.0458	0.0331
Total Phenolics	<0.010	-	<0.050	<0.0500	<0.0500	0.0200
Alpha BHC	<0.010	0.00071	0.0058	<0.0005	<0.0005	0.0024
Beta BHC	<0.010	0.00002	0.0058	<0.0005	<0.0005	0.0023
Delta BHC	<0.010	0.00016	<0.0005	<0.0005	<0.0005	0.0015
Gamma BHC	<0.010	0.00059	<0.0005	<0.0005	<0.0005	0.0013

* 'less than' values included at 0.5 detection limit.

TABLE 8

ORGANIC COMPOUNDS IN USGS WELLS

ADJACENT TO THE FALLS STREET TUNNEL - NYPA CROSSING

Well Number	NFB-11	NFB-12	NFB-13
Priority Pollutant			
Organic Compounds			
Volatiles			
Benzene	180	250	-
Chloroform	-	-	-
Ethylbenzene	5.6	1.4	1.4
Tetrachloroethylene	LT	3.4	8.8
Toluene	34	5.7	2.2
1,2 trans-dichloroethylene	1,400	1,400	2.4
Trichloroethylene	LT	15	2.6
Trichlorofluoromethane	-	-	-
Semi Volatiles			
Bis (2 ethylhexyl) phthalate	13	10	9.4
Butylbenzylephthalate	36	61	-
Chlorobenzene	15	35	LT
1,2 dichlorobenzene	15	33	-
1,3 dichlorobenzene	18	30	-
1,4 dichlorobenzene	10	65	-
Di-N-butylphthalate	17	18	-
Di-N-octylphthalate	-	-	-
Hexachlorobenzene	0.47	-	0.09
Naphthalene	31	LT	-
Nitrobenzene	8.5	-	-
1,2,4 trichlorobenzene	11	27	-
Pesticides			
Alpha BHC	0.44	1.4	0.78
Beta BHC	0.26	1.4	0.25
Endosulfan	-	-	-
Heptachlor	LT	-	LT
Lindane	LT	0.13	LT

(TABLE 3.8 FROM O'BRIEN AND GERE 1987)

All results in ug/L

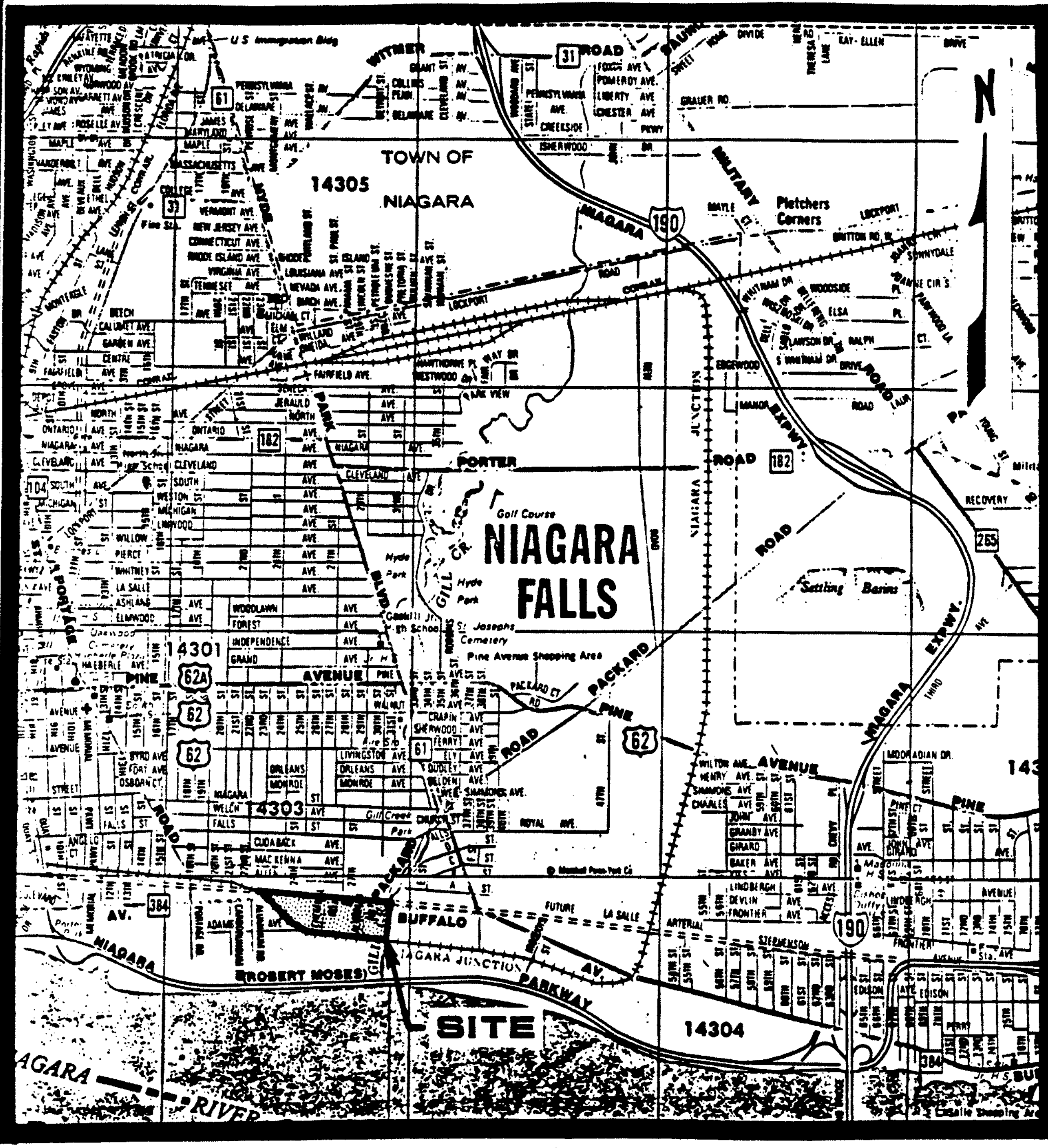
- \- Not detected
- LT Less than the laboratory's quantification limit
- NA Not analyzed

TABLE 9
A-Zone Ground Water Outflow
From The Niagara Chemical Plant

Year	Total Infiltration Depth (ft/yr)	Total Outflow (ft^3/yr)	Total Outflow (ft^3/day)
1983	1.268	1,990,636	5454
1984	1.242	1,949,818	5342
1985	1.355	2,127,217	5828
1983-1985 average	1.288	2,022,034	5540
1941-1980 average	1.279	2,007,905	5501

TABLE 10
Water Budget Results
A-Zone Outflow Across Perimeter Segments

Outflow Segment	Infiltration Rate (ft/yr)	Total Outflow (cu.ft/day)	Total Load Deep Wells Mean(1) (lbs/day)	Total Load Deep Wells Mean(2) (lbs/day)	Total Load Shallow Wells Mean(1) (lbs/day)	Total Load Shallow Wells Mean(2) (lbs/day)
Buffalo Ave.	1.279	311	0.179	0.177	0.0355	0.0343
Gill Creek	1.279	350	0.201	0.199	0.0399	0.0386
South	1.279	2323	NA	NA	NA	NA
Southwest	1.279	2516	NA	NA	NA	NA



REGIONAL LOCATION OF NIAGARA FALLS PLANTS

SCALE 1:24,000

0 ½ 1 MILE

OLIN CORPORATION
CHARLESTON, TENNESSEE

FILE: 87B226C
MAY, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 1

LEGEND

- CB — CATCHBASIN
- MH — MANHOLE
- HYDRANT
- POWER POLE
- LIGHT POLE
- DOUBLE LIGHT POLE
- S — SIGN
- ×570.3 — SPOT ELEVATION
- TREE
- TRAFFIC LIGHT
- GUIDE RAIL
- FENCE
- SIDEWALK
- BRUSH
- TANK LINE
- RAILROAD
- TREELINE
- RETAINING WALL
- CURB LINE

1 FOOT CONTOUR INTERVAL

NOTES:

1. This map was produced entirely by photogrammetric methods from 1"=400' photography taken on April 12, 1988. The user of this map is cautioned that certain areas obscured by shadow and heavy vegetation may require field verification. The outline of all buildings is the roof line.

2. Vertical accuracies can be expected to be +/- one half contour interval for contour lines, spot elevations +/- one quarter of a contour interval in 90% of the areas which were clearly visible photogrammetricly.

3. In instances where digital information is supplied to a client on magnetic medium, we can not be responsible for the accuracy of any subsequent computer generated mapping, beyond the original intended map scale.

GROUND WATER ASSESSMENT
BUFFALO AVENUE PLANTS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

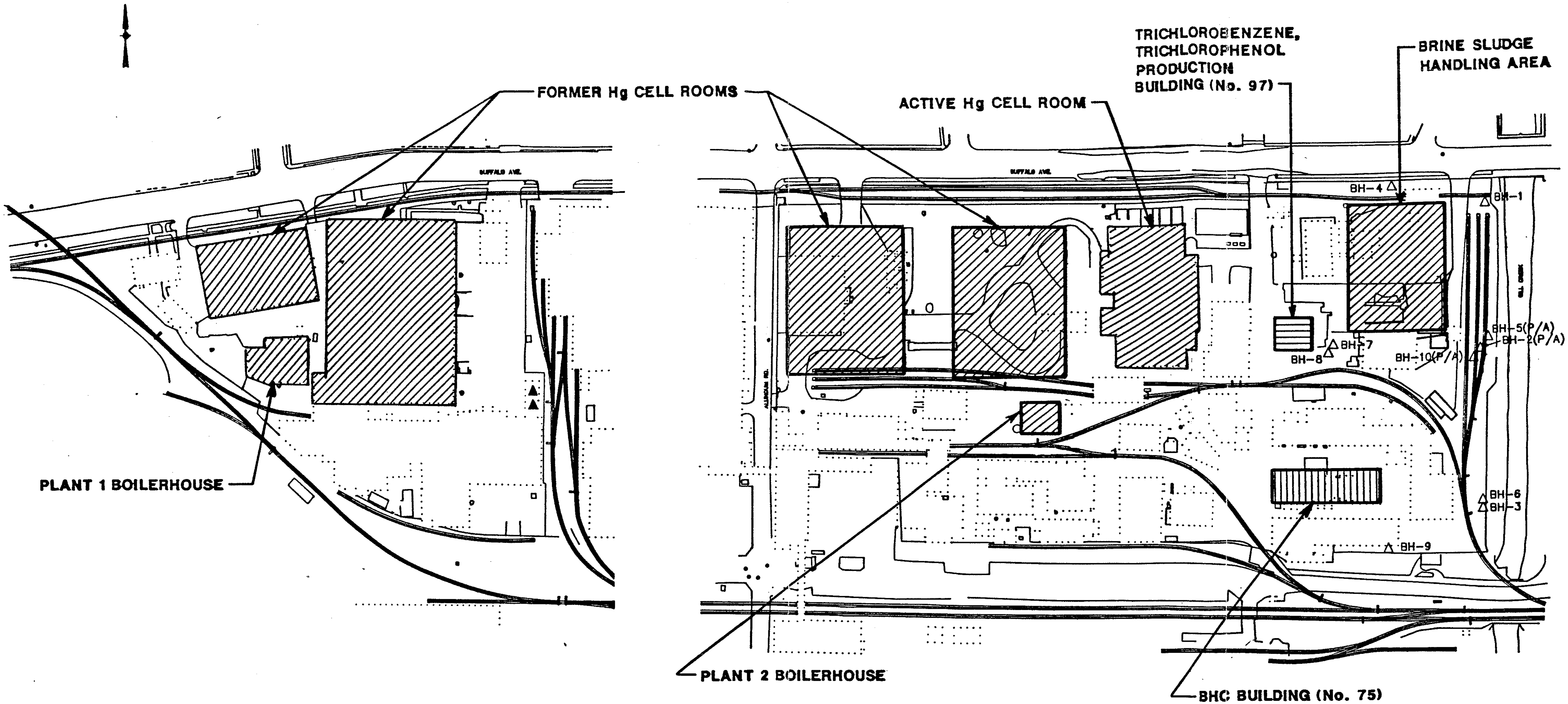
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

SCALE: 1"=50'	MADE BY: A.L. / CHECKED BY:	DATE: 6/2/88 / DATE:	FILE NO. 87B226C
	SITE PLAN		FIGURE 2

McINTOSH & McINTOSH, P.C.
CONSULTING ENGINEERS, LAND SURVEYORS, PLANNERS
LOCKPORT, NEW YORK PHONE 434-9138 — BUFFALO, NEW YORK PHONE 625-8360

RESURVEYED	REVISION

TOPOGRAPHIC MAP OF PART OF LANDS OF OLIN MATHIESON CHEMICAL CORP.
LOCATION: CITY OF NIAGARA FALLS, NIAGARA COUNTY, NEW YORK
JOB No. 5377 SCALE: 1" = 50' DATE: APRIL 12, 1988



LEGEND:

▲ PRODUCTION WELLS

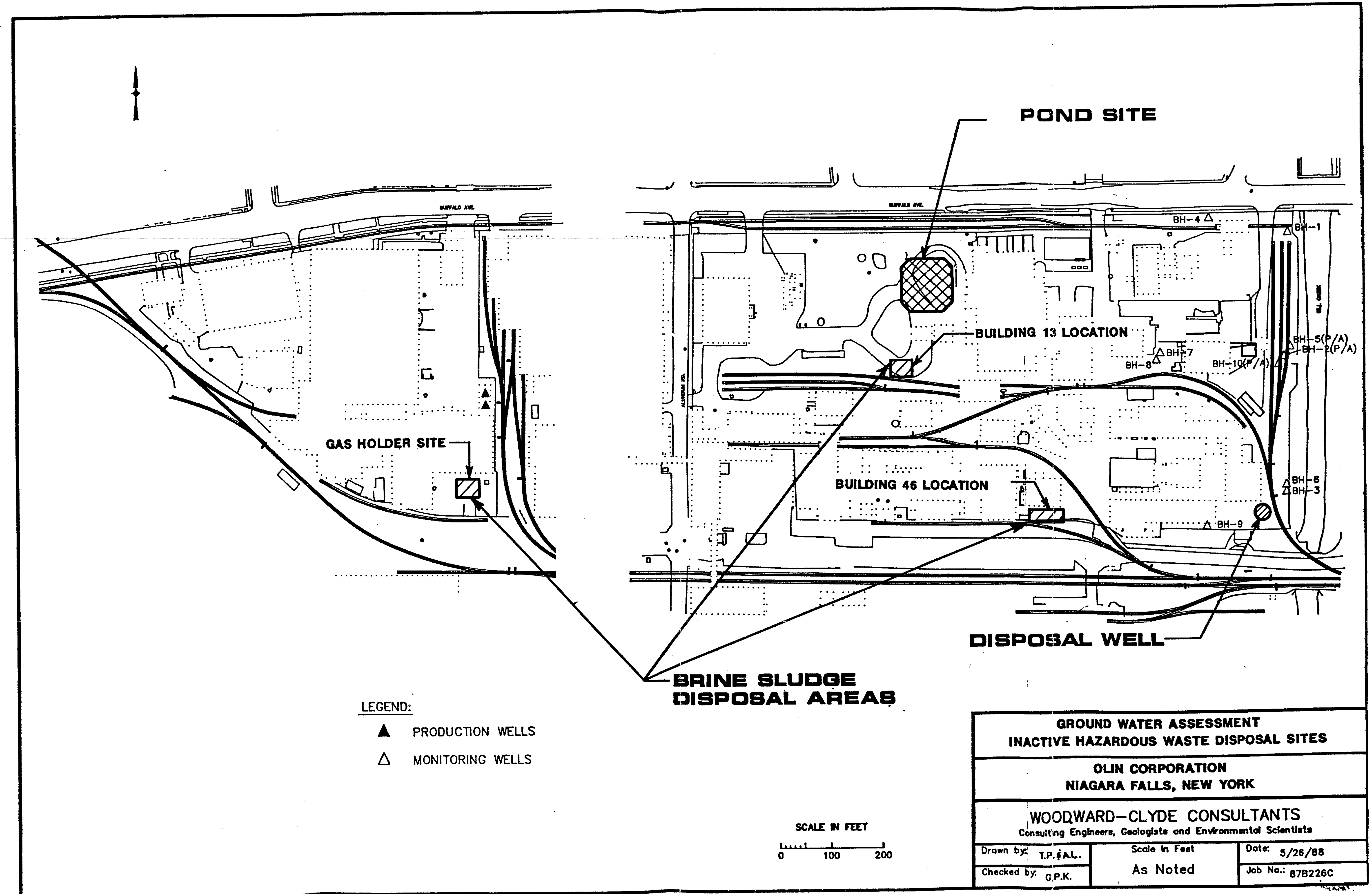
△ MONITORING WELLS

SCALE IN FEET

0 100 200

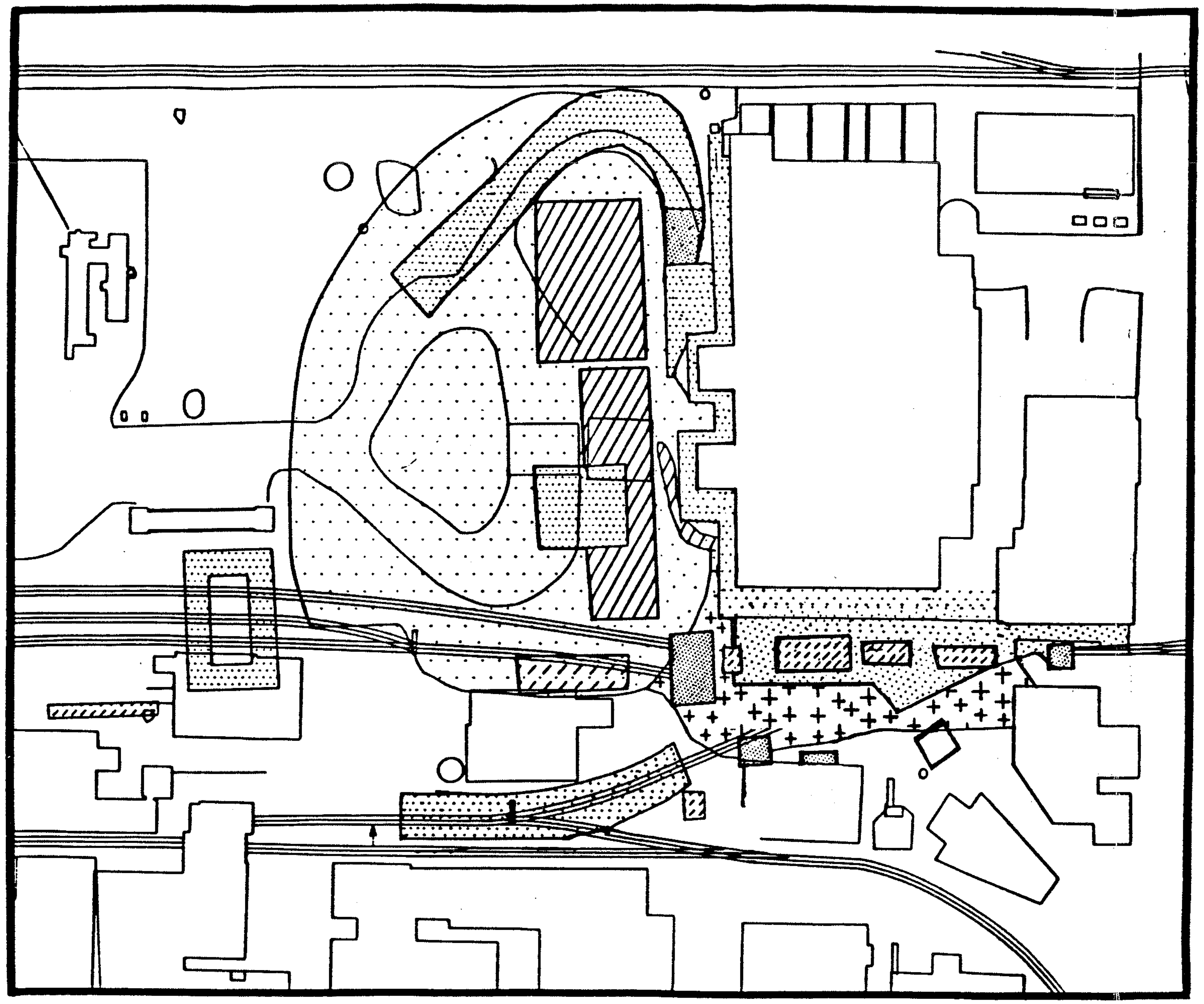
GROUND WATER ASSESSMENT PAST AND PRESENT PLANT OPERATIONS		
OLIN CORPORATION NIAGARA FALLS, NEW YORK		
WOODWARD-CLYDE CONSULTANTS Consulting Engineers, Geologists and Environmental Scientists		
Drawn by: T.P.	Scale In Feet	Date: 5/26/88
Checked by: G.P.K.	As Noted	FIGURE 3

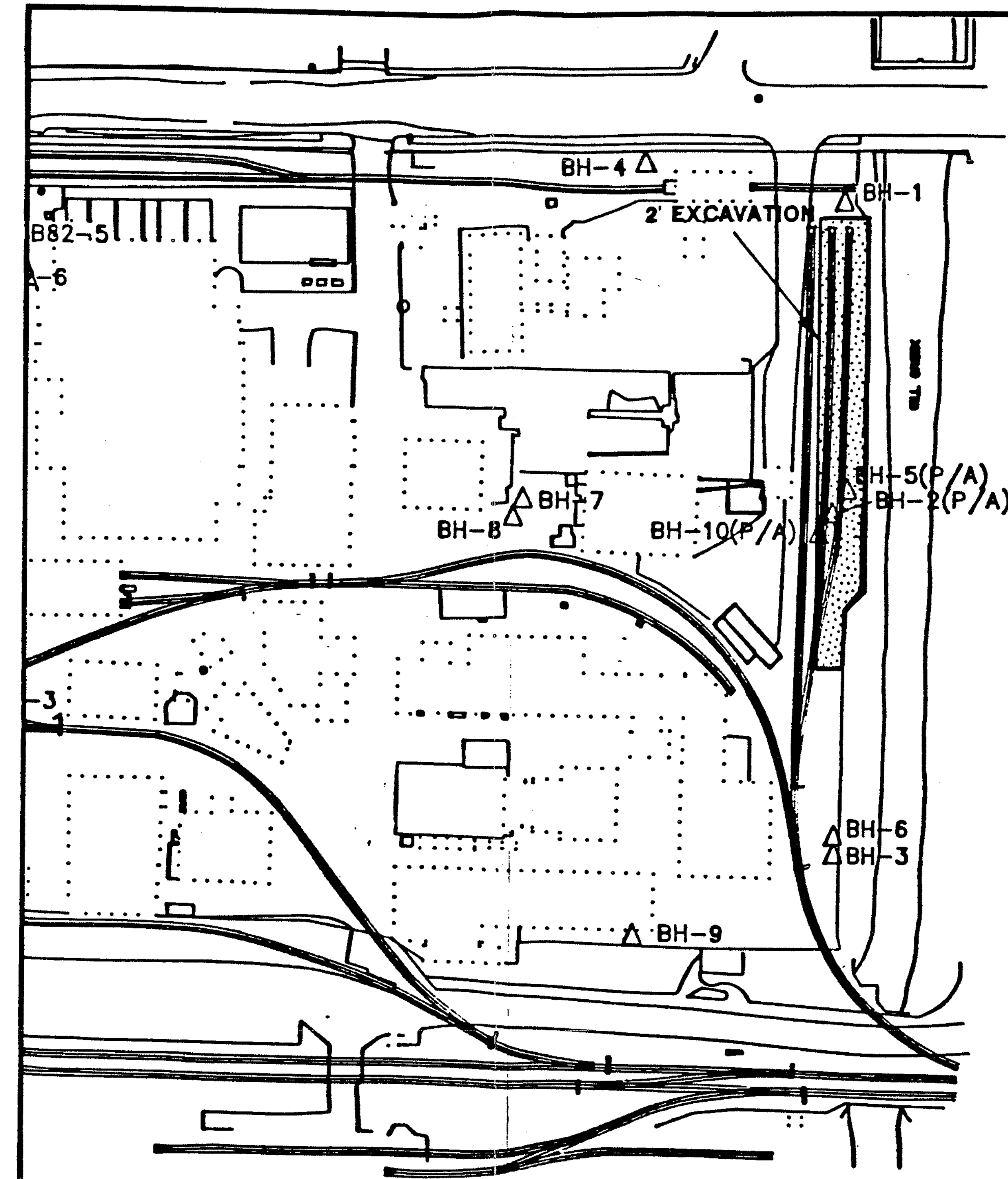
FIGURE 3

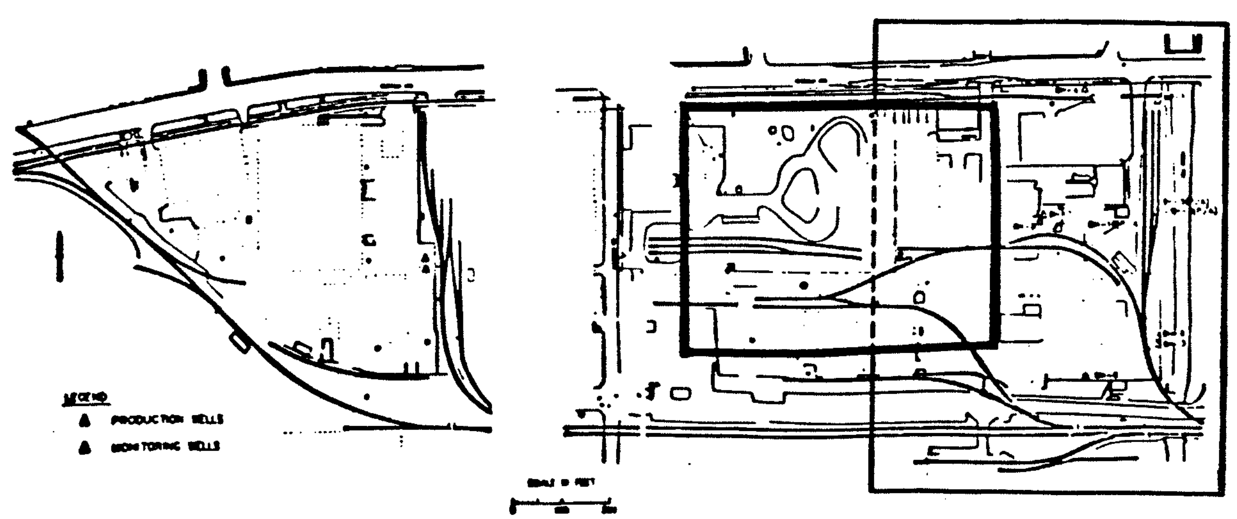


POND SITE
BUILDING 13 LOCATION
BUILDING 46 LOCATION
GAS HOLDER SITE
DISPOSAL WELL
BRINE SLUDGE DISPOSAL AREAS
BH-1
BH-2(P/A)
BH-3
BH-4
BH-5(P/A)
BH-6
BH-7
BH-8
BH-9
BH-10(P/A)
LEGEND:
PRODUCTION WELLS
MONITORING WELLS
SCALE IN FEET
0
100
200
GROUND WATER ASSESSMENT
INACTIVE HAZARDOUS WASTE DISPOSAL SITES
OLIN CORPORATION
NIAGARA FALLS, NEW YORK
WOODWARD-CLYDE CONSULTANTS
Consulting Engineers, Geologists and Environmental Scientists
Drawn by: T.P./A.L.
Checked by: G.P.K.
Scale In Feet
As Noted
Date: 5/26/88
Job No.: 87B226C

FIGURE 4







LEGEND:

- 0.5' Excavation
- 1' Excavation
- 2' Excavation
- 4' Excavation
- Excavation to bedrock
- Unknown excavation depth

GROUND WATER ASSESSMENT

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MADE BY: BG	DATE: 8/18/88	FILE NO.
CHECKED BY: -	DATE:	87B266C

PLANT 2 SOILS EXCAVATION

FIGURE 5

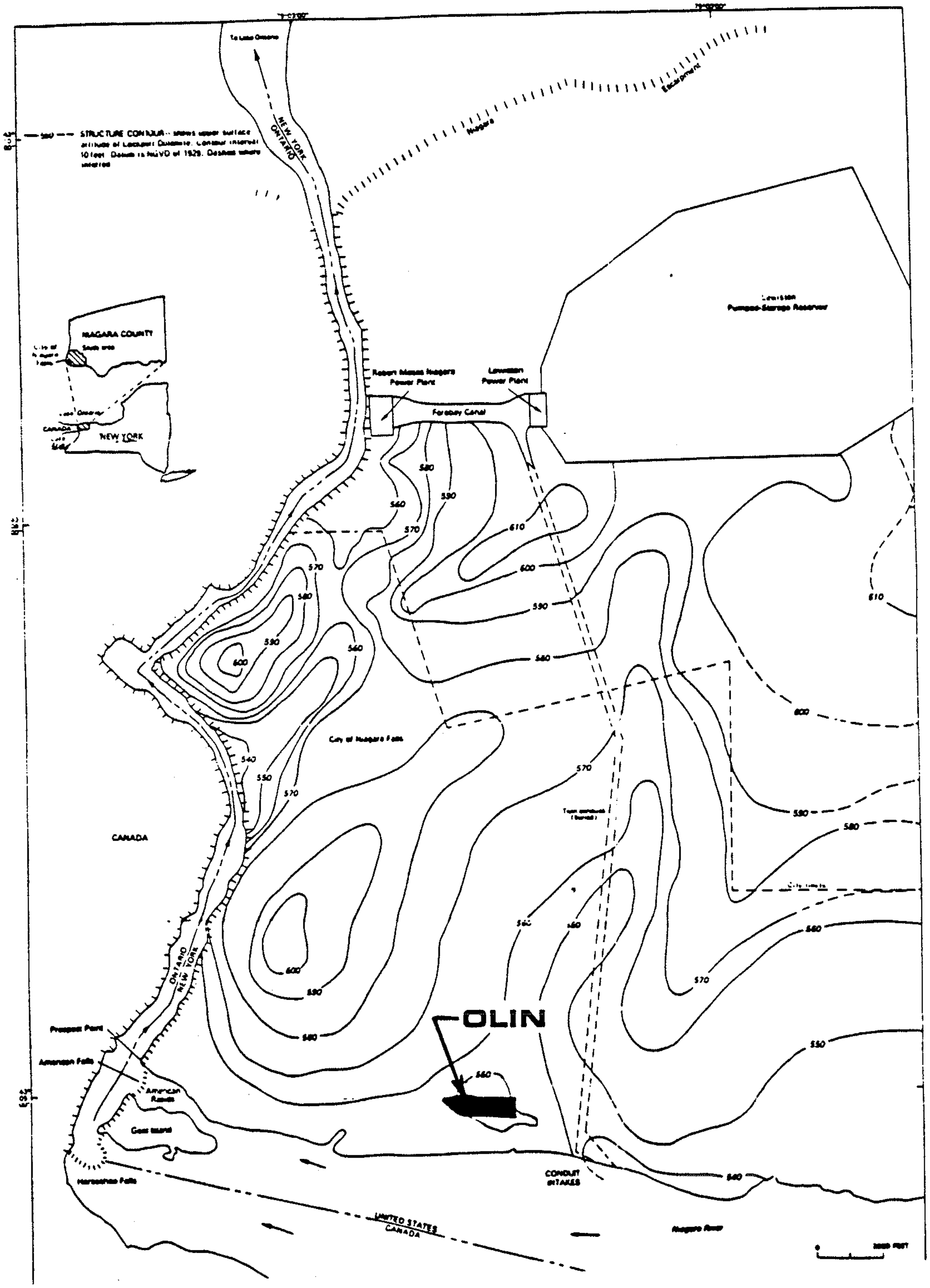
FIGURE 6 --**Water-bearing characteristics of unconsolidated deposits and bedrock in the Hyde Park area.**

(Maslia and Johnston, 1982)

Water-bearing unit	Thickness (feet)	Lithologic description	Water-bearing characteristics	Hydraulic properties
Undifferentiated lake deposits	0-20	Laminated clay and silt and thin beds of fine sand.	Clay and silts have low permeability and yield little water.	Hydraulic conductivity range: 0.0014 to 0.27 ft/d[1].
Glacial till ("Hardpan")	0-10	Mixture of boulders and pebbles in a matrix of sand, silt, and clay.	Water occurs principally in thin sand lenses in till and a "washed zone" at the top of the bedrock.	
Lockport Dolomite	90-130	Dark-gray to grayish-brown massive to thin bedded dolomite, locally containing algal reefs, small masses of gypsum, limestone, and shaly beds at base.	Only important aquifer in Niagara Falls area. Ground water occurs principally in water-bearing zones parallel to bedding which are much more permeable than the surrounding rock. The upper 10 to 15 feet is the most permeable interval and contains vertical joints and small cavities formed by solution of gypsum. Well yields 10 to 100 gal/min mostly.	Average transmissivity is 300 ft^2/d;[2] probable hydraulic conductivity range: 10 ft/d (upper 15 feet) to 1 ft/d (lower part).
Rochester Shale	60	Dark-gray calcareous shale.	Very low permeability shale. Yields no significant water to wells.	Unknown. Hydraulic conductivity assumed to be 2 to 3 orders of magnitude less than that of Lockport Dolomite.

