S - AREA HYDROGEOLOGIC EVALUATION

REPORT TO

NIAGARA RIVER STEERING COMMITTEE

ONTARIO MINISTRY OF ENVIRONMENT

FINAL REPORT

August 24, 1982

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FOREWORD

This report has been prepared for the Niagara River Steering Committee of the Ontario Ministry of the Environment. The purpose of the report is to provide the Ministry of Environment with an independent technical review and interpretation of the hydrogeologic conditions at the S-Area landfill site, owned and previously operated by Hooker Chemicals and Plastics Corporation (HCPC).

A complaint against HCPC and parent companies was filed in June, 1980 in the United States District Court, Western District of New York. The Plaintiff is the United States of America, and the complaint is signed by a representative of the United States Department of Justice and Attorneys of the Western District of New York. Counsel are listed as representatives of the United States Environmental Protection Agency. The City of Niagara Falls and the State of New York are also listed as defendants as they have substantial interest in the proceedings.

Discussions have been undertaken between HCPC and the Plaintiffs concerning a settlement agreement, however this has not as yet been filed with the court. Consequently it is not feasible to comment directly on proposed or potential remedial action. A separate report is in preparation concerning possible remedial action alternatives. It is hoped that this report and the subsequent report concerning remedial action can be used to assist in developing an understanding of the existing hydrogeologic conditions and to derive satisfactory remedial measures for the area.

DATA INTERPRETATION

The data utilized for preparation of this report has been obtained from numerous sources. Attempts have been made to identify source documents via frequent referencing as well as a comprehensive list of references cited and additional sources consulted.

Some important assumptions concerning the data have been made and it is important to note these at this point.

- It has been assumed that each piece or set of data, either chemical, water level, elevation or otherwise is as accurate as the next; i.e. that the data are comparable over time and space irrespective of such differences as analytical methods.

- It has not been possible to comprehensively evaluate Quality Assurance procedures, such as chain-of-custody documentation or protocol for water quality samples, therefore no attempts have been made to remove 'suspect' data on these bases.

- Notwithstanding the first two points, some 'judgement' has been invoked where experience or circumstances have required same. For instance, ground water samples with sampling dates either prior to piezometer or well installation or within 3 to 4 weeks after installation have been neglected. The documented data as well as experience suggest that stabilization and equilibration with the ground water system require some length of time. Even so, many of the remaining samples still show substantial effects of "nonequilibration" (i.e. apparent cement contamination or erratic concentrations).

- Where data from various sources are conflicting, for instance well locations or facility boundaries, attempts have been made to clarify the discrepancies.

- Much use is made in this report of hydrogeologic data and concepts presented in the report by Johnston (1964). This report is considered a comprehensive overview of the hydrogeologic conditions in the Niagara Falls, New York area, from a water supply standpoint. It must be recognized that, although the basic natural systems considered in water supply hydrogeology and contaminant hydrogeology are the same, the manner in which the data are interpreted is usually quite different. Where water supply hydrogeology may consider a geologic unit as 'uneconomic' with 'very little water', the contaminant hydrogeology perspective may be simply that the unit is 'somewhat less permeable' but still capable of transmitting contaminants.

- Many quotes are taken directly from Johnston (1964) and considerable credibility is assigned to his interpretation of the ground water system. However, the principles of contaminant hydrogeology rather than water supply hydrogeology are foremost in the interpretation of the immediate S-Area site as well as the general contaminant transport potential of the subsurface system in the Niagara Falls, N.Y. area.

- Contour diagrams presented in this report are based on linear interpolation, in an attempt to reduce, as much as possible, the subjectivity often associated with data contouring. It is obvious from some of the

contoured figures that there is limited data and that the validity of developing contours from the limited data may be questioned. It was considered, however, that the contoured data is sufficiently consistent between data sets. The ground water flow directions and chemical concentration trends do not appear to be in conflict and the general patterns established by the contouring are useful in developing an overall hydrogeologic interpretation.

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1.0 BACKGROUND

The S-Area disposal site (Figure 1) is owned by Hooker Chemicals and Plastics Corporation (HCPC). The disposal site, approximately 4 acres in size (Civil Action 988, 1980) is located adjacent to Hooker's Niagara Falls, New York plant on the southeast corner of the 16 acre property (Hooker, 1979b). The site is bounded on the south by Robert Moses Parkway, on the east by 53rd Street and by Hooker property on the north and west. The City of Niagara Falls Water Treatment Plant (WTP) is located directly east of S-Area (approximately 200 yards) and the Niagara River is located immediately south (approximately 200 yards). The nearest homes are approximately one-quarter mile to the northwest. The area is about 3 miles upstream of the Niagara Falls (Figure 2) at a point where flow in the Niagara River is westward.

The S-Area site was formerly submerged by the Niagara River until as late as 1924 (NYPIRG, 1981). The shoreline extended to between Adams and Buffalo Avenue north of the present S-Area site. The area was reclaimed from the river, by dumping various fill materials, between 1938 and 1947. Hooker (1979b) noted that the City of Niagara Falls and many other local industries used the site as a common dump ground before its purchase by Hooker in 1947.

After the S-Area site was purchased by Hooker in 1947 it was used for chemical waste disposal until 1975 (Interagency Task Force, 1979) although major use of S-Area was phased out after 1961 when a thermal destruction operation was implemented. Disposal of sulphur/chlorine residues continued until about 1967, and wastes from equipment cleaning operations were disposed at S-Area until 1975. Waste

products were dumped from the production of over 250 chemicals. The major products produced at the plant have been caustic soda, chlorine, chlorotoluenes, dechlorane (Mirex), halogenated organic chemicals, and various sulfur and phosphorous compounds. The total disposal at S-Area and the adjacent N-Area (Table 1) is estimated at 70,400 tons (Hooker, 1978: Report by HCPC of the waste site survey. Prepared for Interagency Task Force; accompanies letter dated Nov. 17, 1978 by J.A. Cull, HCPC: Total reported estimate is 74,400 tons, however the sum of wastes listed in all reports is 70,400 tons).

Between 1957 and 1958 the Durez plant, also owned by Hooker, hauled approximately 250 tons of liquid phenolic residue and 500 tons of liquid phenolic tars (containing chlorinated benzenes) to S-Area site for disposal (Interagency Task Force, 1979).

The general method of disposal at S-Area consisted of dumping liquid, solid or semi-solid wastes into parallel trenches 15 to 18 feet deep (Interagency Task Force, 1979). Liquids were transported in trailers or drums and drained into the trenches. Hooker documents also indicate that tank cars as well as drums are buried at the site (Interagency Task Force, 1979). The trenches are now covered.

After waste disposal ceased, two clay-lined calcium flouride settling lagoons, which are currently in operation, were constructed above-grade on the site. The lagoons occupy an area of approximately one acre.

2.0 GEOLOGY

2.1 Regional Geology

The geology in the Niagara Falls area consists of a thin layer of unconsolidated glacial deposits overlying Paleozoic sedimentary bedrock. The unconsolidated deposits consist of glacial till overlain by glaciolacustrine clay, silt and some fine sand. The till is relatively unstratified glacial drift consisting of clay, sand and boulders. The till directly overlies the bedrock throughout the Niagara Region.

The depth of the glacial deposits varies significantly between the north and south sides of the Niagara escarpment. S-Area is located south of the escarpment where glacial deposits are generally 5 to 15 feet thick. Thicknesses of glacially derived materials north of the escarpment range up to 90 feet thick (Johnston, 1964).

The bedrock in the Niagara area consists of relatively flat lying beds of dolomite, shale, limestone and sandstone. Formations dip to the south at about 30 feet per mile, or 0.3° (Johnston, 1964). Cross-sections through the bedrock formations are shown in Figures 3 and 4.

The uppermost bedrock formation in the immediate Niagara Falls area is the Lockport Dolomite, which is up to 150 feet thick throughout the Niagara area (Johnston, 1964). The thickness of the Lockport beneath the City of Niagara Falls, N.Y. varies from about 140 feet just north of S-Area to about 100 feet beneath the power storage reservoir (see Figure 2) at the north end of the city. The Lockport formation consists mainly of dolomite along with thin beds of limestone and shaly dolomite. Five distinct zones within the Lockport were identified by Johnston (1964). From uppermost to lowermost these zones are:

a) brownish-grey, coarse-to medium-grained dolomite, locally saccharoidal (finely textured) with thin intervals of curved bedding (algal structures)
b) grey to dark grey, fine-grained dolomite, containing abundant carbonaceous partings
c) tannish-grey, fine-grained dolomite
d) light grey, coarse-grained limestone containing abundant crinoid fragments (Gasport Limestone Member)
e) light grey, shaly dolomite, laminated in part (Decew Member).

Most of the beds in the Lockport formation are described as "thick" (1 foot to 3 feet), or "thin" (1 inch to 1 foot); however, massive beds up to eight feet thick and very thin beds (1/4 to 1 inch) occassionally occur within the formation (Johnston, 1964). The bedding is normally straight, but some curved bedding exists. Several extensive and open bedding joints exist throughout the Lockport Dolomite.

The Rochester Shale formation, part of the Clinton Group, immediately underlies the Lockport Dolomite. Johnston (1964) also provides a discussion of the geology of the Clinton and underlying Albion Groups and the Queenston Shale (Figure 4). "The Clinton and Albion Groups are a series of shales, sandstones, and limestones which crop out along a narrow belt parallel to the Niagara escarpment. The Clinton rocks are composed principally of the dark-grey Rochester Shale at the top, but also contain two thin limestones (Irondequoit and Reynales) and a thin shale (Neahga) at the base. The Albion Group underlying the Clinton consists of two thin sandstones which are separated by a sequence of alternating shale and sandstone".

"The Queenston Shale, beneath the Albion Group, consists mostly of brick-red, sandy shale and thin beds of greenish-grey shale and greenish-grey sandstone. The thickness of the Queenston is 1,200 feet. However, only 200 feet are exposed in the area; the remainder of the formation crops out under Lake Ontario".

Laboratory tests conducted on the Lockport have indicated that the formation is structurally sound and durable when subjected to many cycles of freezing and thawing, or wetting and drying (American Falls International Board, 1974). The Rochester shale, which underlies the Lockport, and the shale beds in the Neahga, Grimsby and Queenston Formations are, on the other hand, weaker and less durable; breaking down when subjected to similar tests (American Falls International Board, 1974).

Soils in the Niagara area are slightly acidic, dark greyish to reddish-brown silty clay loam overlying slightly acidic compact, mottled reddish-brown silty clay with few stones (Experimental Farms Service, 1935).

Topography can be described as smooth and undulating with very little relief except for the Niagara Escarpment and the Niagara River Gorge.

2.2 Local (S-Area) Geology

The local geological situation in the unconsolidated deposits at S-Area varies significantly from the regional due to the presence of large quantities of fill material (Figure 5). The fill material, dumped to reclaim land from the Niagara River, overlies the glaciolacustrine clay and silt and the glacial till. The fill extends in an east-west direction along the entire river frontage at the HCPC Niagara Plant site. Borehole logs through the fill material describe it as highly heterogeneous. It is noted to contain sand, silt, clay, gravel, bricks, cinders, slag, ash, wood, friable material, rock fragments, root material, glass, mud, concrete, rubber, and shot rock (Leggette, Brashears and Graham, 1980a). Of all these materials, sand is the only one which displays any signs of homogeneity. In fact, the sand appears to have been the original fill placed for the purpose of reclaiming the land from the river. The sand overlies the glacial clay and till up to approximately Niagara River elevation. Once the former riverbed was apparently reclaimed with the sand fill, the site was used for dumping the random assortment of fill with various wastes intermixed. During the dumping procedures, the sand appears to have been intermixed with the other wastes to a certain degree, creating an indistinct transition between the two zones. The term 'overburden' is used throughout the remainder of this report to describe the fill material and/or glacially derived deposits.

Additional fill was placed along the shoreline of the Niagara River in the early 1960's to facilitate construction of the Robert Moses Parkway. Leggette, Brashears and Graham (1979e) describe the present shoreline geology as follows: "The sediments in the Parkway area consist generally of a few feet of fine-grained fill at the surface, underlain by about 20 feet of 'shot-rock' fill. Natural sediments underly the fill

and consist of about 1 to 9 feet of till which overlies the dolomite bedrock". 'Shot rock' fill beneath the Parkway is believed to originate from the conduit excavations for the Power Authority of the State of New York (PASNY). The material excavated was the Lockport Dolomite.

Topography in the S-Area vicinity generally slopes gently southward to the Niagara River (Figure 6) with the exception of a localized high point at S-Area. This mound rises about 8 feet above the surrounding landscape and is due to the placement of fill upon which two clay-lined calcium fluoride sedimentation-clarification lagoons are located. The land surface is also built up between S-Area and the Niagara River to form the Robert Moses Parkway.

In general, the glacially-derived deposits at S-Area decrease in thickness from north to south (Figure 5). Near the southerly limit of the site, glaciolacustrine deposits appear to taper out completely in localized areas. The depth of the glacial sediments immediately below S-Area is reported to average 13 feet (Leggette, Brashears and Graham, 1979a), although there is a complete absence of till or glaciolacustrine sediments in the log of borehole 14 on the southwest side of S-Area (Figure 5). A contour diagram of the combined thickness of the clay and till is presented in Figure 7.

Bedrock conditions at S-Area are representative of conditions on a regional scale. The upper surface of the Lockport Formation is relatively smooth as is evident in Figure 8. Local lows in the topography of the bedrock surface appear to occur on the northeast corner of S-Area and beneath approximately the center of U-Area. The Lockport Dolomite immediately underlies the till, and the upper 10 to 15 feet are believed to be relatively highly fractured as compared to

greater depths. The thickness of the Lockport in the S-Area vicinity is approximately 125 feet (PASNY Niagara Power Project, Drawing 11G-106, Rev. 2, 1958). The thickness of the Rochester Shale, as inferred from observations at the Niagara Gorge, is approximately 60 feet.

3.0 HYDROGEOLOGY

Groundwater flow in the Niagara area occurs through both the glacial deposits and the bedrock. In the unconsolidated glacial deposits, water is able to flow through the pores or interstices between the individual grains. There has been no indication in the reports reviewed that the glacial till or lacustrine clay exhibit any fractures. Some fracturing in these deposits is expected, however their importance is somewhat relative, since these deposits are absent in at least one borehole beneath S-Area, allowing direct access to the bedrock of the contaminated fill zone ground water in the fill. In the bedrock, compaction and cementation has reduced the size of the intergranular pore spaces, restricting flow through them. Flow of groundwater in the sedimentary rock is essentially confined to fractures, joints and interconnected solution cavities in the rock.

The Niagara Gorge is a major ground water discharge zone in the Niagara Falls area. The gorge, roughly 300 feet deep, cuts through the glacial deposits, the Lockport Dolomite, Clinton and Albion Groups and into the Queenston Shale. The areal extent of influence of the gorge on the ground water system is problematic. However, previous interpretations (Johnston, 1964) suggest that the gorge has a significant effect on groundwater flow beneath the city of Niagara Falls.

There are insufficient recent data available to attempt a regional scale ground water flow contour map in either the bedrock or the glacial deposits.

3.1 Regional Hydrogeology

3.1.1 Glacial Deposits

In the Niagara Falls region,the water table is located in the glacially derived materials and tends to reflect the topography at a depth of several feet below the land surface. Because the topography is quite flat, horizontal gradients in the overburden are low. The relatively impermeable clays, silts and tills limit regional ground water movement in the overburden to relatively small amounts. The strongest gradients which exist are generally downwards. This downward flow path is the principal means of bedrock recharge on a regional scale.

3.1.2 Bedrock

3.1.2a Lockport Dolomite

The Lockport Dolomite is the only important aquifer within the Niagara Falls area. Within the Lockport, ground water is present in bedding joints, vertical joints and solution cavities. Of these, bedding joints are believed to be the dominant mechanism of ground water flow (Johnston, 1964). The nearly horizontal bedding joints, which follow the dip of the formation, are usually less than 1/8 inch in size although some have been enlarged by gypsum dissolution (Johnston, 1964). The bedding joints are of much higher permeability than the surrounding bedrock. The bedding joints are fairly continuous in areal extent (observed in PASNY conduit excavations over distances of up to 3 or 4 miles) so that groundwater may flow over long distances within a single bedding joint. Johnston (1964) identified seven distinct water bearing bedding joints within the

Lockport formation. Piezometric levels within these joints were found to drop progressively with depth.

Groundwater movement through vertically oriented joints is relatively significant in the top 10 to 15 feet of the formation (Johnston, 1964). In this zone, weathering and dissolution has widened the joints and created a relatively good aquifer at the top of the dolomite. This upper zone is generally considered much more permeable than the remainder of the sedimentary formations in the area.

Recharge to the Lockport over the entire region occurs by a number of mechanisms, of which infiltration from precipitation dominates. This infiltrating water enters the water bearing bedding joints in the bedrock via two means (Johnston, 1964): 1) downward movement of water through the vertical joints and 2) recharge directly to the water-bearing zones at the outcrop of the bedding planes. The latter is likely the most important since the major vertical jointing is confined to the top 10 to 15 feet of the bedrock (Johnston, 1964). Precipitation reaches the Lockport throughout the region by migrating through the glaciolacustrine sediments and glacial till. Somewhat higher recharge rates are believed to occur along the Niagara Escarpment where overburden is thin or absent.

In the immediate area surrounding Niagara Falls, N.Y., additional means of recharge exist. One of the important recharge sources is the 1900 acre storage reservoir (see Figure 2) operated by the Power Authority of the State of

New York (PASNY). This reservoir averages 25 feet in depth with a 20 foot variation from low to high level (Johnston, 1964). The water in the reservoir is retained by clay-cored earth and rock-fill dykes. Approximately 10 feet of clay and silt overlie the Lockport beneath the reservoir, and the entire depth of the Lockport below the dykes was grouted to prevent seepage losses. However, monitoring wells indicate that substantial leakage occurs. Upon filling the reservoir in 1961, "significant increases in water levels were observed in the upper part of the bedrock, and locally artesian flow commenced" (Johnston, 1964). The reservoir represents a permanent and significant source of bedrock recharge in the Niagara Falls area.

The Niagara River is a source of bedrock recharge in locations such as between the City of Niagara Falls Water Treatment Plant (east of S-Area) and the Falls, where a positive head differential exists between the river and the Lockport. In many areas the river bottom remains covered by glacial sediments and these along with any accumulated bottom sediments impede direct recharge to the bedrock. However, areas of high bedrock recharge are known to exist in a 1/2 mile section of the river about 2 miles upstream of Niagara Falls (Johnston, 1964). In this section of river, fast moving water has apparently removed the bottom sediments, allowing a good hydraulic connection directly to bedrock.

Several high yield industrial wells located along the river take advantage of the good interconnection between the river and the upper Lockport. The Olin Corporation plant, located about 2 miles upstream of the Falls,

operates 2 wells with an average total pumping rate of 5400 gallons per minute (G. Pietraszek, NYSDEC, personal communication, 1982). Both wells are located in the bedrock and are believed to create a marked influence on the ground water flow conditions in the immediate vicinity of the Olin Plant. However, the zone of influence from the pumping apparently does not reach as far as S-Area.

3.1.2b Clinton and Albion Groups

The uppermost formation of the Clinton Group is the Rochester Shale, which directly underlies the Lockport Dolomite. The hydrogeologic characteristics of the Rochester Shale have been the subject of concern between various parties in the recent Hyde Park Settlement Agreement proceedings. The opposing viewpoints on the shale can be stated as:

- The Rochester Shale is virtually impermeable and contaminant transport through the shale is negligible;

- The Rochester Shale contains a sufficiently interconnected fracture system to allow significant contaminant flux, principally in the vertical direction, to the underlying limestone/sandstone sequences which subsequently transport the contaminants to the Niagara River.

A recommended field investigation and hydraulic testing program has been recently submitted (GTC, 1982) which included suggested minimum requirements for quantitative evaluation of the shale's hydraulic characteristics. The potential for contaminant transport across the shale can

be inferred from the proposed hydraulic testing program. Actual tracer tests across the shale could be conducted with the proposed instrumentation if sufficient hydraulic connectivity is found.

The Rochester Shale is described as "massive" (American Falls International Board, 1974), with few joints, or fractures. The American Falls International Board report indicates the existence of apparent water bearing (stained) fractures is limited as one goes inland from the gorge face. Horizontal drillholes indicated fracture spacing varied from inches to tens of feet, with spacing increasing further away from the gorge. Their investigation was related to the rockfall areas around the Falls and, therefore, the data are concentrated in that area.

In the shale the vertical joints represent the most significant pathways for potential contaminant transport. It is virtually impossible to utilize a vertical borehole drilling and well/piezometer instrumentation program to evaluate widely spaced vertical joints. As a result, any existing boreholes, or new vertically oriented boreholes, are unlikely to provide the necessary information. The recommended borehole drilling, testing and instrumentation program (GTC, 1982) utilizes inclined boreholes to evaluate the vertical hydraulic continuity across the shale.

At this point it can only be stated that the role of the Rochester Shale with respect to contaminant transport in the general Niagara Falls area is uncertain. However, it is clear that the overall permeability of the Rochester is quite low and that the volumetric flux of contaminants

through the shale is unlikely to be as significant as the contaminant flux in the Lockport.

With regard to the role of the Rochester and other lower formations in a regional hydrogeologic context, the following discussion is excerpted from Johnston (1964).

"The Clinton and Albion Groups are little utilized as sources of ground water, mainly because they are overlain everywhere, except along the Niagara escarpment, by the more productive Lockport Dolomite. Accordingly, not much is known about their water-bearing properties. In general, the limestones and sandstones are the most permeable units in the Clinton and Albion Groups. The abundance of both vertical and bedding joints in outcrops and quarries in the limestones and sandstones suggests that they are as permeable as the Lockport. However, the position of the relatively impermeable Rochester Shale at the top of the Clinton Group drastically limits recharge to the more permeable sandstones and limestones below. As a result the uppermost part of the more permeable limestone units in the Clinton Group is dry in many places. Because of the lack of recharge, the average yield of wells in the Clinton and Albion Groups is only 2 to 3 gpm which is adequate only for small domestic and farm supplies".

3.1.2c Queenston Shale

The Queenston Shale is relatively insignificant to the overall hydrogeologic regime under discussion in this report, other than to represent a definitive lower boundary to the active hydrogeologic regime. The following discussion is also excepted directly from Johnston (1964).

"Ground water occurs principally within a fractured and weathered zone at the top of the shale. This zone, according to drillers, is generally less than one foot thick. The unweathered Queenston Shale is less permeable than the overlying rocks in the Clinton and Albion Groups and much less permeable than the Lockport Dolomite. Considerable difficulty is experienced in developing adequate water supplies in areas where the fractured zone at the top of the Queenston is dry."

3.1.3 PASNY Conduits

A pair of subsurface conduits, each with a flow area of 2800 square feet and height of 70 feet, transport water beneath the city of Niagara Falls from the upper Niagara River to the PASNY power storage reservoir (Figure 2). These conduits are located in the bedrock and slope to the north at about 3.2 feet/mile. The conduits are lined with concrete and constructed to prevent flow either in or out. There is, however, an external system of drains beneath and to the sides of the conduits. These drains are likely well connected to the Lockport Dolomite ground water system. The effect of the conduits on the regional groundwater flow system is uncertain since a comprehensive water level measurement program has not been undertaken since completion of the Niagara River Power Project.

However, the drain system located along the entire length of the conduits likely provides excellent vertical hydraulic connection throughout the greater portion of the Lockport Dolomite. At the conduits' intake structures, approximately 500 yards west of S-Area, the conduits'

excavations extended to within 75 feet of the bottom of the Lockport. The depth of the conduits increases to the north at the rate of 3.2 feet per mile, while the bottom of the Lockport rises at about 15 feet per mile. The Lockport Dolomite is fully penetrated by the northern portions of the conduit excavations as well as by the open canal leading from the reservoir to the gorge. The implications of this vertical hydraulic communication in the context of contaminant transport are discussed in Section 4.

3.2 Local (S-Area) Hydrogeology

3.2.1 Overburden

Most ground water flow in the overburden occurs in the relatively permeable fill material placed above the clay and till (see Figure 5). As discussed earlier, the fill is comprised of a lower sandy unit immediately overlying the clay and till, and a coarse, upper heterogeneous unit which includes the wastes disposed in solid, liquid or drummed form. Permeabilities for the overburden zones in S-Area have been tabulated from various sources (Table 2). The tabulated permeabilities of the course upper fill and fine sand fill range from 3×10^{-3} to 5×10^{-5} cm/s. A composite value of 4.7×10^{-3} cm/s for the entire fill depth is also listed in Table 2.

The relatively impermeable clay and till which directly overlie the bedrock throughout most of S-Area serve to impede the vertical movement of ground water, although there are relatively strong downward gradients across the clay and till. There is, in addition, at least one localized zone (i.e. borehole 14) on the southwest side of S-Area where the clay and till are reported as completely absent and the fine sand fill is in direct contact with the bedrock. This situation clearly allows direct access of overburden ground water to the upper water bearing zone (top 10 to 15 feet) of the Lockport Dolomite.

Water table elevations were monitored over the Hooker Niagara Plant Site and surrounding property during the period October 1979 to August 1981 (Conestoga-Rovers and Assoc., 1981a). Attempts were made to prepare water table contour maps, based on linear interpolation techniques, for specific dates corresponding to periods of low and high ground water levels

during the year 1981 (Figures 9 and 10). There does not appear to be sufficient data to confidently develop a water table map for either of these periods without utilizing some subjectivity. This is likely due to a combination of factors, including the fact that the overburden wells are screened over various lengths, and that watermain exfiltration and sewer infiltration tend to considerably complicate the shallow subsurface flow regime.

In general the plan view direction of ground water flow in the overburden appears to be towards the Niagara River. However significant downward vertical gradients from the overburden into the bedrock also exist and there are several anomalous areas, such as the ground water lows found along Buffalo Avenue between 47th and 53rd Street. These lows, in addition to the low at the north end of 47th Street, are likely due to sewer infiltration while the anomalously high areas are probably related to watermain leakages. The water levels in individual wells for the periods of high and low ground water levels vary, on an absolute scale, by 1 to 2 feet, however the general flow direction appears similar for both periods i.e., towards the Niagara River.

The hydrogeologic system and hydraulic head pattern in the immediate S-Area vicinity are strongly influenced by the ground water mound created by the sedimentation-clarification lagoons. The lagoons appear to act as a permanent recharge source to the ground water system, despite the clay lining, resulting in water table levels 2 to 3 feet above those measured in the surrounding overburden wells. These relatively high water table levels also result in strong vertical gradients across the clay and till into the bedrock, as well as increased lateral flow in the fill material away from S-Area in all directions.

A second overburden ground water mound, in addition to that caused by the S-Area lagoons, is observed to the north of the Water Treatment Plant (WTP). This mound may be due to some extent to leakage from the WTP finished water reservoir, although three points of watermain leakage along 53rd Street have also been identified in this area, with total losses of approximately 40 gallons per minute (Conestoga-Rovers and Associates, 1981b). The reservoir covers roughly one acre and has a capacity of 7 million gallons. The ground water high north of the WTP appears to serve somewhat as a counterbalance to the S-Area ground water mound, deflecting some of the overburden ground water flow which originates in S-Area away from the WTP complex.

Sewers throughout the study area are also subject to some infiltration from overburden ground water. For instance the north-south trunk sewer located between S-Area and N-Area has been reported (Conestoga-Rovers and Associates, 1980b) to receive, from infiltration, approximately 7% of the total (8.2 cubic feet per second) outflow to the River (see Figure 15 for location of sewer). This sewer also receives overflow from the sedimentation-clarification lagoons via a 700 foot sewer line running west from the south end of the lagoons. This particular discharge is covered under HCPC's State Pollutant Discharge Elimination System (SPDES) permit.