[1]Based on well-recovery test data from Conestoga-Rovers Associates.

[2]Based on steady-state analysis of 18,000-foot section of dewatered conduit penetrating the Lockport Dolomite; average gradient (0.017 ft/ft) and average pumping rate (1,400,000 gal/d) (Johnston, 1964).



Ref: MODIFIED FROM MILLER AND KAPPEL (1986).

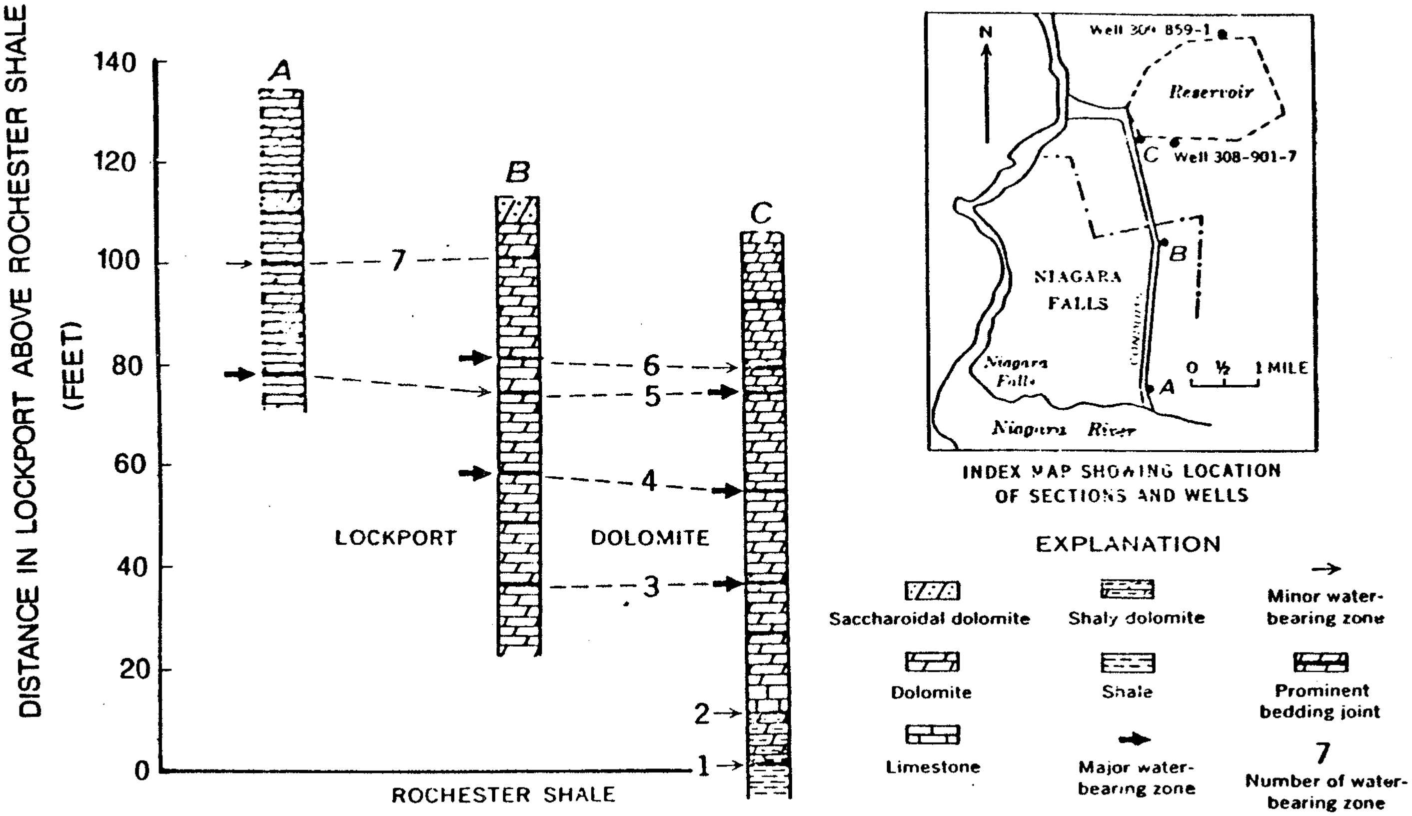
UPPER SURFACE OF LOCK PORT DOLOMITE

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 7



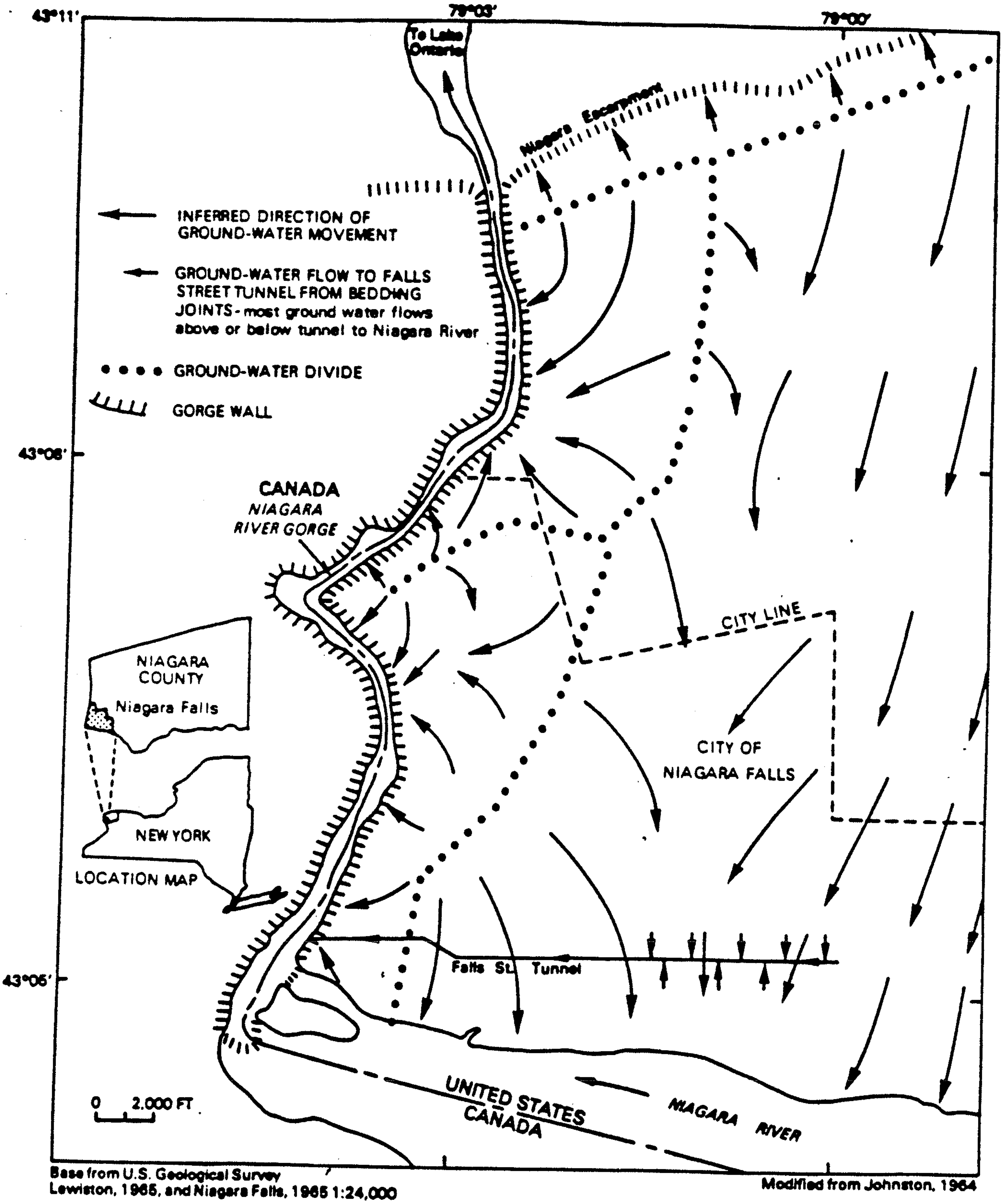
CROSS-SECTION ALONG ROUTE OF NYPA EXCAVATION (Johnston 1962)

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 8

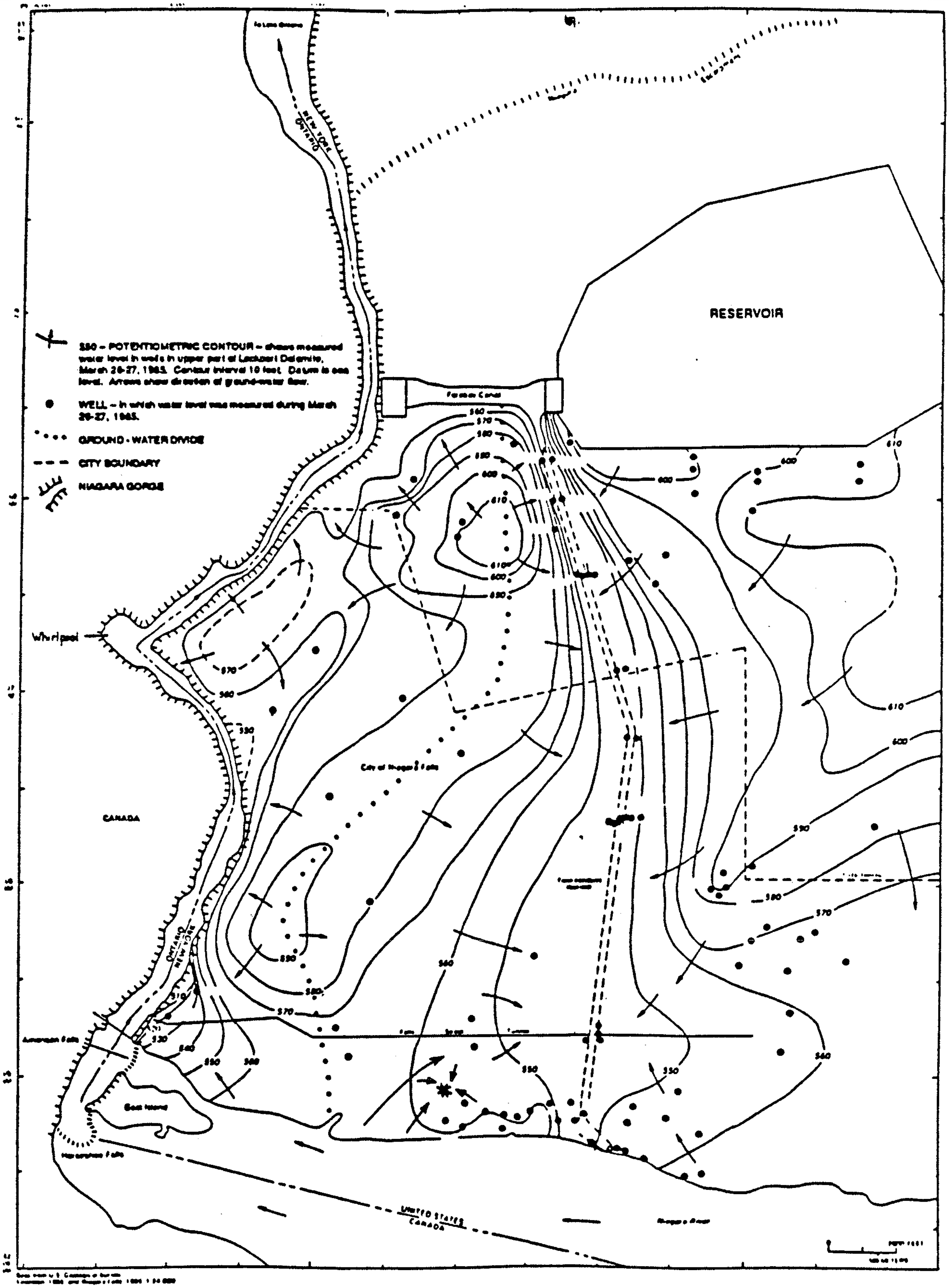


Ref. FROM MILLER AND KAPPEL 1986.

Inferred directions of ground-water movement in the upper part of the Lockport Dolomite in the Niagara Falls area before any major construction.

GROUND WATER FLOW PRIOR TO 1900

FIGURE 9



Generalized potentiometric surface and direction of ground-water flow in the upper part of the Lockport Dolomite. (Modified from Miller and Kappel, 1987.)

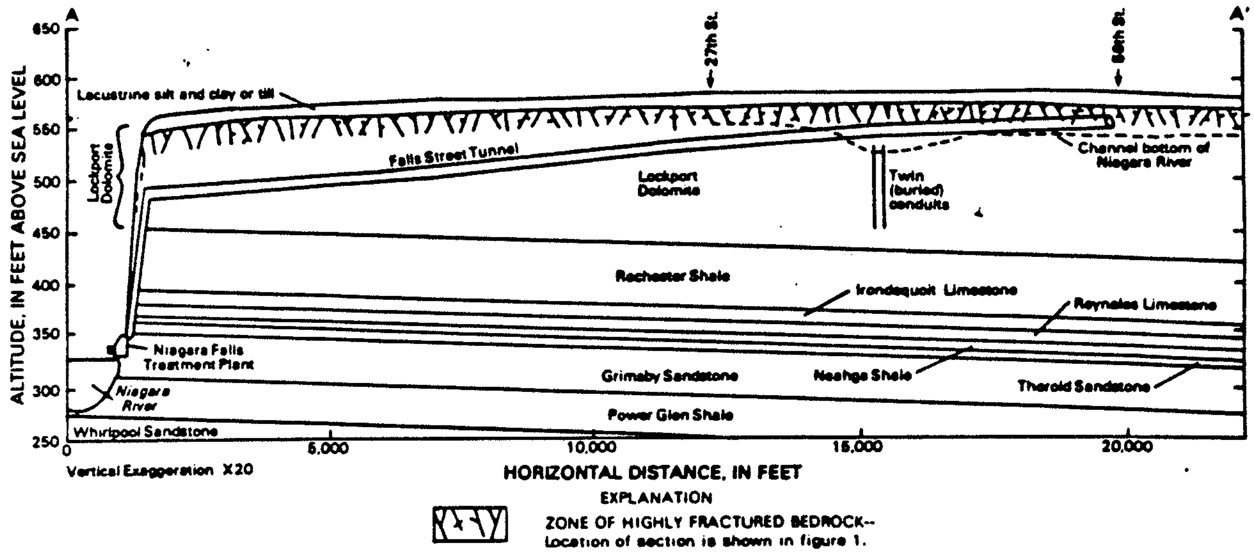
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

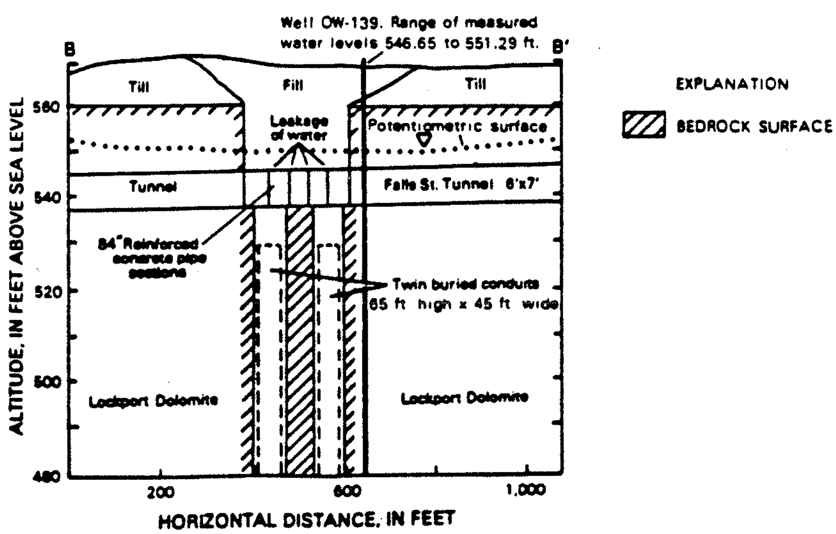
WOODWARD-CLYDE CONSULTANTS

FIGURE 10

A.



B.



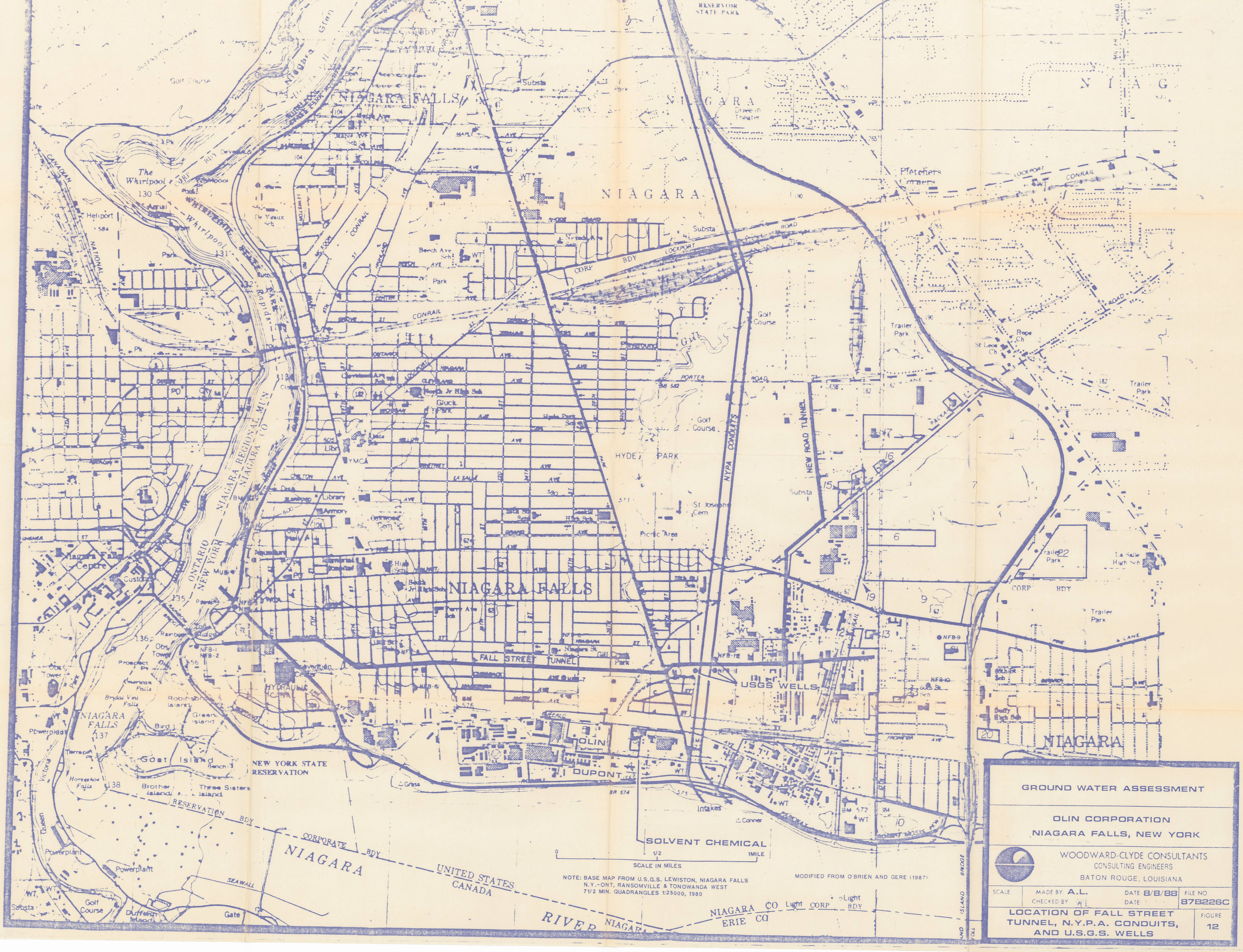
FALL STREET TUNNEL CROSSING OF NYPA CONDUITS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 11



NIAGARA FALLS
NIAGARA
FALL STREET TUNNEL
USGS WELLS
NYPA CONDUITS
NEW ROAD TUNNEL
OLIN
DUPONT
SOLVENT CHEMICAL
HYDE PARK
Goat Island
NEW YORK STATE RESERVATION
UNITED STATES
CANADA
NIAGARA RIVER
The Whirlpool
Intakes
SCALE IN MILES
NOTE: BASE MAP FROM U.S.G.S. LEWISTON, NIAGARA FALLS N.Y.-ONT, RANSOMVILLE & TONOWANDA WEST 71/2 MIN. QUADRANGLES 1:25000, 1980
MODIFIED FROM O'BRIEN AND GERE (1987)
GROUND WATER ASSESSMENT
OLIN CORPORATION
NIAGARA FALLS, NEW YORK
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA
MADE BY A.L.
DATE 8/8/88
FILE NO 87B226C
LOCATION OF FALL STREET TUNNEL, N.Y.P.A. CONDUITS, AND U.S.G.S. WELLS
FIGURE 12

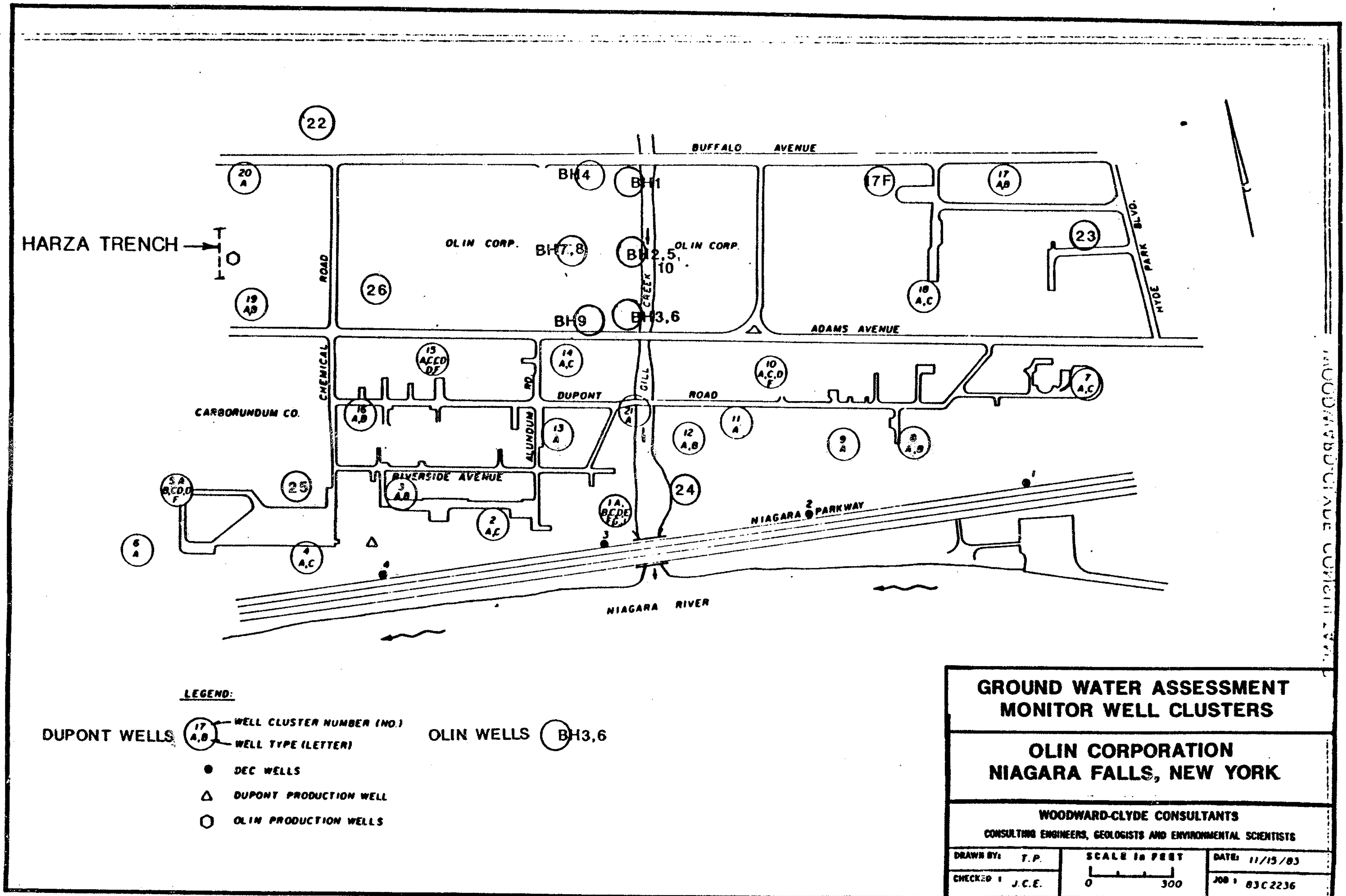
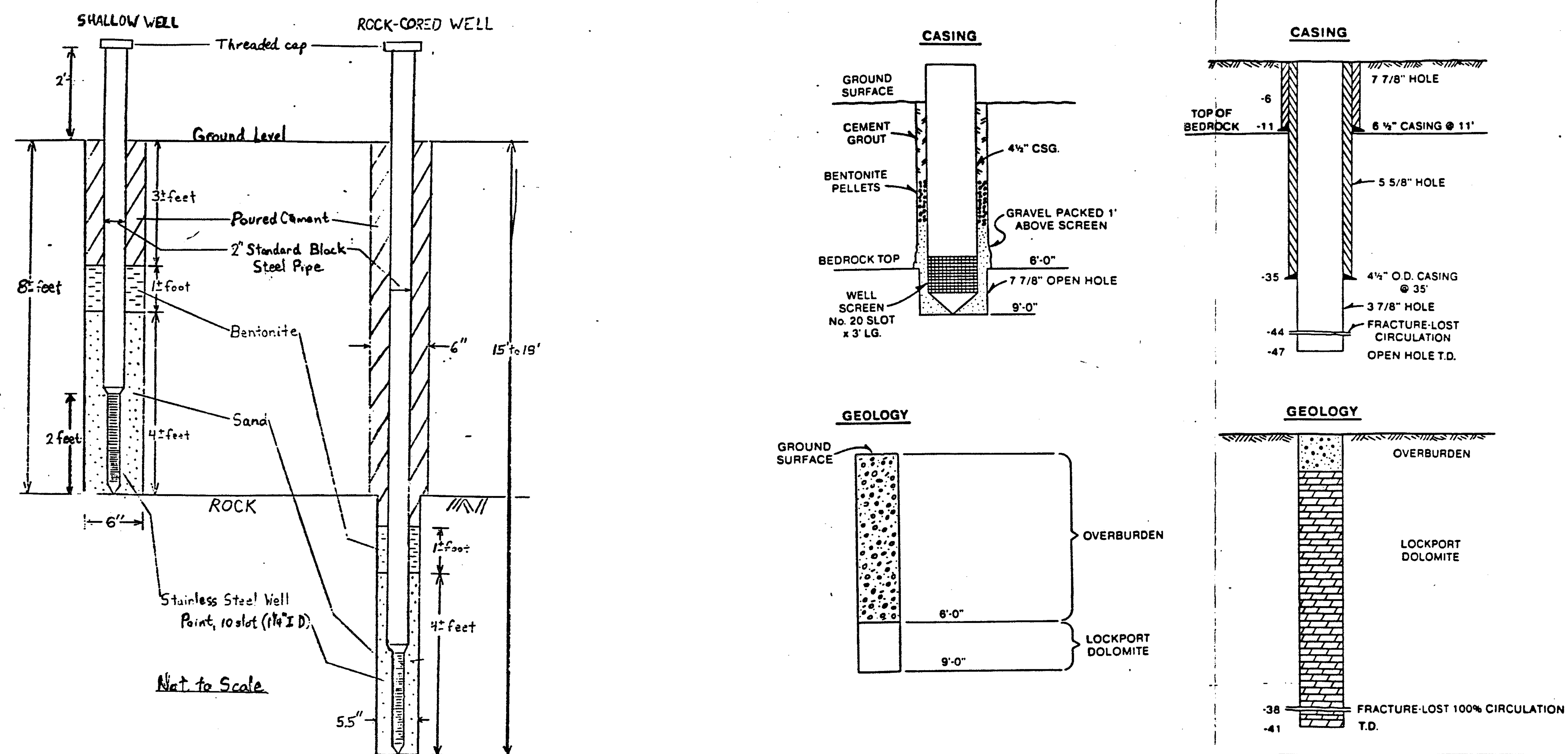