The PASNY conduits intake structure also appears to have a significant influence on ground water flow in the overburden in the study area. The intake area is a major ground water low in the overburden. Ground water movement is from the overburden (predominantly shot rock, fill overlying a very thin till layer) into the bedrock suggesting that the permeable shot rock fill may be in close

hydraulic connection with the bedrock. The bedrock water levels are apparently controlled by the exterior drainage system around the conduits as well as the berms and grout curtains installed during the construction phase of the conduits (Figures 9 and 10). The intake structures do not have a direct effect on the immediate S-Area overburden water levels, where the lagoon dominates and the north-south trunk sewer between S and N area appears to intercept westward ground water flow.

3.2.2 Lockport Dolomite

The Lockport Dolomite bedrock hydrogeologic system under discussion in this section is essentially that which exists in the upper 10 to 15 feet of the bedrock. Specific mention is made when this is not the case. Permeability data and estimates for various portions of the Lockport Dolomite are listed in Table 3.

Ground water levels in the upper Lockport beneath S-Area are controlled by recharge from the Niagara River. Piezometric levels in the Lockport in the vicinity of S-Area are generally lower than the water level in the river, resulting in flow into the bedrock. Piezometric levels in the upper Lockport range from 562 feet above sea level along the river to approximately 550 ft along the NYCRR tracks (Figures 11 and 12). The Niagara River is maintained at a long term average level of 561.65 (Hooker Datum)* in the Grassy Island pond slightly downstream of S-Area (D. Manion, Ontario Hydro, personal communication, 1982) and at 561.85 (Hooker Datum) at the PASNY intakes (J. Fitzgerald, PASNY, personal communication, 1982). This river level variation is restricted, by international agreement, to maximum daily fluctuations of 1.5 feet.

*Several datums are in effect in the Niagara Falls area. (i.e. USLS, IGLD, Hooker). The datum used in this report is the Hooker datum, as most data available uses this reference. The relationship between datums is provided in Appendix I.

There is a reasonably good hydraulic connection between the Niagara River and the Lockport Dolomite at S-Area. The depth of unconsolidated deposits of till, clay, and river bottom sediments varies between 10 and 20 feet along the Water Treatment Plant intake tunnel (City of Niagara Falls, 1980). [The Water Treatment Plant intake tunnel extends 5,125 feet to approximately the center of the Niagara River.] Reports by Leggette, Brashears and Graham (1979f) indicate that the response of wells in the upper Lockport along the river to fluctuations in the level of the Niagara River is approximately 100% over a period of 1 to 1.5 hours. Piezometric levels measured in a well located deeper in the Lockport (SS-2, completion zone 24 to 39 ft below top of rock) responded with a water level change about one third the change in the level of the Niagara River, suggesting that the lower sections of the Lockport are less well connected hydraulically to the Niagara River, although there is some degree of interconnectivity (the drillers log indicates that "grout from the shore shaft pilot hole appears to have partially plugged the fracture").

Piezometric contour drawings (Figures 11 and 12) for the upper Lockport Dolomite (10 to 15 feet) have been prepared using available data for periods corresponding to periods of low and high ground water levels. The data used are from the study conducted between October 1979 and August 1981 (Conestoga-Rovers and Associates, 1981a). The river levels are from Ontario Hydro records. The Figures show that although absolute water levels in the upper Lockport changed on different dates, virtually the same ground water flow patterns in the S-Area vicinity are observed. It should be noted that the piezometric contours (as well as chemical data) are prepared using

some wells or piezometers which straddle the lower overburden and upper Lockport Dolomite (Table 4). These data are assumed to be applicable to the upper Lockport.

The ground water flow patterns for the upper Lockport indicate that, in the vicinity of S-Area, water flows from the Niagara River into the bedrock in a north-northwesterly direction. The PASNY conduit intake structure has a considerable effect on the ground water flow pattern. There is a grout curtain (shown on the Figures) completely surrounding the intakes which extends approximately 90 feet into the Lockport Dolomite (to elevation 454.7, Hooker datum (PASNY, 1963)). Although not shown on the Figures, the grout curtain extends into the river and parallels the shore line at a distance of about 630 feet from shore. The portion of the grout curtain which is located along the river shoreline appears to substantially restrict south-north water flow from the Niagara River across the intake structure area. Since the grout curtain restricts south-north flow from the river into the Lockport Dolomite, most of the ground water moving in an east-west direction near the intake structure has entered in the upstream river reaches, including S-Area.

The Niagara River Gorge to the west has a strong influence on the general bedrock ground water flow directions throughout the Niagara Falls area. The majority of ground water flow beneath the City of Niagara Falls has been interpreted as being directed towards the gorge (Johnston, 1964). However, the external drain system of the PASNY conduits must also be an important factor in the area to the immediate west of Iroquois Street. The drain system extends to elevation 488 ft,

which represents approximately one third the thickness of the Lockport Dolomite. The hydraulic heads in the lower bedding plane joints are substantially lower than those in the upper portions of the Lockport (Johnston, 1964).

Given these circumstances, there is the strong likelihood that a good vertical hydraulic connection exists over at least the upper 50 feet of the Lockport, with vertical ground water movement occurring from the upper to the lower zones.

The open drain system also allows lateral continuity across the conduits, although water must follow a circuitous path within the drainage system to cross the sealed conduits. The drain system slopes north to the open canal near the reservoir, and water can also move in that direction with relative ease.

A relatively steep hydraulic gradient exists just west of 53rd Street north of the intersection of 53rd Street and Buffalo Avenue. The cause of this apparent anomaly is uncertain. There is insufficient data on both water levels and sewer infiltration rates in this area to draw a conclusive correlation, however it is suspected that sewer infiltration may be responsible for the relatively abrupt change in hydraulic gradient.

From the available information it is uncertain whether the effect of the heavy industrial pumping at the Olin plant (about one mile downstream of S-Area) is noticeable on the upper Lockport Dolomite piezometric levels. The bedrock is apparently in relatively direct contact with the River at the pumping site, therefore the extent of the pumping influence in the bedrock may be quite limited.

4.0 GROUND WATER CONTAMINATION

Several ground water quality monitoring programs have been conducted at the Hooker Niagara Falls Plant site to date (Arthur D. Little, 1980 a to d; 1981a; 1982). Various parameters have been measured at different times, with the result that more extensive data exists for some constituents than for others. The constituents measured most extensively are pH, chloride, conductivity, alkalinity, total organic carbon (TOC) and total organic halogens (TOH). The TOC, TOH, conductivity and chloride data are summarized in Appendix III. As noted in the report by Arthur D. Little (1981a), many of the wells had not chemically stabilized prior to the last sampling, i.e. there appeared to be significant cement contamination in at least 18 of the wells (Table 5) on the last date sampled. In addition, procedures and analytical methods varied between laboratories, and complete documentation (i.e. chain of custody documents and protocol) have not been assessed for the preparation of this report. The chemical data should, therefore, be considered to be extremely approximate, indicative only of general patterns.

Some studies were concerned with individual toxic organic chemicals and heavy metals. The wells and piezometers sampled were limited in number and the constituents analysed were not consistent between samples. However, these data are presented for completeness in Appendix IV in table and diagrammatic form. As there are more extensive specific constituent data for overburden wells than for bedrock (upper Lockport Dolomite) wells, the entire Niagara Plant area is shown in the overburden figures in Appendix IV. The bedrock specific constituent data was available only for wells in the immediate S-Area vicinity and is presented in a single figure in Appendix IV.

The parameters TOH and TOC have been selected to represent the general ground water contamination patterns in the overburden and bedrock resulting from the organic chemical disposals. Other parameters indicate somewhat similar patterns, however they do not serve to illustrate the presence of organics in the ground water beyond the selected parameters. The chloride concentration and conductivity are presented in contoured form in Appendix III. Contours on the TOH and TOC diagrams under discussion in this section as well as all others in the report are based on principles of linear interpolation. Minor subjectivity has been introduced only where the paucity of data necessitates.

The data used to develop the ground water contamination figures are selected from the aforementioned studies using the following procedure:

- Samples with reported sampling dates prior to well installation are not utilized

- Samples taken within approximately 3 to 4 weeks of well installation are not utilized

- Averages of the remaining samples are taken where several values exist

- Single values are used where there are not several samples

- It is assumed that samples from wells SP8 and SP8A dated 1978 are actually 1979 (i.e. typographical or labelling error)

The resulting concentrations and number of samples on which these are based are presented in Appendices III and IV. The samples were analyzed by six different laboratories; EPA, Hydroscience, Radian, New York State, Raltech and Hooker.

4.1 Overburden*

The concentration of total organic halogens (TOH) in the overburden ground water system is presented in Figure 13. S-Area contains the highest overburden values for TOH found in the Hooker Niagara Plant Area. The TOH values reach a maximum of 300,000 µg/L in approximately the centre of S-Area (Well 7S). It appears quite clear that S-Area represents a significant source of TOH to the overburden ground water system, although some relatively high values also occur elsewhere within the plant site (i.e. in the vicinity of F and D areas, values of 50,000 and 30,000 µg/L, respectively, are shown in Figure 13).

The TOC concentrations (Figure 14) also show the highest values (866 mg/L) in the vicinity of S-Area, although a high of similar magnitude (750 mg/L) also occurs near D-Area. The somewhat elevated TOC concentrations in the overburden in the vicinity of U-Area correlate to some extent with TOH. However, many samples utilized in the data set (Appendix III) did not always have TOH and TOC analyzed on the same samples, therefore Figures 13 and 14 may not be directly comparable.

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*Some installations have a shallow and deep piezometer installed in the overburden. In the immediate S-Area average concentrations for the shallow and deep overburden piezometers are taken to be representative of the overburden because the overall fill is relatively permeable (CW1A and 1B; CW6A and 6B; CW14A and 14B). At well 40 the shallowest piezometer (40A) is utilized as it is located in the silt layer as are other wells in the surrounding area. Well 40B is located in the till zone at a depth 15 to 20 feet.

TOH and TOC concentration contours decrease radially from S-Area, with a slight apparent elongation to the west. The elongation may be due simply to the presence of N-Area, which was also utilized for chemical disposal, or the elongation may be due to drainage to the north-south main sewer line between S and N-Areas, leading to outfall 003 (Figure 15). The water table contour maps (Figures 9 and 10) suggest that this sewer line may be receiving overburden ground water and draining contaminated ground water from N and S-Area. The sewer outfall data show a fairly significant contaminant load (in 1980, outfall 003 contained approximately 23.3 lbs/day of total organic halogens) of which 53% was attributed to contaminated ground water infiltration or unidentified stub flow (Conestoga-Rovers and Associates, 1980a). The total sewer flow rate was about 5.3 MGD.

The principal overburden ground water flow direction at S-Area is southward (although a complicated flow system is depicted in Figures 9 and 10). The contaminated overburden ground water is most likely discharging to the Niagara River south of S-Area, however only a limited number of monitoring wells exist between S-Area and the River. Consequently, the exact nature and pattern of the ground water contamination between S-Area and the River is difficult to ascertain. However, two of the wells (SP-4A and SP-8A) show high TOH concentrations, and SP-8A, nearest the river, contains concentrations of tetrachlorobenzene, carbon tetrachloride and dichlorobenzenes of 12,590 µg/L, 9,285 µg/L and 1,345 µg/L, respectively (see Appendix IV).

A rough calculation can be made to determine the potential order of magnitude of TOH loading of the Niagara River from overburden ground water discharge. With reference to Figures 5, 9, 10, and 13, the following are assumed:

- The total length of river reach receiving overburden ground water discharge from S-Area is about 1200 feet (distance between 53rd Street and the 003 sewer outfall)

- The permeability (K) of the fill is taken as the composite value of 4.7×10^{-3} cm/s (Leggette, Brashears and Graham, 1979e)

- The thickness of fill is approximated at 20 feet (Figure 5)

- The hydraulic gradient between S-Area and the River is approximated at 4.38×10^{-3} (1.75 ft in 400 ft, the head difference and distance, respectively between 14A and SP-8A)

- The TOH concentration of discharging overburden water is assumed to be 20,000 µg/L

Using these assumptions, an approximation of the TOH loading to the Niagara River from overburden ground water discharge can be calculated:

TOH Load = Ground Water Discharge (Q) x Concentration

$$Q = 1200 \text{ ft} \times 20 \text{ ft} \times 4.7 \times 10^{-3} \frac{\text{cm}}{\text{s}} \times 3.28 \times 10^{-2} \frac{\text{ft}}{\text{cm}} \times 4.38 \times 10^{-3} \times 86400 \frac{\text{s}}{\text{day}} \times 28.316 \frac{\text{L}}{\text{ft}^3}$$

$$Q = 39646 \frac{\text{L}}{\text{day}}$$

$$\text{TOH Load} = 39646 \frac{\text{L}}{\text{day}} \times 20000 \frac{\mu\text{g}}{\text{L}} \times 2.204 \times 10^{-9} \frac{\text{lb}}{\mu\text{g}}$$

$$\text{TOH Load} = 1.75 \frac{\text{lb}}{\text{day}}$$

The calculated TOH load to the Niagara River is about 1.75 lb/day. However, given the uncertainty in the ground water-related input data and the lack of concentration data between S-Area and the River, this value is considered very approximate. It is only used to attempt to place the ground water discharge from S-Area to the river in perspective with the sewer outfall loadings and other discharges. Considering the fact that previous reports (Conestoga-Rovers and Associates, 1980a) attributed 12.35 lb/day TOH load from sewer outfall 003 to either contaminated ground water infiltration to the sewer or unidentified sewer stub, the above TOH load calculation is considered to be representative.

4.2 Lockport Dolomite

The TOH and TOC concentrations (Figures 16 and 17) for the Lockport Dolomite represent those wells which are situated in the upper 10 to 15 feet of the Lockport, as well as some wells which are located across the interface between the Lockport and the overlying till (Table 4). In the S-Area vicinity TOH concentrations in the upper Lockport range as high as 38,000 µg/L, however there are few data points directly beneath S-Area on which to base conclusions. The S-Area upper Lockport TOH concentrations are sufficiently high to indicate that there is hydraulic connection between the overburden and the upper Lockport, with resultant contaminant transport from the overburden at S-Area into the upper Lockport. There are, however, no bedrock wells located in the area of most interest, i.e. at 14A and 14B where the clay and till were not logged and the relatively permeable fill was found to be in direct contact with the bedrock.

The upper Lockport concentration patterns over the entire Niagara Plant area are uncertain due to limited data, however the upper Lockport TOH and TOC contamination zone can be considered to extend generally across the entire southern portion of the HCPC Niagara Plant site, with somewhat less extensive contamination in the northern portion of the plant area. Highest TOH values are recorded in U-Area while highest TOC values appear in N-Area. Relatively, the upper Lockport TOH contamination at S-Area is significantly lower than that at U-Area, while the TOC measured at S-Area is lower than either U or N-Areas. It would be speculative to attempt to relate contamination between areas or to attribute the TOH and TOC in the upper Lockport to a single source area.

Groundwater in the upper Lockport beneath the Water Treatment Plant (WTP) appears to have substantially lower TOH concentrations than the groundwater to the west. This is likely a reflection of the north-northwesterly flow pattern in the upper Lockport (Figures 11 and 12) which serves to transport dissolved constituents away from the WTP. The TOC ground water data at the WTP are too limited in number for discussion.

The conductivity data (Appendix III) for the wells in the upper Lockport show that 3 of the 4 wells nearest the Niagara River reflect the inflow of water from the River into the bedrock (Niagara River conductivity is approximately 0.2 mmho/cm; Ontario Ministry of Environment, 1968-1982 Niagara River records). The exception is well SP-8, which shows a conductivity of 1.5 mmho/cm as well as TOH concentration of 17,000 µg/L. It is possible that this reflects an interconnection between the overburden and bedrock provided by the drilled borehole ("black, oily" liquid was encountered through the lower overburden portion of the hole; Leggette, Brashears and Graham, 1980a). This may also be the case in other bedrock installations, although those in S-Area have the "oily" liquid notation in the overburden portion of the holes more frequently than others (i.e. no oily liquid was noted in boreholes 5, 6, 7 or 8, although chemical odors are indicated).

The transport of ground water, and concomitantly dissolved contaminants, in the bedrock is generally in a north-northwest direction, towards the PASNY conduits and the Niagara Gorge. The drainage system around the conduits provides for good vertical hydraulic connection between the upper Lockport and the deeper bedding joints. As discussed in Section 3.1.3, the base of the conduits' excavation at the intakes is within 75 feet of the base of the Lockport Dolomite, and at Royal Avenue, (approximately 1 mile north of the intakes) where drainage pump

station A is located, the base of the excavation extends to within about 40 feet of the base of the Lockport. Virtually all the contaminants in the upper Lockport ground water system will be intercepted by the drainage system around the PASNY conduits. This drainage system will allow vertical communication throughout the greater portion of the Lockport Dolomite. The route that contaminants will take after reaching the conduit drainage system is uncertain. Gate valves in pump station B at the northern end of the conduits (Figure 2) maintain the hydraulic head in the northern sections of the drainage system at elevation 550.65 ft (Hooker Datum) or less, while similar valves at Royal Avenue maintain the head 10 feet higher, at 560.65 ft or less. However, the head control in the drainage system may be supplemented by the natural vertical variation in hydraulic head within the Lockport Dolomite. The conduits' drainage system allows good vertical connection, and the lower water bearing bedding joints are believed to have substantially lower hydraulic head than the upper Lockport. In fact, during drilling, Johnston (1964) found that often, once the lower zones were penetrated by drilling, they drained the upper zones. Some portion of the water in the drainage system will undoubtedly enter these lower water bearing zones.

The PASNY conduit drainage system raises several points with regard to bedrock contamination and potential contaminant transport to the Niagara River:

- In the vicinity of the HCPC Niagara Plant, approximately the upper 1/2 of the Lockport Dolomite may be accessed by contaminated water (or even the upper 2/3 if pump station A at Royal Avenue is considered)

- The full thickness of the Lockport is breached by the drainage system in the northern section of the conduits, as well as the open canal leading from the power reservoir to the gorge.

- Pump station A may represent a fairly good bedrock ground water sampling station (if pumped) and, in conjunction with the drainage system, may also represent a relatively effective interceptor capability for contaminated ground water

- Contaminated water collected in the drainage system may migrate northerly along the conduits to emerge at the reservoir canal; or, depending on the relative gradients, westerly to the gorge by migrating around the conduits through the drainage system and out bedding joints on the west side of the conduits

The drainage system around the PASNY conduits can be regarded, in any case, as a major factor in the assessment of the bedrock ground water flow system and potential contaminant transport pathways.

5.0 WATER TREATMENT PLANT

The City of Niagara Falls Water Treatment Plant (WTP) is located on property which borders S-Area at the east end of Hooker's Buffalo Avenue Plant. The location of the WTP is shown in detail on Figure 18, which was adapted from Leggette, Brashears and Graham (1979b,c) and City of Niagara Falls (1979a, 1980). A discussion of the history of the WTP, adapted from NYPIRG (1981) is included in Appendix V.

In a report by the City of Niagara Falls (1979c) it was reported that the WTP is constructed on fill which is "mainly municipal refuse. Private communications revealed that the shoreline in 1918 was a common disposal area for ashes from local industry as well as the general public". The 1 to 2 foot layer of municipal refuse overlies the native lacustrine clay. Above this are 4 to 6 feet of dense, fine-grain sands and 4 to 5 feet of organic ('river basin bottom') material. Various fill materials are present up to grade (City of Niagara Falls, 1979c). No attempts have been made to relate the municipal refuse layer to contaminants in the ground water or WTP facility.

On December 18, 1979, the City of Niagara Falls commenced using an emergency 48" steel intake line to draw water from the East Channel of the Niagara River (NYPIRG, 1981). Approximately 40 MGD of the total 50 MGD of water supplied to the city's customers was drawn through this line. The remaining 10 MGD was drawn from the Emerald Channel through the main intake system. (Camp, Dresser and McKee, 1980a as referred in NYPIRG 1981). This change in operating procedure was in response to the 1978 discovery of contaminants in the main intake tunnel. Visual inspection by divers found that non-aqueous phase contaminants were present in the sediment

at the bottom of the shore shaft and along the bottom of the intake tunnel in the vicinity of the shore shaft (Camp, Dresser and McKee, 1980a). The properties of the non-aqueous phase contaminant "when in a liquid state show it to be denser than water, sticky like tar and dark brown in color" (City of Niagara Falls, 1979). Apparently a similar chemical residue was found in the shore shaft and pump station forebays in 1969 (Camp, Dresser and McKee, Inc. 1980b). At that time it appears that the abandoned 54" steel pipe was considered the source of the contaminants and it was plugged with concrete and a steel plate installed where it enters the shore shaft. Plans were undertaken to replace the section of tunnel to 1725 ft from the shore shaft by May 1980 (Camp, Dresser and McKee, Inc, 1979b).

The composition of the non-aqueous phase chemicals found in the shore shaft and intake tunnels is presented in Table 6. Also presented in Table 6 are the compositions of non-aqueous phase samples obtained from S-Area wells 18A, TRW1 and 36A (for locations see Figure 1). The Water Treatment Plant Investigatory Team (City of Niagara Falls, 1980) comprised of representatives of the City, NYSDOH, NYSDEC, USEPA, HCPC and Niagara County, identified four indicator parameters which they attributed to chemicals originating from S-Area. These were trichlorobenzenes, hexachlorobutadiene, tetrachlorobenzenes, and hexachlorocyclopentadiene. At least three of these indicators have been found (in dissolved form) in water samples obtained from piezometers installed in holes in the intake tunnel floor as far out into the Niagara River as 1725 ft from the shore shaft (Camp, Dresser and McKee, 1980a).

Improvements to the water intake system recommended by the Investigatory Team included:

1. Replacement of the existing intake tunnel with an intake pipe to a distance of 1725 ft from the shore shaft, at which point an abandoned (around 1950 due to bacterial contamination of the East Channel) intake is located. The new intake would be located above the bedrock and connected to the Emerald Channel intake structure via the existing (abandoned) intake shaft.

2. If an investigation of the existing intake tunnel from 1725' to Emerald Channel reveals the presence of contaminants, then a new intake line would be constructed above the bedrock over this reach as well.

5.1 Implications for Dense Contaminant Movement

The principle implication of the above discussion regarding non-aqueous phase and dissolved contaminants in various portions of the WTP shore shaft and intake tunnel is that the potential is quite high for transport of denser-than-water organic liquids along the bedding joints and through the upper fractured zone of the Lockport Dolomite. It is clear that organic liquids have migrated through the bedrock and entered the WTP shore shaft and intake tunnel areas. Since the general slope of the upper bedrock surface, as well as the bedding joints is to the south, dense organic liquids may migrate, under gravity control, toward the Emerald Channel intake, Navy Island and the Canadian side of the Niagara River.

The southward migration of non-aqueous phase organics under density control through the upper Lockport weathered zone or the bedding joints may be indicated by the low, but measurable, concentrations of indicator organics in water samples from the piezometer taps in the base of the intake tunnel. The southward migration is against a slight opposing hydraulic gradient to the northwest near the River, however, beneath the river this gradient is likely substantially less or non-existent. Density controlled transport is quite feasible (see Appendix VI for a discussion of density dominated flow) since the density of some of the contaminants is significantly greater than water (eg. specific gravity of trichlorobenzene is 1.460 at 25°C; Mellan, 1950).

6.0 CONCLUSIONS

Interpretation of the hydrogeologic data and evaluation of the reports reviewed for preparation of this report on the Hooker Chemicals and Plastics Corporations S-Area disposal site has resulted in the following conclusions, which are considered to be relevant to Niagara River water quality.

- Ground water flow in the fill, which was placed to reclaim sections of the Niagara River, and in the glacially derived sediments in the vicinity of S-Area, together termed the "overburden", is heavily contaminated (concentrations as high as 300,000 µg/L) by organic constituents originating from S-Area disposals.

  The ground water flow direction in plan view in the overburden is primarily in the direction of the Niagara River. There is also a downward hydraulic gradient from the overburden into the underlying Lockport Dolomite. The glacially derived clay and till, which can impede downward water movement, are reported as absent in one borehole along the southwest side of S-Area. The fill material appears to be in direct contact with the underlying Lockport Dolomite at this borehole.

  Direct discharge of contaminated ground water from the overburden into the Niagara River south of S-Area is estimated to provide a total organic halogen (TOH) loading to the river of approximately 1.75 lb/day. In perspective, this estimate is 7.5% of the estimated 1980 daily TOH load for the 003 sewer outfall located between S and N-Areas. Over

50% of the TOH load in the 003 sewer has been attributed, by other consultants reports, to infiltration of contaminated ground water into the outfall sewer lines, or to unidentified sewer stubs.

- The upper weathered zone (10 to 15 feet) of the Lockport Dolomite, which directly underlies the glacially derived deposits, shows TOH concentrations of the order of 3,000 to 38,000 µg/L in the vicinity of S-Area. The direction of groundwater movement in the upper Lockport beneath S-Area is to the northwest, away from the Niagara River. The contaminated ground water beneath S-Area in the upper Lockport, along with the extremely high TOH's in the ground water in the vicinity of U-Area, will eventually reach the Niagara River. The water will either 1) directly discharge to the gorge after migrating from the source area, or 2) discharge from the external drainage system of the PASNY conduits into the open canal at the north end of the conduits. The conduits' external drainage system also allows contaminated ground water in the upper Lockport access to lower bedding joints and water bearing zones. Approximately half the thickness of the Lockport is breached by the conduits' external drainage system near the PASNY intakes. The Lockport Dolomite is fully penetrated by the northern portions of the conduit excavations as well as by the open canal leading from the reservoir to the gorge.

- Data from the contamination investigation of the City of Niagara Falls Water Treatment Plant (WTP) had led to the implication that there is reasonable potential for vertical transport of denser-than-water organic liquids through the upper fractured zone and along the bedding joints of the Lockport Dolomite. Organic liquids, in a "non-aqueous" phase have migrated into the WTP shore shaft and intake tunnel areas. Since the general slope of the upper bedrock surface as well as the bedding joints is to the south, dense organic liquids may migrate southward under gravity control.

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TABLE 1

Summary of Wastes Disposed at S and N-Areas during 1947 to 1975 (after Hooker, 1978)

Waste Category	Physical State	Total Estimated Quantity - Tons	Container
Organic Phosphates	L, S	200	D, B
Misc. Acid Chlorides	L, S	400	D, B
Phenol Tars	L	800	B
Thionyl Chloride	L	4,200	D
Chlorendic Acid (HET)	L, S	500	D, B
Misc. Chlorination Residues	L, S	400	D, B
Dodecylmercaptans (DDM)	L, S	8,100	D
Trichlorophenols (TCP)	L, S	200	D
Benzoyl Chloride	L, S	3,300	D, B
Liquid Disulphides/ Monochlorotoluene (LDS/MCT)	L, S	2,200	D, B
Metal Chlorides (catalysts)	S	900	D
Hexachlorocyclopentadiene (C-56)	L, S	17,400	D, B
Chlorobenzenes	L, S	18,900	D, B
Benzyl Chlorides	L, S	1,600	D, B
Thiodan (Endosulfan)	L, S	700	D, B
Sulfides	S	4,200	D
Misc. 10% of above		6,400	
	TOTAL	70,400	

Notes:

L = Liquid waste

S = Solid waste

D = drummed

B = in bulk

TABLE 2
PERMEABILITY DATA FOR OVERBURDEN

SOIL/ROCK TYPE	PERMEABILITY	ANISTROPY Kx/Kz	LOCATION	COMMENTS	SOURCE
Composite of fine sand fill and coarse fill.	4.7×10^{-3} cm/s		S-Area	measured using pumping tests	Progress Report No. 5, Leggette, Brashears and Graham, Inc. 1979e
Composite	10^{-6} cm/s - 10^{-4} cm/s		Hyde Park	method of measurement unknown	Conestoga-Rovers Table A-3, Exhibit 32 in: "Hyde Park Landfill, Hydrogeological Review, Final Report" Gartner Lee Assoc. Ltd., 1982, pg. 3, Appendix A
Till, Undifferentiated Lake Deposits	4.9×10^{-7} - 9.5×10^{-5} cm/s			measured from well recovery tests	Conestoga-Rovers & Assoc. Ltd. in: "Simulation of Groundwater Flow in the Vicinity of Hyde Park Landfill, Niagara Falls, N.Y." R.H. Johnston & M.L. Maslia, 1982 pg 6
Interface and Bedrock	6.9×10^{-7} cm/s		Hyde Park	calculated from leachate collection system flow rate	"Evaluation of Remedial Work, Hyde Park - Bloody Run" Conestoga-Rovers & Assoc. 1980d, pg. 14
Fine Sand Fill	5×10^{-6} - 5×10^{-4} cm/s		S-Area	measured using pumping tests	Progress Report No. 7, Leggette, Brashears and Graham, Inc. 1980c
Upper Coarse Fill	3×10^{-3} - 5×10^{-3} cm/s		S-Area	measured using pumping tests	" " "
Till	9.9×10^{-6} cm/s	2.5:1	Hyde Park	result of numerical model calibration	"Simulation of Groundwater Flow in the vicinity of Hyde Park Landfill, Niagara Falls, N.Y." R.H. Johnston and M.L. Maslia, 1982, p. 13

TABLE 3
PERMEABILITY DATA FOR BEDROCK

SOIL/ROCK TYPE	PERMEABILITY	ANISTROPY Kx/Kz	LOCATION	COMMENTS	SOURCE
Lockport Dolomite	10^{-3} cm/s		PASNY conduits Niagara Falls, N.Y.	from measured seepage flows into conduit excavation	Calculated from transmissibilities and saturated thickness in "Groundwater in the Niagara Falls Area, N.Y." R.H. Johnston, 1964, pp. 33
	2.4×10^{-2} cm/s		Niagara Falls N.Y.	measured from well hydraulically connected to Niagara River at E.I. du Pont de Nemours & Co.	" " "
	3.7×10^{-4} cm/s		Niagara Falls N.Y.	measured from well located in lower 40 ft of formation	" " "
	5.1×10^{-3} cm/s (3.7×10^{-4} cm/s - 2.4×10^{-2} cm/s)		Niagara Falls N.Y.	average and range of values obtained by Johnston (1964)	" " "
	10^{-3} cm/s			upper 15 ft of formation. method of measurement unknown	"Hydraulic Containment, Hyde Park", Conestoga-povers and Assoc., 1980c p. 5
	5.3×10^{-4} - 7.1×10^{-4} cm/s	1000:1	Hyde Park	lower part of Lockport formation. Result of numerical model calibration.	"Simulation of Groundwater Flow in the Vicinity of Hyde Park Landfill, Niagara Falls, N.Y." R.H. Johnston & M.L. Maslia, 1982, pg 13

CONTINUED

TABLE 3 (CON'T)
PERMEABILITY DATA FOR BEDROCK

SOIL/ROCK TYPE	PERMEABILITY	ANISTROPY Kx/Kz	LOCATION	COMMENTS	SOURCE
	1.7×10^{-3} - 2.3×10^{-3} cm/s	100:1	Hyde Park	upper part of the Lockport formation. Result of numerical model calibration	"Simulation of Ground-water Flow in the Vicinity of Hyde Park Landfill, Niagara Falls, N.Y." R.H. Johnston & M.L. Maslia, 1982 pg 13
Rochester Shale	7.1×10^{-6} cm/s	1000:1	Hyde Park	from numerical model calibration	" " "
					" " "
					" " "
					" " "
	3.4×10^{-5} cm/s		East of Welland Canal	average of 13 pressure packer tests by Gartner Lee near Welland Canal, Ont.	"Hyde Park Landfill, Hydrogeological Review Final Report" Grant Anderson, Gartner Lee Assoc. Ltd. 1982 pg 2, Appendix A
Irondequoit Limestone	1.1×10^{-4} cm/s 7.2×10^{-5} cm/s - 1.5×10^{-4} cm/s		East of Welland Canal	average of 2 pressure packer tests by Gartner Lee near Welland Canal, Ont.	"Hyde Park Landfill Hydrogeological Review, Final Report" Grant Anderson, Gartner Lee & Assoc.,1982 pp 2-3, Appendix A

TABLE 4

Bedrock wells which are screened across both
the upper lockport dolomite and the lower overburden

Well	Screened Interval (Depth-ft)	Bedrock Depth
1	14-24	22.5
2	18-28	22.5
3	14.1-24.1	21.5
4	16-26	20.3
5	21-31	24.5
6	21-31	27.0
10	20.5-30.5	25.5
13	25-30	27
23	22-27	24
28	21.5-26.5	22.5
32	19-29	24.5
CW6	34-37	36
CW13	35.5-40.5	36

TABLE 5

Wells which showed high pH
(apparent cement contamination)
on last sampling when pH was measured

Well	pH
5A	11.7
6A	12.3
7	12
7A	12.1
8	10.9
8A	12
9A	12.7
10	10.7
10A	10.7
19	9.2
20	12
26	10.3
28	12.3
28A	10.3
30 (? Erratic)	12.2
40B	11.3
SP1A	11.3

Table 6 Composition of Non Aqueous Phase Samples from Wells in or near S-Area
(sampling procedure in wells unknown)

	Shore Shaft Samples (µg/kg)				Non Aqueous Phase Well Samples (% of total)			
	Tar from Side of Shaft	Residue In Shaft	Beneath Shore Shaft	Pump Station Sediment Samples	18A(1980)	18A(1981)	TRWI	36A
Carbon Tetrachloride	-1*	-1	-1	300	0.1	-**	0.2	0.3
Trichloroethylene	-1	-1	-1	33	2.1	0.2	-	0.1
Toluene	-1	-1	-1	0.39	3.3	3.6	3.7	1.8
Dichlorobenzenes	-1	-1	140,000	2,600,000	1.0	0.9	1.1	0.6
Hexachloroethane	-1	-1	-1	15,000,000	0.6	0.7	0.7	0.9
Hexachlorobutadiene	66,000,000	1,400,000	70	43,886,000	2.9	2.2	2.8	4.4
Hexachlorocyclopentadiene	230,000,000	4,800,000	180	115,429,000	10.6	11.1	11.9	13.9
Hexachlorobenzene	20,000,000	420,000	200	22,220,000	2.8	2.1	2.6	2.6
Trichlorobenzenes	25,000,000	530,000	130,000	83,686,000	9.9	9.4	10.8	9.6
Tetrachlorobenzenes	450,000,000	9,400,000	47,000	141,429,000	32.5	30.5	34.8	30.6
Monochlorotoluenes	-1	-1	-1	260,000	1.4	1.3	1.6	1.0
Dichlorotoluenes	-1	-1	-1	460,000	-1	-1	-1	-1
Octachlorocyclopentene	-1	-1	1,970	-1	11.6	10.1	11.7	16.3
Hexachlorocyclohexanes (BHC)	2,700,000	57,000	9,200	1,436,000	-1	-1	-1	-1
Mirex	2,600,000	55,000	280	1,015,000	-1	-1	-1	-1
Tetrachloroethylene	-1	-1	-1	25,000	11.4	11.0	6.8	13.0
Pentachlorobenzene	-1	-1	-1	-1	6.2	5.5	6.2	5.5
Monochlorobenzene	-1	-1	-1	-1	3.2	3.3	3.6	3.1
TOTAL	796,000,000	16,662,000	338,000	427,446,000	99.6	91.9	98.5	103.7

* -1 - Not analyzed
** - - Not detected

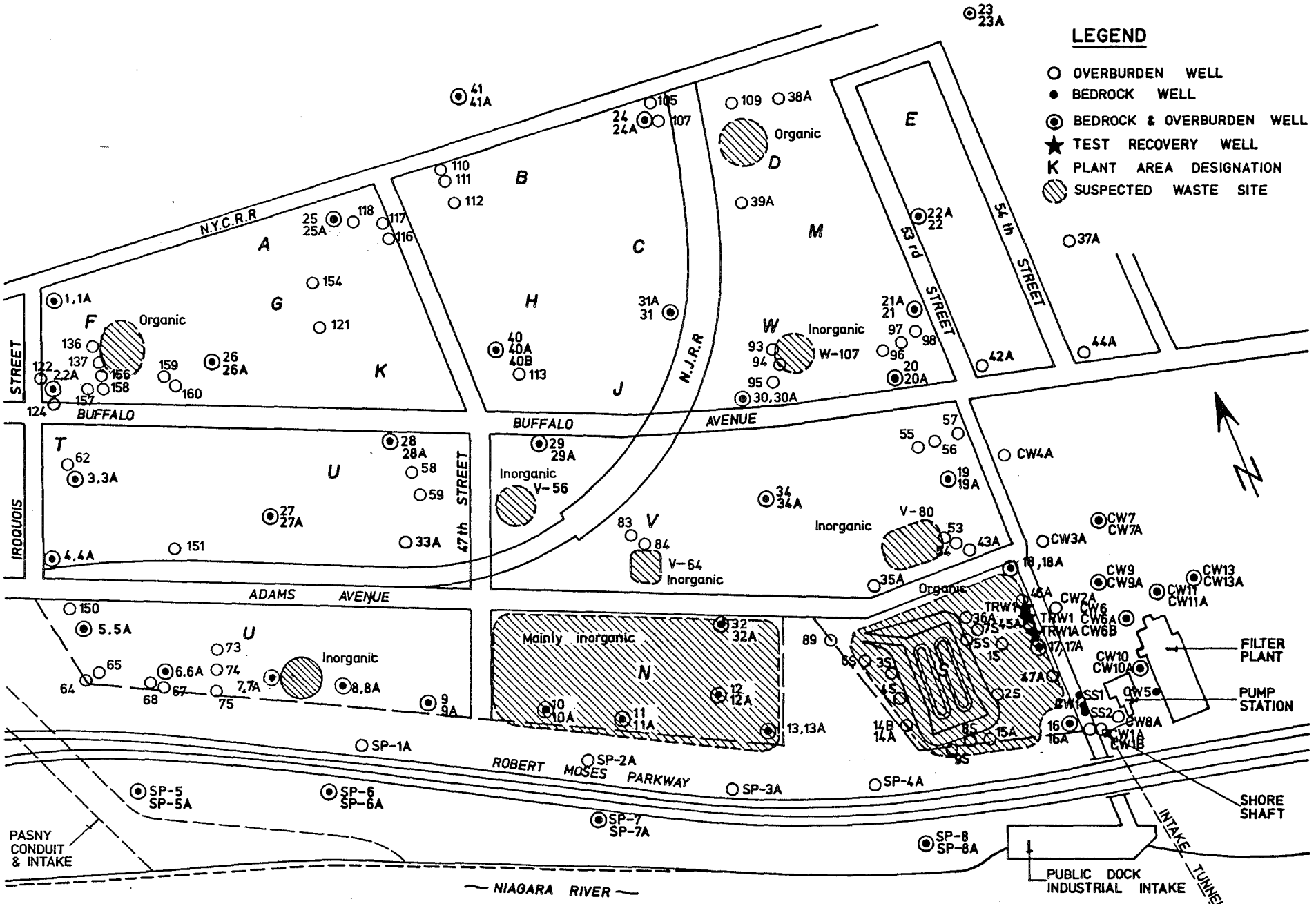


Figure 1. Plan of Hooker Chemical and Plastics Corporation (HCPC) Niagara Plant Site showing letter designated plant areas and well locations. Other possible waste disposal sites (from Conestoga-Rovers and Associates, 198 1b) in addition to S-Area are also shown.

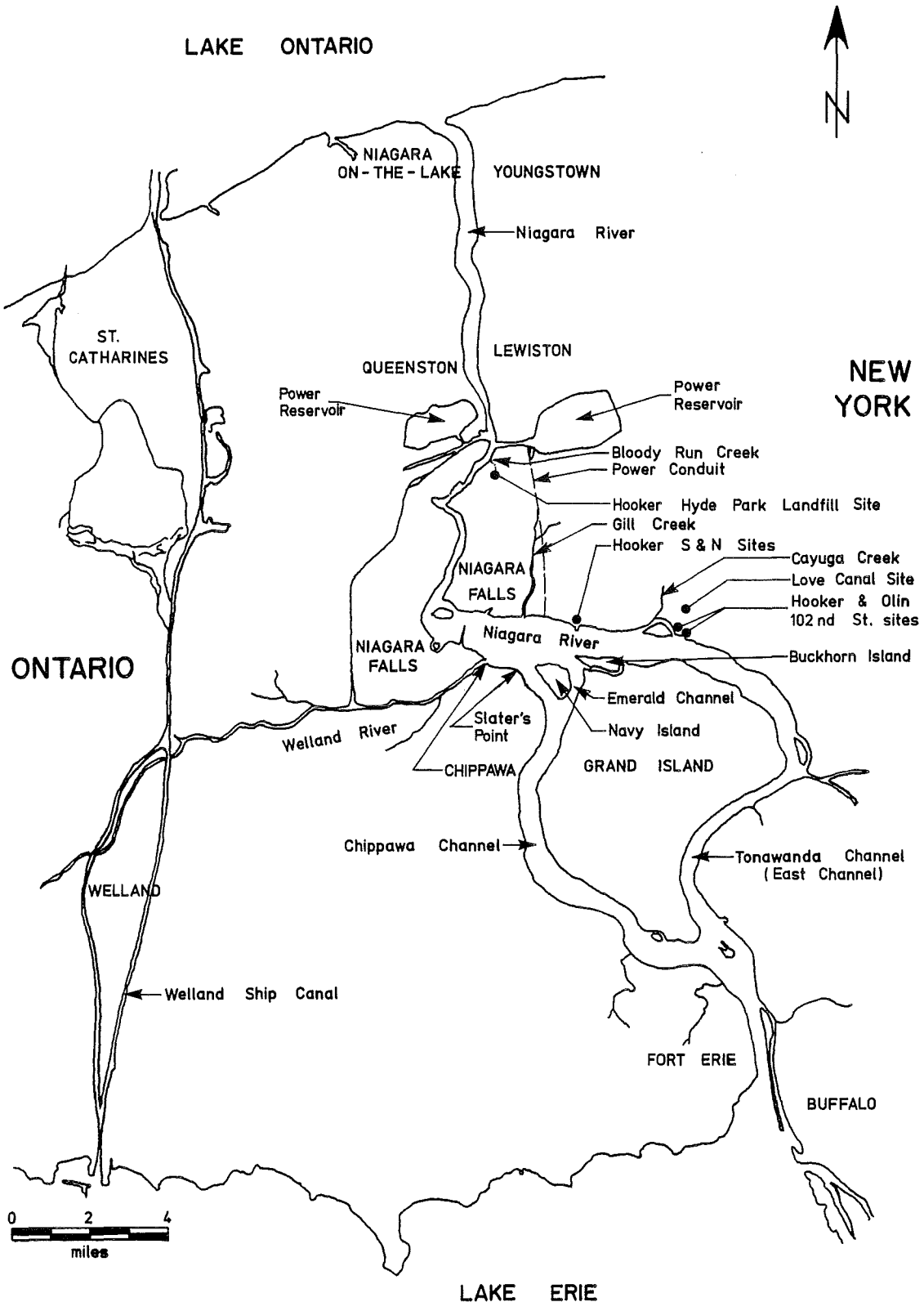
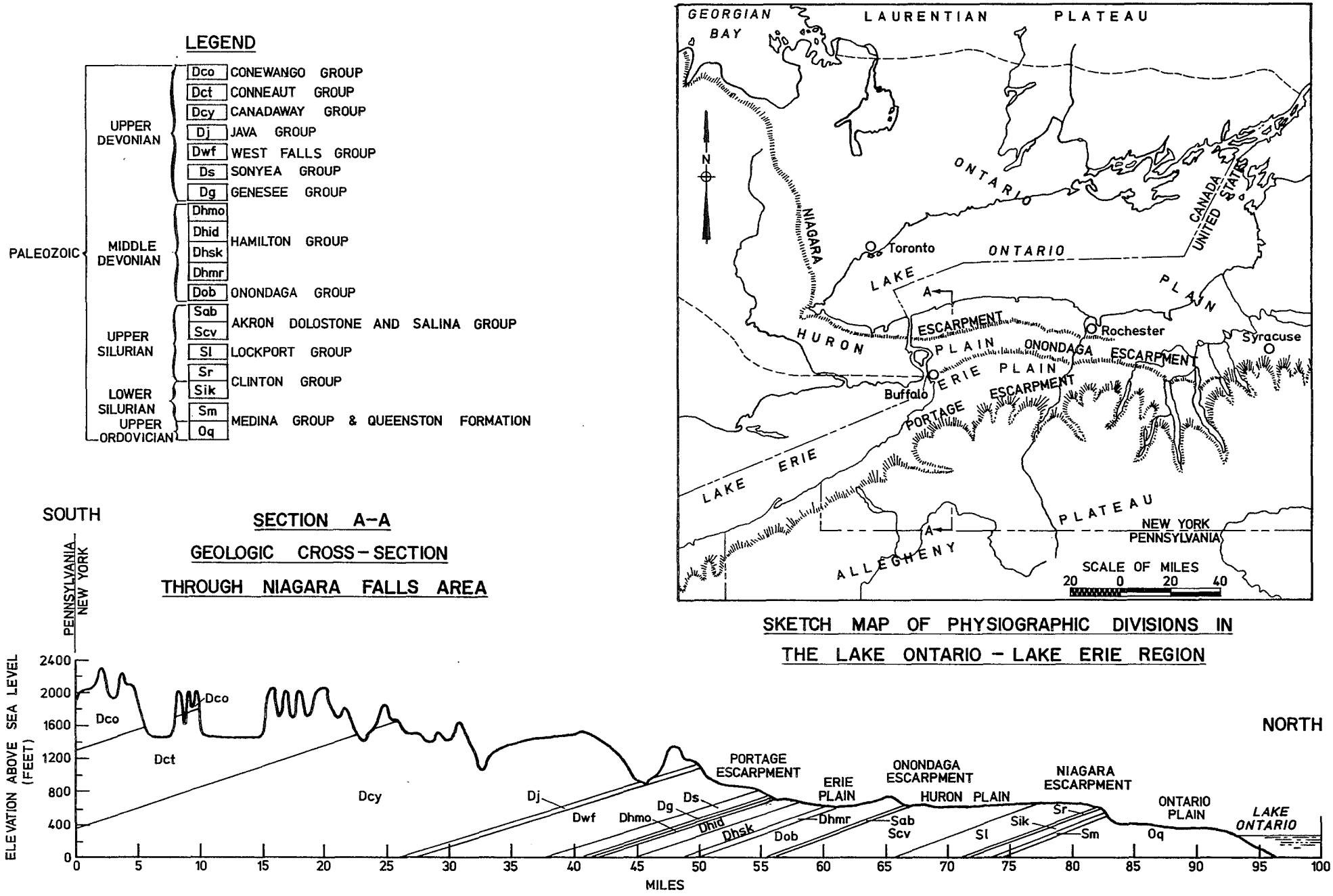


Figure 2. Plan of Niagara Falls and surrounding area.



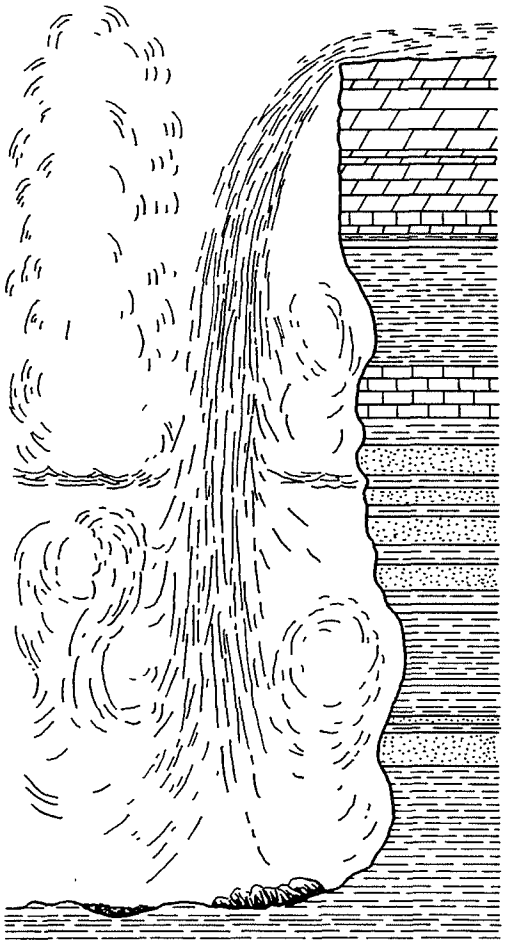
SECTION A–A

GEOLOGIC CROSS–SECTION

THROUGH NIAGARA FALLS AREA

SKETCH MAP OF PHYSIOGRAPHIC DIVISIONS IN THE LAKE ONTARIO – LAKE ERIE REGION

Figure 3. Regional geology of the Niagara Falls area (after American Falls International Board, 1974.)



System		Group	Formation	Thickness (feet) 1/	Description
Silurian	Middle		Lockport Dolomite	150	Dark-gray to brown, massive to thin-bedded dolomite, locally containing algal reefs and small, irregularly shaped masses of gypsum. At the base are light-gray, coarse-grained limestone (Gasport Limestone Member) and gray shaly dolomite (DeCew Limestone Member of Williams, 1919).
		Clinton	Rochester Shale	60	Dark-gray calcareous shale weathering light-gray to olive.
			Irondequoit Limestone	12	Light-gray to pinkish-white coarse-grained limestone.
			Reynales Limestone	10	White to yellowish-gray shaly limestone and dolomite.
			Neahga Shale of Sanford (1933)	5	Greenish-gray soft fissile shale.
	Lower	Albion	Thorold Sandstone	8	Greenish-gray shaly sandstone.
			Grimsby Sandstone of Williams (1914)	45	Reddish-brown to greenish-gray cross-bedded sandstone interbedded with red to greenish-gray shale.
			Unnamed unit	40	Gray to greenish-gray shale interbedded with light-gray sandstone.
			Whirlpool Sandstone		White, quartzitic sandstone.
Ordovician	Upper		Queenston Shale	1,200	Brick-red sandy to argillaceous shale.

1/ Average figure for area. Thickness at falls is not necessarily the same.

Figure 4. Bedrock formations in the Niagara Falls area as exposed at the Horseshoe Falls (from Johnston 1964)

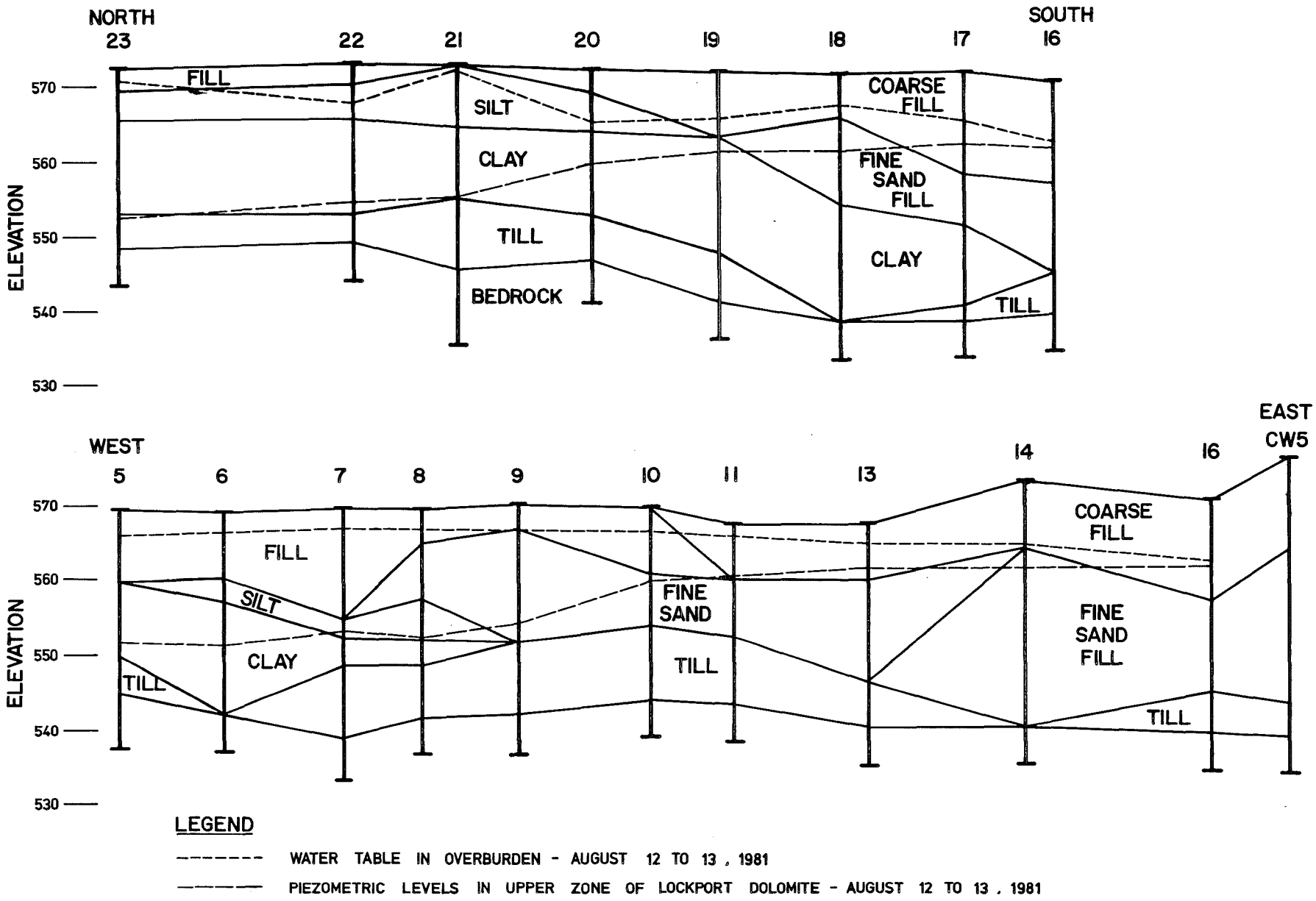


Figure 5. Cross sections through S-Area a) North-South along the eastern edge of S-Area b) West-East from Iroquois Street to 53rd Street.

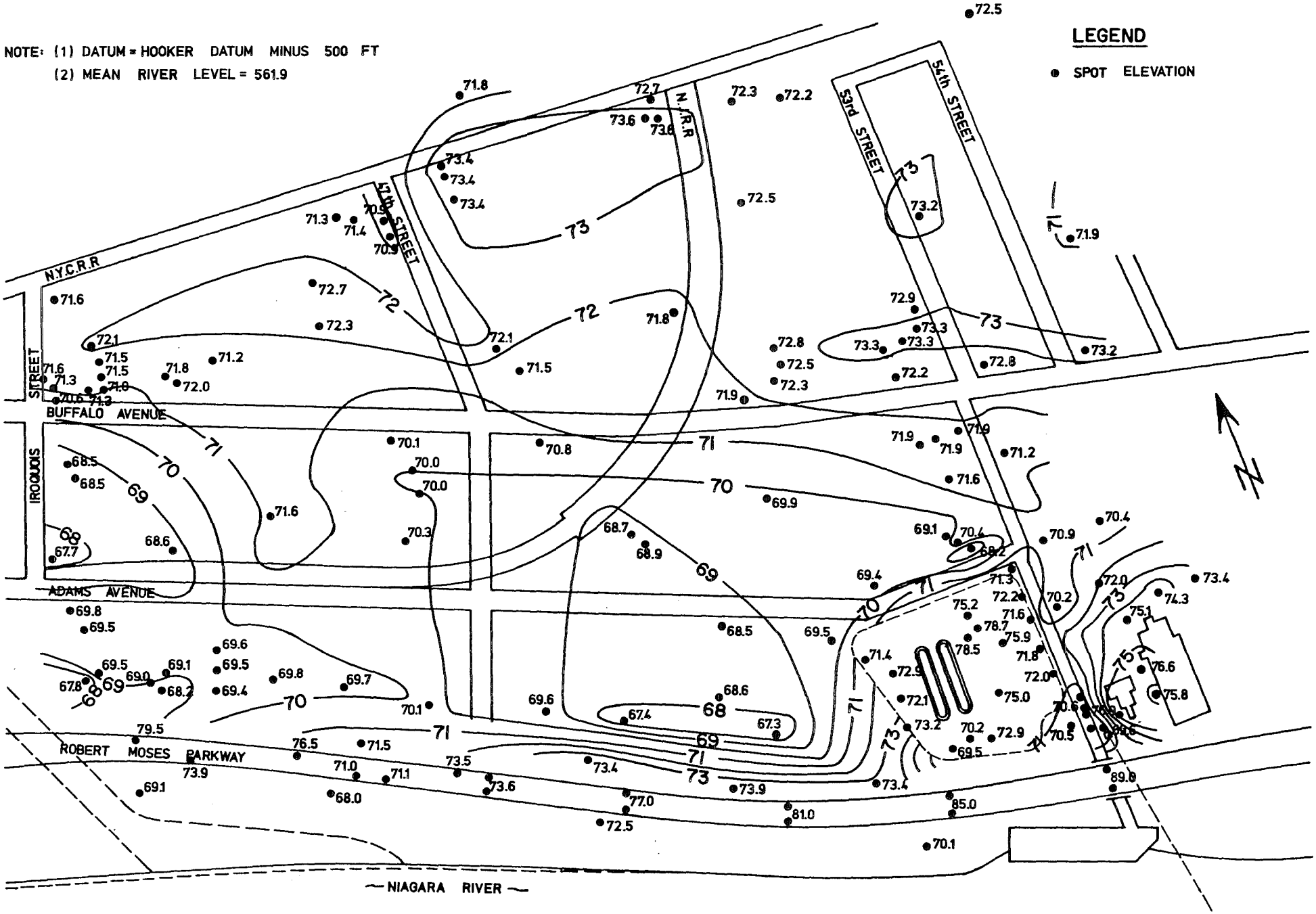


Figure 6. Surface topography in the S-Area vicinity.