HARZA TRENCH
BUFFALO AVENUE
OLIN CORP.
OLIN CORP.
ADAMS AVENUE
CHEMICAL ROAD
DUPONT ROAD
GILL CREEK
ALUNDUM RD.
HYDE PARK BLVD.
CARBORUNDUM CO.
RIVERSIDE AVENUE
NIAGARA PARKWAY
NIAGARA RIVER
BH4
BH1
BH7,8
BH2,5,10
BH9
BH3,6
17F
22
23
24
25
26
LEGEND:
DUPONT WELLS
WELL CLUSTER NUMBER (NO.)
WELL TYPE (LETTER)
OLIN WELLS BH3,6
DEC WELLS
DUPONT PRODUCTION WELL
OLIN PRODUCTION WELLS
GROUND WATER ASSESSMENT
MONITOR WELL CLUSTERS
OLIN CORPORATION
NIAGARA FALLS, NEW YORK
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
DRAWN BY: T.P.
CHECKED: J.C.E.
SCALE in FEET
0 300
DATE: 11/15/83
JOB: 83C2236

FIGURE 13

OLIN
(INSTALLED 1978)

DUPONT
(INSTALLED SINCE 1983)



MONITOR WELL CONSTRUCTION DETAILS

GROUND WATER ASSESSMENT	
WOODWARD-CLYDE CONSULTANTS CONSULTING ENGINEERS BATON ROUGE, LOUISIANA	
OLIN CORPORATION NIAGARA FALLS, NEW YORK	
MADE BY: CHECKED BY: · DATE: DATE: 6/24/88	FILE NO. 87B226C
MONITOR WELL CONSTRUCTION	FIGURE 14

WOODWARD-CLYDE CONSULTANTS

HARZA ENGINEERING COMPANY

Form: SE5

BH-3

Page: 1

Sheet 1 of 1

DESCRIPTIVE LOG

Site: Olin Corporation, Niagara Falls, N.Y.

Logged by: WRC

Drill Hole No.: BH-3

Date: 12/3/78

Depth From	Depth To	Symbol No.	Classification, Description and Remarks	SPT Blows per .5' penetrat:
0	1	GP	Gravel fill, subangular, .5" to 1.0" diameter no fines, poorly graded, very high permeability.	
1	5	ML	Split Spoon Sample #1 3.5 to 5 ft. Clayey silt, grey-brown with some sand and gravel. Very low permeability, very low plasticity. Water hit at 5.0 ft.	6/.5' 6/.5' 7/.5'
5	8.5	GM	Split Spoon Sample #2 8.0 to 8.5 ft. Sandy gravel, with silt and clay, grey gravel sub-angular to rounded gravel poorly graded, low-moderate permeability.	6/.5' 100/0.0'
8.5	18.0		Dolomite: Grey, thickly bedded, irregular stylolitic partings parallel to horizontal bedding. Breaks along partings with medium hammer blow. Fine vuggy porosity, some vugs partially filled with gypsum or calcite. Fracturing: 8-9.5' Fractures averaging every 3" 9.5-11.0 Fractures averaging every 8" 11.0-13.0 Largest piece 3" long 15.0-18.1 Pieces averaging 1.0 ft. 12.0-12.6 Very porous, caused by fine vugs. Bottom of well point set at 18.0 ft.	

HARZA ENGINEERING COMPANY

Form: SE5

BH-1

Page: 1

Sheet 1 of 1

DESCRIPTIVE LOG

Site Olin Corporation, Niagara Falls, N.Y.

Logged by: WRC

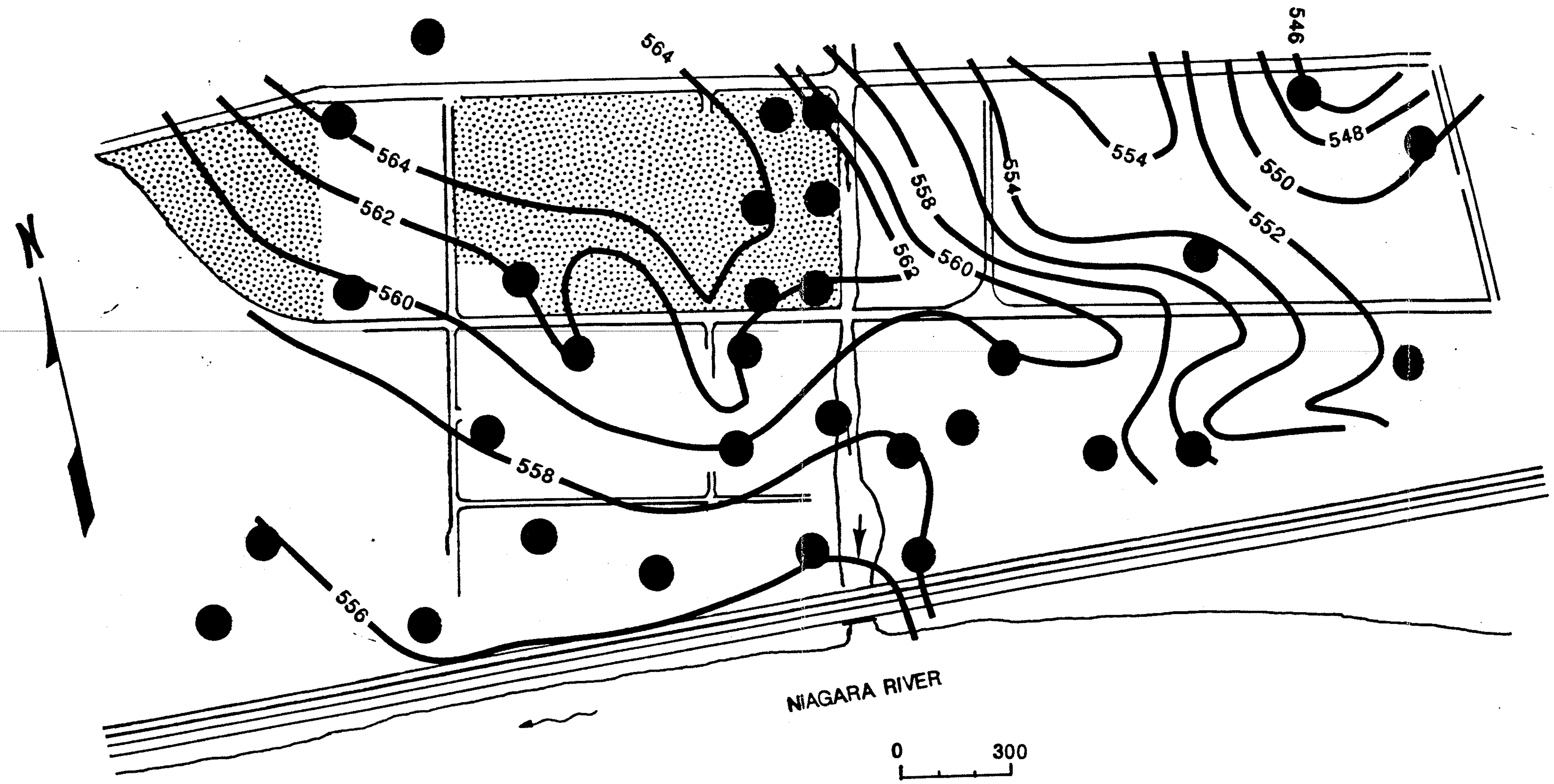
Drill Hole No.: BH-1

Date: 11/30/78

Depth From	Depth To	Symbol No.	Classification, Description and Remarks	SPT Blows per 6" penetration
0	10.1	GW	Sandy gravel fill, gravel less than 1/2 inch diameter, sub - angular, high permeability, poorly graded 5.-6.5 ft. Split Spoon Sample #1 Same as above but some red brick colored fill. Split Spoon #2 9.5-10.1 ft. Hit rock at 10.1 ft. Same as above but with 1 inch diameter pieces of angular red brick.	2/.5' 2/.5' 4/.5' 16/.5' 100/.1'
10.1	11.0		Rock coring Dolomite: Rubble, broken up by corer, grey, crystalline. Largest piece 2" diameter.	
11.0	16.1		Dolomite: Dark grey, crystalline, thickly bedded, irregular stylolitic partings parallel to bedding; bedding horizontal, breaks along partings with medium hammer blow. Fine vuggy porosity throughout, diameter .5 mm to 2.0 mm. Vugs partially filled with calcite, also gypsum. 13.0 ft. - Lost drilling water, cored .5 ft. in 30 seconds. 14.2' Calcite filled vug 1.0" diameter 15.3' Calcite filled vug, .5" diameter 16.1 Finished coring, Recovery 100%. Bottom of well point set at 16.1 ft.	

LOGS OF REPRESENTATIVE GILL CREEK WELLS

FIGURE 1



CONTOUR INTERVAL = 2 FT

● WELL LOCATION

NOTE: TOP OF BEDROCK ELEVATIONS MODIFIED FROM WOODWARD-CLYDE CONSULTANTS (1984)

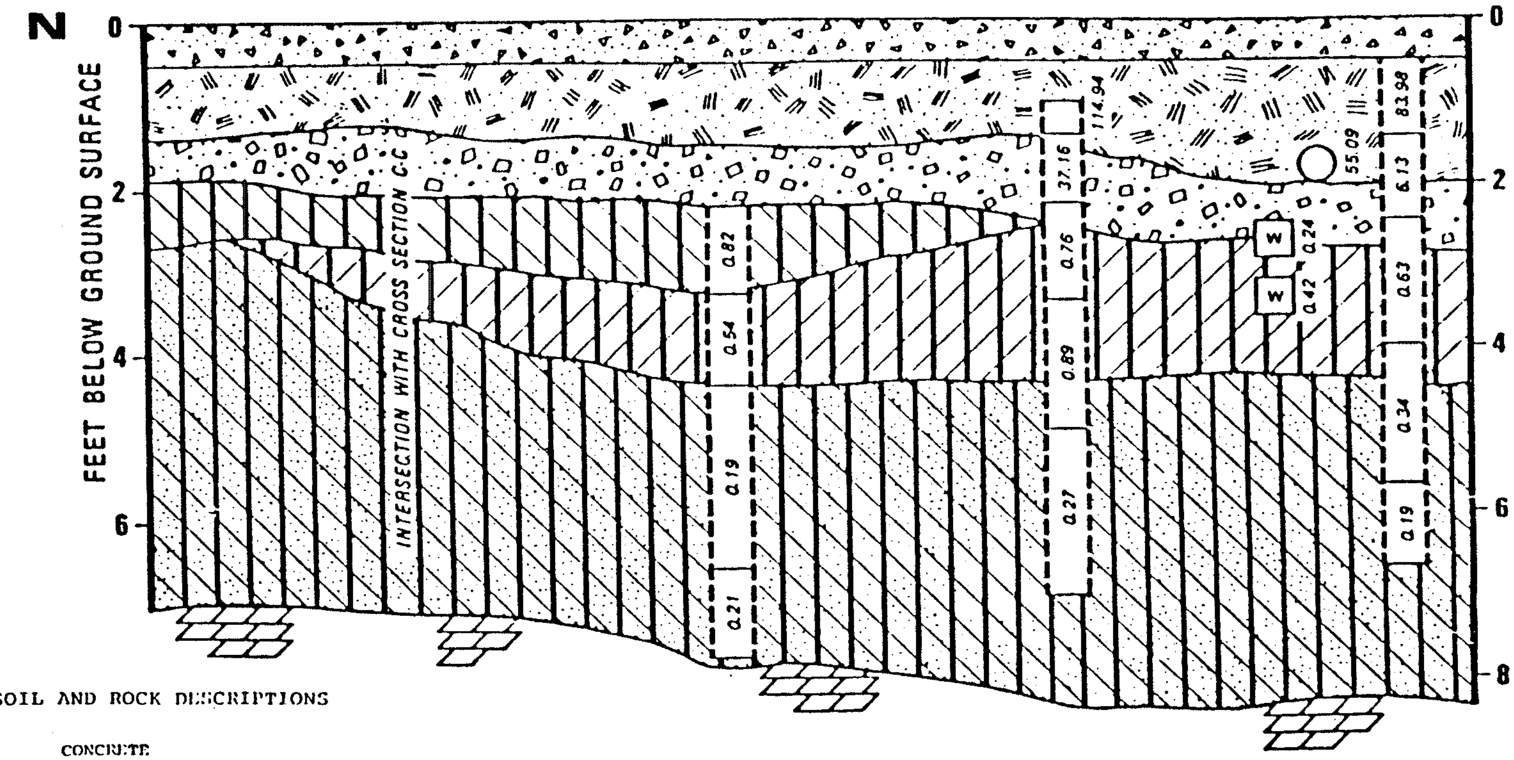
GROUND WATER ASSESSMENT
BUFFALO AVENUE PLANTS

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MADE BY: P.K. CHECKED BY:	DATE: 6/2/88 DATE:	FILE NO. 87B266C
BEDROCK TOPOGRAPHY		FIGURE 16

WOODWARD-CLYDE CONSULTANTS



SOIL AND ROCK DESCRIPTIONS

CONCRETE
Parking lot surface.

FILL
Brown sandy gravel mixture, thickness ranging from 0.7 to 1.4 feet.

FILL
Orange mixture of bricks and gravel; color possibly arising from iron oxide compounds, thickness ranging from 0.5 to 0.8 feet. Very moist and highly permeable.

LAKE DEPOSITS
Brown clayey silt with trace of root fibers. Portions of this layer containing root fibers indicate original ground surface.

LEGEND

Soil Sample

Mercury Concentration (ppm) 0.57

LAKE DEPOSITS
Black clayey silt with trace of root fibers, very stiff. Portions of this layer containing root fibers indicate original ground surface.

LAKE DEPOSITS
Brown sandy-clayey silt mottled with approximately 5% gray clay, very stiff. Thickness ranged from 3.5 to 4.0 feet.

BEDROCK
Lockport Dolomite; unweathered, dark gray, massive - some widely spaced vertical joints which are tight and trend about N 30° W.

Ref: FROM HARZA ENGINEERING 1979b.

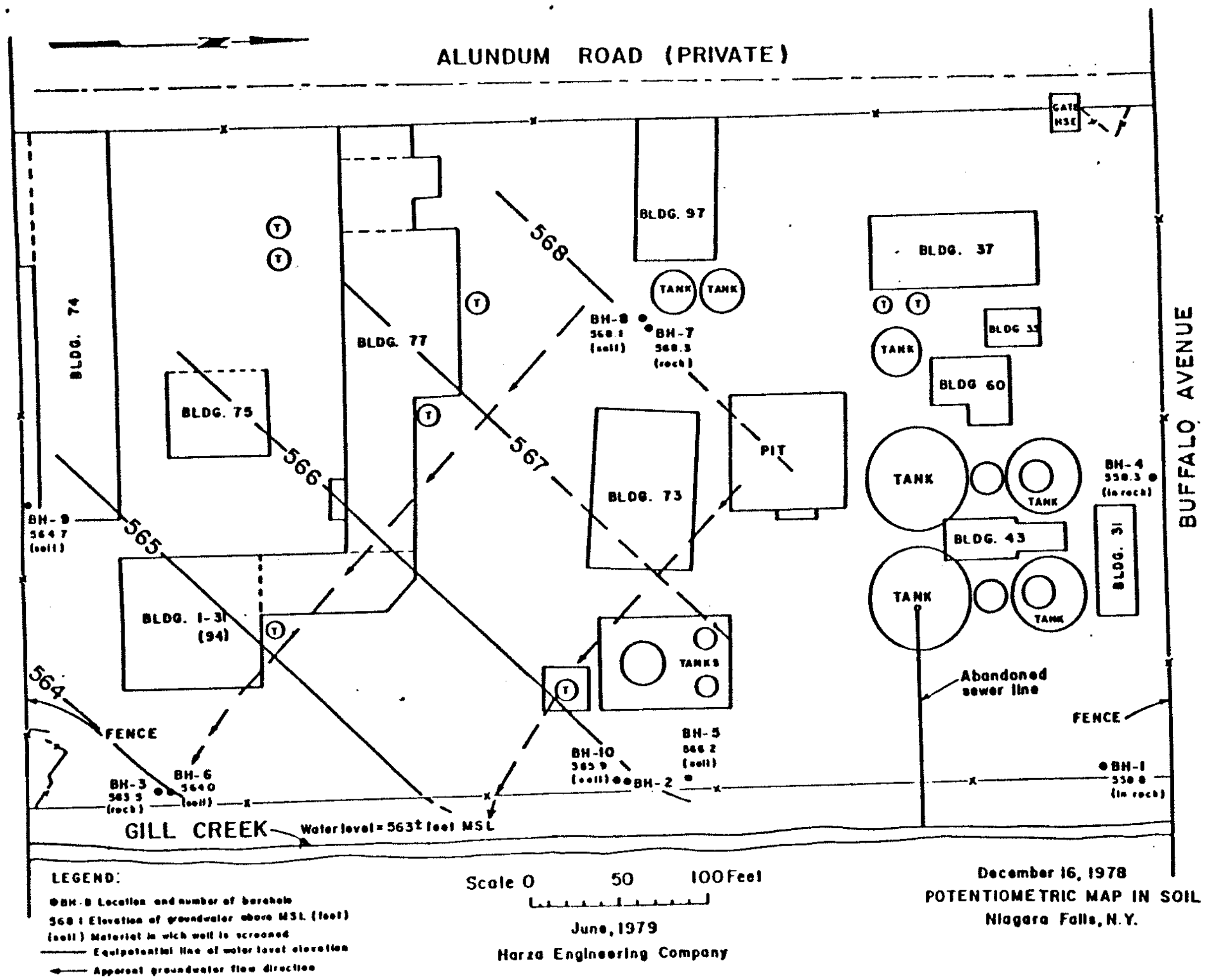
PLANT 1 TRENCH

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE 17

WOODWARD-CLYDE CONSULTANTS

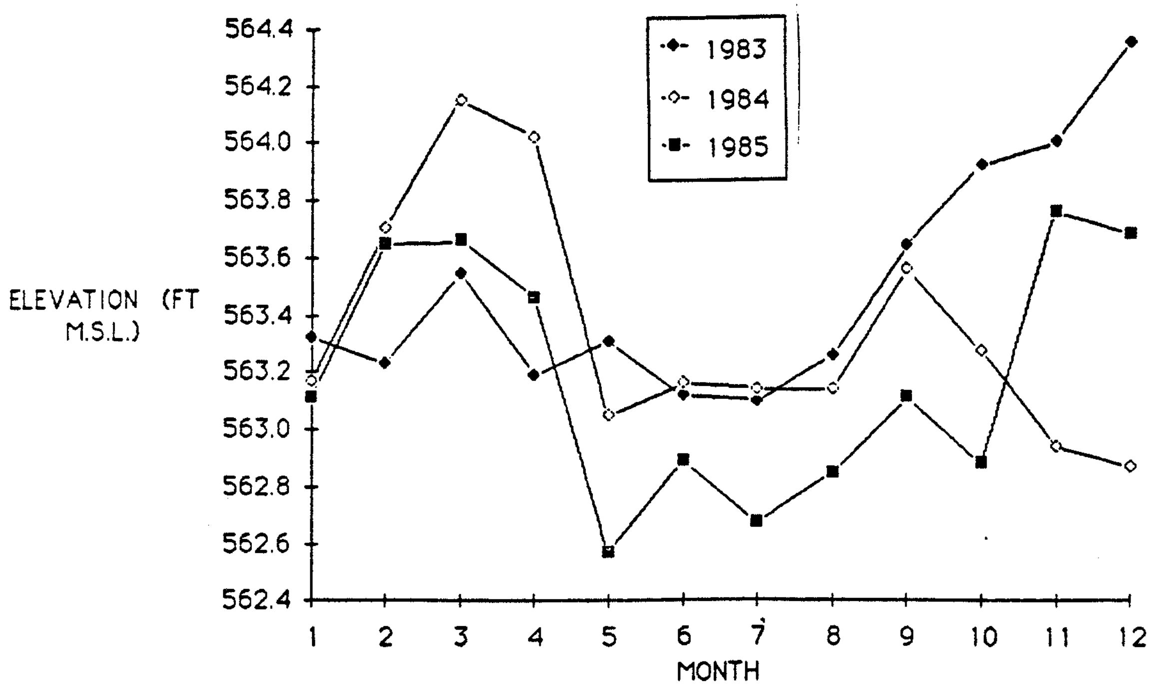


PIEZOMETRIC ELEVATIONS-GILL CREEK WELLS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE 18



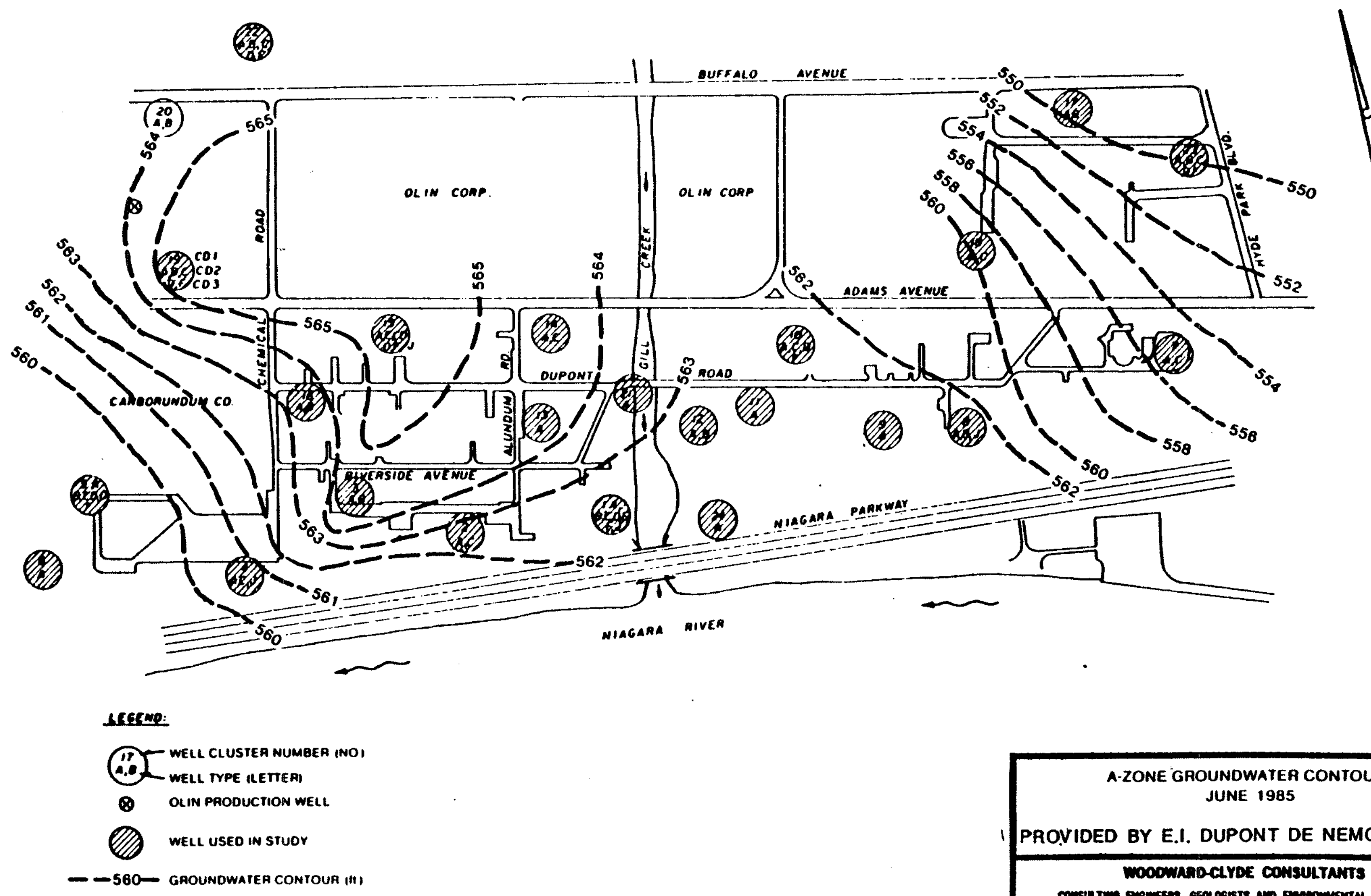
HYDROGRAPHS: ALL OLIN MONITOR WELLS 1983, 1984, 1985

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 19



A-ZONE GROUNDWATER CONTOURS
JUNE 1985

PROVIDED BY E.I. DUPONT DE NEMOURS & C

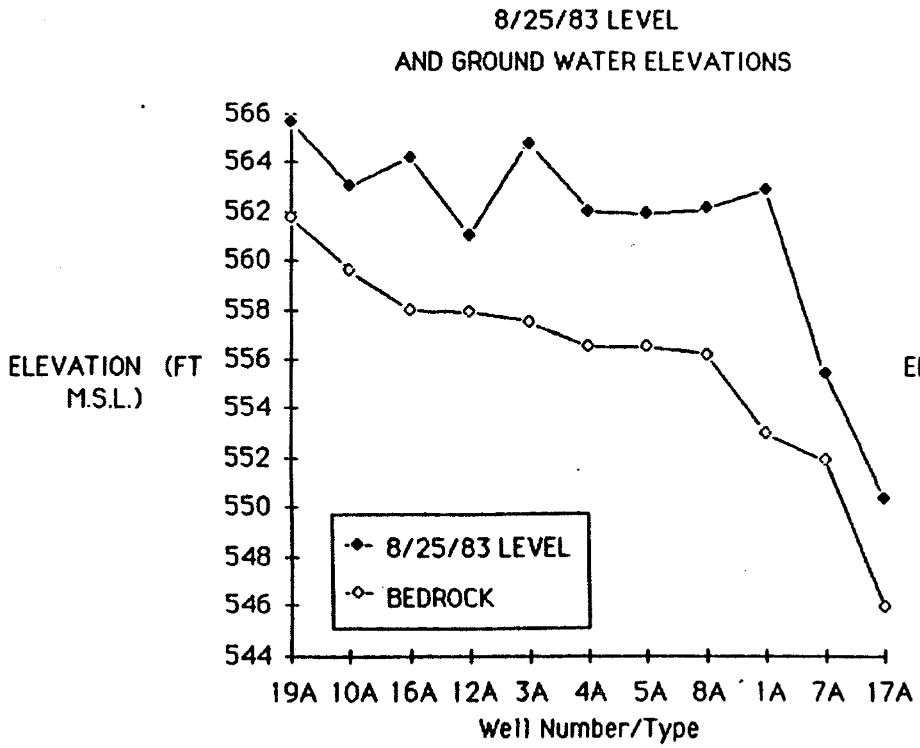
WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