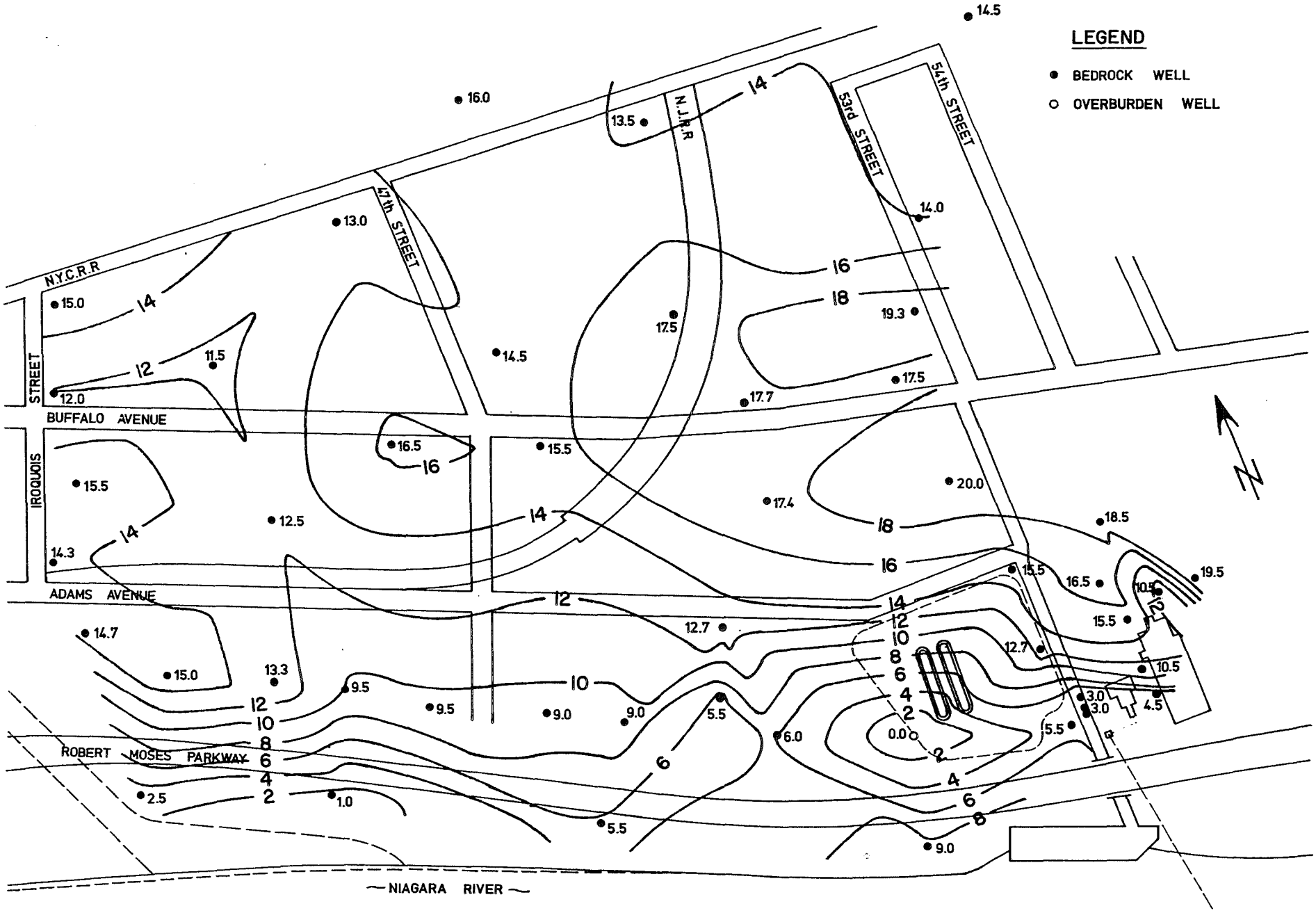


Figure 7. Contour diagram of the summed thickness of glacially derived clay and till.

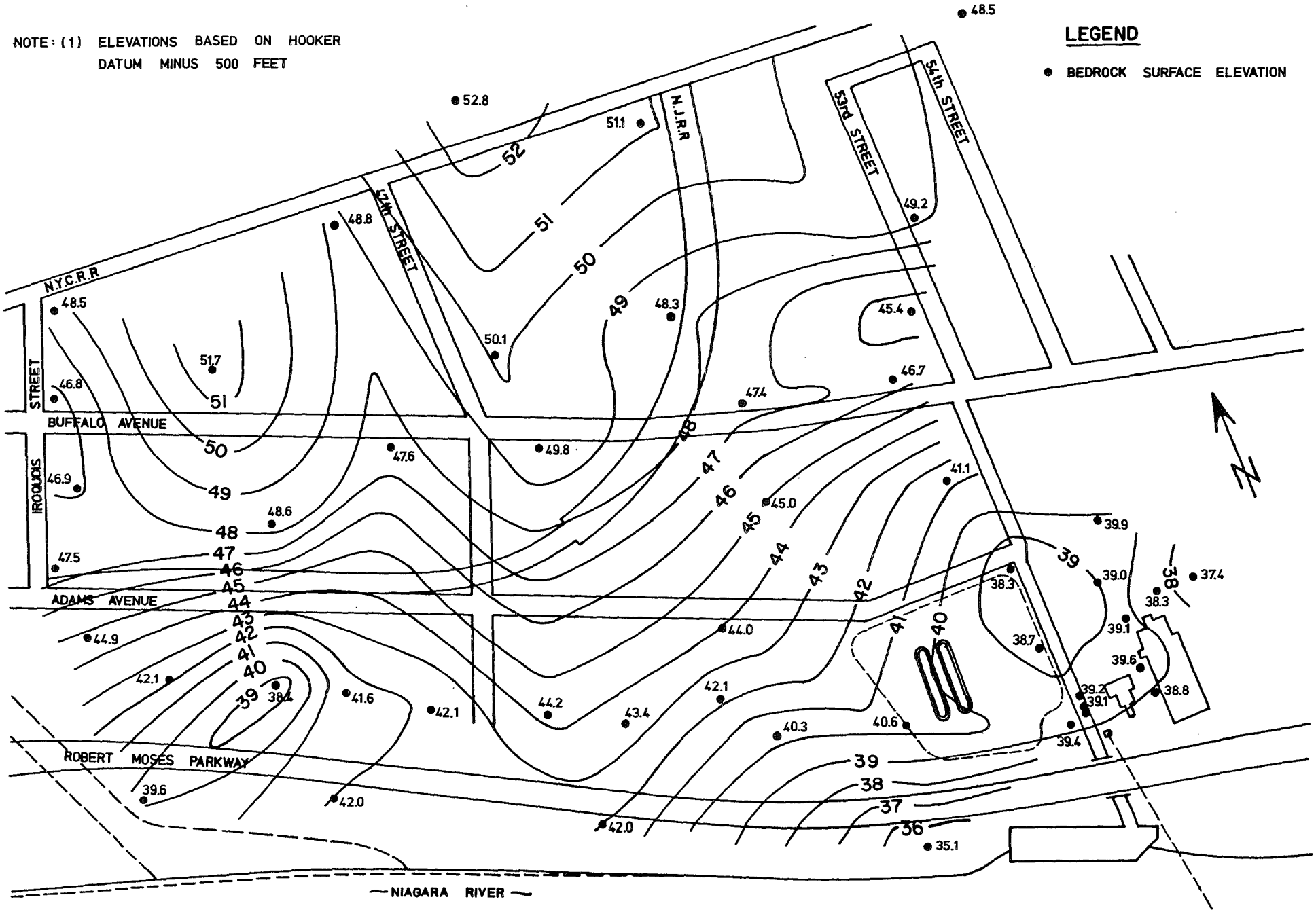


Figure 8. Topography of the upper surface of the Lockport Dolomite in the vicinity of S-Area.

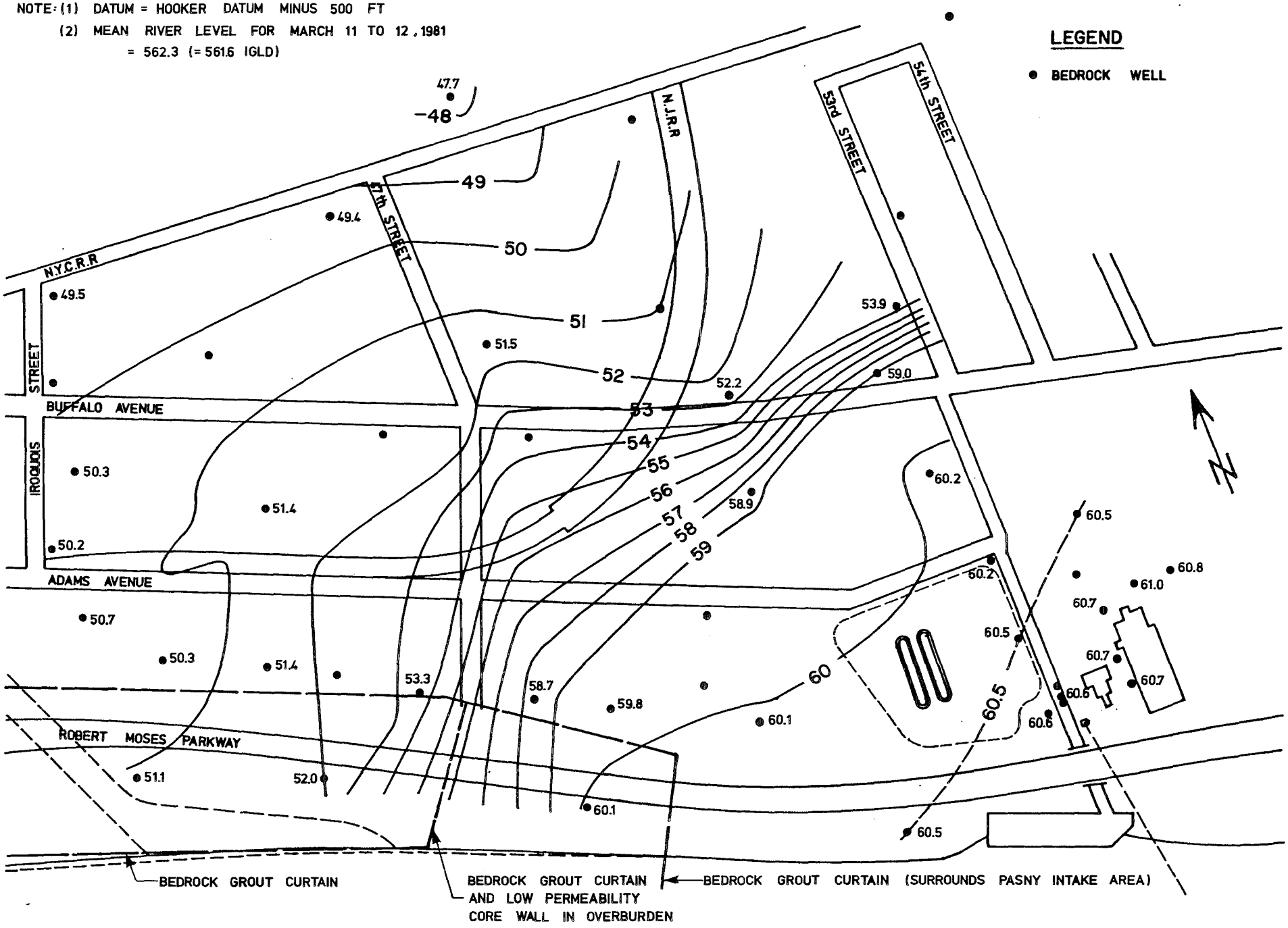


Figure 11. Piezometric contours for the upper zone (10 to 15 ft) of the Lockport Dolomite for period March 11 to 12, 1981.

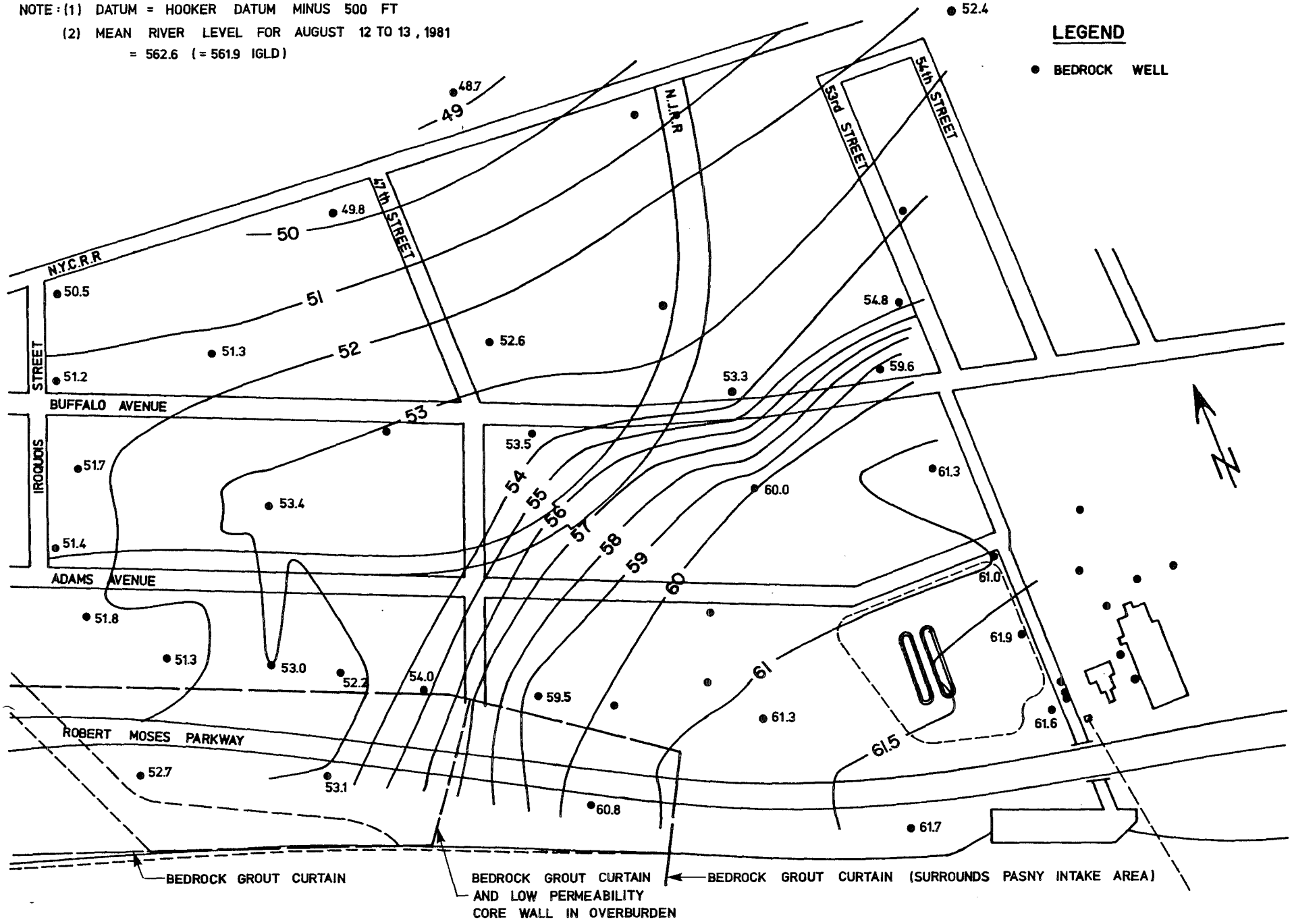


Figure 12. Piezometric contours for the upper zone (10 to 15 ft) of the Lockport Dolomite for period August 12 to 13, 1981.

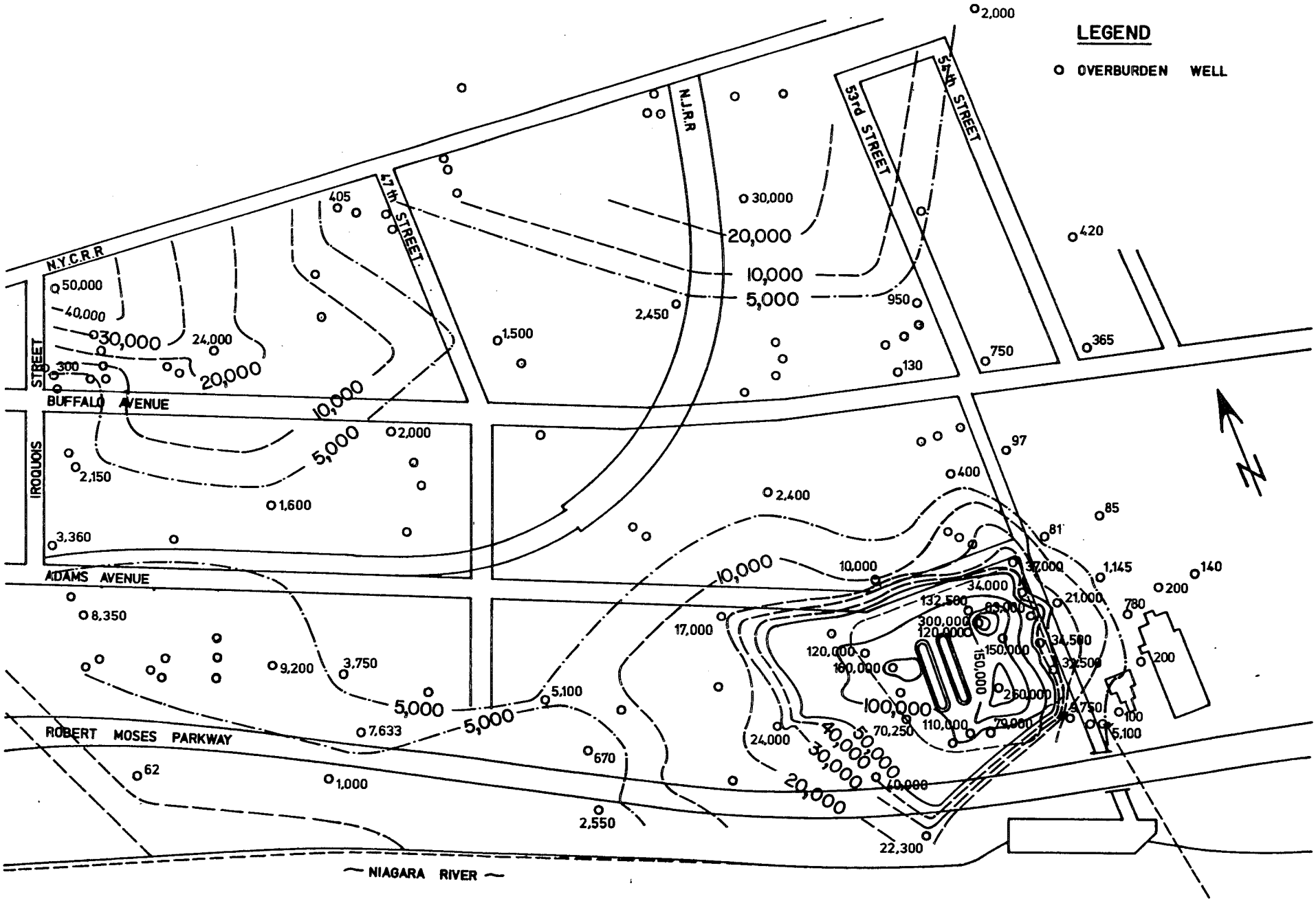


Figure 13. Contour diagram of averaged total organic halogen (TOH) concentrations (µg/L) measured in overburden wells.

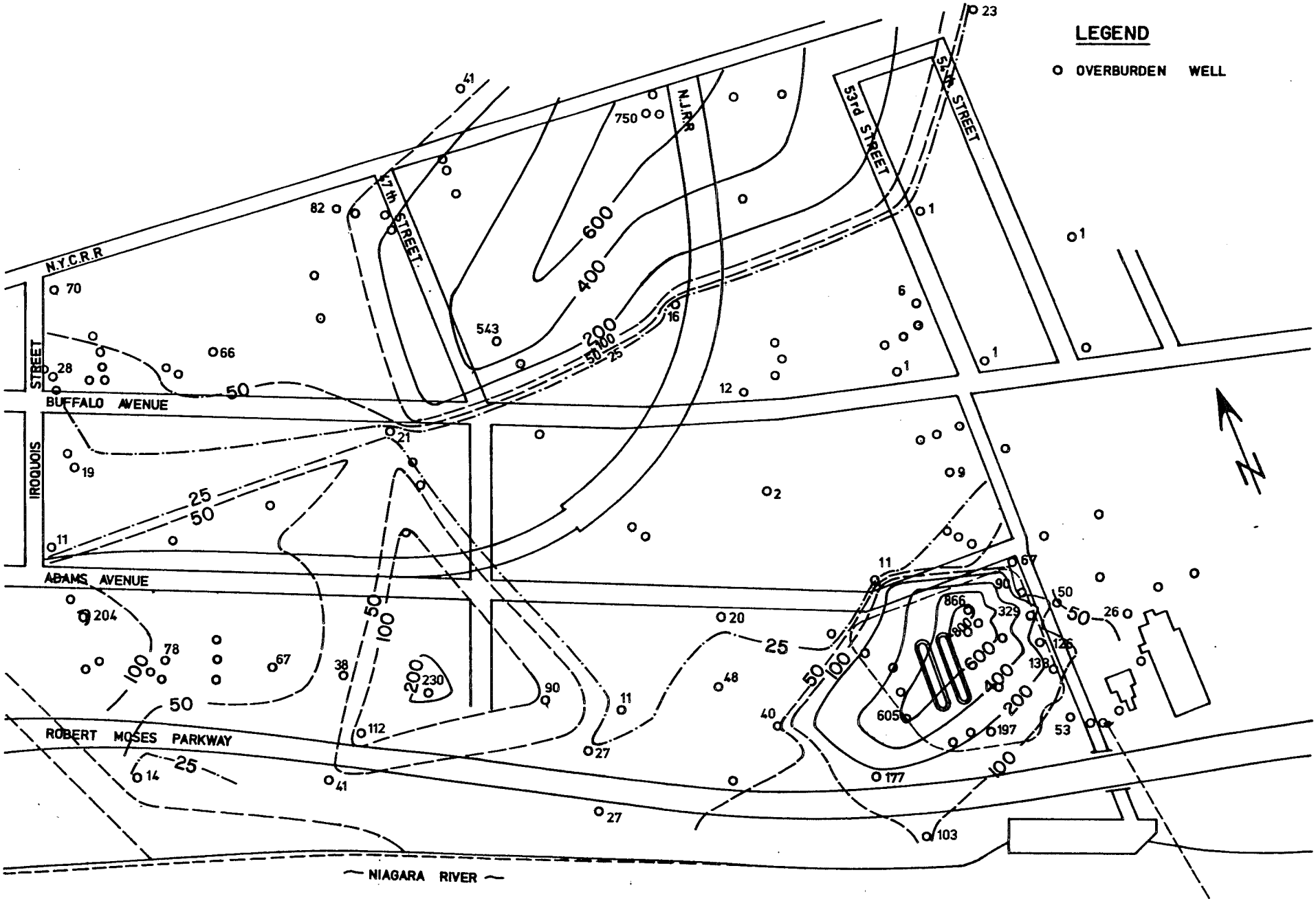


Figure 14. Contour diagram of averaged total organic carbon (TOC) concentrations (mg/L) measured in overburden wells.

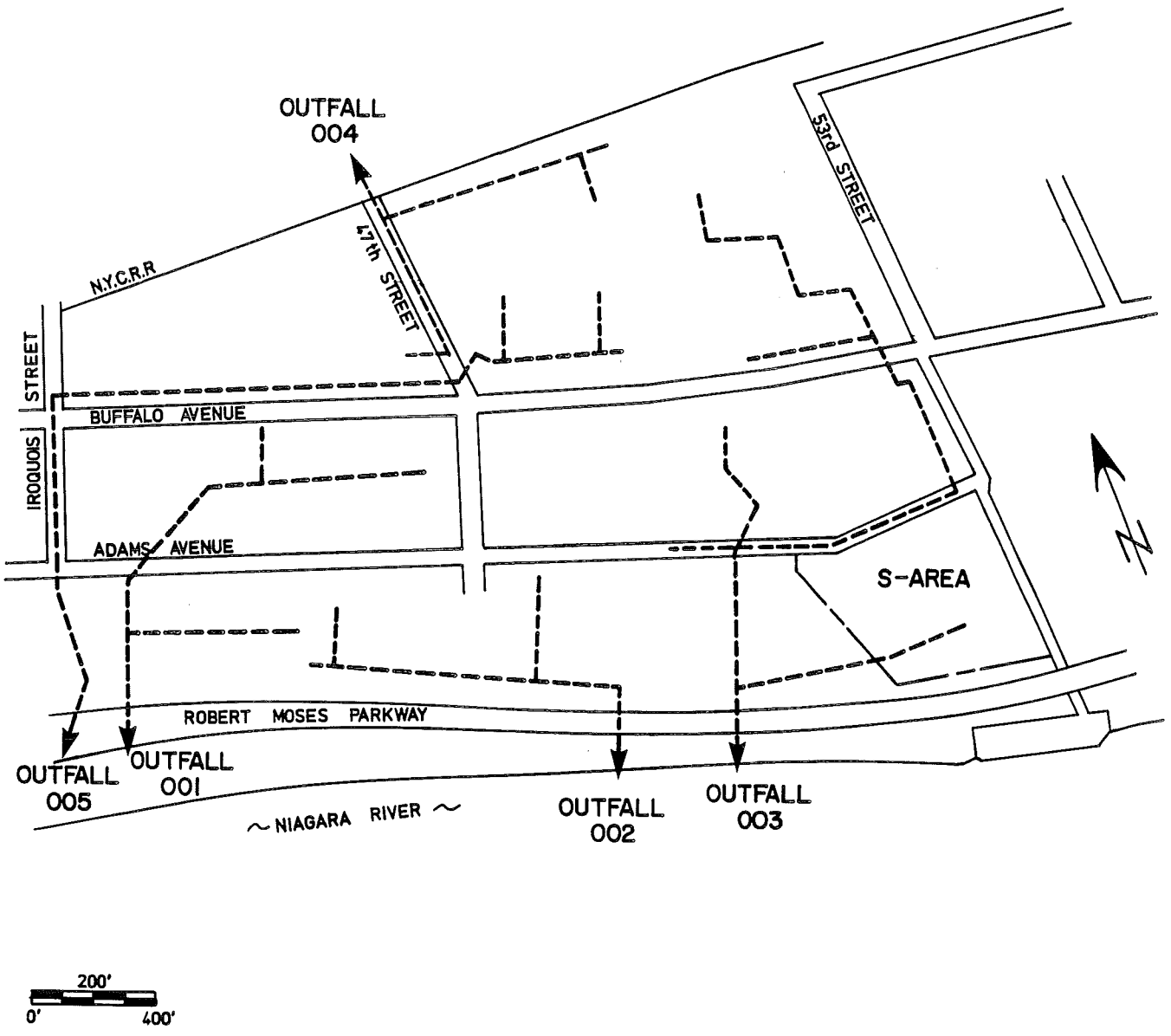


Figure 15. Location map of wastewater outfall sewer systems (after Hooker, 1979a).