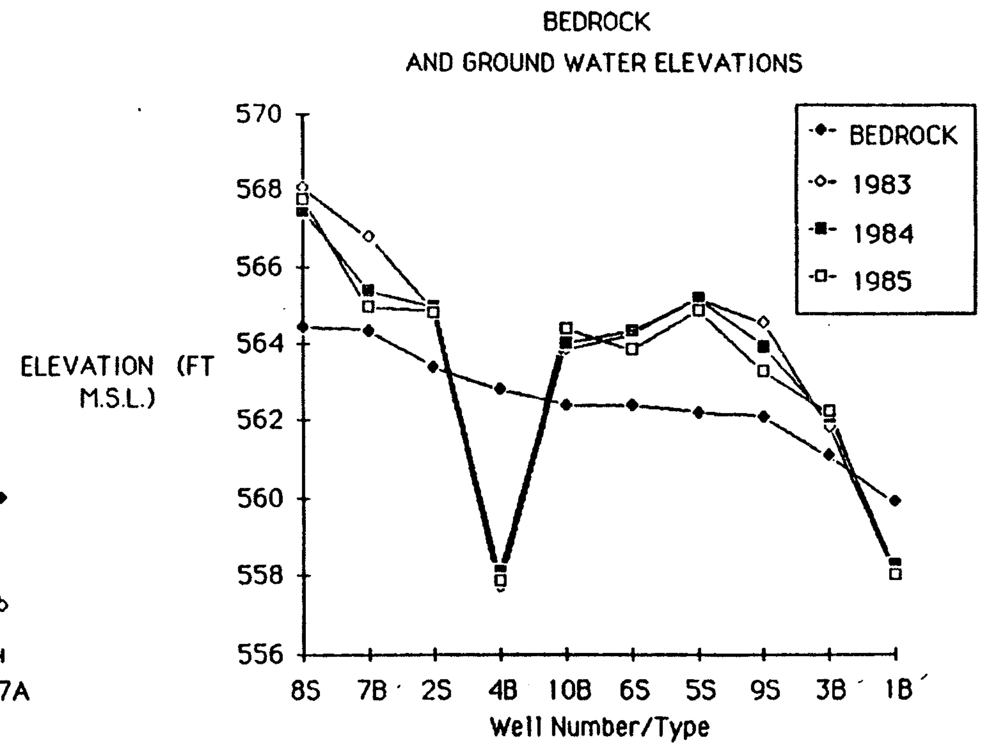
DRAWN BY: T.P.	SCALE in FEET 0 300	DATE: 3/21/86
CHECKED: KRM		JOB: 83C2236-8

FIGURE 20

WOODWARD-CLYDE CONSULTANTS



A. DuPONT A-ZONE WELLS



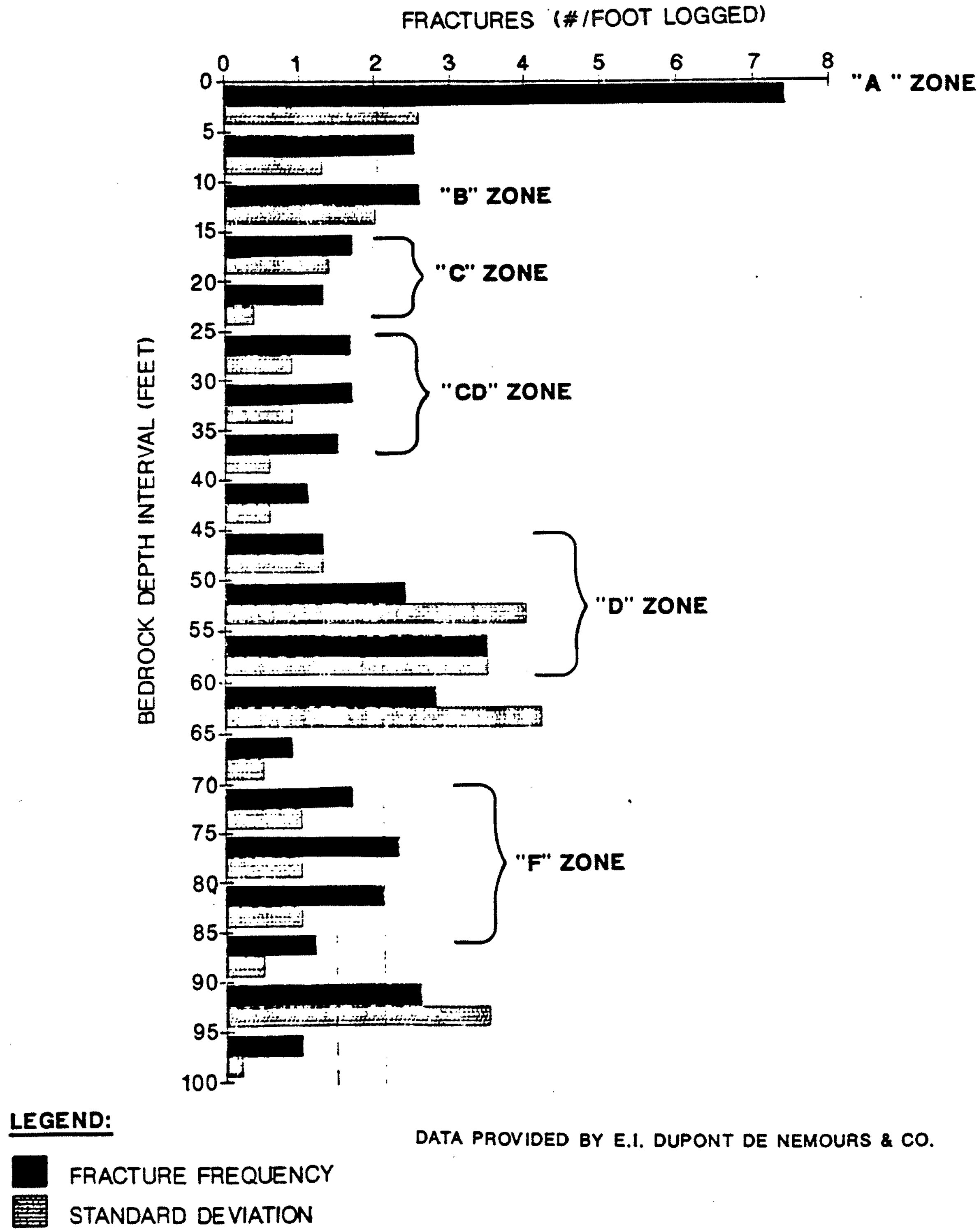
B. OLIN WELLS

BEDROCK AND A-ZONE GROUND WATER ELEVATIONS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE 21



DATA PROVIDED BY E.I. DUPONT DE NEMOURS & CO.

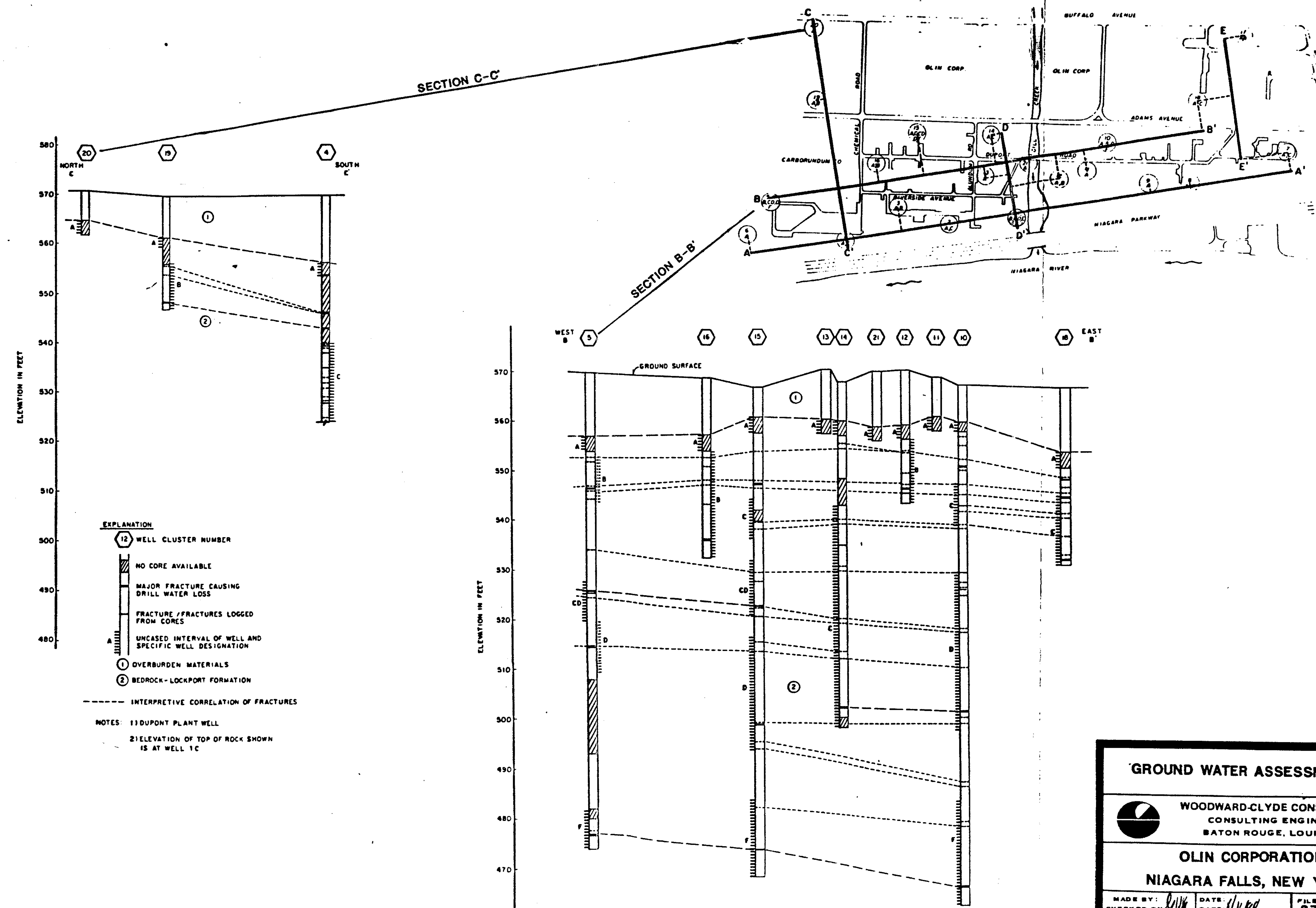
FRACTURE FREQUENCY IN DuPONT CLUSTER WELLS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 22



DATA PROVIDED BY E.I. DUPONT DE NEMOURS & CO.

GROUND WATER ASSESSMENT

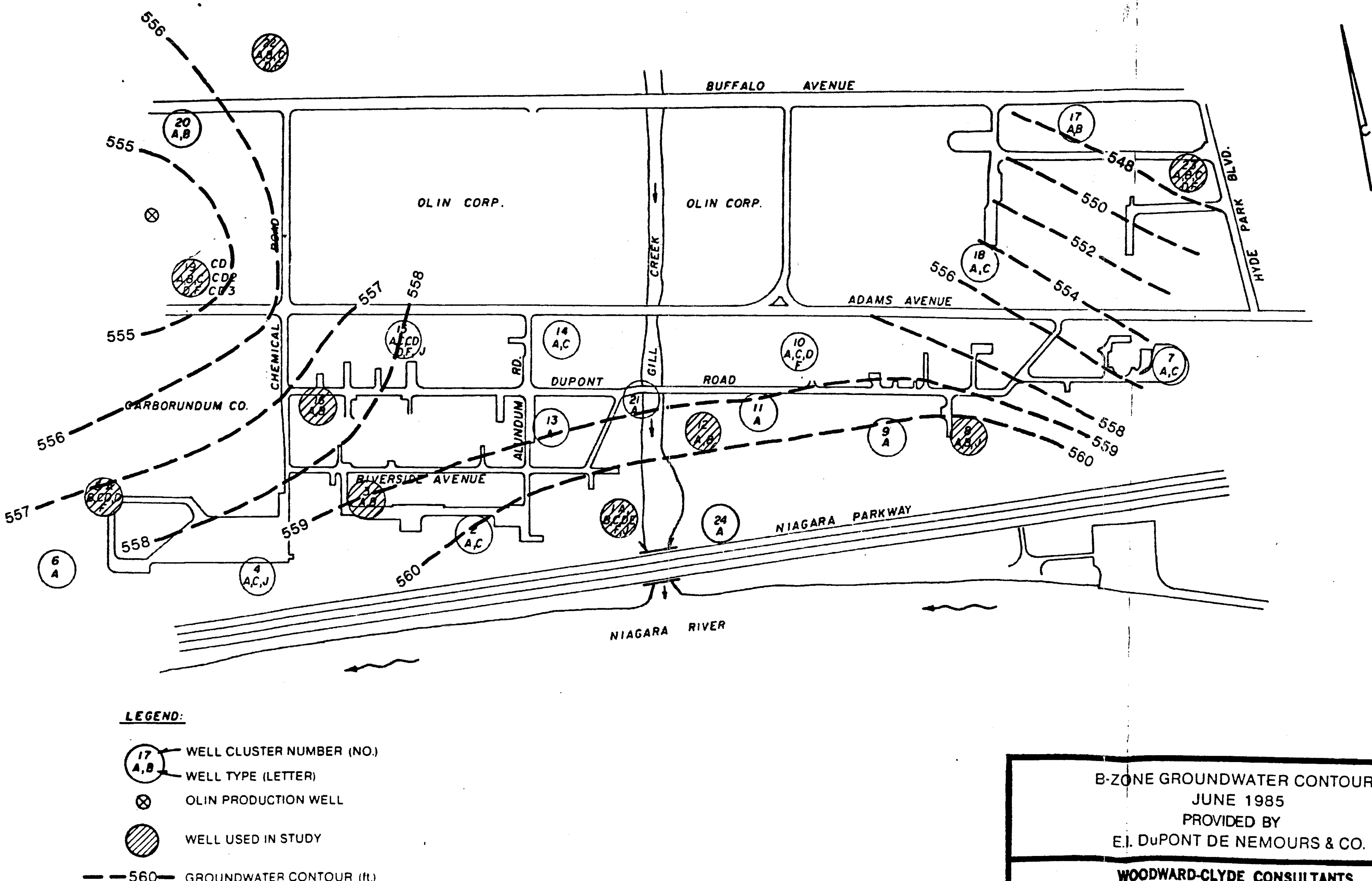
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MADE BY: CHECKED BY: DATE: DATE: FILE NO. 87B226C

WATER-BEARING FRACTURE ZONES

FIGURE 23

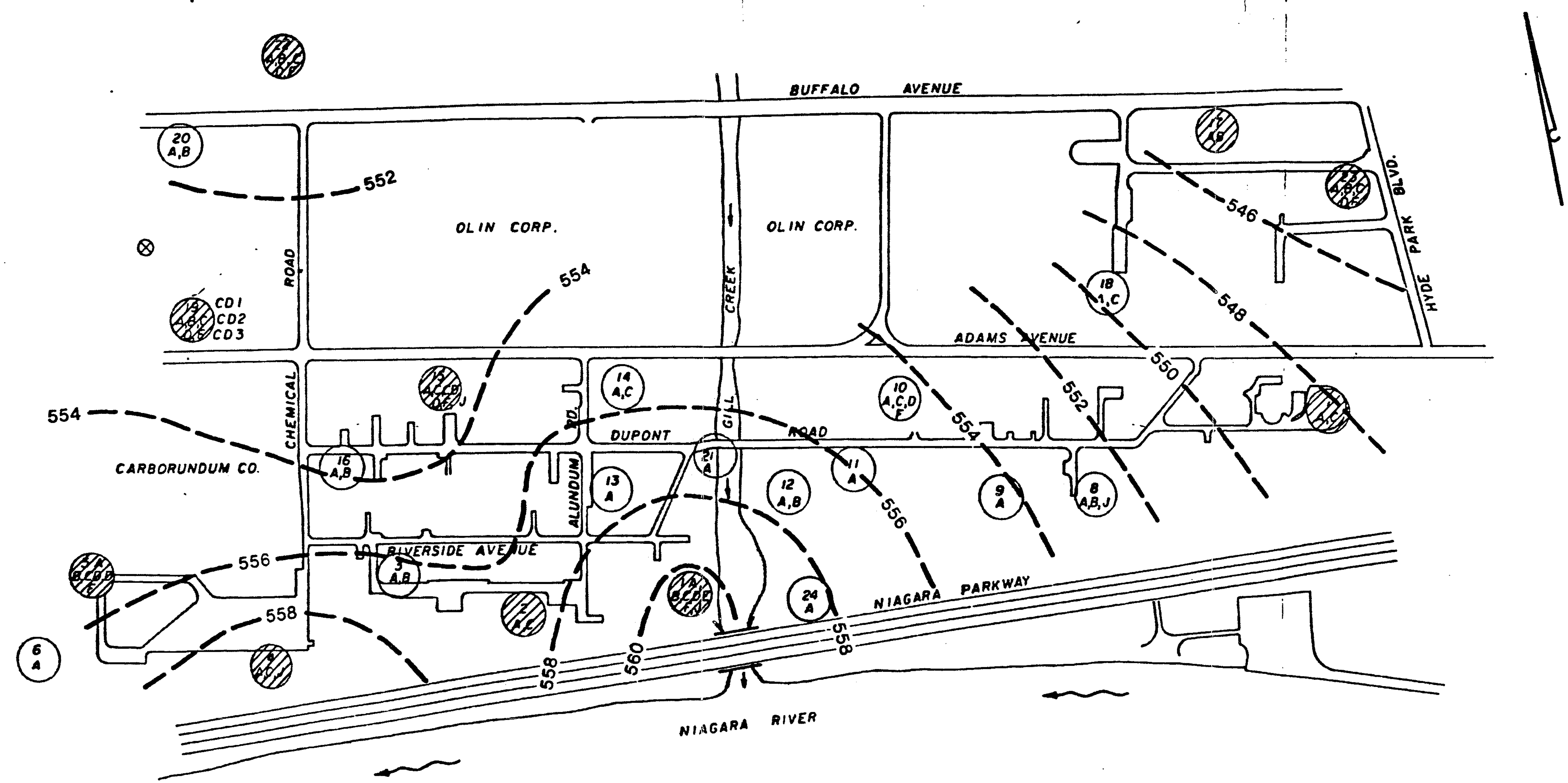


B-ZONE GROUNDWATER CONTOURS
JUNE 1985
PROVIDED BY
E.I. DuPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET	DATE: 3/21/86
CHECKED: K.R.M.	0 300	FIGURE 24



LEGEND:

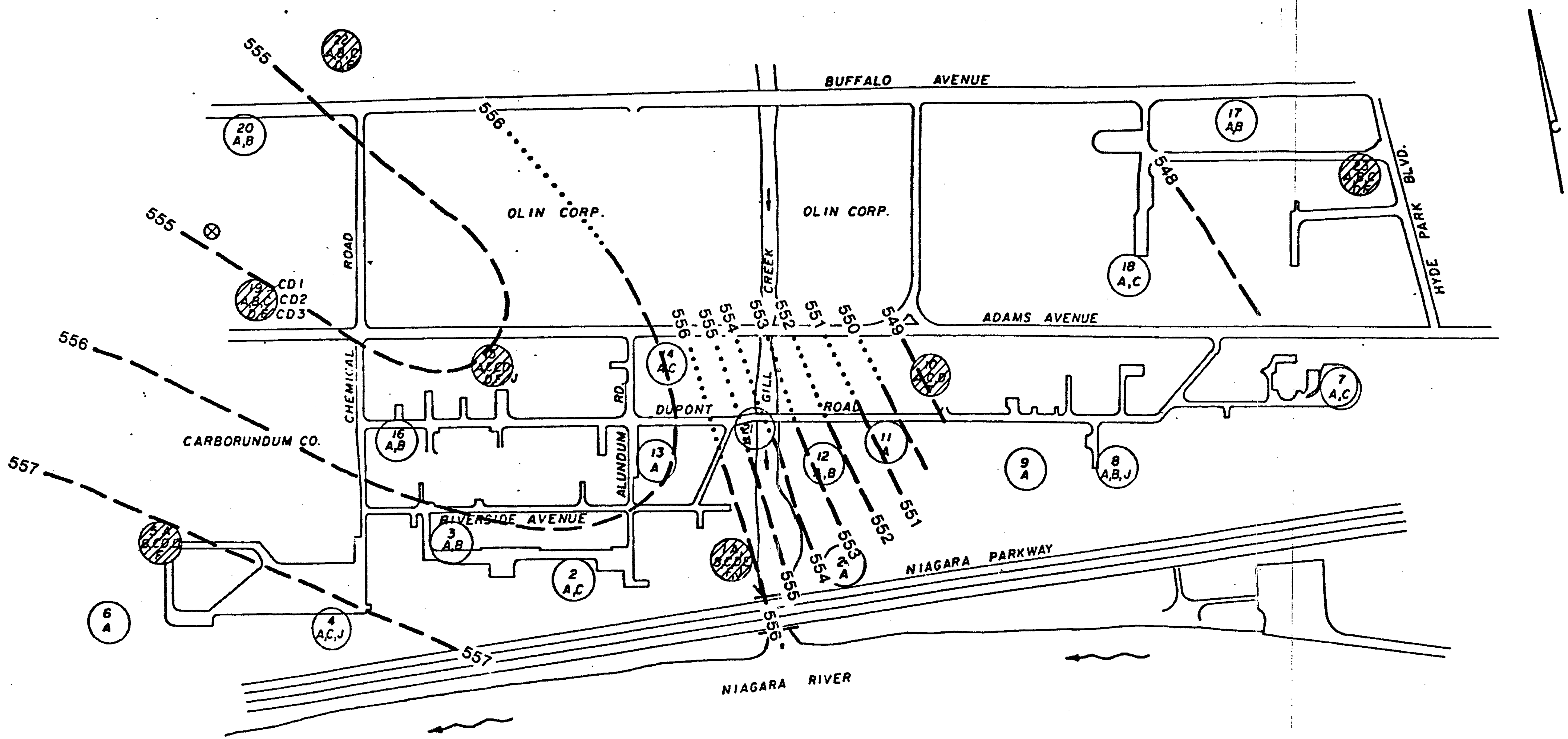
- WELL CLUSTER NUMBER (NO.)
- WELL TYPE (LETTER)
- ⊗ OLIN PRODUCTION WELL
- WELL USED IN STUDY
- — —560— GROUNDWATER CONTOUR (ft)

CD-ZONE GROUNDWATER CONTOURS
JUNE 1985
PROVIDED BY
E.I. DuPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE IN FEET 0 — 300	DATE: 3/21/86	
CHECKED: K.R.M.		FIGURE 25	



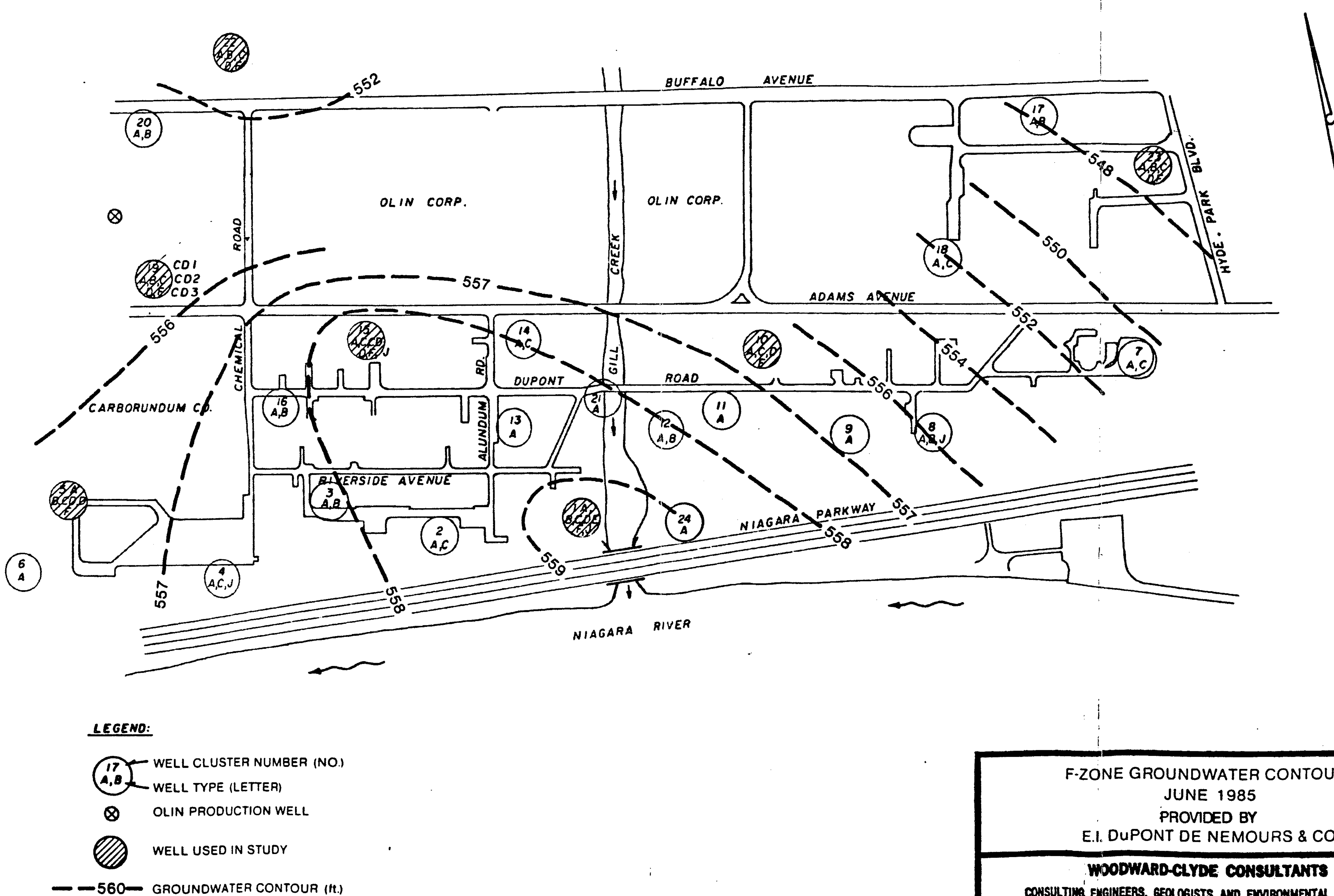
LEGEND:

- WELL CLUSTER NUMBER (NO.) / WELL TYPE (LETTER) (e.g. 17 A,B)
- ⊗ OLIN PRODUCTION WELL
- WELL USED IN STUDY
- ···—560— GROUNDWATER CONTOUR (ft.)

D-ZONE GROUNDWATER CONTOURS
JUNE, 1985
PROVIDED BY
E. I. DuPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET		DATE: 3/21/86
CHECKED: K.R.M.	0	300	FIGURE 26

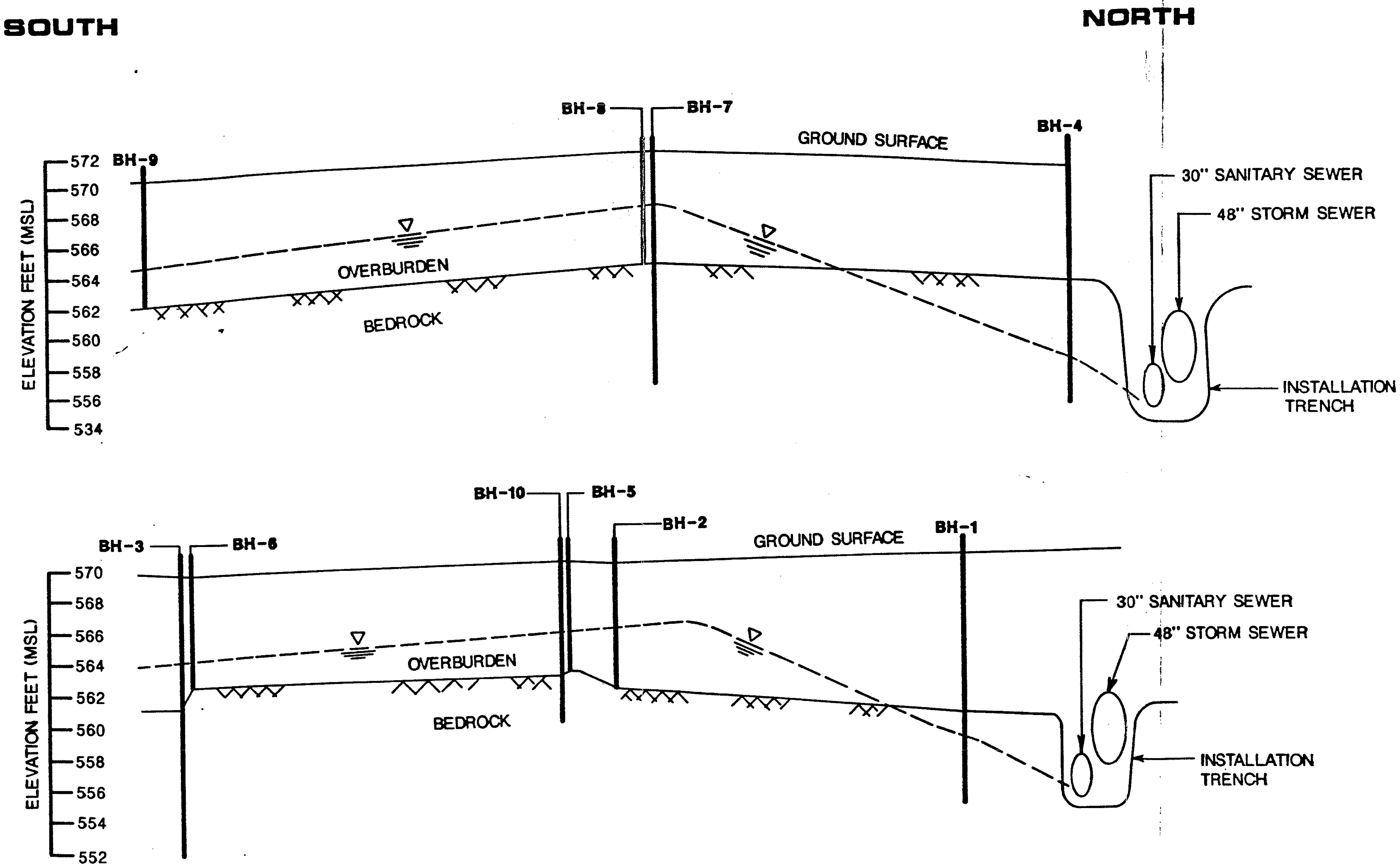


F-ZONE GROUNDWATER CONTOURS
JUNE 1985
PROVIDED BY
E.I. DuPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET	DATE: 3/21/86	
CHECKED: K.R.M.	0 300	FIGURE 27	



LEGEND:

———— POSTULATED PIEZOMETRIC SURFACE

OVERBURDEN BEDROCK SURFACE

SOURCE: HYDROGEOLOGIC FIELD INVESTIGATION NEAR GILL CREEK AT OLIN PLANT NO. 2 HARZA, JUNE 1979.

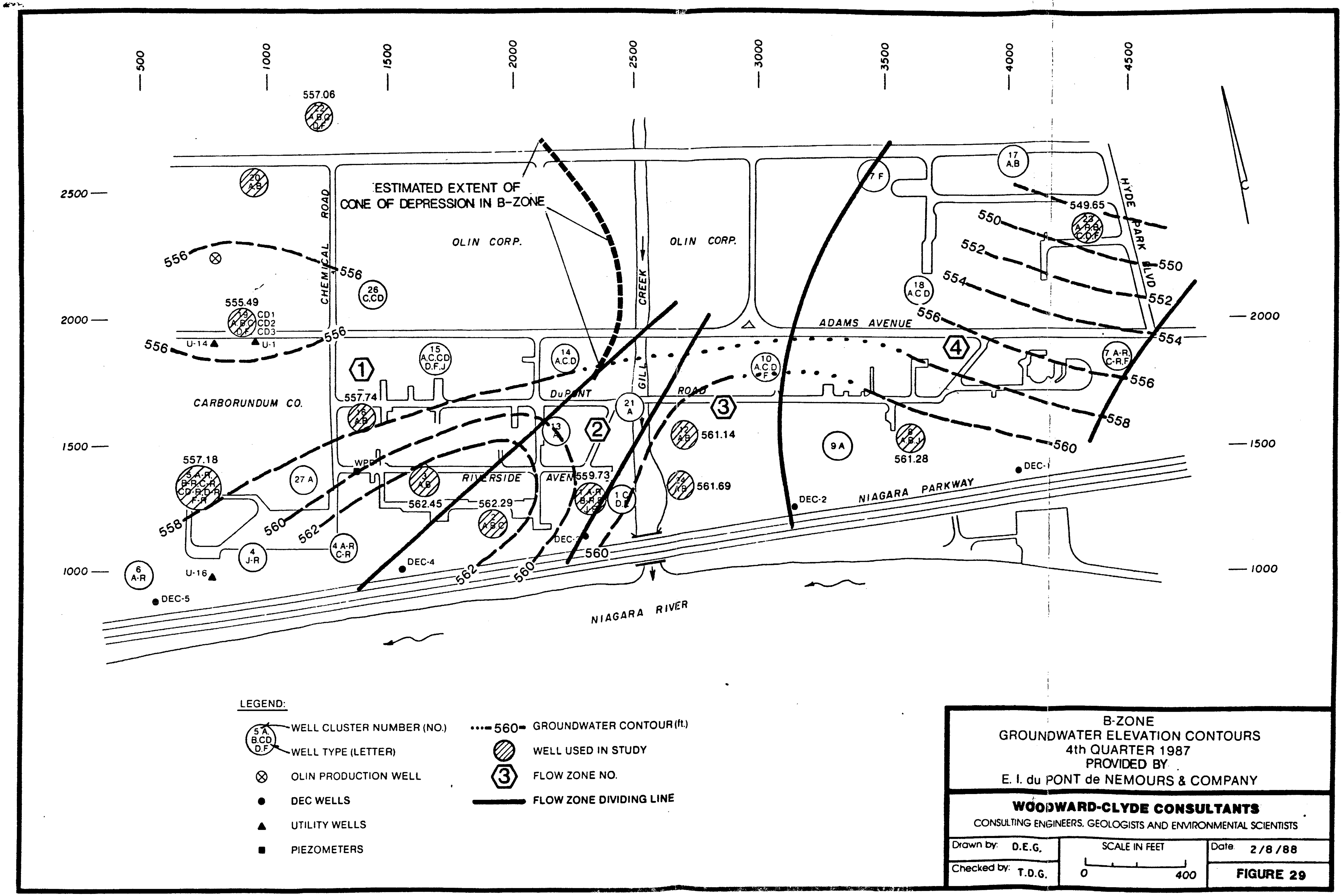
ALUNDUM ROAD - GILL CREEK SECTION

GROUND WATER ASSESSMENT

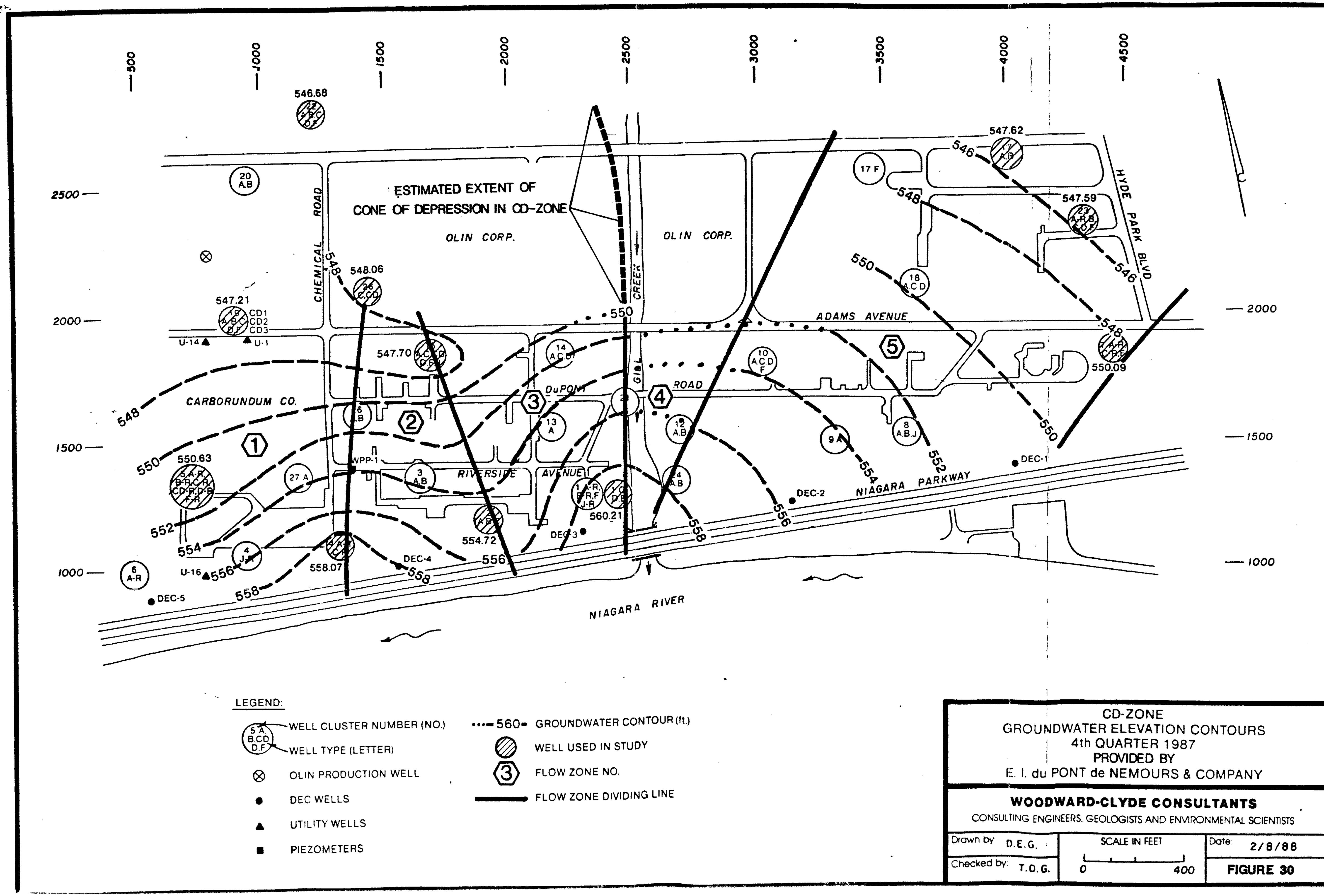
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MADE BY: A.L. CHECKED BY:	DATE: 8/5/88 DATE:	FILE NO. 87B226C
HYDROGEOLOGIC CROSS-SECTIONS		FIGURE 28



500
1000
1500
2000
2500
3000
3500
4000
4500
2500
2000
1500
1000
ESTIMATED EXTENT OF
CONE OF DEPRESSION IN B-ZONE
OLIN CORP.
OLIN CORP.
CHEMICAL ROAD
CREEK
GILL
ADAMS AVENUE
HYDE PARK BLVD
CARBORUNDUM CO.
DuPONT ROAD
RIVERSIDE AVE
NIAGARA PARKWAY
NIAGARA RIVER
557.06
555.49
557.74
557.18
562.45
562.29
559.73
561.14
561.69
561.28
549.65
556
558
560
562
550
552
554
DEC-1
DEC-2
DEC-4
DEC-5
U-14
U-1
U-16
WPP
LEGEND:
WELL CLUSTER NUMBER (NO.)
WELL TYPE (LETTER)
OLIN PRODUCTION WELL
DEC WELLS
UTILITY WELLS
PIEZOMETERS
GROUNDWATER CONTOUR (ft.)
WELL USED IN STUDY
FLOW ZONE NO.
FLOW ZONE DIVIDING LINE
B-ZONE
GROUNDWATER ELEVATION CONTOURS
4th QUARTER 1987
PROVIDED BY
E. I. du PONT de NEMOURS & COMPANY
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS
Drawn by: D.E.G.
Checked by: T.D.G.
SCALE IN FEET
0 400
Date 2/8/88
FIGURE 29

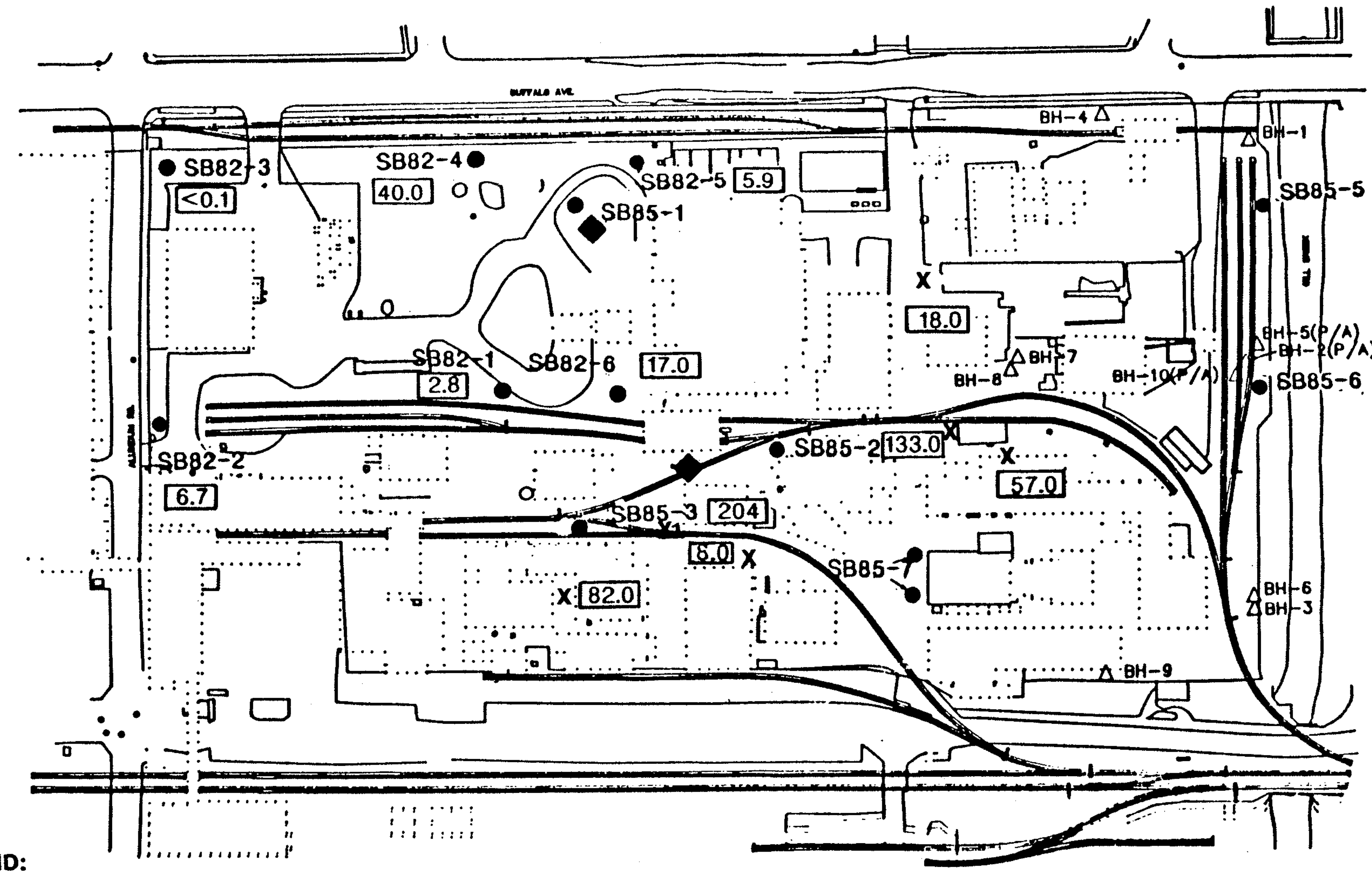


CD-ZONE
GROUNDWATER ELEVATION CONTOURS
4th QUARTER 1987
PROVIDED BY
E. I. du PONT de NEMOURS & COMPANY

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

Drawn by: D.E.G.	SCALE IN FEET 0 400	Date: 2/8/88
Checked by: T.D.G.		**FIGURE 30**

WOODWARD-CLYDE CONSULTANTS



LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

◆ ELEMENTAL MERCURY BEADS FOUND DURING 1986 EXCAVATION

MERCURY

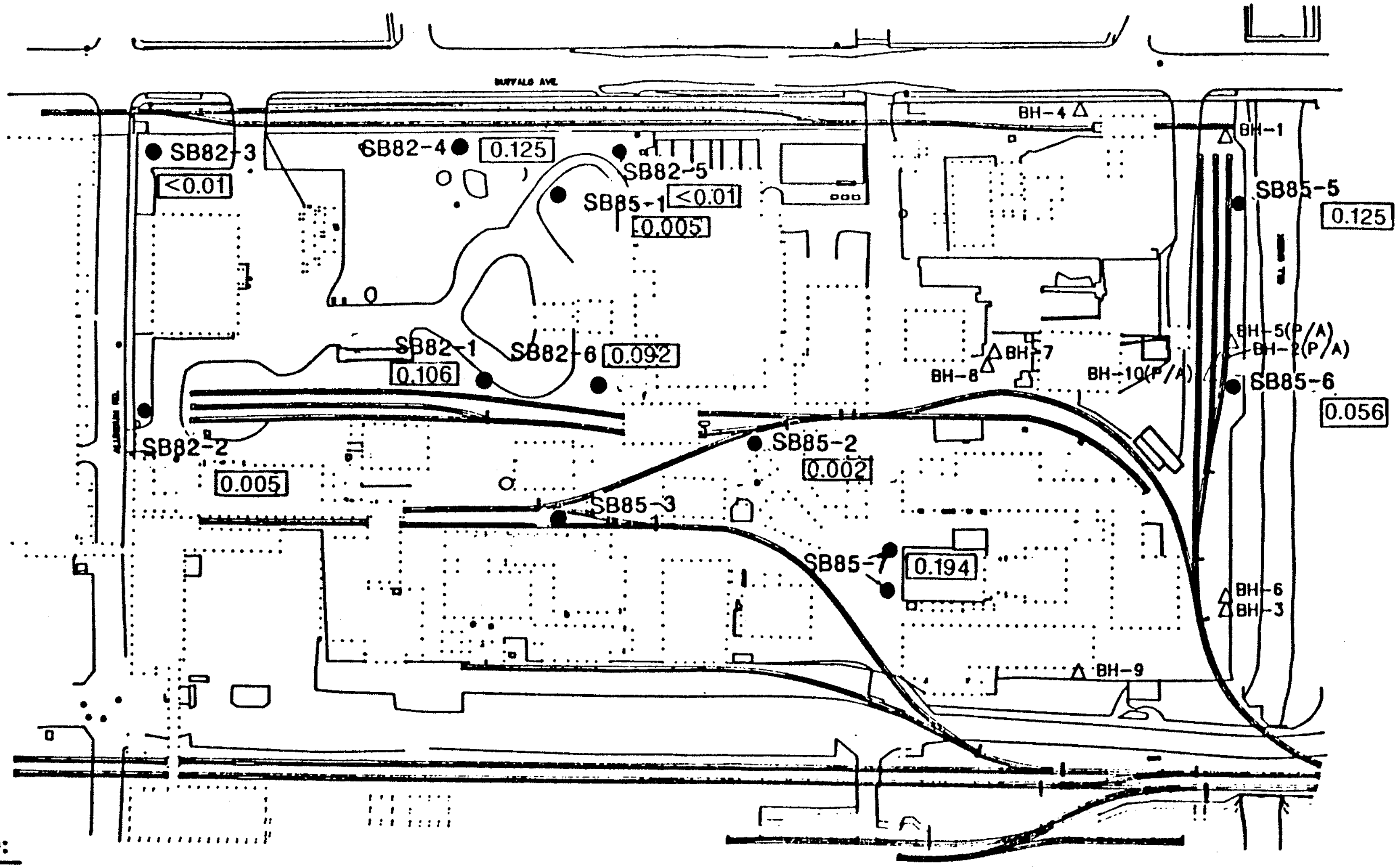
CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE **31**



LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

WOODWARD-CLYDE CONSULTANTS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

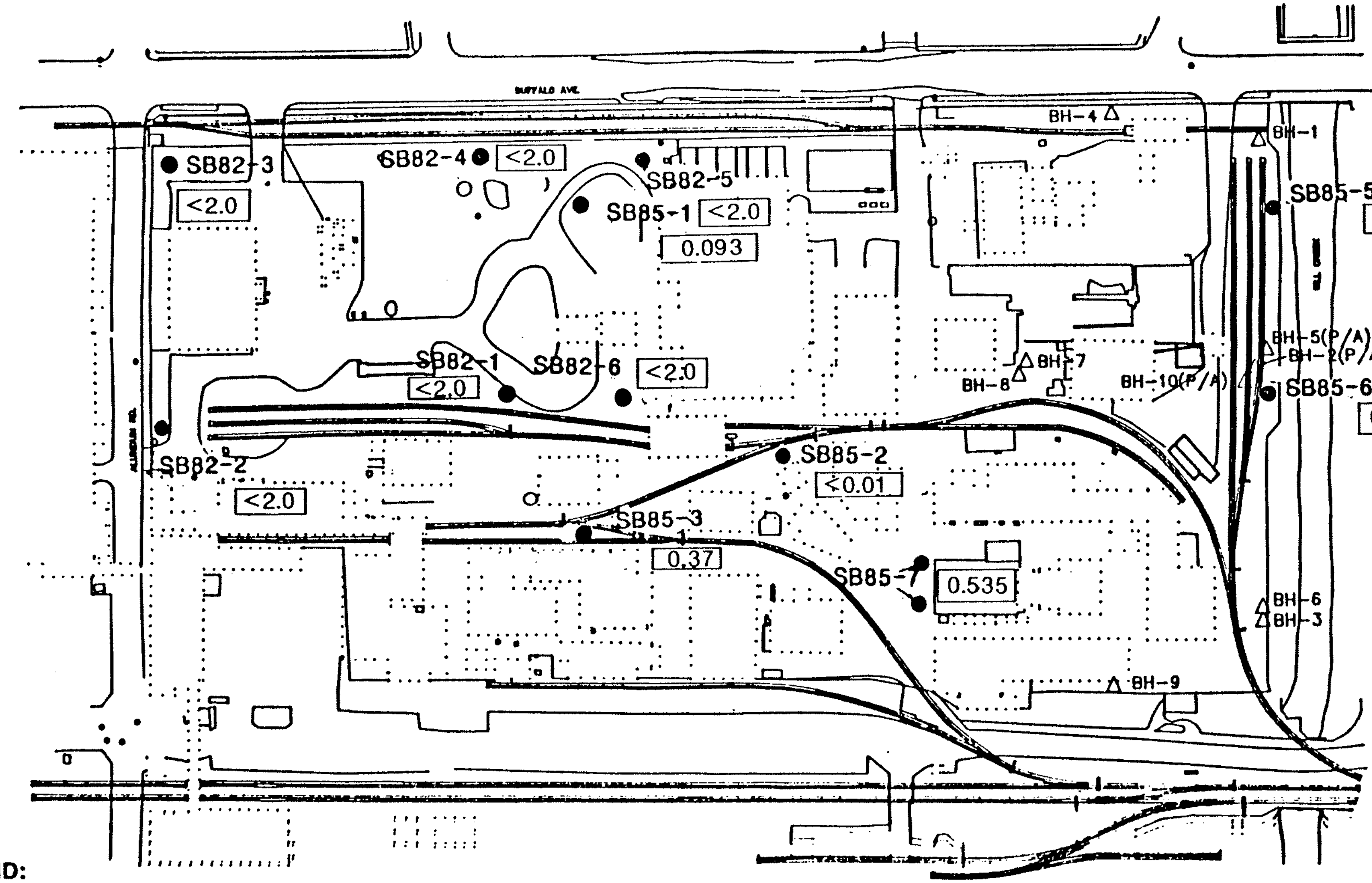
BHC

CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

FILE: 87B226C
JUNE, 1988

FIGURE 32



WOODWARD-CLYDE CONSULTANTS

DICHLORO, TRICHLOROBENZENES

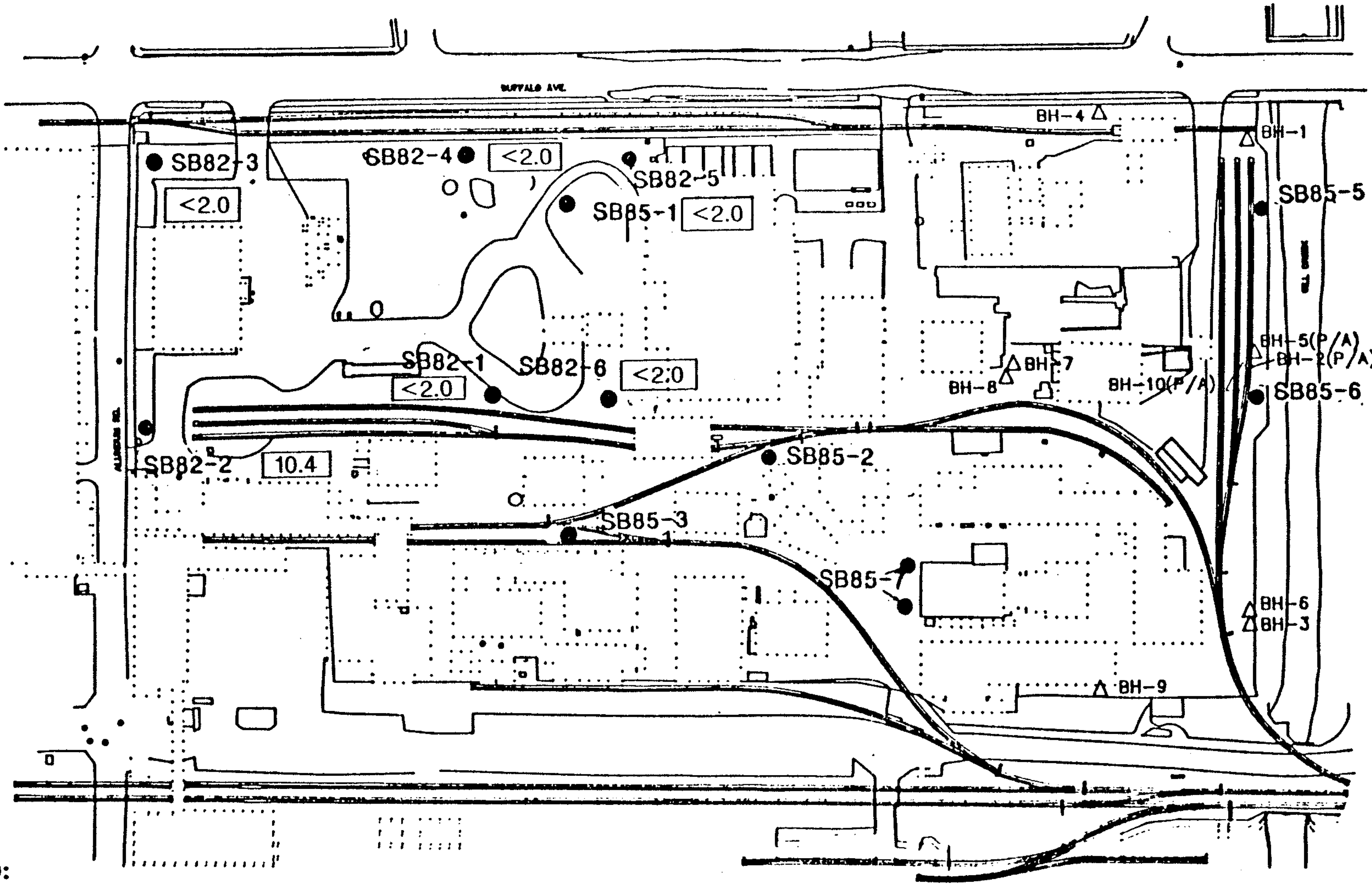
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