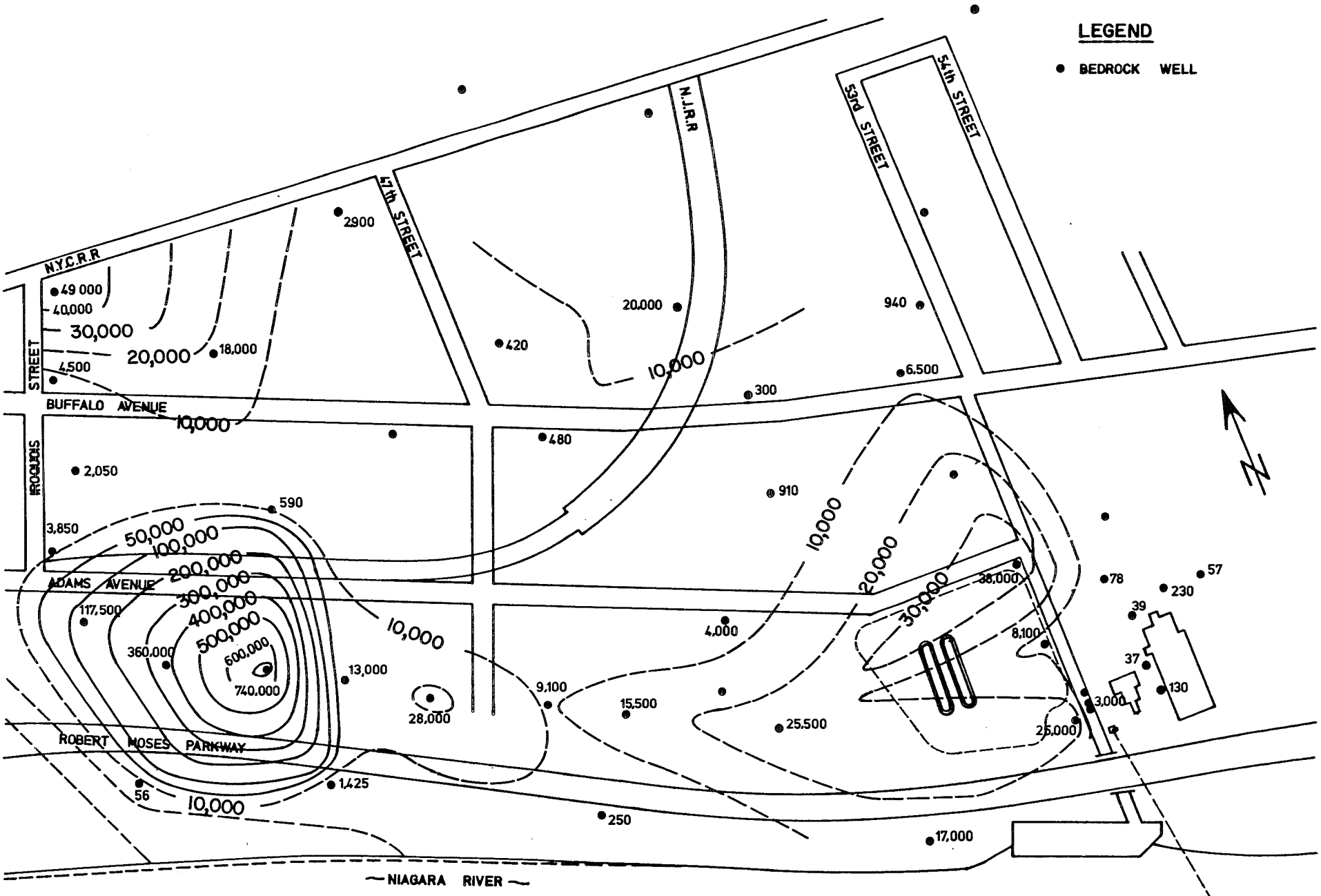


Figure 16. Contour diagram of averaged total organic halogen (TOH) concentrations (µg/L) measured in wells screened in the upper portion of the Lockport Dolomite (or across the upper Lockport and lowermost overburden; see Table 4).

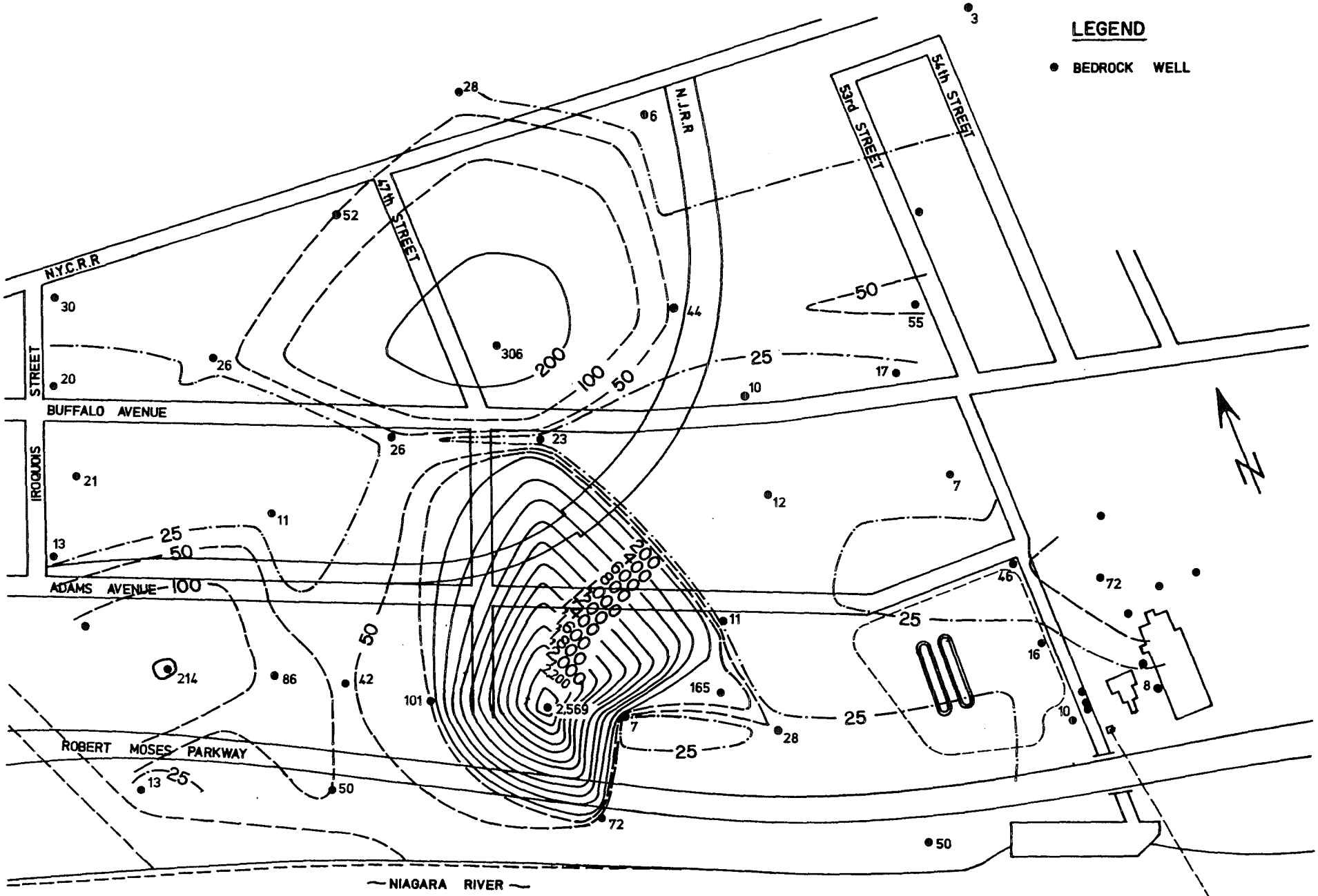


Figure 17. Contour diagram of averaged total organic carbon (TOC) concentrations (mg/L) measured in wells screened in the upper portion of the Lockport Dolomite (or across the upper Lockport and lowermost overburden; see Table 4.)

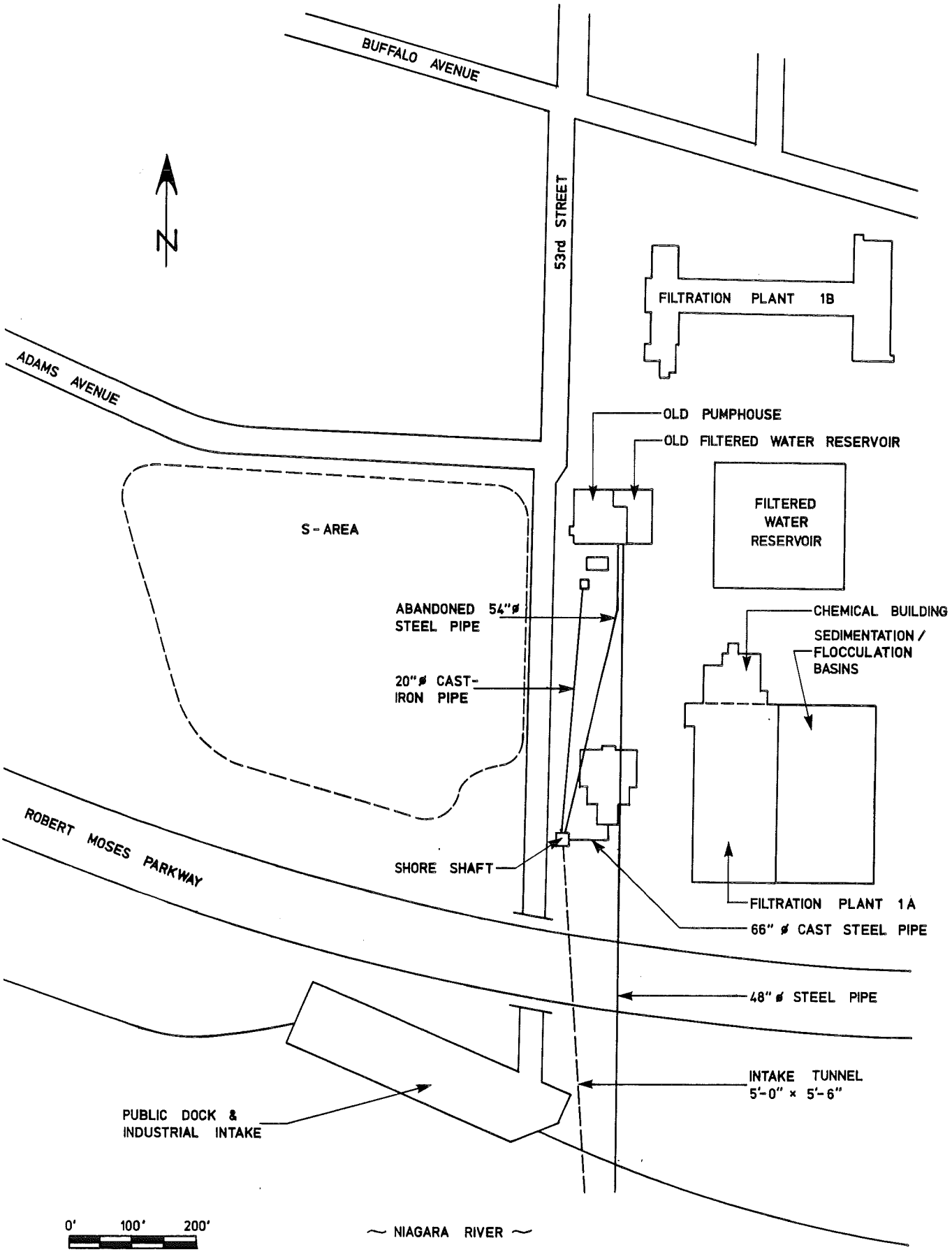


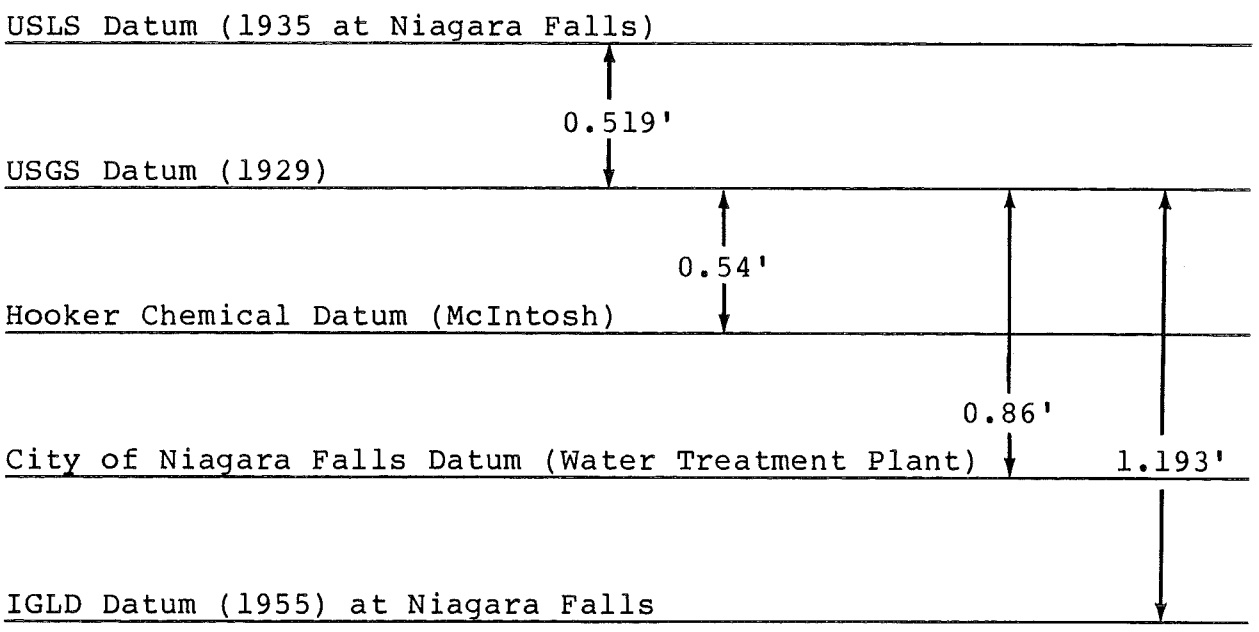
Figure 18. Plan of Water Treatment Plant Facilities.

APPENDIX I

Summary of Datums in the Niagara Falls Area

Summary of Datums in Existence
in the Niagara Falls Area

(from Leggette, Brashears and Graham, 1980b)



APPENDIX II

Sedimentation-Clarification Lagoons

SEDIMENTATION - CLARIFICATION LAGOONS

At the present time, two sedimentation-clarification lagoons are in operation at the former S-Area disposal site. The lagoons are constructed on grade on top of a mound of variable composition fill which rises several feet above the surrounding landscape (see Figure 6). Operations involve calcium-fluoride settling of effluent from prefluorination off-gas scrubbers located in S-Area (Conestoga-Rovers and Assoc., 1980a). Prefluorination is part of the production of parachlorobenzotrifluoride.

Overflow from the lagoons is discharged to wastewater outfall sewers at the south end of the lagoons. Wastewater sewers discharge directly to the Niagara River under Hooker's SPDES permit. High infiltration detected in some sewer reaches could be due to the following (Conestoga-Rovers and Assoc., 1980b):

1. The trunk sewers are 3 to 5 feet below the ground water level.
2. There are few sanitary sewers in this area.
3. The wastewater sewers are old and as a result points of leakage have developed throughout.
4. Watermain exfiltration recharges the area which subsequently is a source of water for sewer infiltration.

All of these reasons may be applicable to the S-Area vicinity.

Chemical loading studies at outfall 003 near S-Area (see Figure 15) identified the sedimentation-clarification lagoons as the source of 45% of the total chemical outfall loadings of which the total was 23.3 lbs/day (Conestoga-Rovers and Assoc., 1980b). Also, 53% of the total chemical load was attributed to infiltration or unidentified point sources in S-Area (Conestoga-Rovers and Assoc., 1980a).

Remedial measures planned by Hooker (Conestoga-Rovers and Assoc., 1980a) include a reduction in flow to the S-Area lagoons of 0.086 MGD as a result of consolidating off-gas scrubbing operations. In addition, wastewater treatment technology indicates fluoride concentrations in the lagoon effluent can be reduced through applying proper control of calcium fluoride crystallization and flocculation.

APPENDIX III

Contaminant Monitoring Data

Contaminant Monitoring Data
Average Concentrations for Overburden
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
1A	782 (1)	2.3 (2)	70 (2)	50,000 (2)
2A	2,256 (2)	6.6 (2)	28 (2)	300 (1)
3A	937 (1)	4.0 (1)	19 (1)	2,150 (2)
4A	87 (2)	0.5 (3)	11 (3)	3,360 (2)
5A	3,583 (1)	11.1 (2)	204 (2)	8,350 (2)
6A	1,196 (2)	8.7 (2)	78 (2)	--
7A	320 (2)	8.6 (3)	67 (3)	9,200 (2)
8A	2,070 (1)	11.6 (3)	38 (3)	3,750 (2)
9A	1,895 (2)	21.7 (2)	230 (2)	--
10A	2,305 (2)	8.7 (4)	90 (3)	5,100 (2)
11A	1,096 (2)	4.0 (2)	11 (1)	--
12A	2,114 (2)	5.9 (2)	48 (2)	--
13A	452 (1)	3.1 (2)	40 (2)	24,000 (2)
14A	3,019 (3)	9.3 (5)	456 (4)	68,500 (2)
14B	37,773 (3)	65.0 (4)	754 (3)	72,000 (2)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Overburden
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
15A	1,716 (3)	6.8 (4)	197 (3)	79,000 (1)
16A	2,427 (2)	7.4 (3)	53 (2)	9,750 (2)
17A	5,995 (2)	12.7 (2)	126 (3)	34,500 (2)
18A	1,037 (3)	3.9 (4)	67 (4)	37,000 (1)
19A	592 (2)	2.9 (3)	9 (2)	400 (1)
20A	452 (1)	3.8 (1)	1 (1)	130 (1)
21A	1,774 (1)	4.0 (2)	6 (2)	950 (1)
22A	1,583 (1)	3.1 (2)	1 (1)	—
23A	3,166 (1)	8.0 (2)	23 (2)	2,000 (1)
24A	4,619 (2)	10.5 (2)	750 (2)	—
25A	2,679 (1)	4.1 (2)	82 (2)	405 (2)
26A	1,622 (1)	4.3 (1)	66 (1)	24,000 (1)
27A	—	—	—	1,600 (1)
28A	1,775 (2)	5.1 (3)	21 (3)	2,000 (1)
29A	—	—	—	—

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Overburden
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
30A	3,931 (2)	9.2 (2)	12 (2)	—
31A	3,714 (2)	11.0 (4)	16 (4)	2,450 (2)
32A	5,071 (2)	12.8 (2)	20 (2)	17,000 (1)
34A	—	8.9 (1)	2 (1)	2,400 (1)
35A	—	2.2 (2)	11 (2)	10,000 (1)
36A	—	97 (1)	866 (1)	132,500 (2)
37A	—	3.6 (1)	1 (1)	420 (2)
39A	—	—	—	30,000 (1)
40A	—	36.7 (3)	543 (3)	1,500 (1)
40B	—	11.2 (1)	1,029 (1)	820 (2)
41A	88 (1)	0.9 (1)	41 (1)	—
42A	—	1.9 (1)	1 (1)	750 (1)
43A	—	—	—	—
44A	—	—	—	365 (2)
45A	—	28 (1)	329 (1)	63,000 (2)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Overburden
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
46A	—	7.0 (2)	90 (2)	34,000 (1)
47A	—	12.8 (1)	133 (1)	32,350 (2)
SP-1A	—	4.3 (3)	112 (3)	7,633 (3)
SP-2A	—	3.3 (2)	27 (2)	670 (1)
SP-3A	—	--	--	--
SP-4A	—	23.0 (2)	177 (2)	40,000 (2)
SP-5A	—	0.4 (2)	14 (2)	62 (2)
SP-6A	—	0.6 (2)	41 (2)	1,000 (1)
SP-7A	—	1.0 (1)	27 (1)	2,550 (2)
SP-8A	—	0.1 (1)	103 (1)	22,300 (2)
1S	—	—	—	150,000 (1)
2S	—	--	—	260,000 (1)
3S	—	--	—	160,000 (1)
5S	—	--	—	120,000 (1)
6S	—	—	—	120,000 (1)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Overburden
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
7S	—	—	—	300,000 (1)
8S	—	—	—	110,000 (1)
CW-1A	—	—	—	4,100 (2)
CW-1B	—	—	—	6,100 (2)
CW-2A	—	9.9 (1)	50 (1)	21,000 (2)
CW-3A	—	—	—	81 (1)
CW-4A	—	—	—	97 (1)
CW-6A	—	1.6 (1)	26 (1)	780 (2)
CW-6B	—	—	—	780 (2)
CW-7A	—	—	—	85 (2)
CW-8A	—	—	—	100 (2)
CW-9A	—	—	—	1,145 (2)
CW-10A	—	—	—	200 (1)
CW-11A	—	—	—	200 (1)
CW-13A	—	—	—	140 (1)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Bedrock Wells
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
1	2,366 (1)	3.2 (1)	30 (1)	49,000 (1)
2	1,232 (2)	3.3 (3)	20 (3)	4,500 (2)
3	299 (2)	2.5 (3)	21 (3)	2,050 (2)
4	247 (2)	1.5 (3)	13 (2)	3,850 (2)
5	626 (1)	9.9 (1)	—	117,500 (2)
6	2,592 (1)	7.0 (2)	214 (2)	360,000 (2)
7	1,566 (1)	5.2 (2)	86 (2)	740,000 (1)
8	17,514 (1)	15.8 (3)	42 (3)	13,000 (1)
9	20,978 (1)	25.4 (3)	101 (3)	28,000 (2)
10	5,027 (2)	35.7 (3)	2,569 (3)	9,100 (2)
11	852 (2)	3.6 (3)	7 (2)	15,500 (2)
12	1,757 (2)	5.6 (2)	165 (2)	—
13	244 (2)	1.0 (4)	28 (3)	25,500 (2)
16	—	3.0 (2)	10 (2)	25,000 (2)
17	3,027 (1)	7.4 (2)	16 (1)	8,100 (2)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Bedrock Wells
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
18	—	3.9 (2)	46 (2)	38,000 (1)
19	—	0.2 (1)	7 (1)	—
20	—	12.5 (1)	17 (1)	6,500 (2)
21	—	3.8 (1)	55 (1)	940 (1)
22	—	—	—	—
23	108 (2)	2.0 (3)	3 (3)	—
24	1,200 (1)	3.8 (1)	6 (1)	—
25	—	7.3 (3)	52 (3)	2,900 (1)
26	906 (1)	2.6 (1)	26 (1)	18,000 (1)
27	879 (1)	2.9 (1)	11 (1)	590 (1)
28	2,801 (1)	11.0 (1)	26 (1)	—
29	—	2.2 (1)	23 (1)	480 (1)
30	454 (2)	2.3 (2)	10 (1)	300 (1)
31	470 (1)	1.9 (3)	44 (3)	20,000 (1)
32	1,348 (2)	1.6 (2)	11 (2)	4,000 (1)

Note: Number in brackets equals the number of samples in average.

Contaminant Monitoring Data
Average Concentrations for Bedrock Wells
(From Arthur D. Little, 1981a)

Well No.	Chloride (ppm)	Conductivity (mmho/cm)	TOC (ppm)	TOH (ppb)
34	—	2.1 (1)	12 (1)	910 (2)
40	—	17.9 (2)	306 (2)	420 (1)
41	3,817 (1)	8.6 (1)	28 (1)	—
SP-5	—	0.4 (2)	13 (2)	56 (2)
SP-6	—	0.4 (2)	50 (2)	1,425 (2)
SP-7	—	0.5 (2)	72 (2)	250 (1)
SP-8	—	1.5 (1)	50 (1)	17,000 (1)
CW-1	—	—	—	3,000 (1)
CW-5	—	0.9 (1)	8 (1)	130 (2)
CW-6	—	—	—	39 (2)
CW-7	—	—	—	—
CW-9	—	1.8 (1)	72 (1)	78 (2)
CW-10	—	—	—	37 (1)
CW-11	—	—	—	230 (2)
CW-13	—	—	—	57 (1)

Note: Number in brackets equals the number of samples in average.

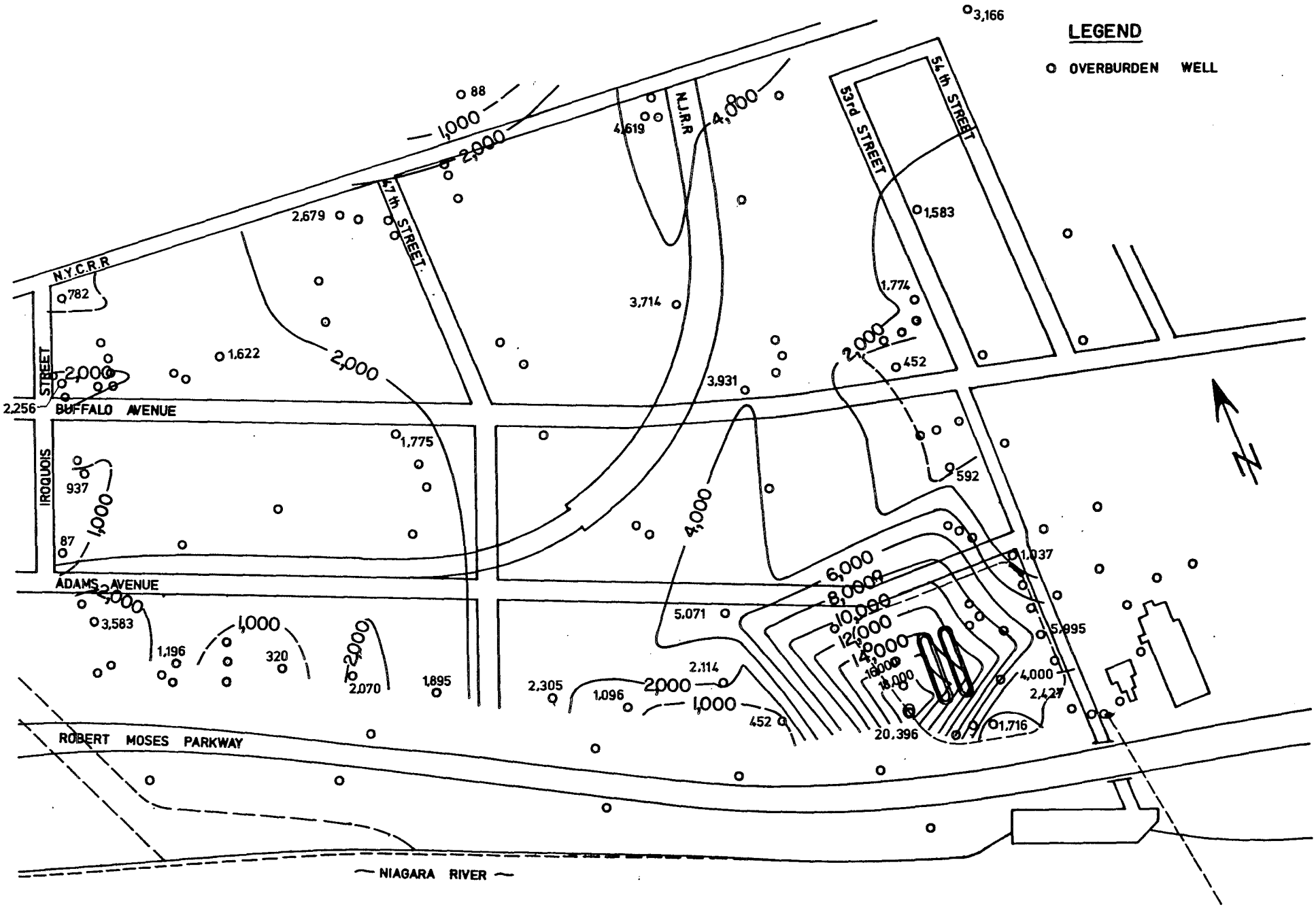


Figure III-1. Contour diagram of averaged chloride concentrations (mg/L) measured in overburden wells.

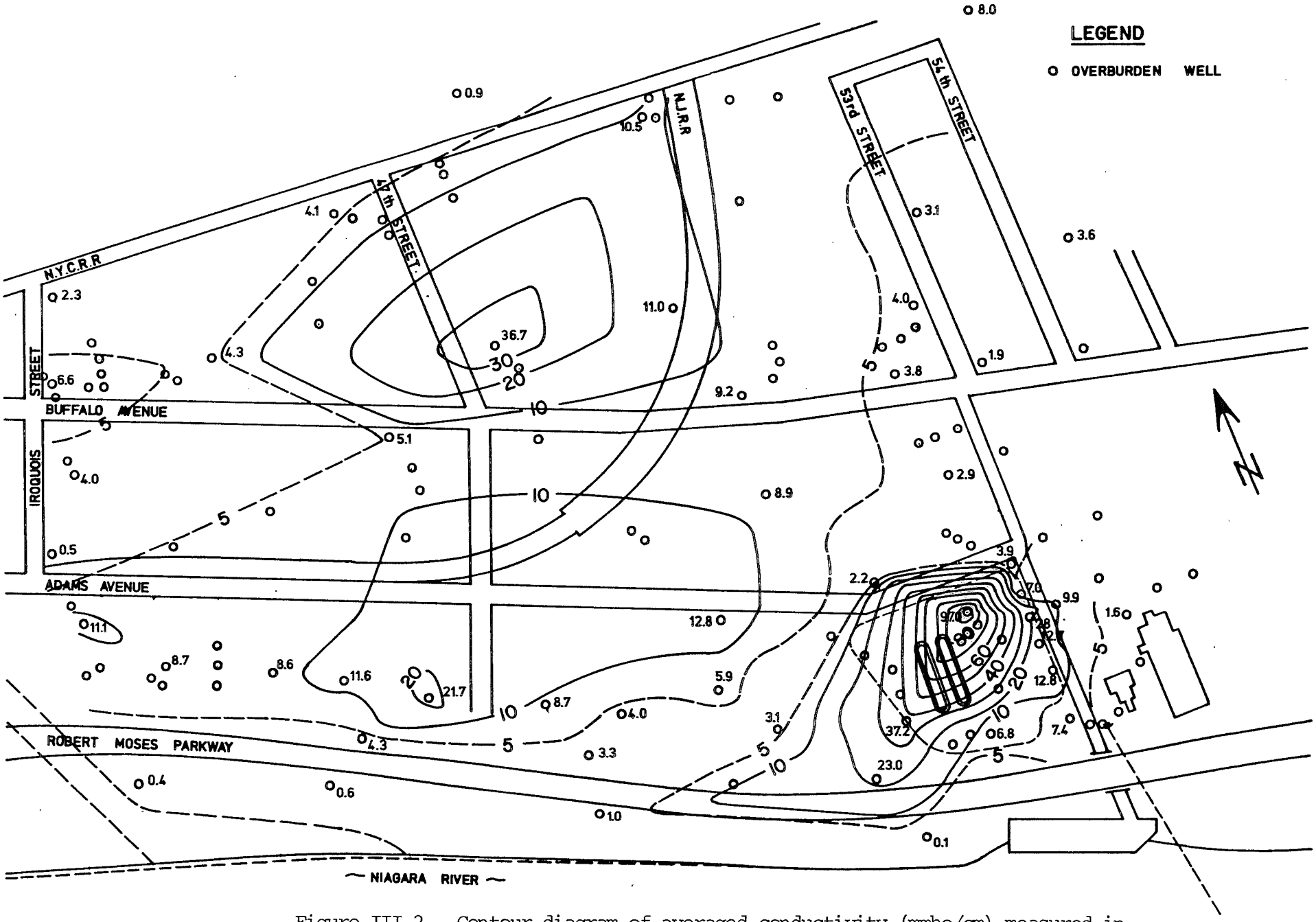


Figure III-2. Contour diagram of averaged conductivity (mmho/cm) measured in overburden wells.

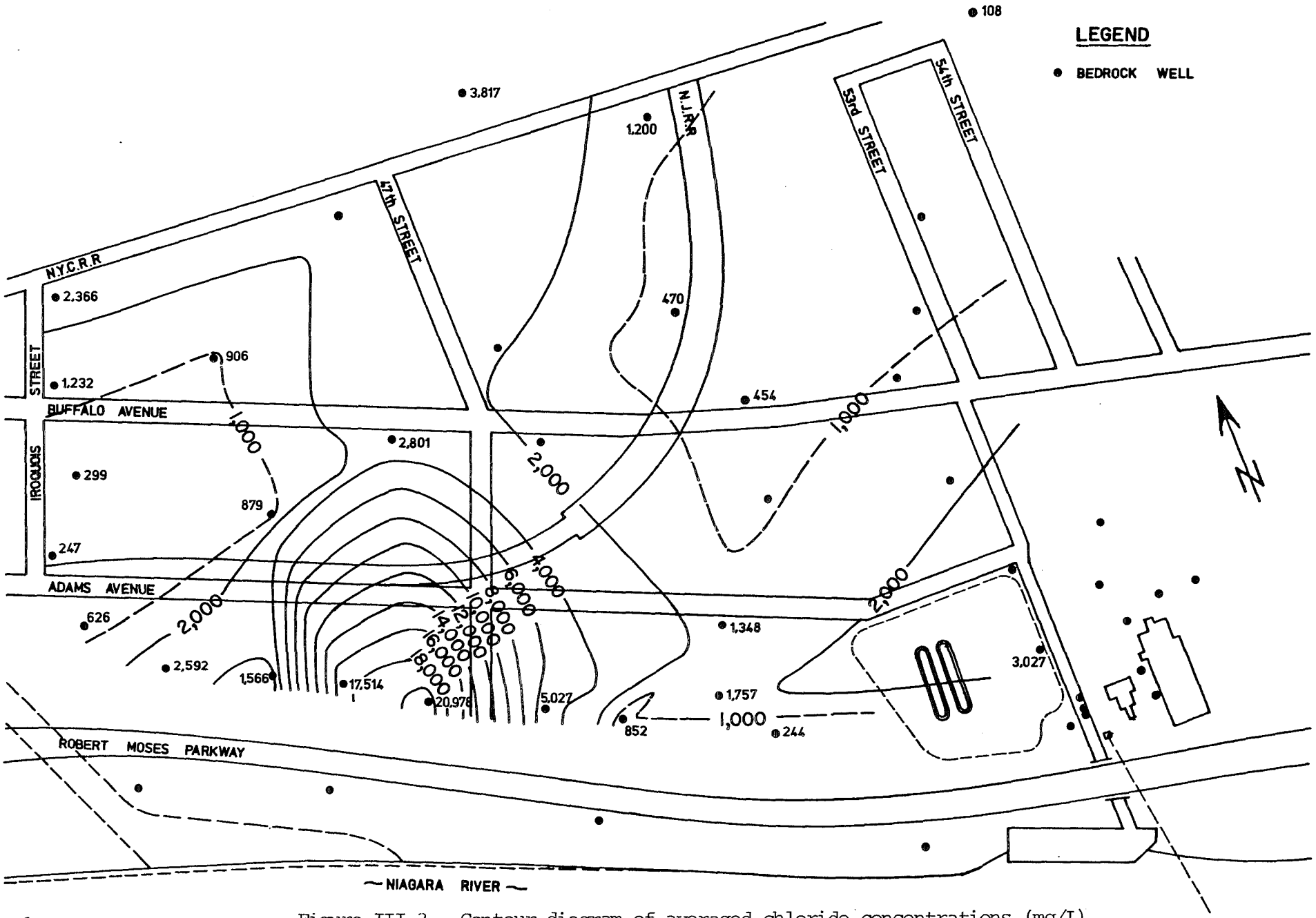


Figure III-3. Contour diagram of averaged chloride concentrations (mg/L) measured in wells screened in the upper portion of the Lockport Dolomite (or across the upper Lockport and lowermost overburden; see Table 4.)

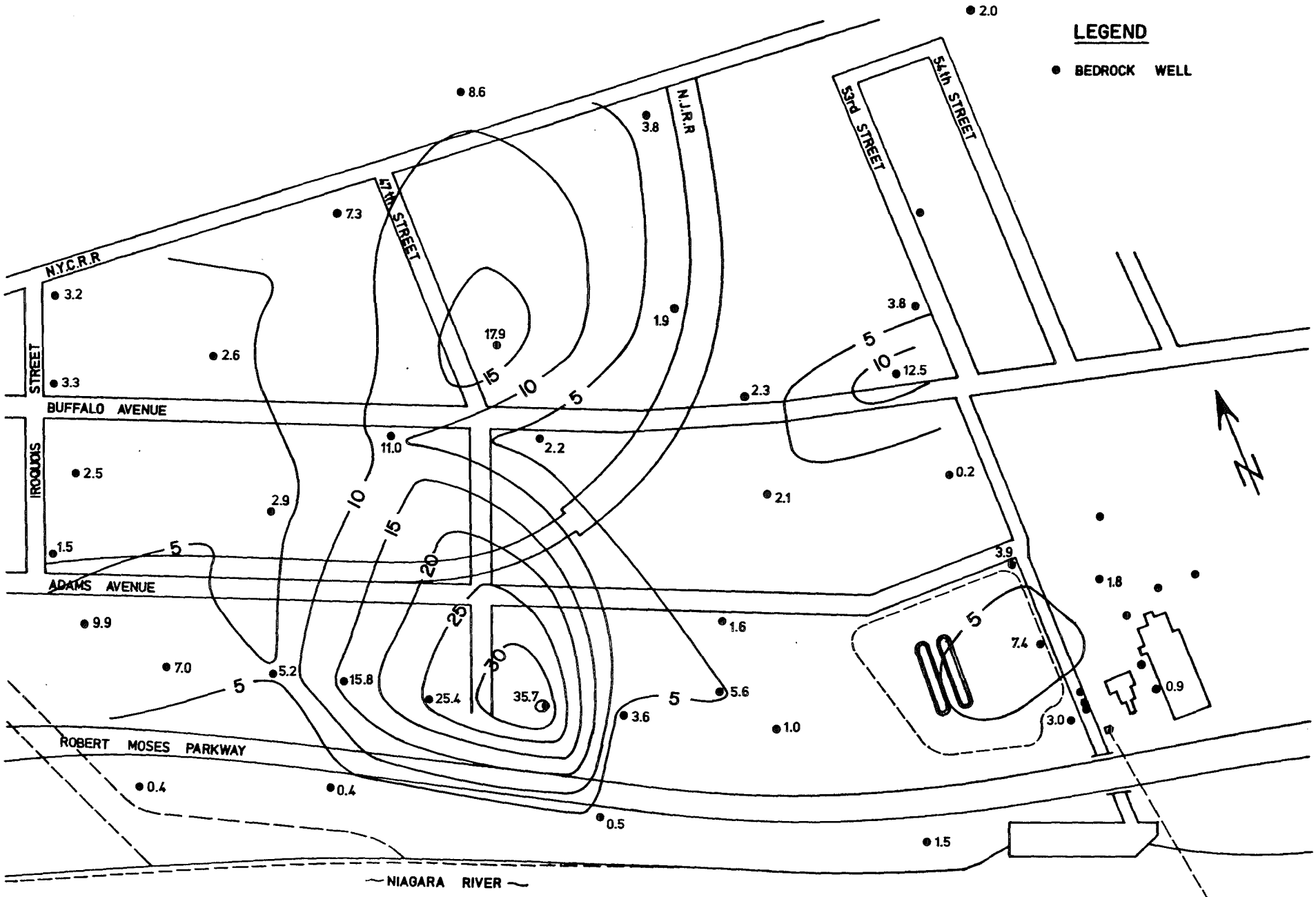


Figure III-4. Contour diagram of averaged conductivity (mmho/cm) measured in wells screened in the upper portion of the Lockport Dolomite (or across the upper Lockport and lowermost overburden; see Table 4.)

APPENDIX IV

Organic and Metal Constituents Analyzed at S-Area

ORGANIC AND METAL CONSTITUENTS ANALYZED AT S-AREA

The individual organic contaminants listed in this Appendix have been selected from various data sources to correspond to those which contribute substantially, on a mass loading basis, to the total sewer outfall load of the nearest sewer outfall (003) (see Figure 15 for location). Since infiltration of contaminated ground water into the sewers is considered responsible for a substantial portion of the total outfall chemical load, it was considered informative to present these. In addition these contaminants have the most extensive data base (Arthur D. Little, 1980a,c, d, 1982). The metals listed in this table are those which showed relatively high concentrations. The total list of metals analyzed included antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
1A	0	31 (1)	0 (1)	0 (1)	40 (1)	260 (1)	0 (1)
2A	33 (2)	31 (2)	9 (2)	0 (2)	0 (2)	16 (2)	3 (2)
4A	4 (2)	4 (2)	4 (2)	0 (2)	0 (2)	0 (2)	2 (2)
5A	400 (3)	180 (3)	16,700 (3)	0 (3)	980 (3)	31,000 (3)	29,667 (3)
7A	240 (1)	150 (1)	460 (1)	0 (1)	37 (1)	0 (1)	2,300 (1)
8A	6 (2)	24 (2)	21 (2)	0 (2)	23 (2)	3,350 (2)	46 (2)
10A	2 (1)	28 (1)	5 (1)	0 (1)	82 (1)	390 (1)	4 (1)
13A	47 (1)	30 (1)	12 (1)	0 (1)	1,200 (1)	111 (1)	40 (1)
14A	4,820 (2)	5,883 (5)	1,673 (4)	0 (5)	812 (3)	599 (5)	12,395 (3)
15A	222,615 (2)	50,394 (5)	6,865 (4)	12,000 (5)	1,422 (3)	2,981 (5)	15,380 (3)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
1A	0 (1)	1,200 (1)	730 (1)	0 (1)	—	—	—
2A	0 (2)	0 (2)	0 (2)	0 (2)	—	—	—
4A	0 (2)	0 (2)	0 (2)	2 (2)	—	—	—
5A	0 (3)	333 (3)	3,567 (3)	0 (3)	—	—	—
7A	13 (1)	0 (1)	280 (1)	0 (1)	—	—	—
8A	5 (2)	1,025 (2)	38 (2)	0 (2)	—	—	—
10A	406 (1)	220 (1)	800 (1)	12 (1)	—	—	—
13A	24 (1)	140 (1)	79,000 (1)	16 (1)	—	—	—
14A	—	—	—	—	3,455 (2)	1,831 (2)	565 (2)
15A	—	—	—	—	6,655 (2)	1,465 (2)	1,750 (2)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
16A	359 (3)	173 (7)	120 (6)	0 (7)	382 (5)	74 (7)	239 (5)
17A	9,740 (2)	21,795 (7)	3,097 (6)	1,075 (7)	15,681 (5)	2,430 (7)	11,192 (5)
18A	2,758 (3)	16,879 (6)	3,000 (4)	3,838 (6)	7,792 (4)	1,515 (6)	8,700 (4)
19A	31 (2)	24 (2)	23 (2)	0 (2)	0 (2)	0 (2)	9 (2)
20A	0 (2)	22 (2)	2 (2)	0 (2)	0 (2)	0 (2)	10 (2)
25A	15 (2)	16 (2)	3 (2)	0 (2)	0 (2)	9 (2)	1 (2)
26A	1,210 (3)	1,757 (3)	6 (3)	0 (3)	70 (3)	7,700 (3)	17 (3)
27A	91 (2)	10 (2)	3 (2)	0 (2)	0 (2)	55 (2)	3 (2)
35A	49,000 (2)	22,000 (2)	210 (2)	7,000 (2)	34 (2)	23,000 (2)	2,150 (2)
39A	31 (2)	5,850 (2)	1,200 (2)	0 (2)	160 (2)	11,000 (2)	37,500 (2)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
16A	—	—	—	—	933 (2)	1,384 (2)	435 (2)
17A	—	—	—	—	5,160 (3)	16,657 (3)	1,510 (3)
18A	—	—	—	—	2,245 (2)	8,120 (2)	112 (2)
19A	—	—	—	—	—	—	—
20A	0 (2)	0 (2)	0 (2)	0 (2)	—	—	—
25A	0 (2)	0 (2)	0 (2)	4 (2)	—	—	—
26A	0 (3)	8,067 (3)	112 (3)	9 (3)	—	—	—
27A	0 (2)	31 (2)	0 (2)	0 (2)	—	—	—
35A	0 (2)	185 (2)	365 (2)	4,600 (2)	—	—	—
39A	26 (2)	0 (2)	1,075 (2)	188 (2)	—	—	—

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
40A	22 (2)	22 (2)	4 (2)	0 (2)	41 (2)	18 (2)	1 (2)
53	25 (1)	90 (1)	1,600 (1)	0 (1)	660 (1)	90 (1)	700 (1)
54	108 (1)	180 (1)	1,500 (1)	0 (1)	260 (1)	85 (1)	600 (1)
55	9 (1)	10 (1)	154 (1)	0 (1)	3 (1)	0 (1)	6 (1)
56	0 (1)	0 (1)	52 (1)	0 (1)	7 (1)	0 (1)	2 (1)
57	25 (1)	9 (1)	120 (1)	0 (1)	10 (1)	0 (1)	5 (1)
58	0 (1)	0 (1)	2 (1)	0 (1)	27 (1)	0 (1)	0 (1)
59	0 (1)	0 (1)	0 (1)	0 (1)	21 (1)	5 (1)	0 (1)
62	7 (1)	5 (1)	9 (1)	0 (1)	0 (1)	0 (1)	1 (1)
64	170 (1)	53 (1)	81 (1)	0 (1)	34 (1)	0 (1)	8 (1)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
40A	0 (2)	10 (2)	0 (2)	0 (2)	—	—	—
53	36 (1)	1,200 (1)	100 (1)	0 (1)	—	—	—
54	22 (1)	500 (1)	56 (1)	0 (1)	—	—	—
55	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
56	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
57	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
58	3 (1)	0 (1)	0 (1)	0 (1)	—	—	—
59	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
62	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
64	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
65	6 (1)	12 (1)	2,400 (1)	0 (1)	260 (1)	0 (1)	620 (1)
68	0 (1)	11 (1)	22,000 (1)	0 (1)	31 (1)	88 (1)	1,600 (1)
73	0 (1)	0 (1)	310,000 (1)	0 (1)	32 (1)	0 (1)	7,000 (1)
74	0 (1)	0 (1)	400,000 (1)	0 (1)	22 (1)	21 (1)	5,000 (1)
75	0 (1)	0 (1)	40,000 (1)	0 (1)	130 (1)	0 (1)	32,000 (1)
83	0 (1)	0 (1)	0 (1)	0 (1)	5 (1)	0 (1)	0 (1)
84	0 (1)	0 (1)	1 (1)	0 (1)	4 (1)	0 (1)	2 (1)
89	1,400 (1)	2,700 (1)	1,100 (1)	0 (1)	400 (1)	800 (1)	2,300 (1)
93	0 (1)	0 (1)	3 (1)	0 (1)	14 (1)	0 (1)	1 (1)
94	0 (1)	8 (1)	1 (1)	0 (1)	6 (1)	0 (1)	1 (1)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
65	0 (1)	40 (1)	88 (1)	0 (1)	—	—	—
68	0 (1)	15 (1)	36 (1)	0 (1)	—	—	—
73	0 (1)	15 (1)	160 (1)	0 (1)	—	—	—
74	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
75	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
83	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
84	0 (1)	0 (1)	22 (1)	0 (1)	—	—	—
89	1,000 (1)	15,000 (1)	650 (1)	0 (1)	—	—	—
93	0 (1)	600 (1)	0 (1)	0 (1)	—	—	—
94	0 (1)	470 (1)	0 (1)	0 (1)	—	—	—

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
95	0 (1)	0 (1)	1 (1)	0 (1)	13 (1)	0 (1)	2 (1)
96	2 (1)	0 (1)	7 (1)	0 (1)	8 (1)	12 (1)	12 (1)
97	0 (1)	0 (1)	3 (1)	0 (1)	18 (1)	0 (1)	11 (1)
98	0 (1)	7 (1)	0 (1)	100 (1)	0 (1)	0 (1)	2 (1)
105	* (1)	* (1)	0 (1)	* (1)	5,400 (1)	* (1)	23 (1)
107	0 (1)	0 (1)	110 (1)	700 (1)	600 (1)	63 (1)	110 (1)
109	0 (1)	0 (1)	4,500 (1)	2,400 (1)	9,400 (1)	630,000 (1)	55,000 (1)
110	0 (1)	23 (1)	110 (1)	250 (1)	19 (1)	1,200 (1)	1,400 (1)
111	0 (1)	0 (1)	4 (1)	250 (1)	33 (1)	150 (1)	3 (1)
112	0 (1)	5 (1)	4 (1)	310 (1)	6 (1)	65 (1)	3 (1)

Note: Number in brackets equals the number of samples in average.

* Report notes that these results not tabulated because of large interferences.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
95	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
96	3 (1)	0 (1)	11 (1)	18 (1)	—	—	—
97	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
98	0 (1)	0 (1)	0 (1)	0 (1)	—	—	—
105	0 (1)	5,400 (1)	8,300 (1)	*	—	—	—
107	0 (1)	1,800 (1)	5,800 (1)	0 (1)	—	—	—
109	72,000 (1)	100 (1)	4,100 (1)	111,000 (1)	—	—	—
110	67 (1)	96 (1)	7,600 (1)	200 (1)	—	—	—
111	0 (1)	500 (1)	720 (1)	0 (1)	—	—	—
112	0 (1)	190 (1)	540 (1)	0 (1)	—	—	—

Note: Number in brackets equals the number of samples in average.

* Report notes that these results not tabulated because of large interferences.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
113	11,000 (1)	6,400 (1)	0 (1)	520 (1)	240 (1)	400 (1)	21 (1)
116	0 (1)	0 (1)	0 (1)	0 (1)	5 (1)	0 (1)	5 (1)
117	0 (1)	0 (1)	4 (1)	0 (1)	13 (1)	0 (1)	2 (1)
118	0 (1)	0 (1)	2 (1)	0 (1)	0 (1)	0 (1)	0 (1)
121	0 (1)	28 (1)	4 (1)	0 (1)	50 (1)	500 (1)	0 (1)
136	15 (1)	200 (1)	20 (1)	0 (1)	18,000 (1)	150 (1)	17 (1)
137	18 (1)	97 (1)	2 (1)	0 (1)	52 (1)	640 (1)	1 (1)
SP-5A	0 (1)	0 (1)	6 (1)	0 (1)	0 (1)	25 (1)	3 (1)
SP-6A	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
SP-7A	11 (1)	25 (1)	0 (1)	0 (1)	4 (1)	580 (1)	0 (1)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
113	8 (1)	6,000 (1)	140 (1)	42 (1)	—	—	—
116	8 (1)	0 (1)	730 (1)	12 (1)	—	—	—
117	0 (1)	0 (1)	1,600 (1)	53 (1)	—	—	—
118	0 (1)	0 (1)	51 (1)	0 (1)	—	—	—
121	0 (1)	150 (1)	16 (1)	0 (1)	—	—	—
136	0 (1)	600 (1)	130 (1)	0 (1)	—	—	—
137	0 (1)	3,000 (1)	150 (1)	6 (1)	—	—	—
SP-5A	100 (1)	0 (1)	0 (1)	0 (1)	—	—	—
SP-6A	13 (1)	0 (1)	800 (1)	0 (1)	—	—	—
SP-7A	1,700 (1)	20 (1)	3,900 (1)	260 (1)	—	—	—

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
SP-8A	12,590 (1)	9,285 (1)	640 (1)	0 (1)	—	1,345 (1)	—
CW-1A	0 (1)	67 (3)	33 (2)	0 (3)	22 (1)	76 (3)	0 (1)
CW-1B	3 (2)	2 (4)	4 (4)	0 (5)	10 (3)	1 (5)	3 (3)
CW-2A	1,257 (5)	1,975 (10)	934 (7)	496 (11)	1,929 (7)	207 (11)	1,617 (6)
CW-3A	10 (3)	7 (6)	1 (5)	0 (7)	3 (4)	0 (7)	7 (4)
CW-4A	8 (2)	3 (4)	1 (4)	0 (5)	0 (4)	0 (5)	1 (4)
CW-6A	11 (5)	913 (9)	1 (6)	0 (9)	2 (7)	1,646 (9)	0 (5)
CW-6B	29 (1)	52 (1)	2 (2)	0 (2)	1 (2)	455 (2)	0 (2)
CW-7A	2 (3)	1 (6)	0 (6)	14 (7)	0 (5)	0 (7)	0 (5)
CW-8A	1 (3)	0 (6)	1 (7)	0 (7)	9 (7)	4 (7)	10 (7)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
SP-8A	—	—	—	—	—	—	—
CW-1A	—	—	—	0 (2)	1,400 (1)	4,200 (1)	430 (1)
CW-1B	0 (1)	56 (1)	0 (1)	0 (3)	1,025 (2)	1,350 (2)	270 (2)
CW-2A	200 (1)	5,000 (1)	320 (1)	30 (6)	2,546 (4)	3,725 (4)	600 (4)
CW-3A	0 (1)	0 (1)	0 (1)	0 (3)	26,967 (3)	5,567 (3)	2,057 (3)
CW-4A	0 (1)	0 (1)	0 (1)	0 (3)	685 (3)	1,565 (3)	491 (3)
CW-6A	—	—	—	5 (6)	3,510 (4)	13,975 (4)	956 (4)
CW-6B	2 (1)	540 (1)	83 (1)	22 (1)	1,100 (1)	550 (1)	86 (1)
CW-7A	0 (1)	0 (1)	0 (1)	0 (4)	317 (3)	1,914 (3)	144 (3)
CW-8A	1 (1)	0 (1)	0 (1)	0 (3)	8,110 (4)	2,668 (4)	1,250 (4)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
CW-9A	21 (1)	62 (1)	7 (2)	5 (2)	0 (2)	506 (2)	18 (2)
CW-10A	2 (1)	5 (1)	2 (2)	6 (2)	0 (2)	35 (2)	0 (2)
CW-11A	0 (1)	3 (1)	4 (2)	0 (2)	22 (2)	0 (2)	6 (2)
CW-13A	1 (1)	4 (1)	1 (2)	0 (2)	0 (2)	13 (2)	0 (2)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
CW-9A	14 (1)	220 (1)	150 (1)	78 (1)	600 (1)	300 (1)	290 (1)
CW-10A	1 (1)	10 (1)	0 (1)	5 (1)	4,500 (1)	15,000 (1)	1,100 (1)
CW-11A	0 (1)	42 (1)	130 (1)	0 (1)	1,000 (1)	4,600 (1)	180 (1)
CW-13A	0 (1)	0 (1)	0 (1)	6 (1)	240 (1)	150 (1)	21 (1)

Note: Number in brackets equals the number of samples in average.