CONCENTRATION (PPM)
PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

FILE: 87B226C
JUNE, 1988

FIGURE 33

WOODWARD-CLYDE CONSULTANTS



LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

POLYNUCLEAR AROMATIC HYDROCARBONS

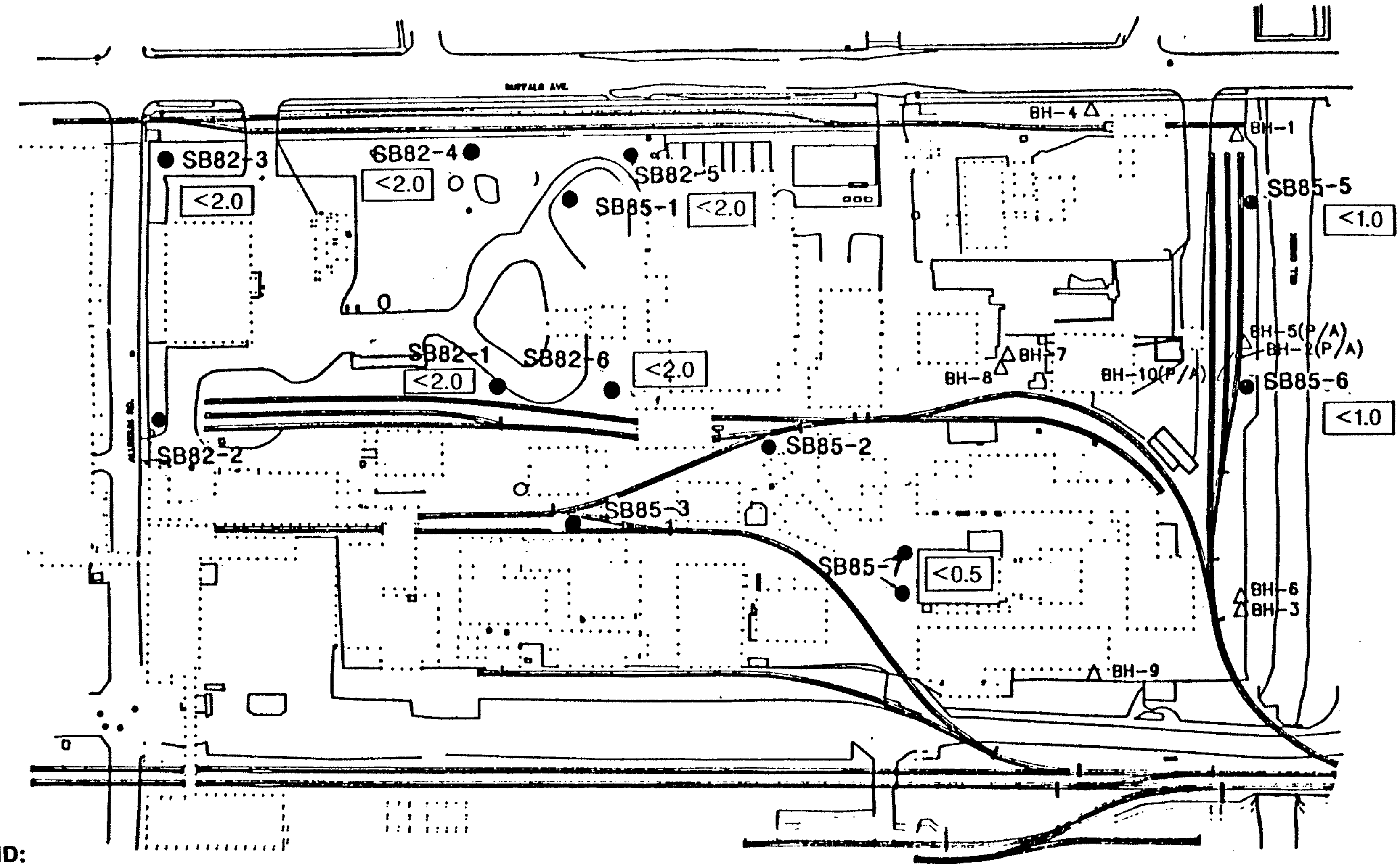
CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE 34



LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

CHLORINATED PHENOLICS

CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

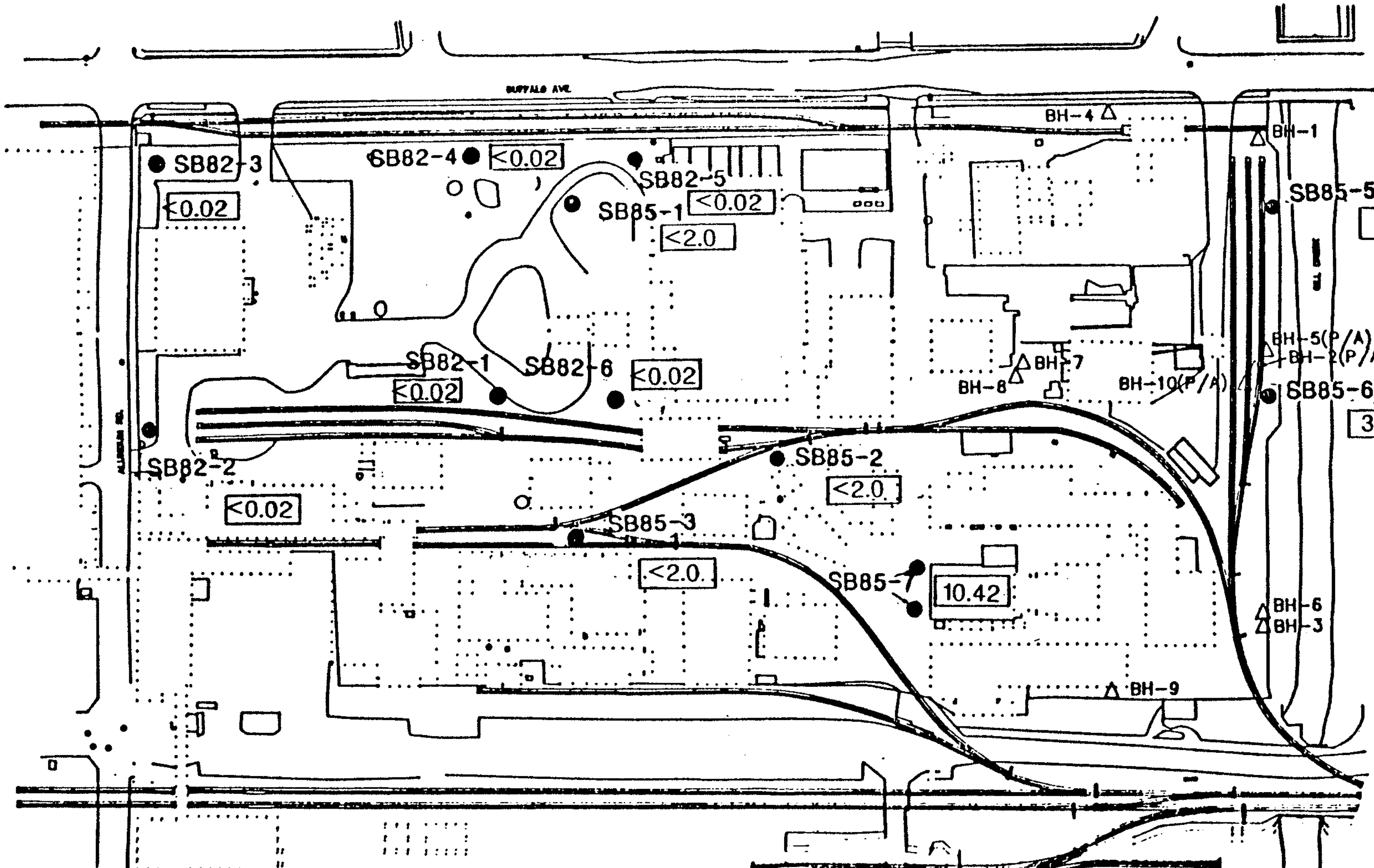
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 35

WOODWARD-CLYDE CONSULTANTS



LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

BENZENE AND CHLOROBENZENE

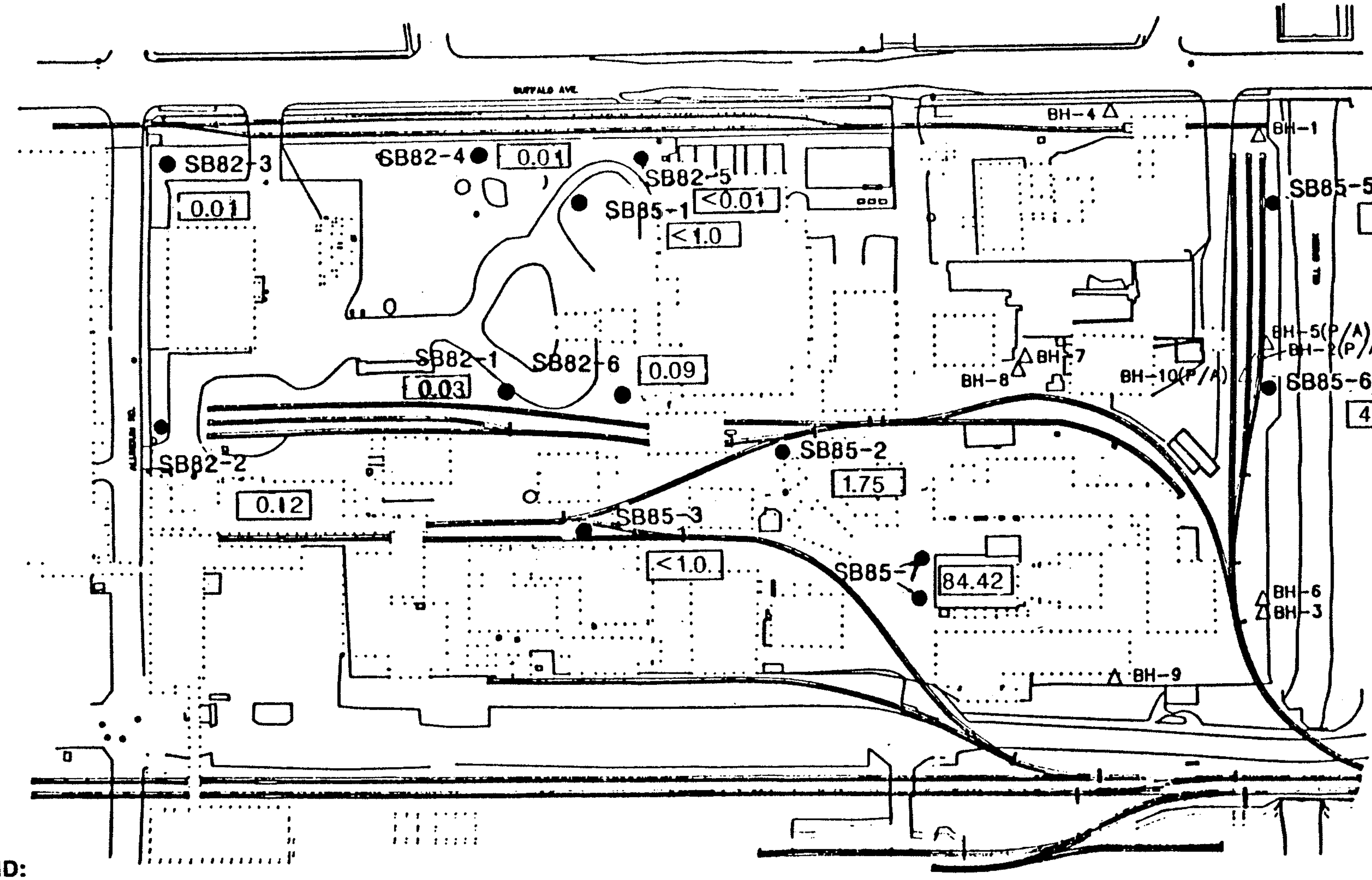
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

FILE: 87B226C
JUNE, 1988

FIGURE 36



WOODWARD-CLYDE CONSULTANTS

LEGEND:

SB82-1 ● SOIL BORING

X SOIL SAMPLE

ALL VOLATILES EXCEPT BENZENE AND CHLOROBENZENE

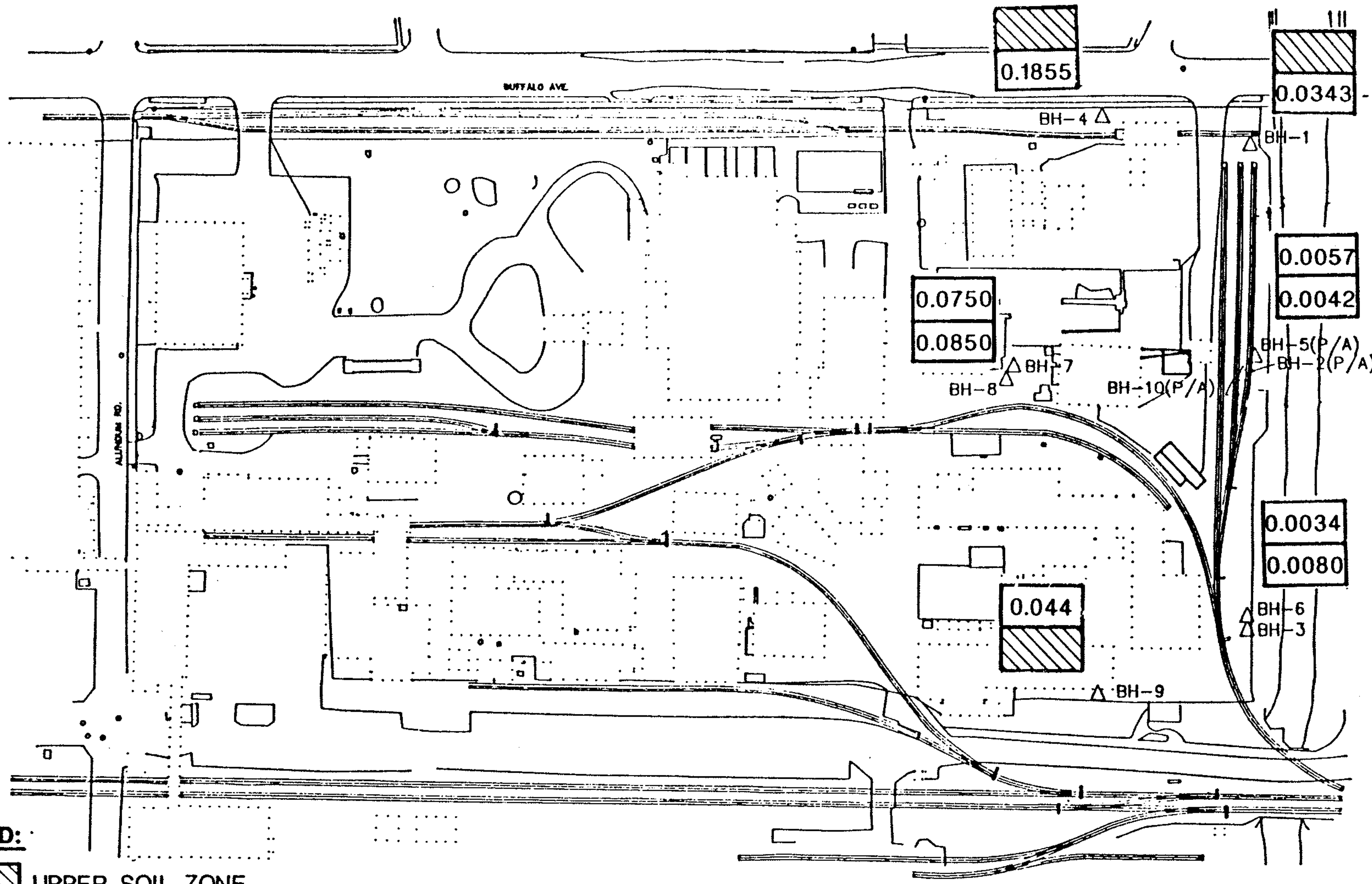
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

CONCENTRATION (PPM)

PLANT 2 SOIL BORINGS AND EXCAVATIONS 1982-1986

FILE: 87B226C
JUNE, 1988

FIGURE 37



LEGEND:

(shaded box)	UPPER SOIL ZONE
0.259	LOWER BEDROCK ZONE (SHADING-NO WELL IN ZONE)

WOODWARD-CLYDE CONSULTANTS

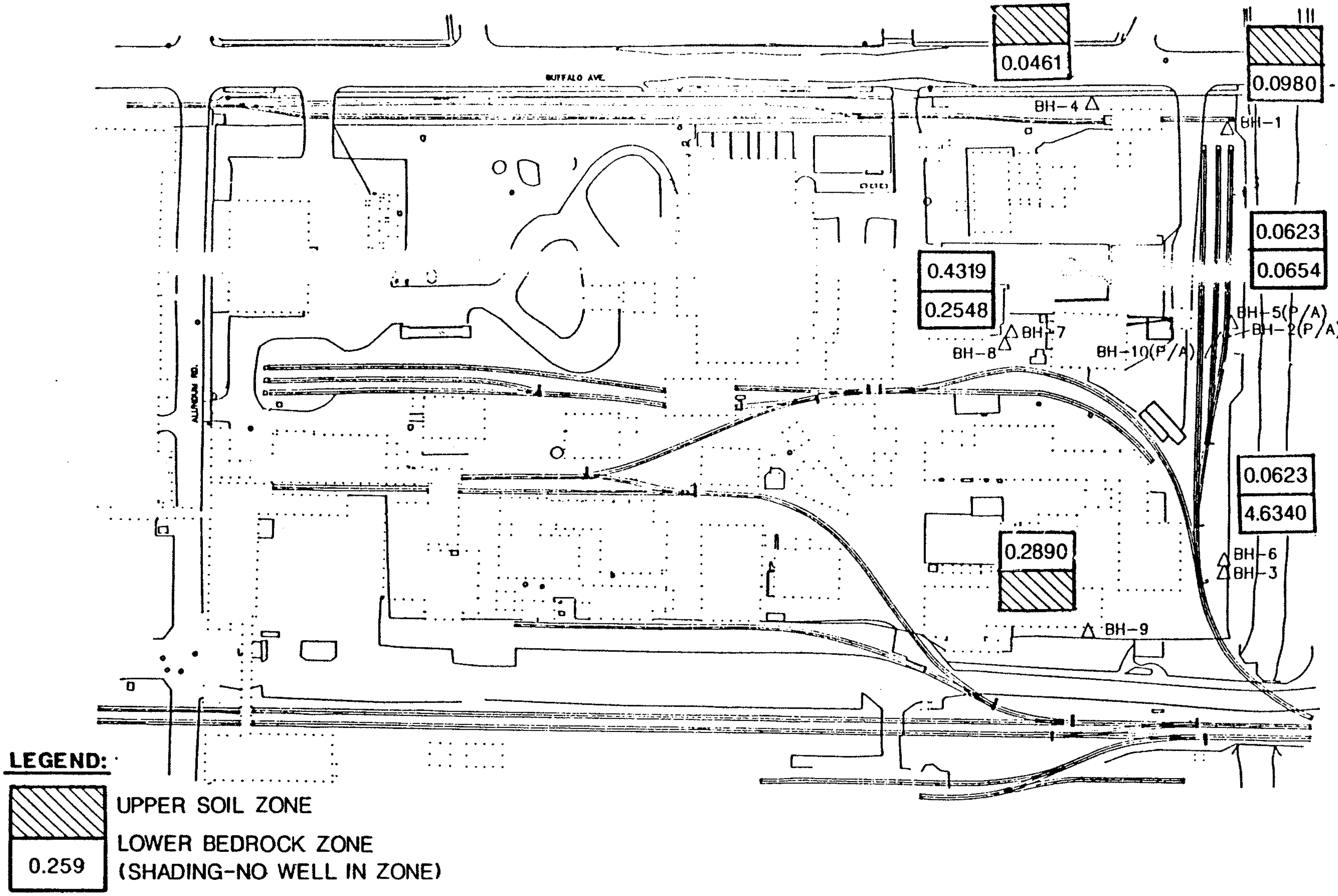
MERCURY

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987
AT GILL CREEK CLUSTERS

FILE: 87B226C
JUNE, 1988

FIGURE **38**



BHC

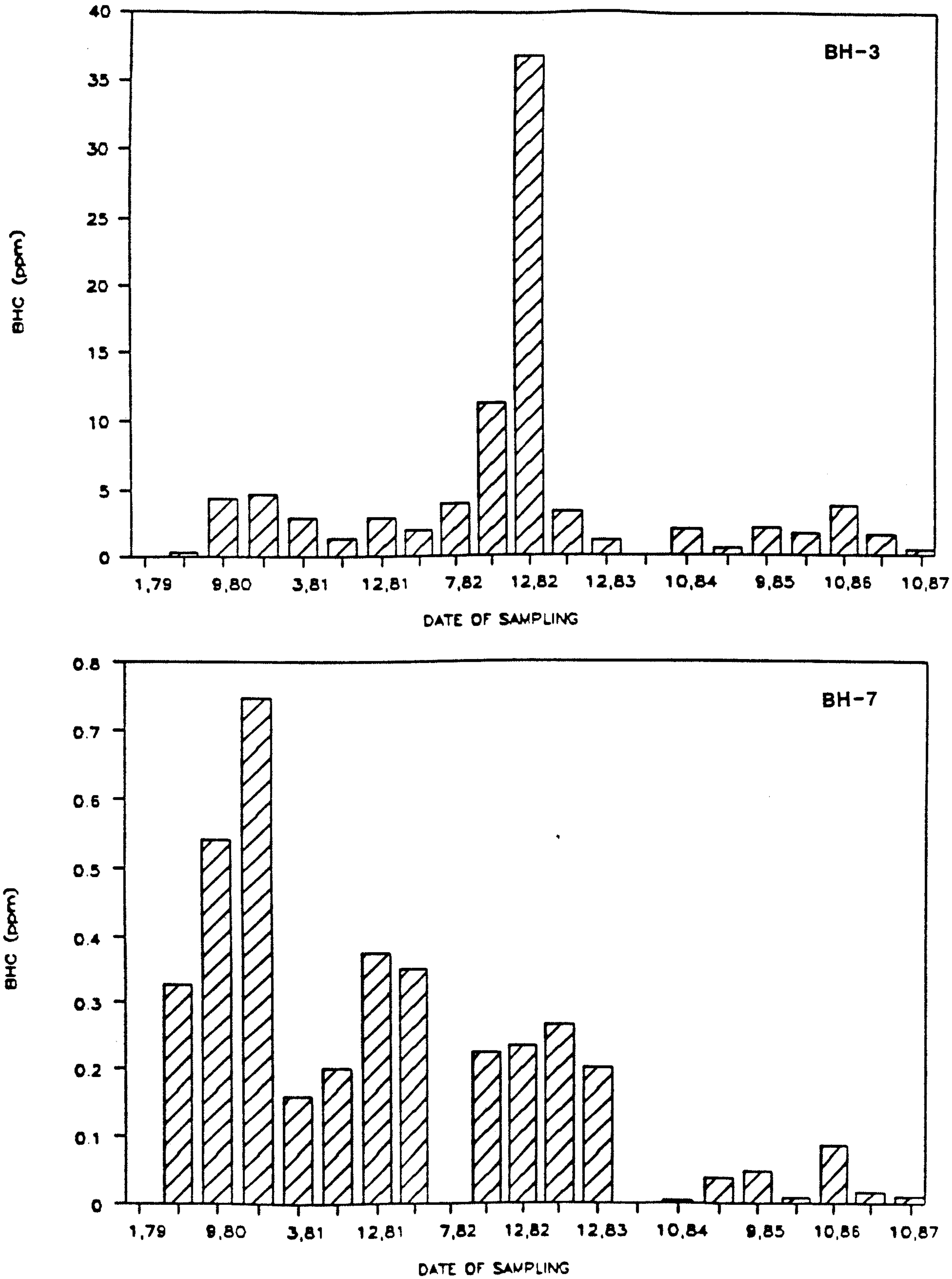
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987
AT GILL CREEK CLUSTERS

FILE. 87B226C
JUNE, 1988

FIGURE 39

TOTAL BHC IN ARGC WELLS IN BH-3 AND BH-7, 1979-1987



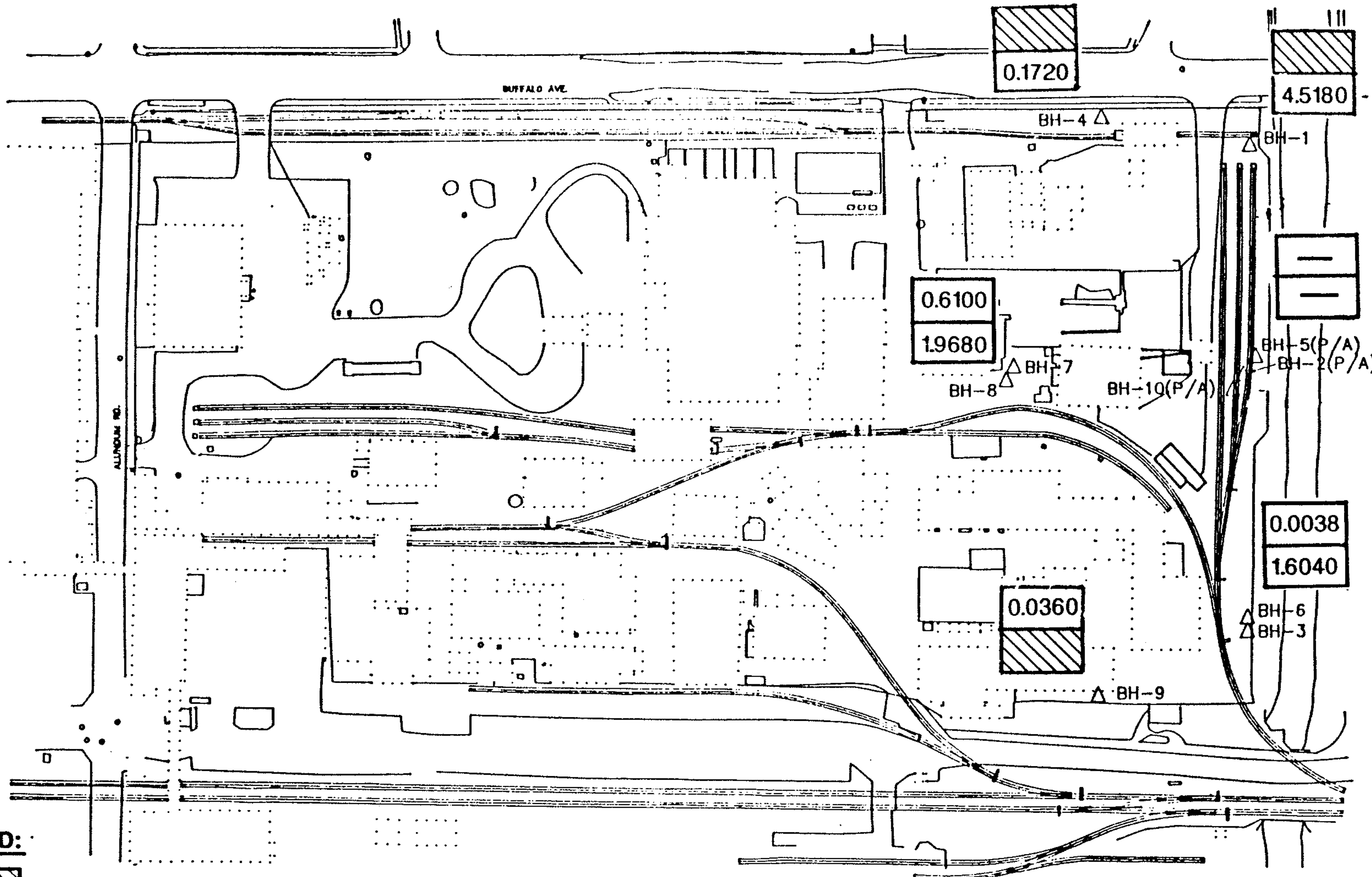
OLIN CHEMICALS
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

WOODWARD-CLYDE CONSULTANTS

FIGURE 40

WOODWARD-CLYDE CONSULTANTS



LEGEND:

UPPER SOIL ZONE

0.259 LOWER BEDROCK ZONE
(SHADING-NO WELL IN ZONE)

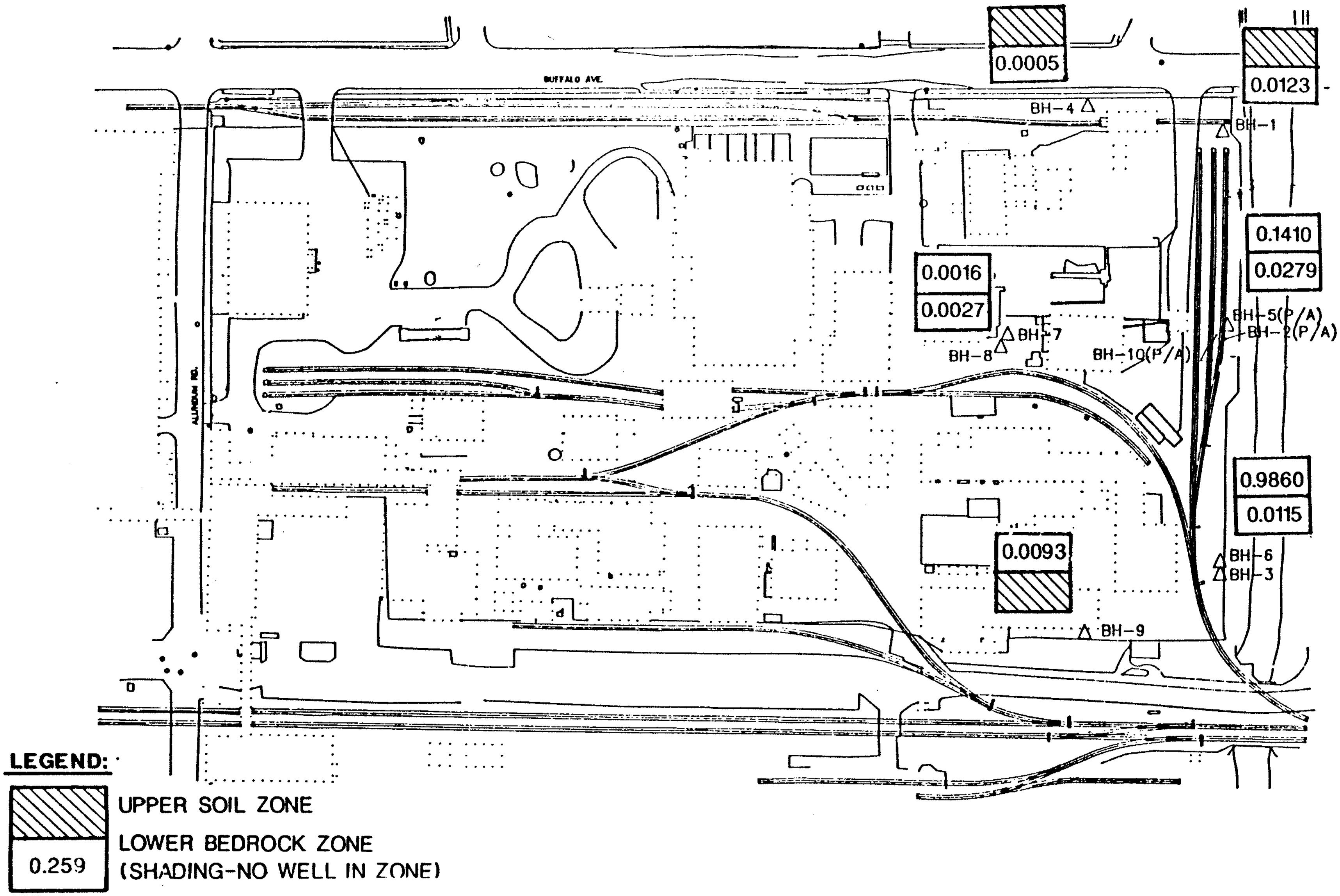
TRICHLOROBENZENE

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987
AT GILL CREEK CLUSTERS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