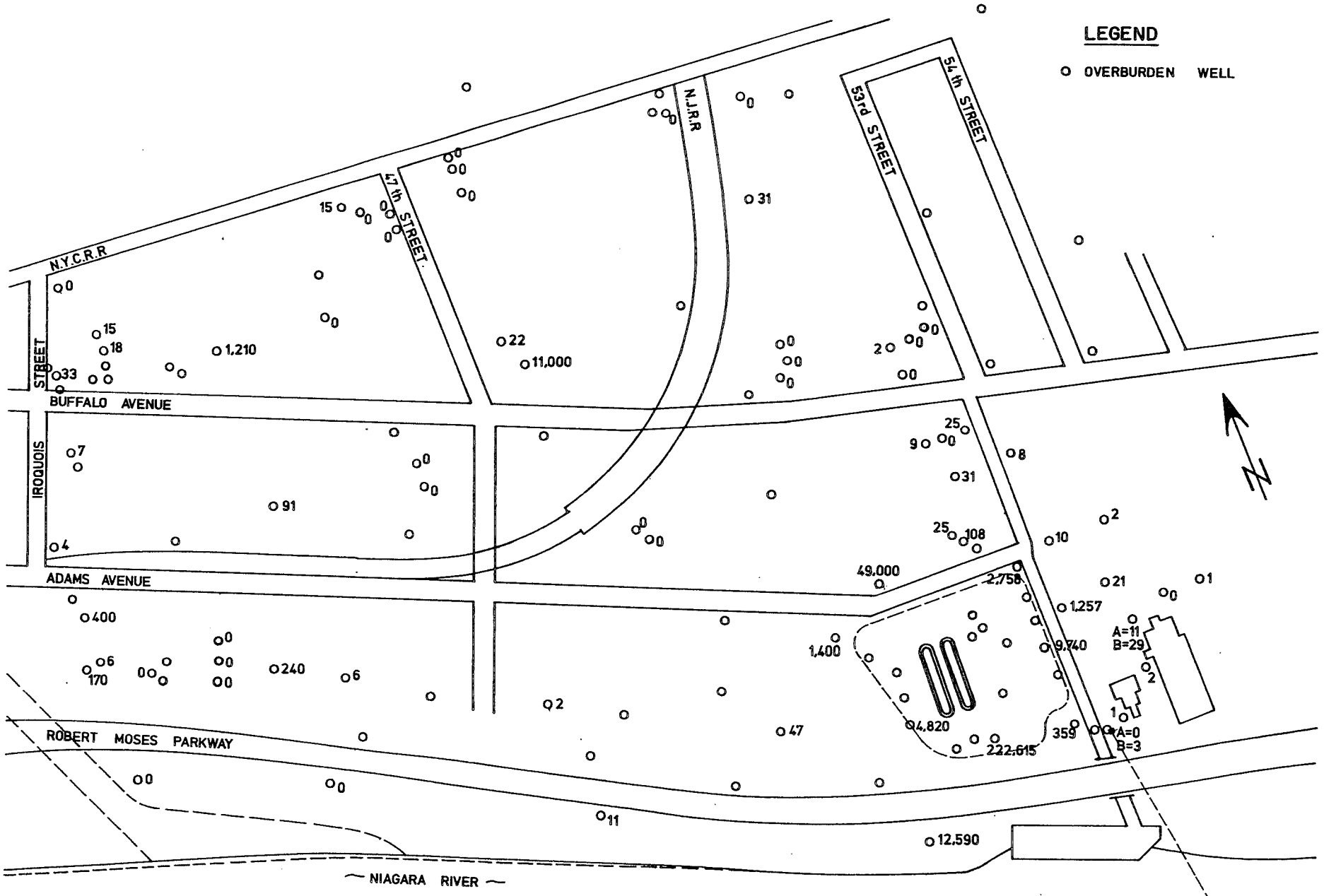


Figure IV-1. Averaged concentrations for tetrachlorobenzenes (ppb) measured in overburden wells.

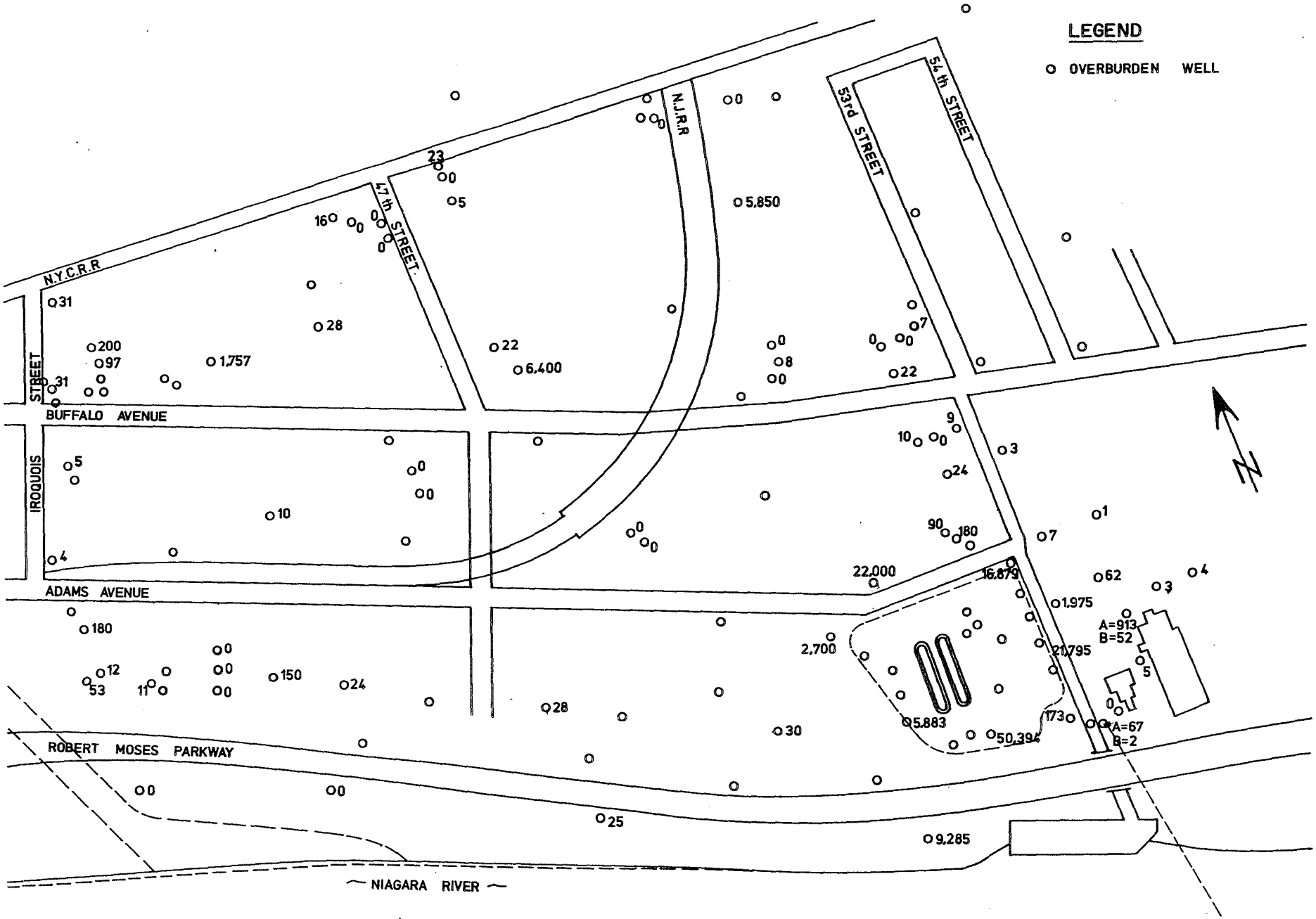


Figure IV-2. Averaged concentrations for trichlorobenzenes (ppb) measured in overburden wells.

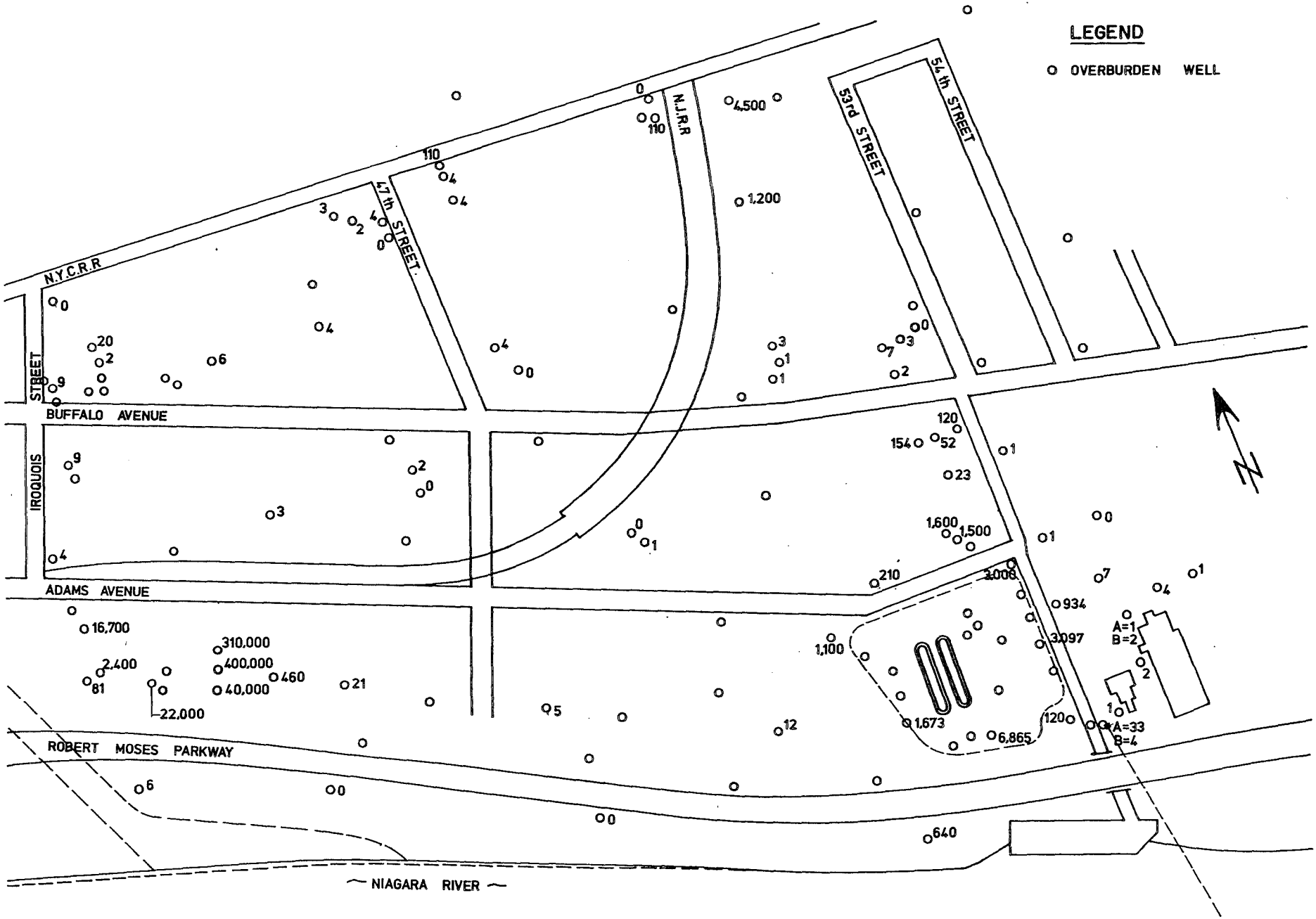


Figure IV-3. Averaged concentrations for trichloroethylene (ppb) measured in overburden wells.

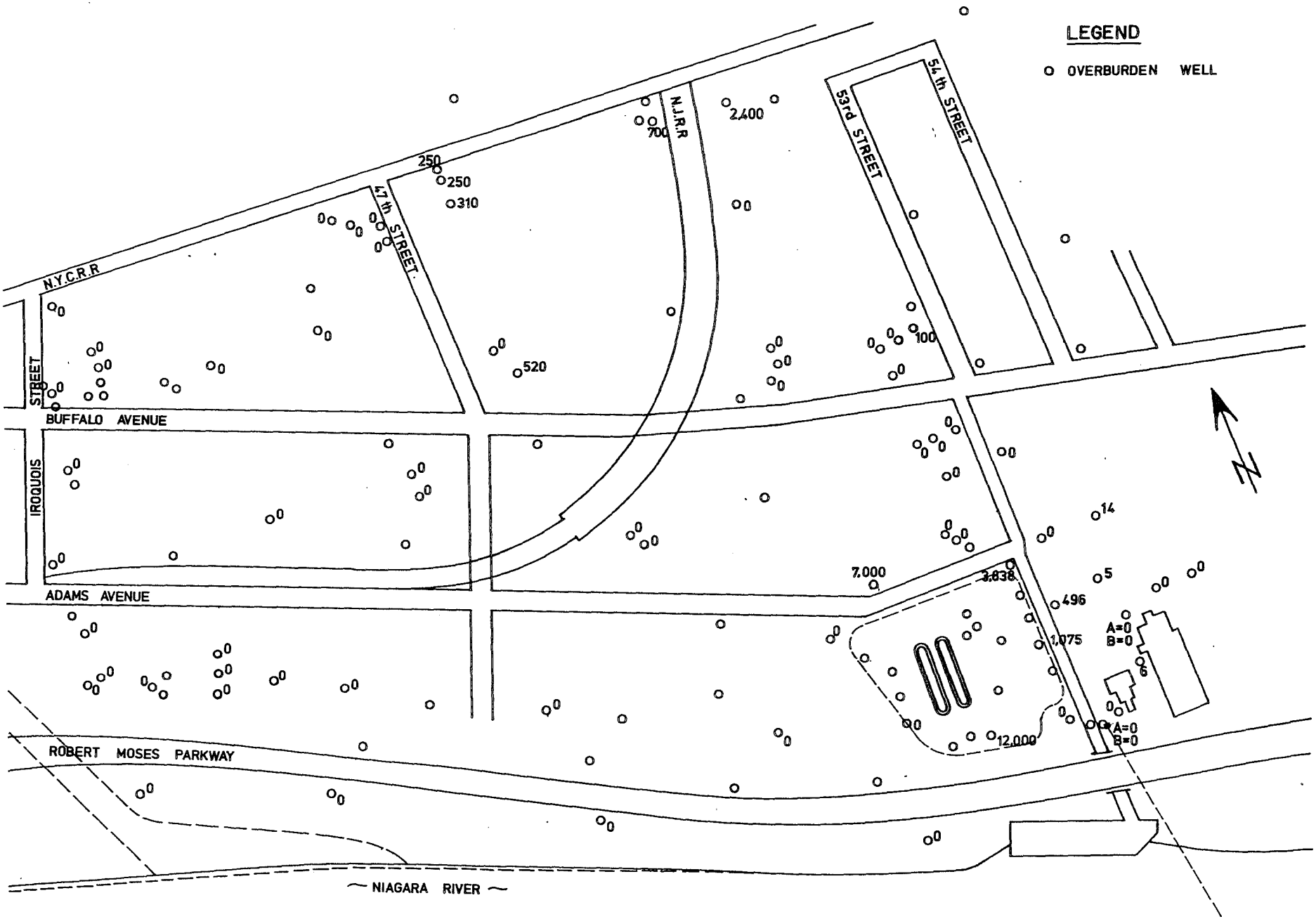


Figure IV-4 Averaged concentrations for hexachlorocyclopentadiene (ppb) measured in overburden wells.

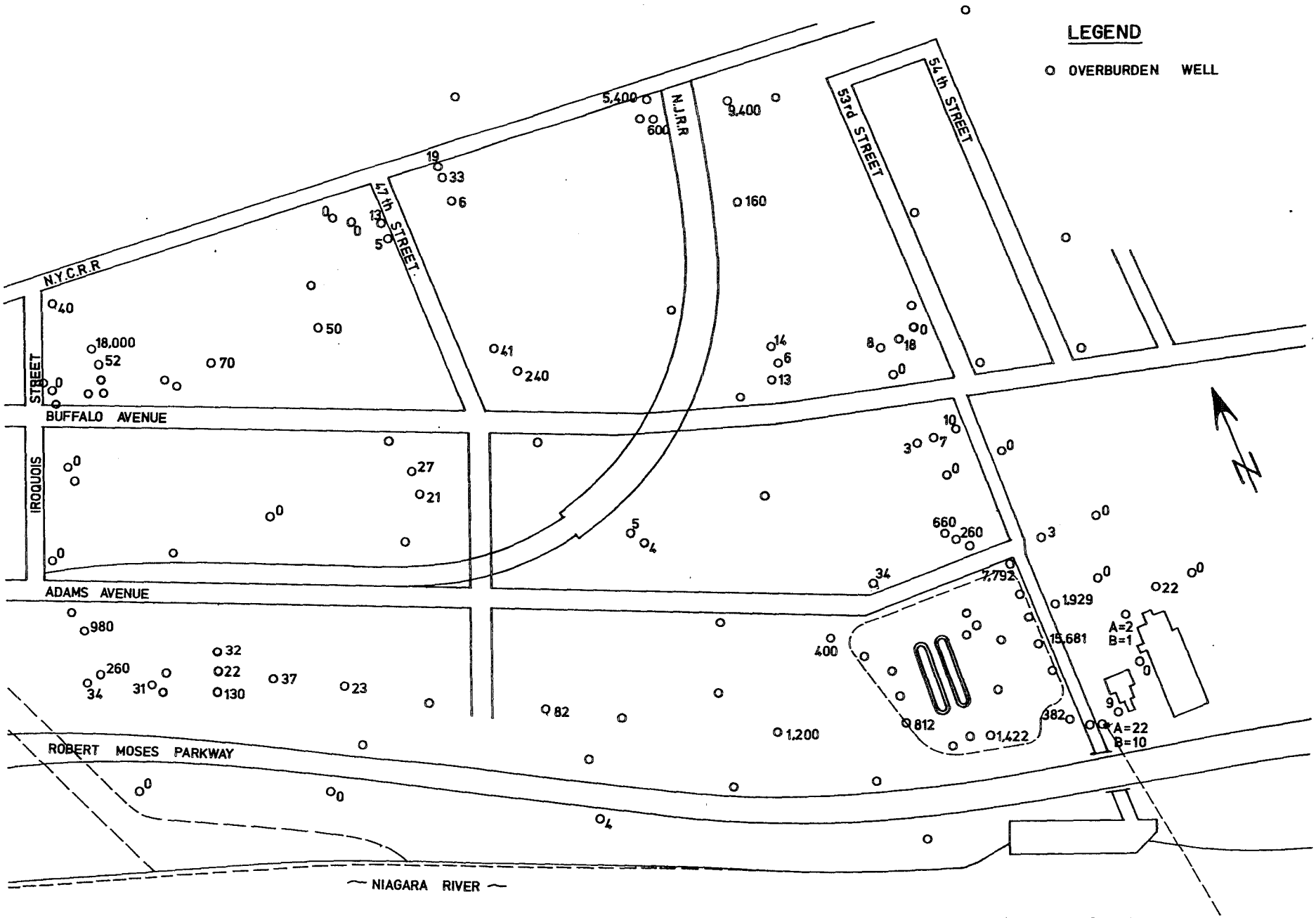


Figure IV-5. Averaged concentrations for toluene (ppb) measured in overburden wells.

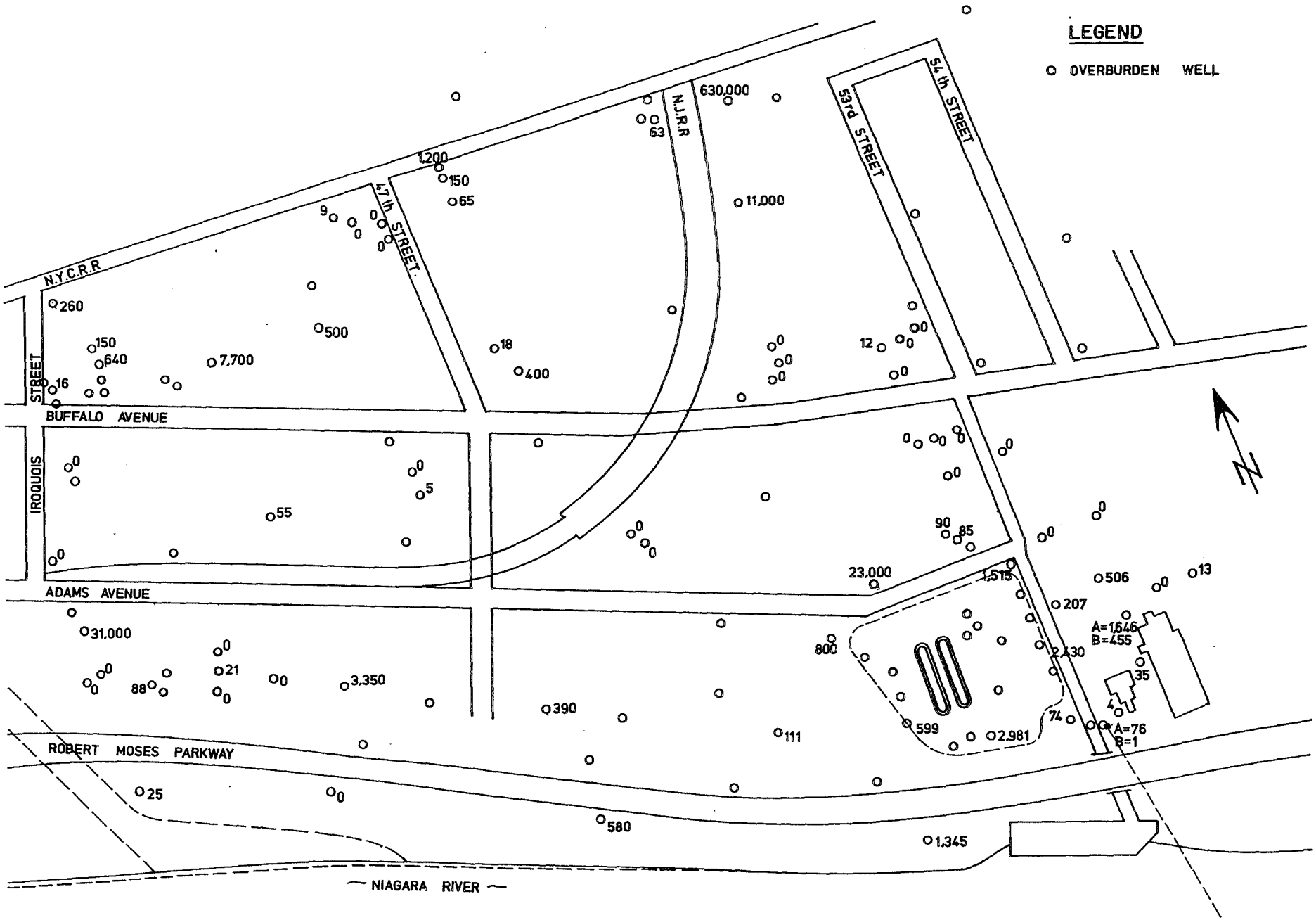


Figure IV-6. Averaged concentrations for dichlorobenzenes (ppb) measured in overburden wells.

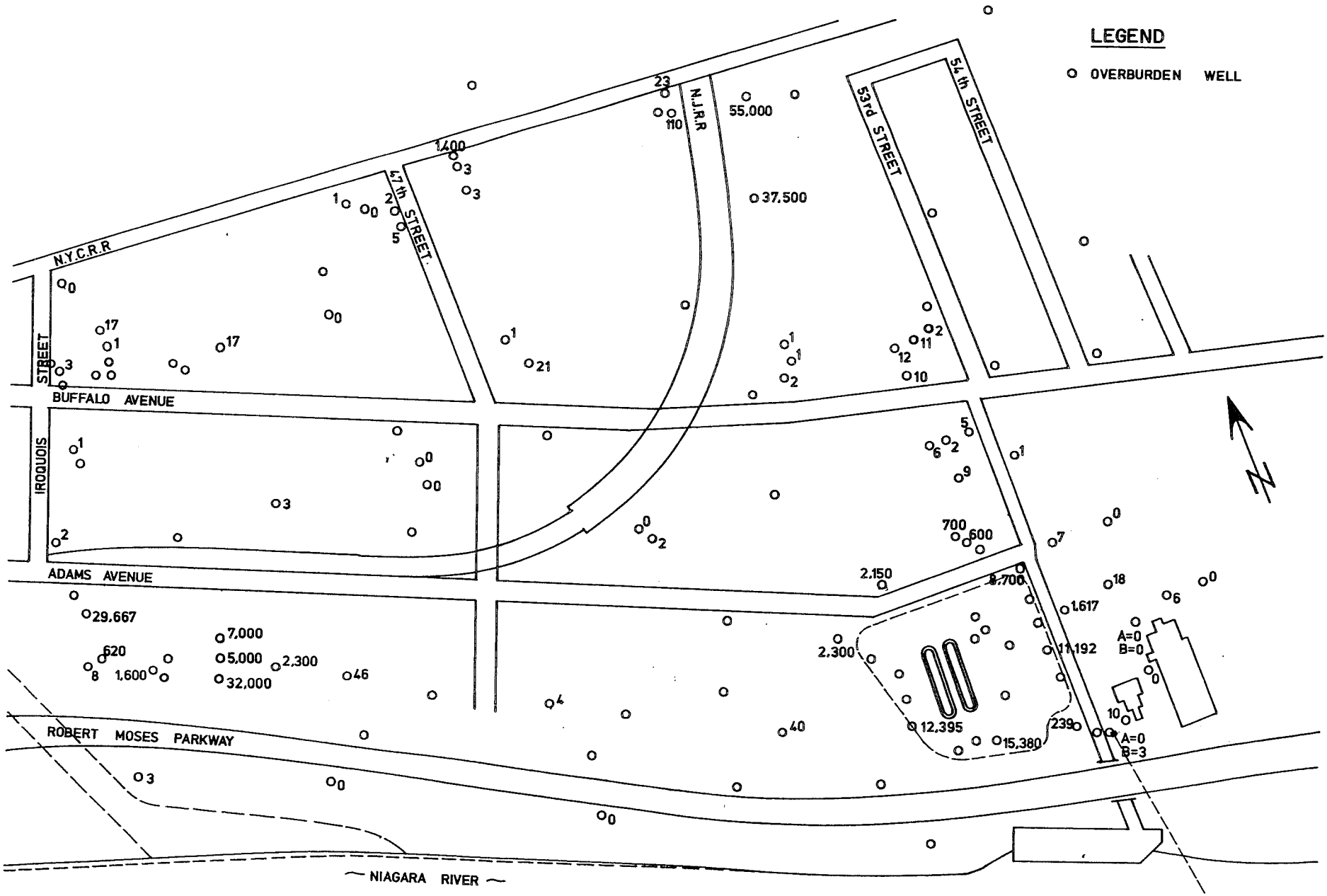


Figure IV-7. Averaged concentrations for tetrachloroethylene (ppb) measured in overburden wells.