FILE: 87B226C
JUNE, 1988

FIGURE 41



WOODWARD-CLYDE CONSULTANTS

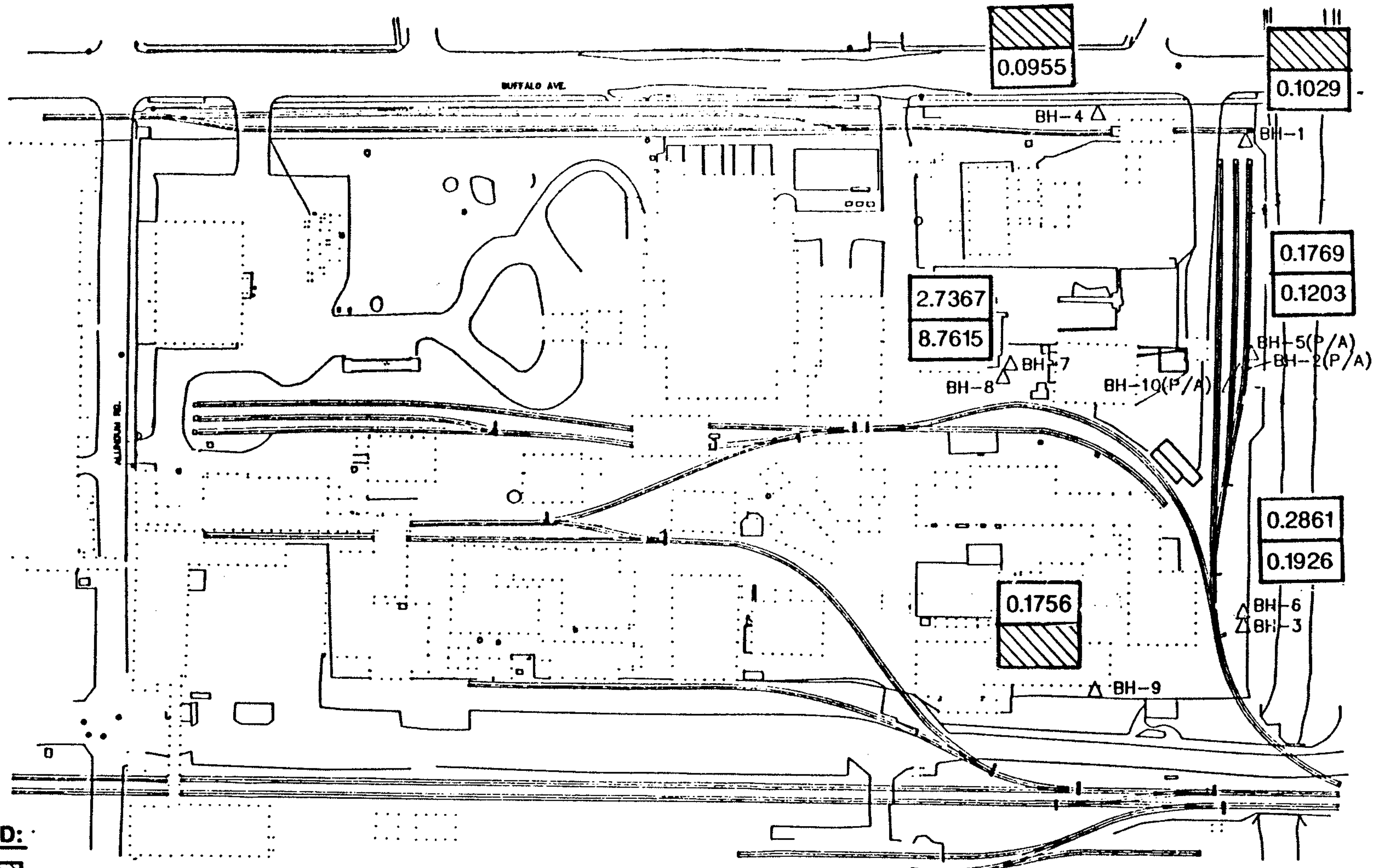
POLY NUCLEAR AROMATIC HYDROCARBONS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987
AT GILL CREEK CLUSTERS

FILE: 87B226C
JUNE, 1988

FIGURE 42



LEGEND:

UPPER SOIL ZONE

0.259 LOWER BEDROCK ZONE (SHADING-NO WELL IN ZONE)

WOODWARD-CLYDE CONSULTANTS

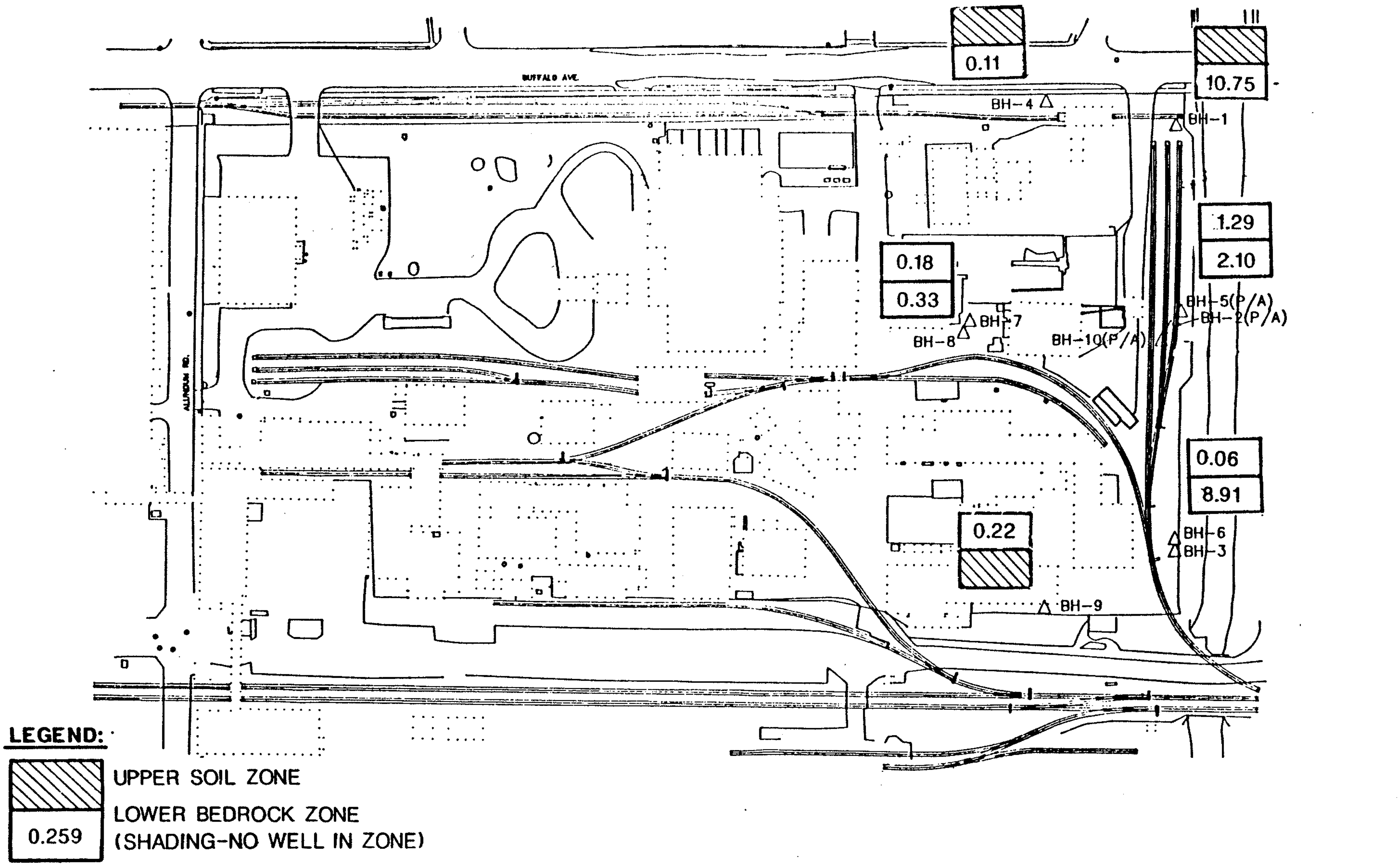
CHLORINATED PHENOLICS

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987 AT GILL CREEK CLUSTERS

FILE: 87B226C
JUNE, 1988

FIGURE 43



WOODWARD-CLYDE CONSULTANTS

BENZENE AND CHLOROBENZENE

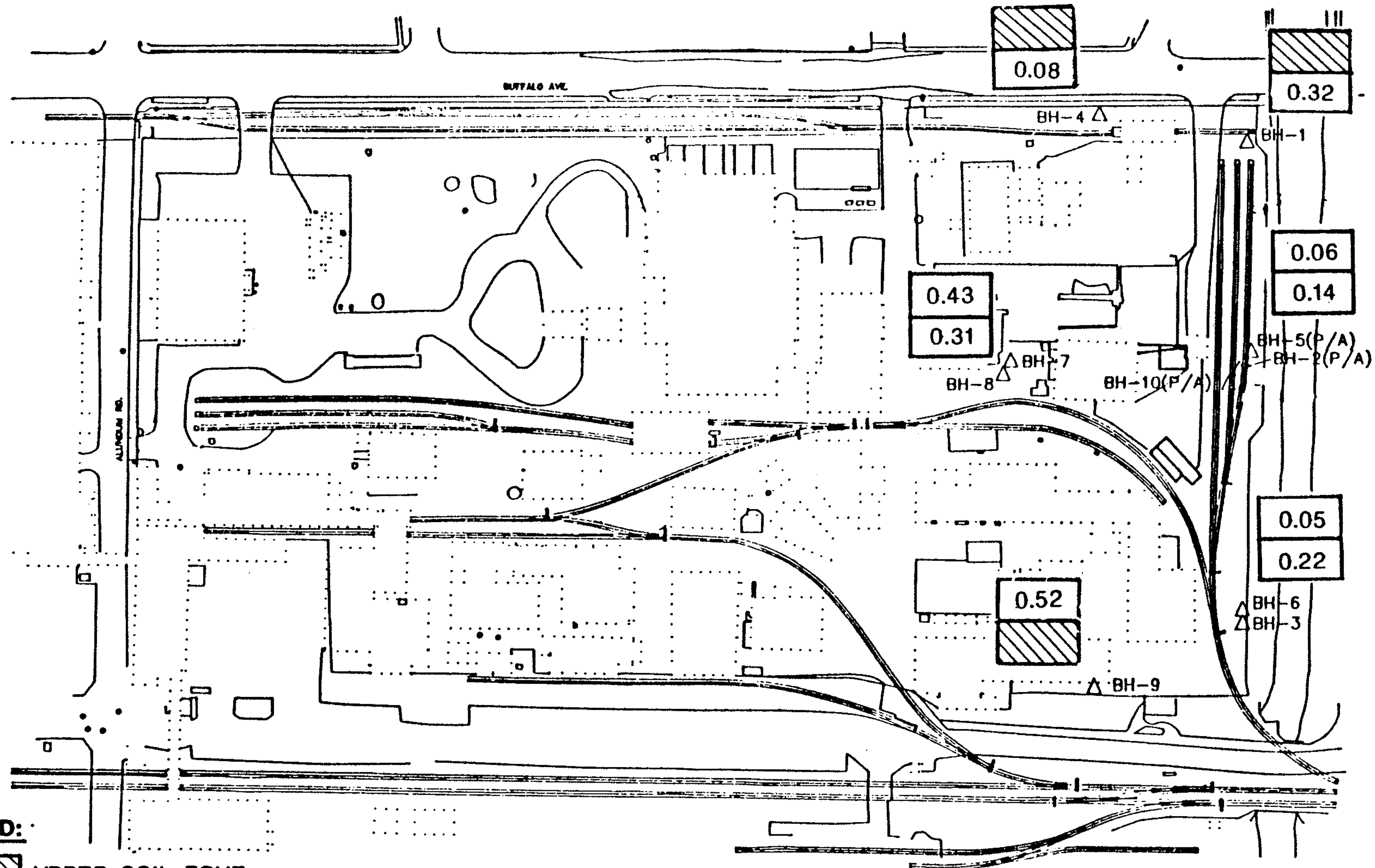
OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987 AT GILL CREEK CLUSTERS

FILE: 87B226C
JUNE, 1988

FIGURE **44**

WOODWARD-CLYDE CONSULTANTS



LEGEND:

UPPER SOIL ZONE

0.259 — LOWER BEDROCK ZONE (SHADING-NO WELL IN ZONE)

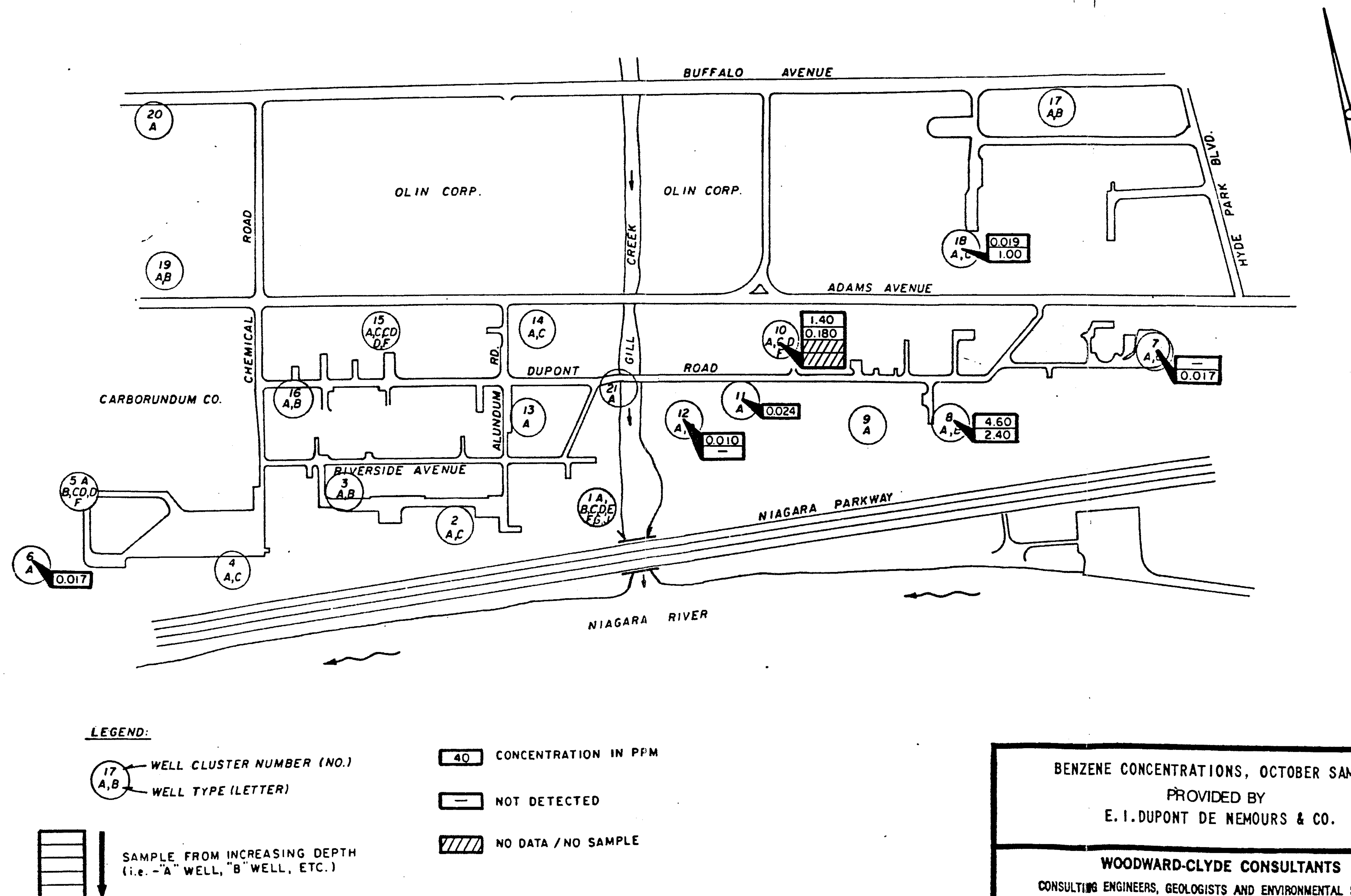
ALL VOLATILES EXCEPT BENZENE AND CHLOROBENZENE

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MEAN GROUND WATER CONCENTRATIONS (PPM) 1979-1987
AT GILL CREEK CLUSTERS

FILE: 87B226C
JUNE, 1988

FIGURE 45

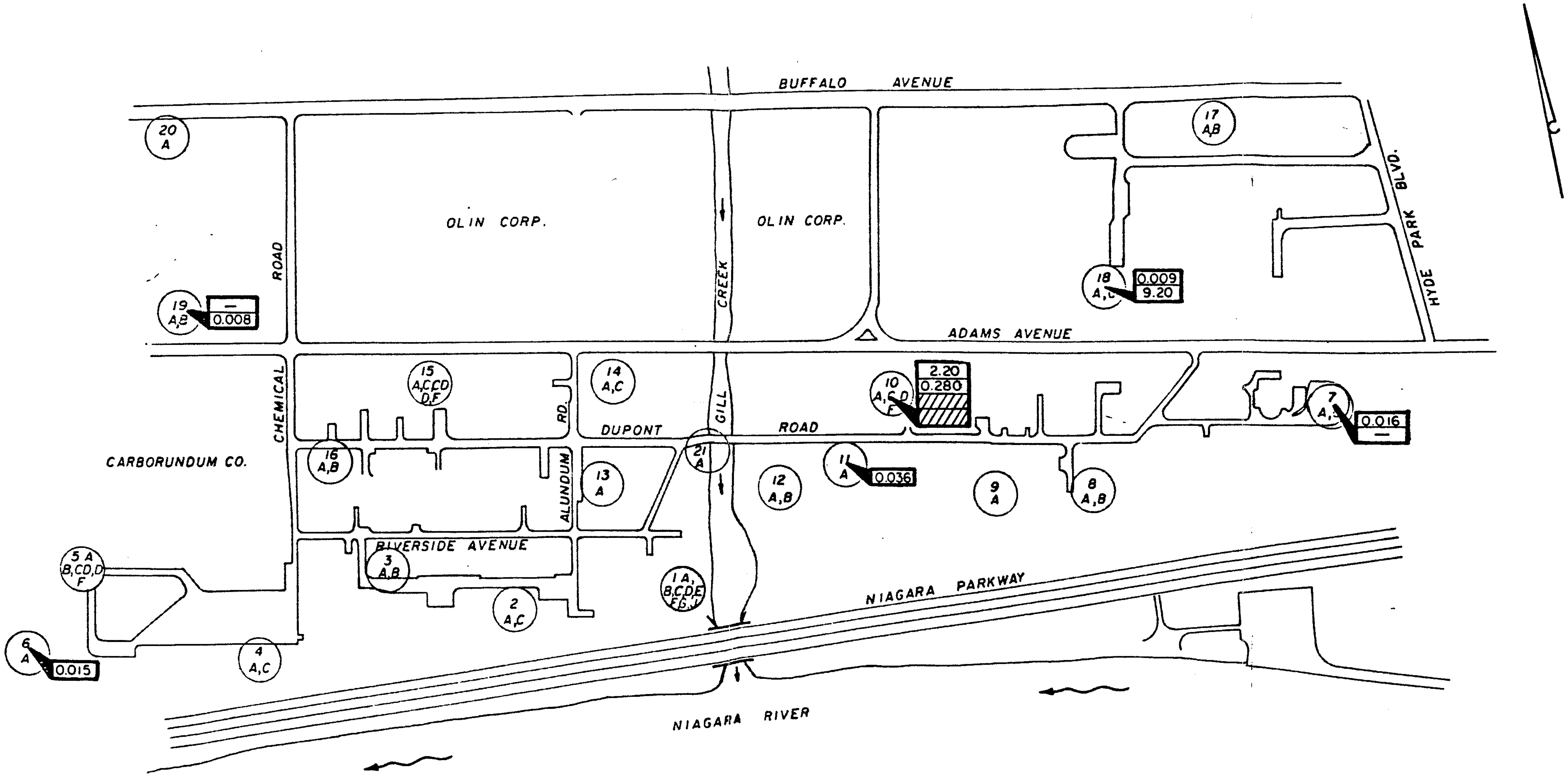


NOTE: RESULTS SHOWN ONLY WHERE COMPOUND WAS DETECTED

BENZENE CONCENTRATIONS, OCTOBER SAMPLING
PROVIDED BY
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T. P.	SCALE in FEET	DATE: 11/15/83	
CHECKED: J.C.E.	0 300	FIGURE 46	



LEGEND:

17 A,B — WELL CLUSTER NUMBER (NO.) — WELL TYPE (LETTER)

SAMPLE FROM INCREASING DEPTH (i.e. -"A" WELL, "B" WELL, ETC.)

[40] CONCENTRATION IN PPM

[—] NOT DETECTED

[////] NO DATA / NO SAMPLE

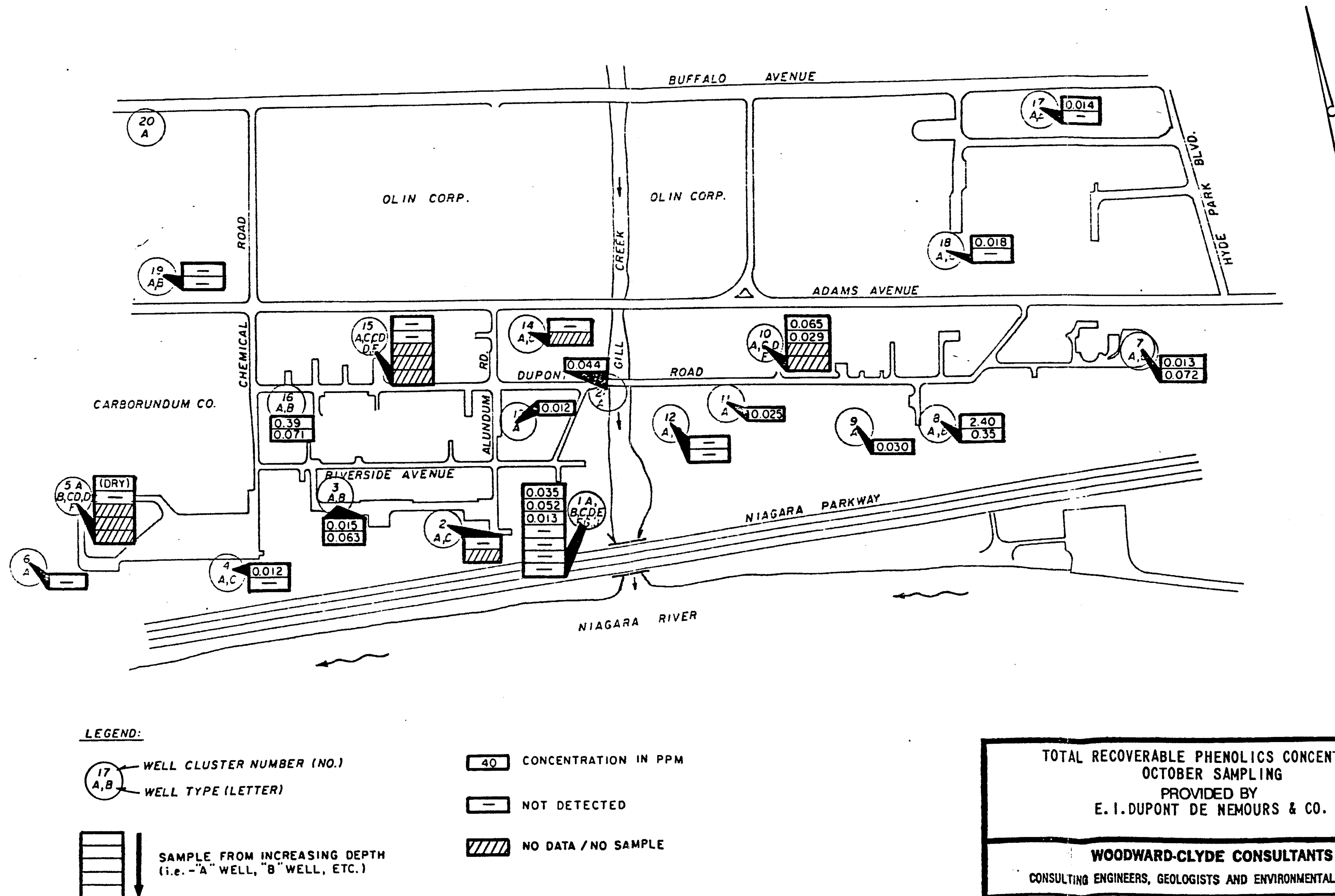
NOTE: RESULTS SHOWN ONLY WHERE COMPOUND WAS DETECTED

CHLOROBENZENE CONCENTRATIONS, OCTOBER SAMPLING

PROVIDED BY
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE IN FEET	DATE: 11/15/83
CHECKED: J.C.E.	0 300	FIGURE 47

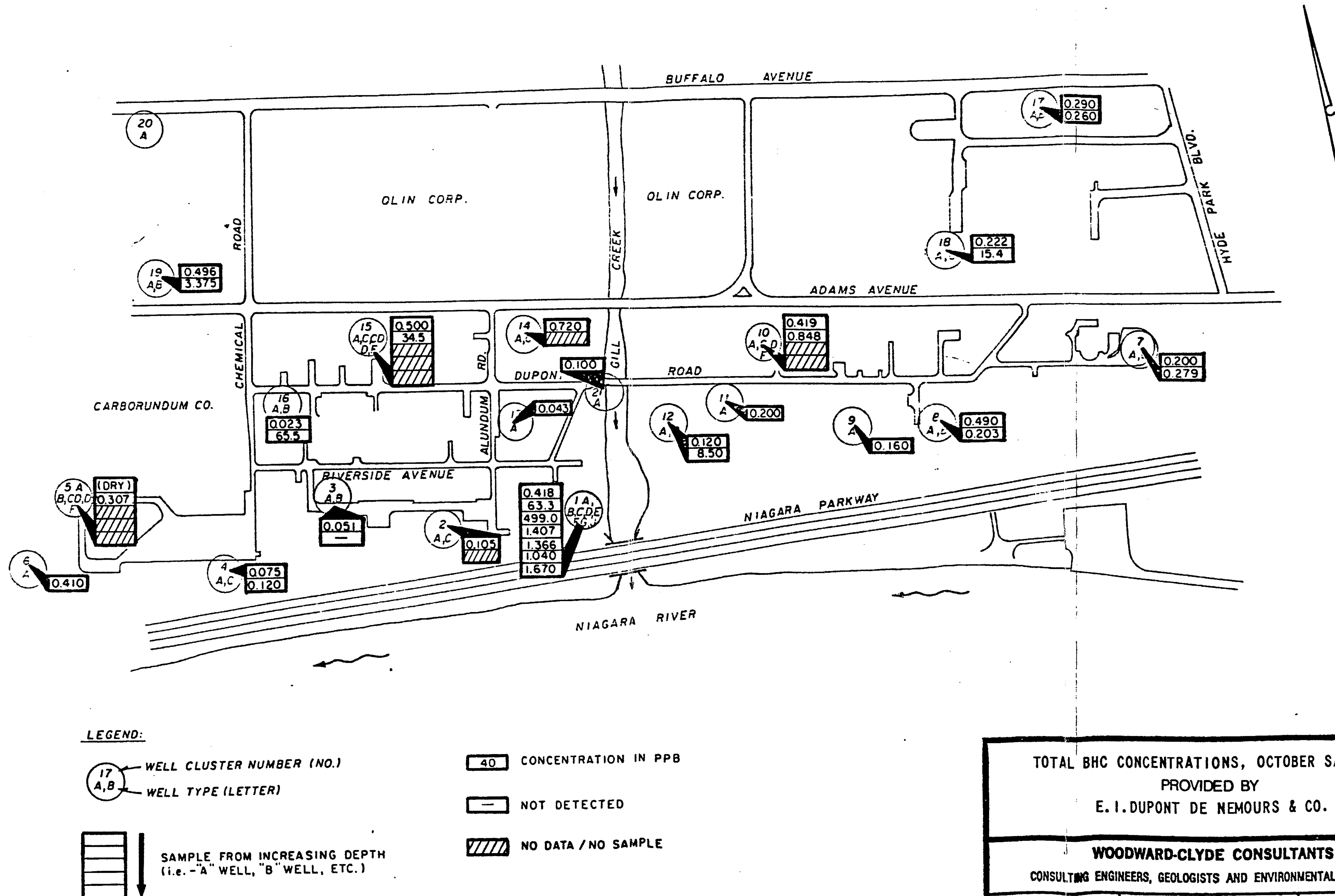


TOTAL RECOVERABLE PHENOLICS CONCENTRATIONS
OCTOBER SAMPLING
PROVIDED BY
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET 0 300	DATE: 11/15/83
CHECKED: J.C.E.		FIGURE 48

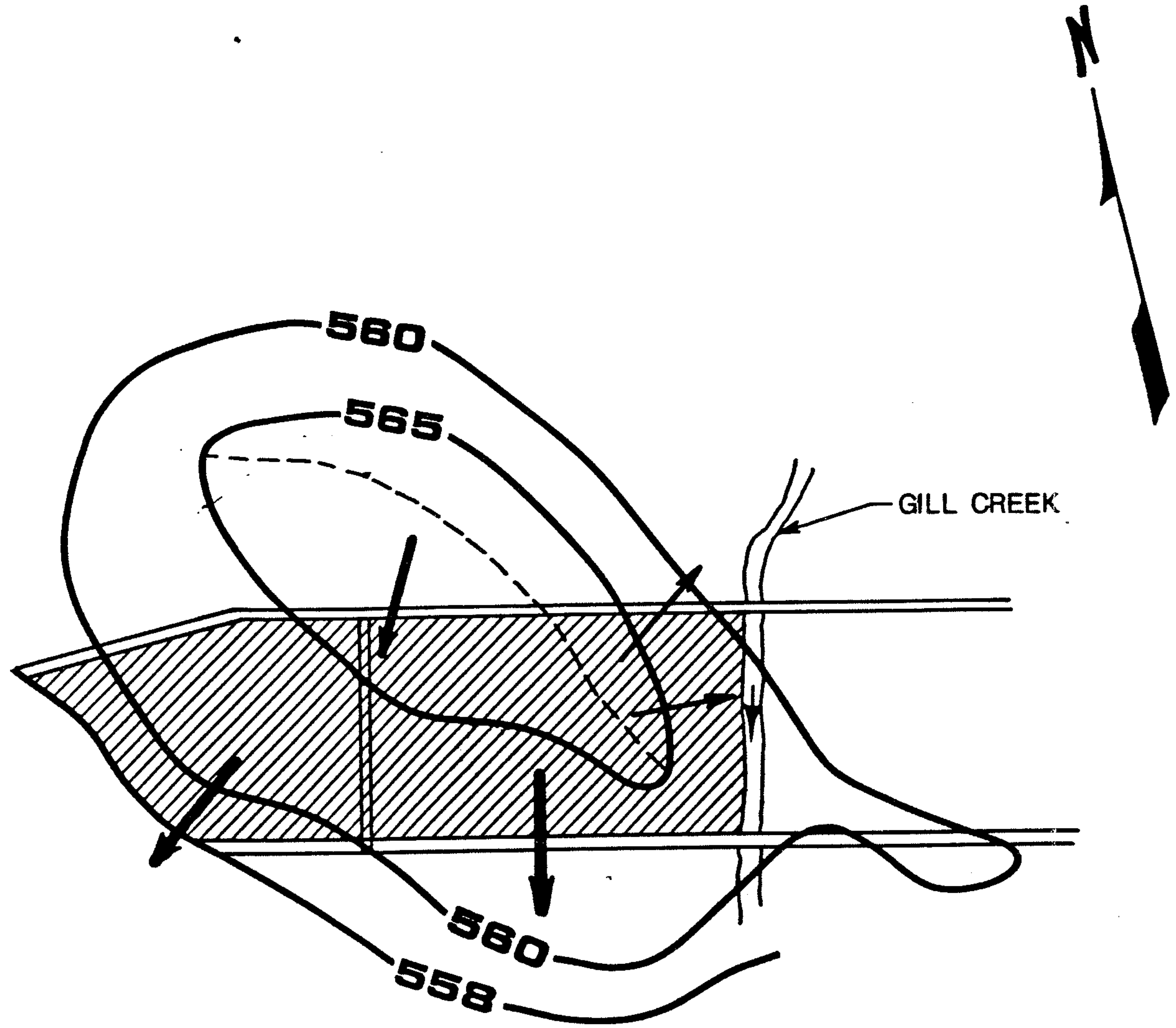


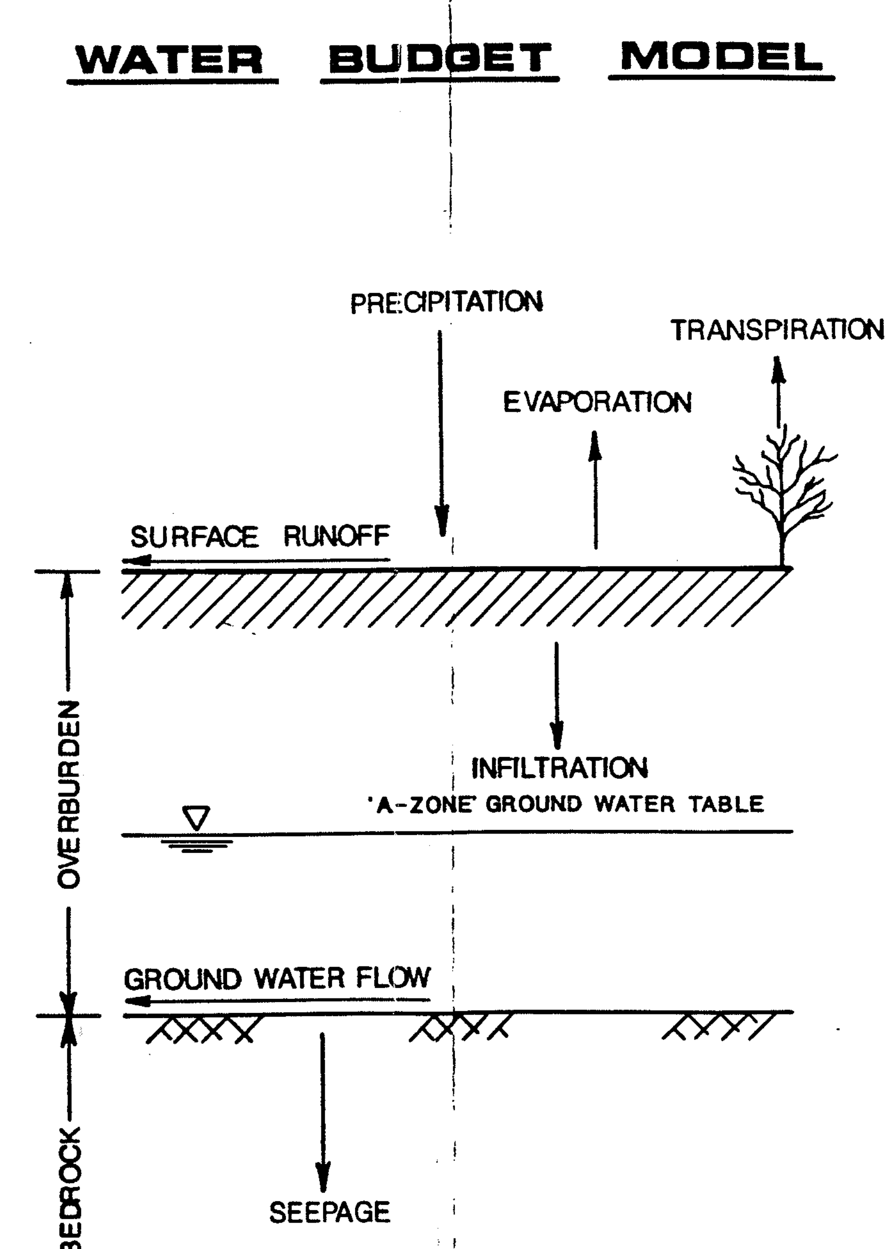
TOTAL BHC CONCENTRATIONS, OCTOBER SAMPLING
PROVIDED BY
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS

CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET	DATE: 11/15/83	
CHECKED: J.C.E.	0 300	FIGURE 49	





LEGEND:

- PLANT SITE
- HYPOTHETICAL GROUND WATER DIVIDE IN "A" ZONE
- POTENTIAL 'A-ZONE' GROUND WATER TRANSPORT (WIDTH INDICATIVE OF RELATIVE MAGNITUDE)
- 565 — TOP OF BEDROCK ELEVATIONS

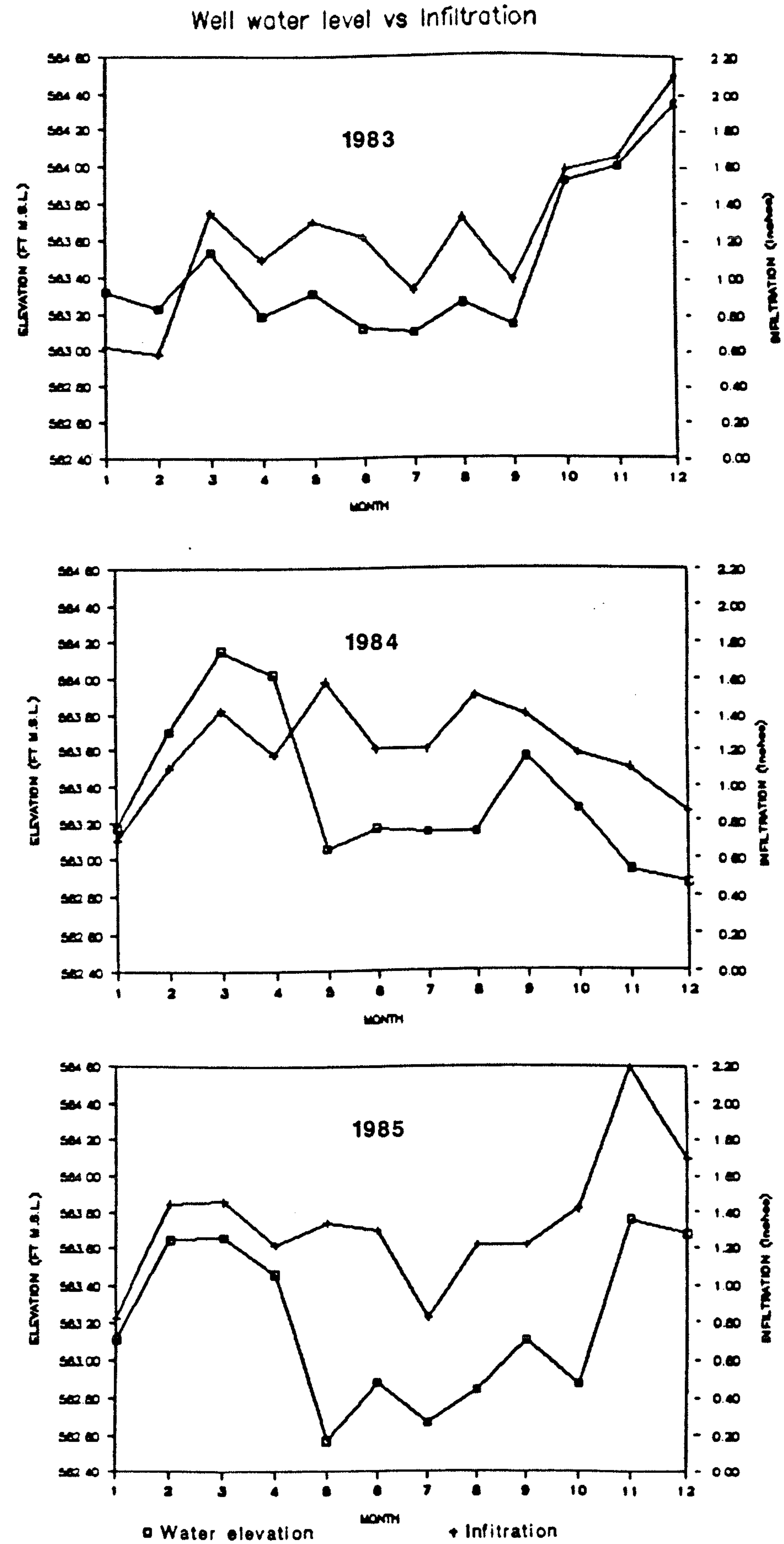
GROUND WATER ASSESSMENT

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS
BATON ROUGE, LOUISIANA

OLIN CORPORATION
NIAGARA FALLS, NEW YORK

MADE BY: A.L. CHECKED BY:	DATE: 8/5/88 DATE:	FILE NO. 87B226C

A-ZONE GROUND WATER RECHARGE MODEL — FIGURE 50



OLIN CHEMICALS
NIAGARA FALLS, NEW YORK

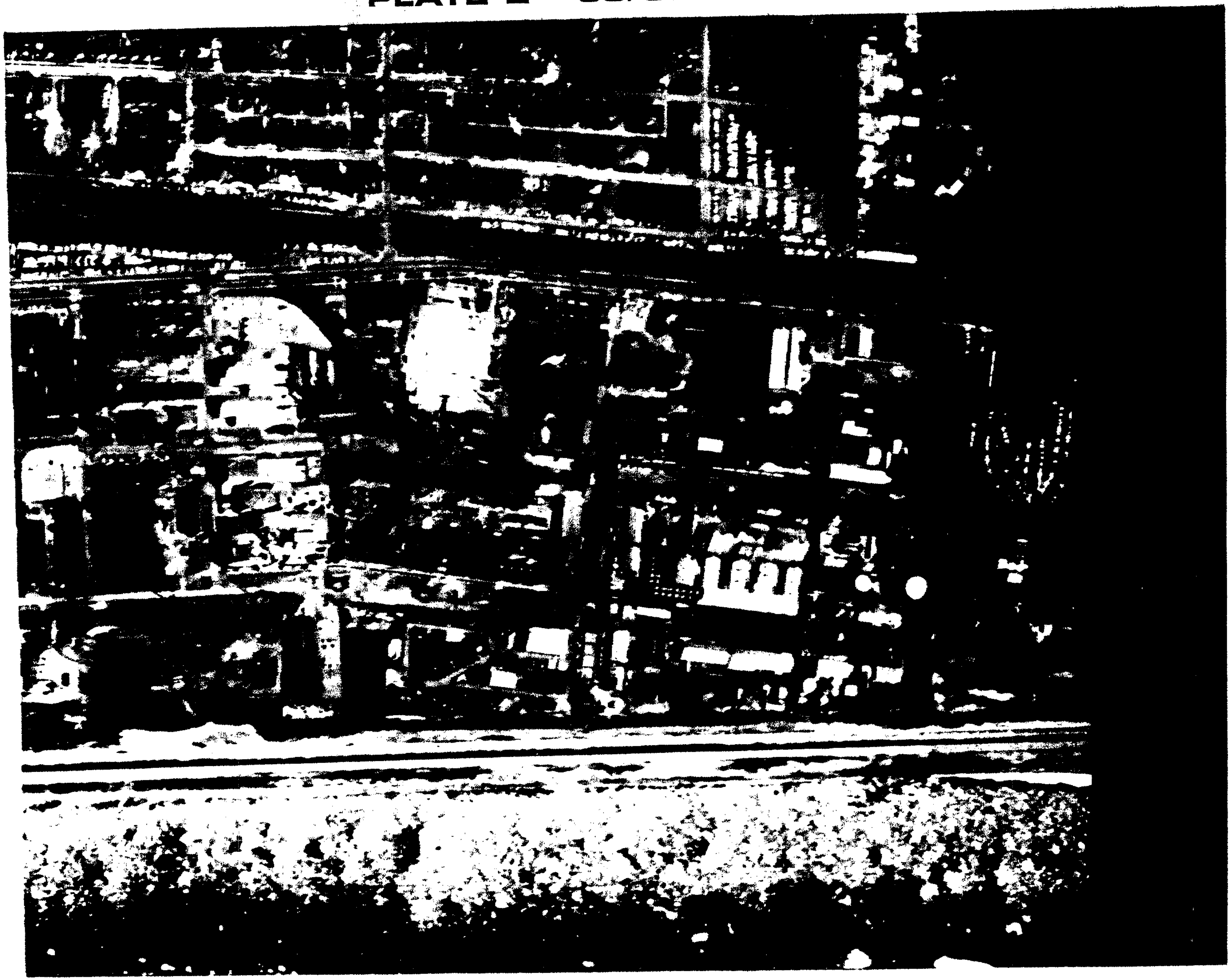
FILE: 87B226C
JUNE, 1988

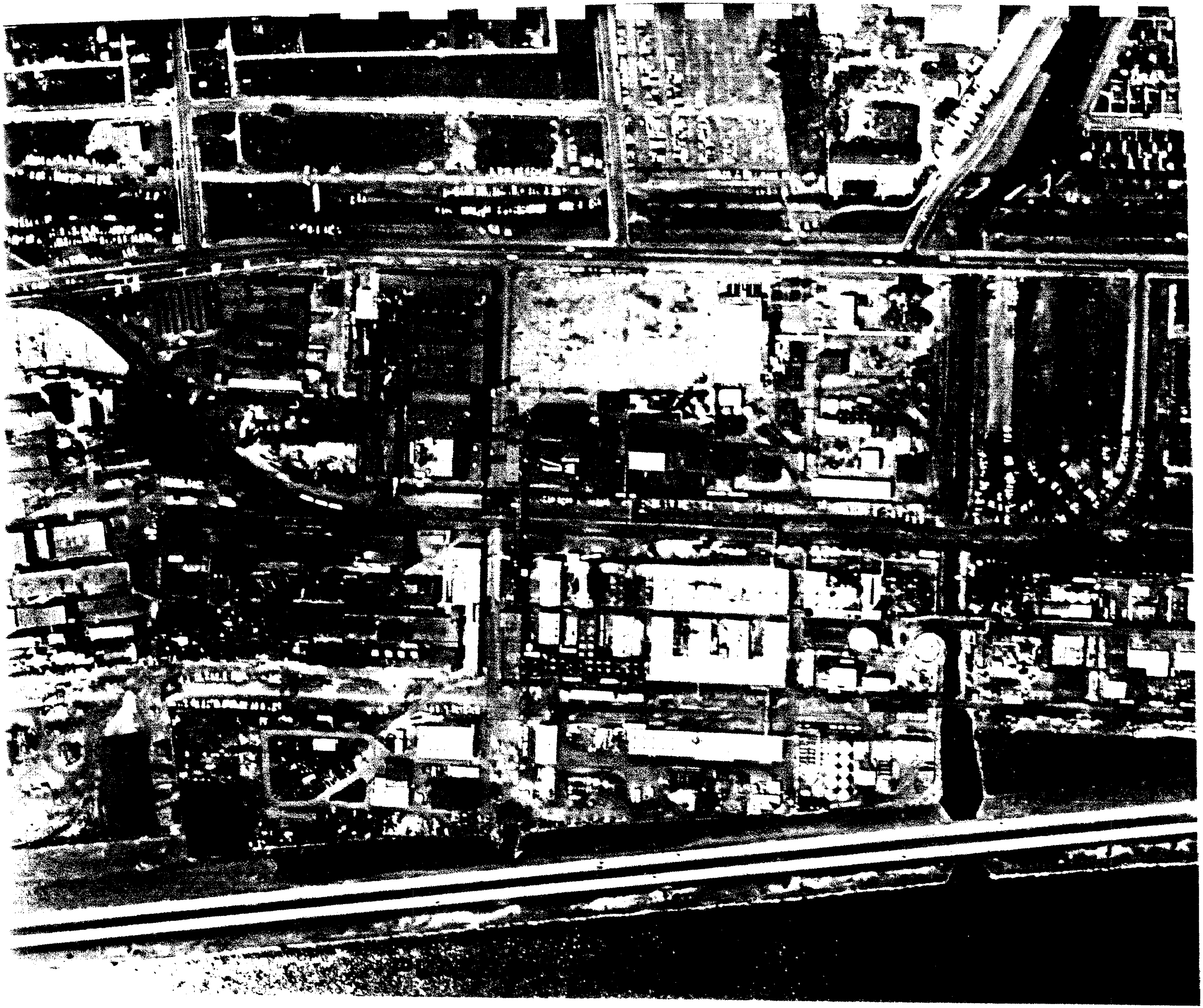
WOODWARD-CLYDE CONSULTANTS

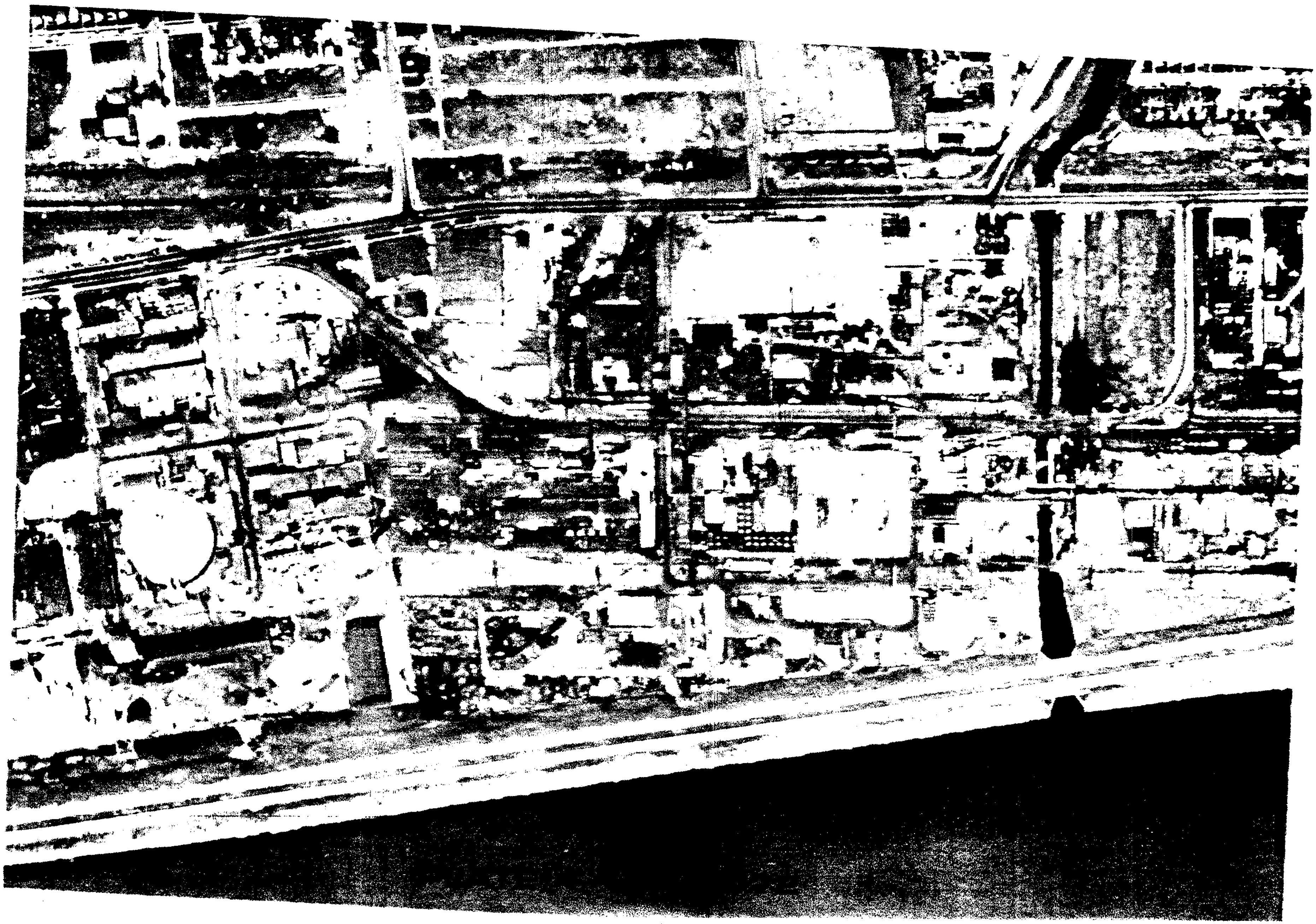
FIGURE 51

PLATE 1 - 09/25/38

PLATE 2 - 05/07/63







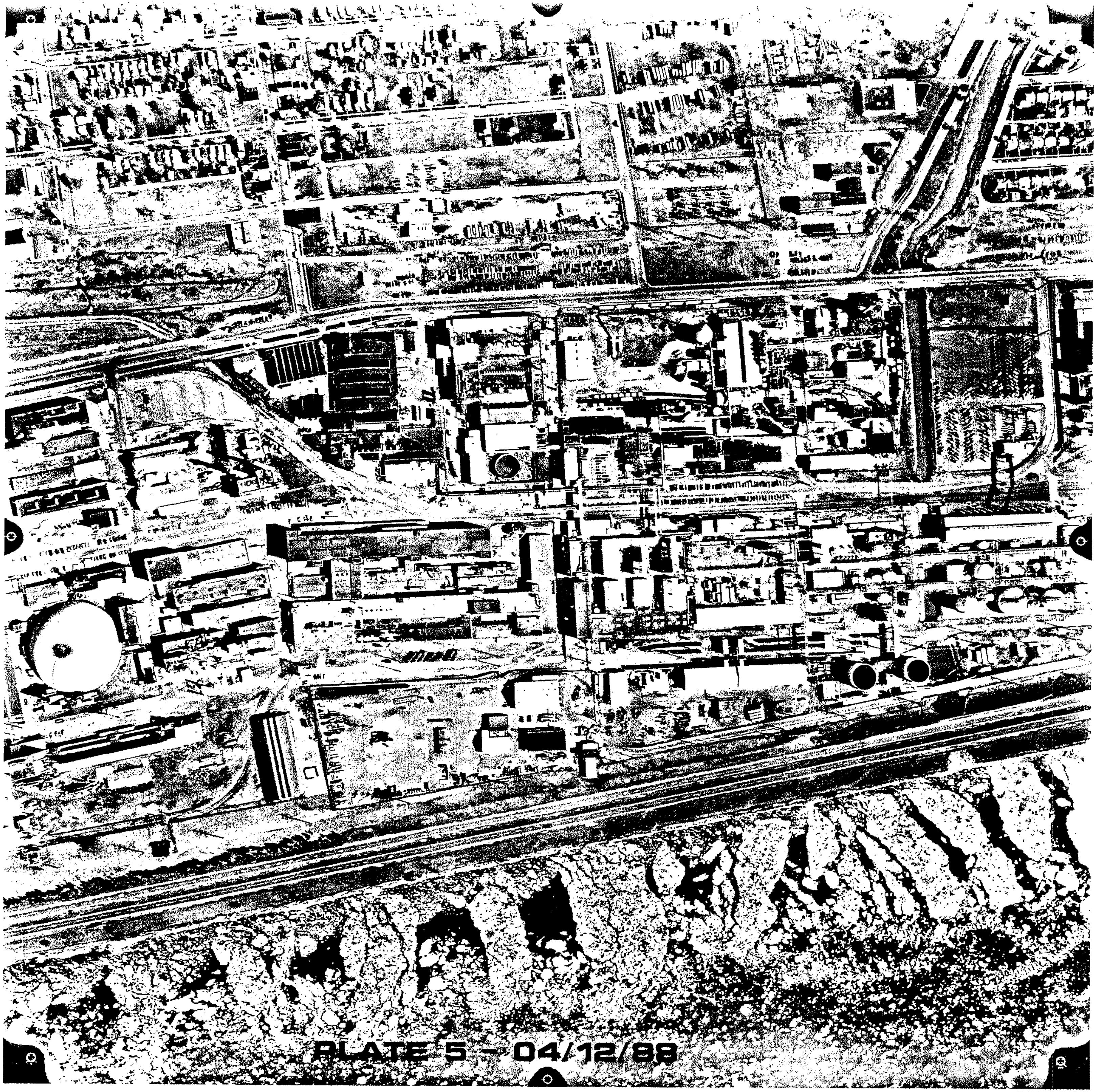


PLATE 5 – 04/12/88