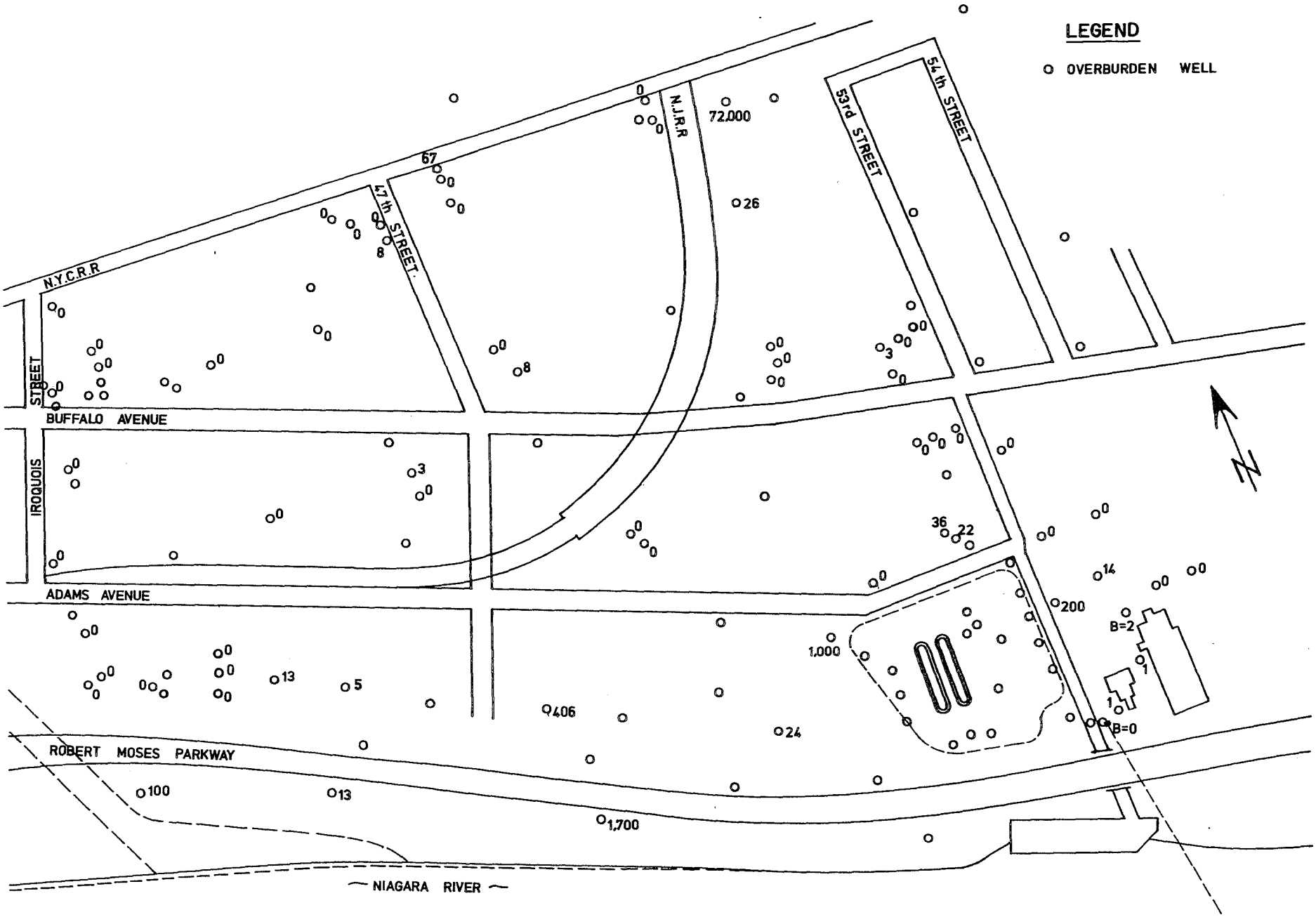


Figure IV-8. Averaged concentrations for chlorobenzotrifluorides (ppb) measured in overburden wells.

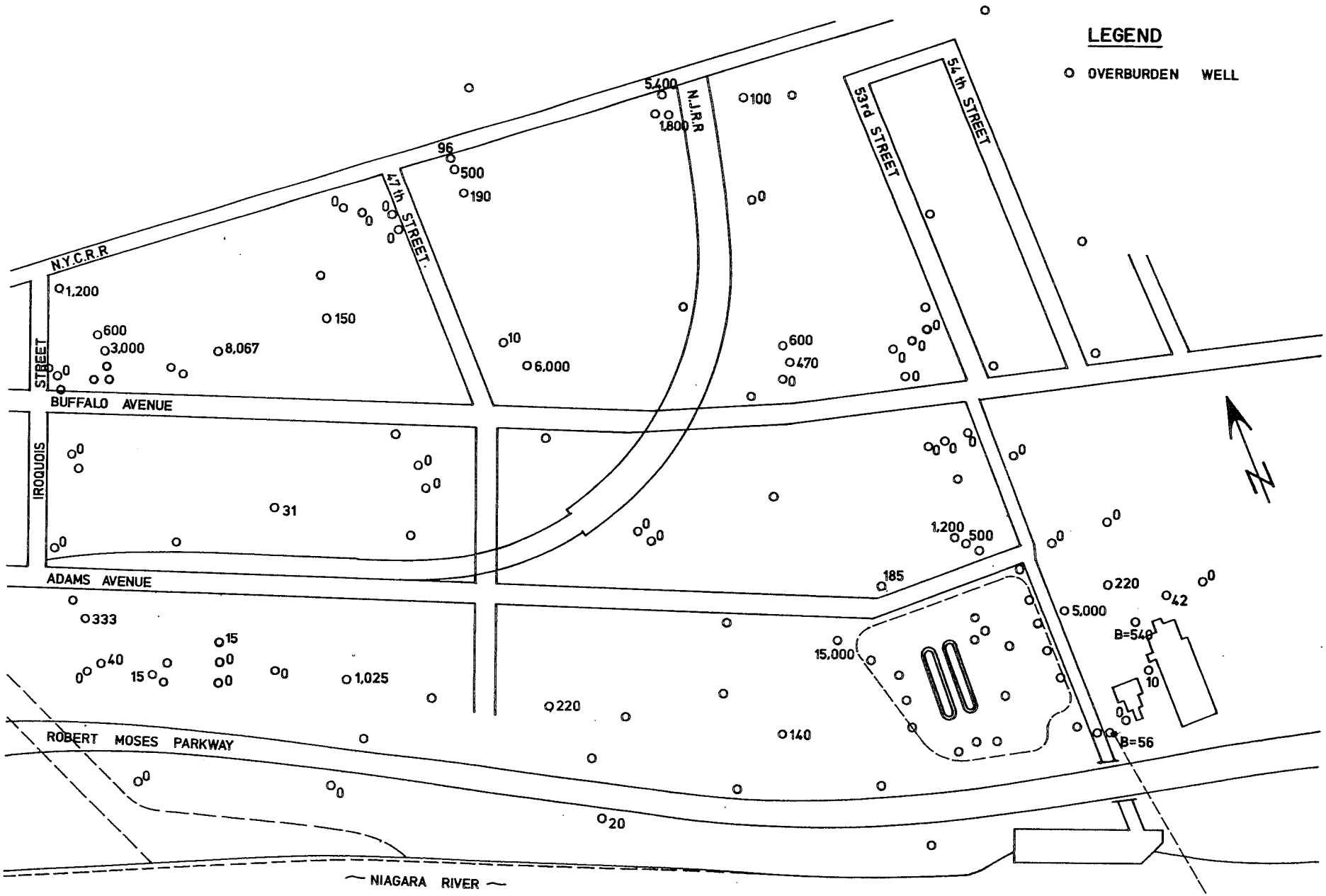


Figure IV-9. Averaged concentrations for monochlorobenzene (ppb) measured in overburden wells.

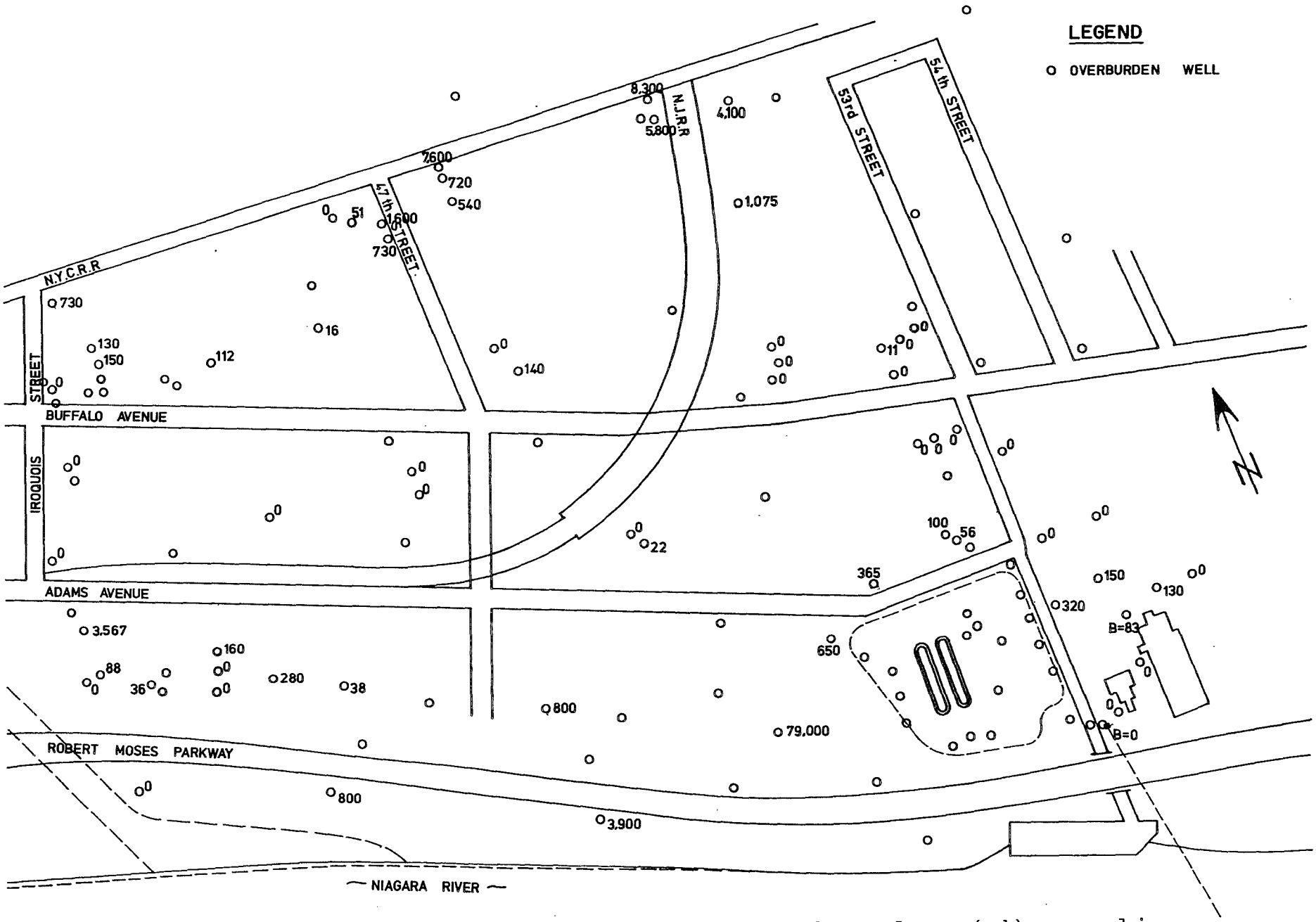


Figure IV-10. Averaged concentrations for chlorotoluenes (ppb) measured in overburden wells.

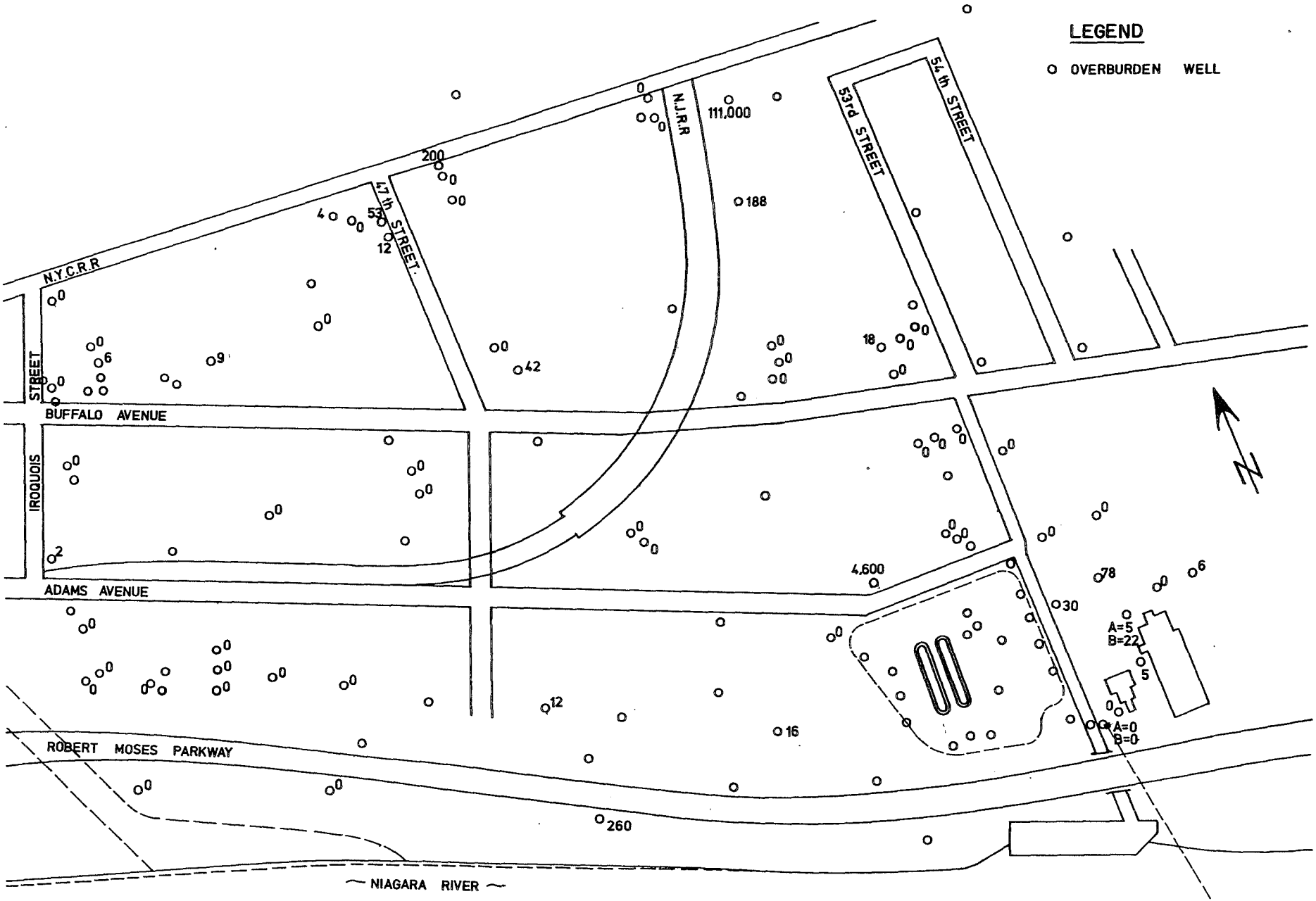


Figure IV-11. Averaged concentrations for dichlorotoluenes (ppb) measured in overburden wells.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Tetrachloro-benzenes (ppb)	Trichloro-benzenes (ppb)	Trichloro-ethylene (ppb)	Hexachloro-cyclo-pentadiene (ppb)	Toluene (ppb)	Dichloro-benzenes (ppb)	Tetrachloro-ethylene (ppb)
16	195 (2)	5 (7)	1 (6)	0 (7)	0 (5)	0 (7)	5 (5)
17	57 (3)	12 (7)	1 (6)	0 (7)	1 (4)	0 (7)	6 (4)
18	1,885 (1)	1,115 (1)	6,270 (1)	0 (1)	—	801 (1)	—
SP-8	7,927 (2)	4,133 (2)	6,455 (2)	0 (2)	—	656 (2)	—
CW-5	31 (4)	20 (8)	5 (7)	0 (8)	19 (5)	0 (8)	46 (5)
CW-7	63 (3)	23 (6)	112 (5)	0 (6)	1 (3)	21 (6)	132 (3)

Note: Number in brackets equals the number of samples in average.

ORGANICS AND METAL CONSTITUENTS ANALYZED AT S-AREA
(from Arthur D. Little, 1980a, c, d and 1982)

Well No.	Chlorobenzo-trifluorides (ppb)	Monochloro-benzene (ppb)	Chlorotoluenes (ppb)	Dichloro-toluenes (ppb)	Copper (ppb)	Lead (ppb)	Chromium (ppb)
16	—	—	—	—	400 (3)	1,121 (3)	112 (3)
17	—	—	—	—	687 (3)	1,377 (3)	113 (3)
18	—	—	—	—	—	—	—
SP-8	—	—	—	—	—	—	—
CW-5	—	—	—	0 (5)	353 (3)	340 (3)	32 (3)
CW-7	—	—	—	3 (4)	459 (2)	1,370 (2)	14 (2)

Note: Number in brackets equals the number of samples in average.

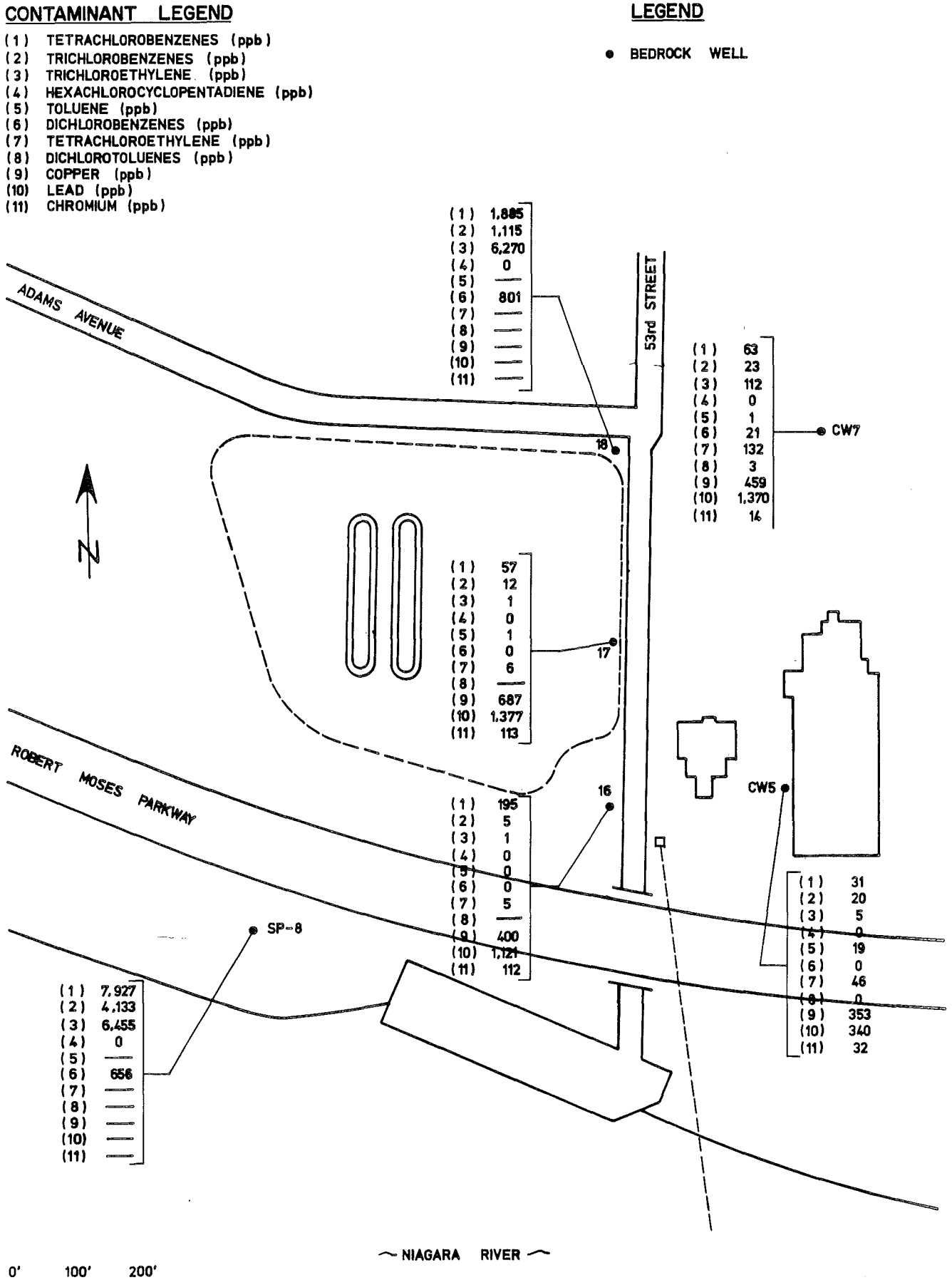


Figure IV-12.
Averaged concentrations for organics (ppb) and metals (ppb) measured in wells screened in the upper portion of the Lockport Dolomite (or across the upper Lockport and lowermost overburden; see Table 4.)

APPENDIX V

Water Treatment Plant

WATER TREATMENT PLANT

(adapted partially from NYPIRG, 1981)

The Water Treatment Plant (WTP), located at 53rd Street and Buffalo Avenue, was originally constructed in 1914. Since then, it has been expanded several times. The original plant, known as 1B, contained a total of 16 one million gallon per day (MGD) capacity rapid sand filters. Raw water was drawn from an intake located in the east branch (Tonawanda Channel or East Channel) of the Niagara River and pumped to the plant by a single pump station (see Figure 18 for plan of WTP facilities). By 1935, eight additional 2 MGD capacity sand filters were installed. In addition, a new river intake tunnel, connected to a vertical shore shaft, was constructed. The shore shaft was connected to the Pump Station via a 54" underground steel line. In times of heavy pumping, the raw water supply was supplemented using a shore pump installed in the shore shaft serving a 20" cast iron line. In 1943, a four million gallon finished water reservoir was added. By approximately 1953, an entirely new filtration plant, designated 1A, was constructed. It was equipped with eight 4 MGD capacity gravity-fed, rapid flow sand filtration units, four underground sedimentation basins, a chemical pretreatment building and four flocculation basins. At the same time, a new pump station and water intake structure were completed. The intake has six 10' x 7' openings in the downstream faces of its hexagonal shape and is located in the Emerald Channel (Figure 2). Water is drawn into the intake and conveyed via a ten foot vertical shaft which extends to a 6' x 6.5' horizontal tunnel 30' below the river bottom. The tunnel runs 3,400 feet to an old intake (in the Tonowanda Channel - Figure 2) and then continues 1,725' (Camp, Dresser & McKee, 1979a) as a 5' X 5.5' tunnel until it connects to the shore shaft. The eight foot wide shore shaft delivers raw water to the Pump Station forebay via a 115' 66" cast steel pipe (Figure 18). The Pump Station is equipped with four low service pumps with a combined capacity of 90 MGD. They deliver raw water

via two 36" lines to the chemical pretreatment building's A and B chemical contact channel. The water flows by gravity into the flocculation basins. There, the water remains for approximately 2.5 hours before passing through the rapid sand filters augmented with 6" of anthracite. After chlorination, the combined effluents of the A and B plants flow through a 2 million gallon clear well and enter the Pump Station. Six high service pumps with a combined 115 MGD capacity deliver the water to the distribution system at 90 pounds per square inch pressure. (Matthews, R.R., Carr, C.W., Stanish, S.N. (1979) as referenced in NYPIRG (1981)).

Little has changed since the plant went into operation. The basic treatment system is the same, with only a few significant changes. The raw water is shock chlorinated after it is pumped from the river, then alum and cationic polymer are added to facilitate flocculation. Powdered activated carbon is added to absorb organic chemicals. The treated water then passes through one stage flocculation, sedimentation and rapid sand filtration. Finally, the water is post chlorinated, fluoridated, and supplied to consumers. (Matthews, R.R., Carr, C.W., Stanish, S.N., (1979) as referenced in NYPIRG (1981)).

Contaminants/Sediment

Investigations by various firms and agencies concerning the organic contaminants found in the forebays, shore shaft and intake tunnel have resulted in the following observations:

1. The contaminated overburden ground water in S-Area extends onto the WTP site. No attempts have been made to relate the 2' layer of municipal refuse on the WTP site to the ground water contamination.

2. The WTP intake tunnel has both designed and non-designed weep holes and joints (Conestoga-Rovers and Assoc., 1979a) and has substantial leakage both

in and out of the tunnel from the shore shaft to a point 1100 feet along the tunnel located below the Niagara River (Camp, Dresser and McKee, 1980a).

3. An abandoned 54" diameter steel pipe is located between the shore shaft and the old pump house running parallel to 53rd Street (Figure 15) (City of Niagara Falls, 1980). The pipe has a concrete plug at a point approximately 18 feet from the shore shaft and a steel plate where it enters the shore shaft. The concrete plug was installed in response to the discovery of contaminants in the forebay in 1969 and the steel plate was installed at a latter date.

4. The intake tunnel and the abandoned 54" diameter steel pipe are both constructed on gravel beds (Camp, Dresser and McKee, 1979a; City of Niagara Falls, 1980) which provide a relatively high permeability path for seepage.

5. Measurements of the bedrock piezometric levels, the intake tunnel hydraulic grade line and Niagara River level along the intake tunnel were made in 1980 (Camp, Dresser and McKee, 1980a). Locations in the tunnel were at the shore shaft and at 500 and 1100 feet from the shore shaft along the intake tunnel running beneath the Niagara River. These measurements indicated the following:

   (i) The Niagara River level is always greater than both the piezometric levels in the bedrock and the hydraulic grade line.

(ii) At the shore shaft, the piezometric levels in the bedrock are always greater than the hydraulic grade line. The pressure differential created results in ground water flow into the intake tunnel, at all times, at this location.

(iii) At 500 feet along the intake tunnel from the shore shaft, the pressure differentials between the hydraulic grade line in the tunnel and the bedrock piezometric levels fluctuate. At times ground water flow is into the tunnel from the bedrock and at other times flow is from the tunnel to the bedrock.

(iv) At 1100 feet, pressure differentials indicate that flow occurs from the tunnel into the bedrock at all times.

(v) Piezometric levels in the bedrock and the hydraulic grade line in the tunnel are both very responsive to changes in the level of the Niagara River. When river levels rise or fall, both the piezometric levels and the hydraulic grade line respond as a direct function of river level changes.

(vi) Piezometric levels in the bedrock at 1100 feet are always higher than at 500 feet.

(vii) Comparing piezometric levels in the bedrock at the shore shaft and at 500 feet along the intake tunnel, it can be seen that the hydraulic gradient often changes direction. That is, at times flow is towards the shore

shaft from the river while at other times the flow reverses and flows from the shore shaft towards the Niagara River. Pressure differentials at the tunnel-bedrock interface are a function of river level and WTP pumping rates. The river level varies with fluctuating power demand and raw water pumping rates vary with consumption demand. Both of these factors fluctuate on a daily basis causing flow directions in and out of the tunnel to vary considerably with respect to time.

6. In the vicinity of the shore shaft, the distribution of piezometric levels, from highest to lowest is as follows: overburden wells, Niagara River level, bedrock wells and intake tunnel hydraulic grade line (Camp, Dresser and McKee, 1980a). Thus, water in the overburden may flow into the Niagara River, the bedrock, or the intake tunnel. Water in the bedrock may enter the intake tunnel but cannot flow into either the river or the overburden as this would oppose the hydraulic gradients.

7. Contaminants have been detected as organic residues in the shore shaft and in many areas of the water treatment plant facility. Inspection of the treatment facility has revealed that contaminants are not entering the system at any point in the treatment process above the bedrock at elevation 533.3 (Hooker datum) (Camp, Dresser and McKee, 1980a). Thus, contaminants must be entering the treatment facility below the bedrock surface.

8. "There is a strong correlation between fracture density and dip" (Leggette, Brashears and Graham, 1980c), the correlation being that, in the vicinity of the intake tunnel, a greater fracture density occurs in the upper 10 to 15 feet of the Lockport Dolomite than in lower zones. The interface at the bottom of the fractured zone roughly follows the dip of the formation.

9. The intake tunnel is located in the lower, less fractured zones of the Lockport Dolomite.

APPENDIX VI

Assessment of Flow Resulting from Fluid Fluid Density Variations

ASSESSMENT OF FLOW RESULTING FROM DENSITY VARIATIONS

Available data has shown that the regional hydraulic gradient in the upper Lockport Dolomite in the S-Area vicinity is generally in a south to north direction. This gradient is estimated to be about 2×10^{-3} on the Ontario side of the Niagara River, near zero under the river, up to 6.6×10^{-4} at the S-Area site using wells 13 and SP-8 and 4×10^{-2} at Buffalo Avenue north of the S-Area site. Wells 17 and 16 at the S-Area site indicate that, at times, the gradient may be much less or even towards the river in localized areas. Some of the relatively dense liquid wastes disposed at the site have the potential for vertical downward migration into the upper more permeable zone of the Lockport dolomite. Since the bedding planes of the Lockport dolomite dip to the south, the potential for southward migration of these heavier contaminants exists.

The transport of fluids due to density variations was assessed using an approximate method described by Jorgensen et al. (1982). The approach is termed the Hydrostatic method and involves testing for the existence of hydrostatic conditions. The method can be used to develop an inequality in terms of the formation dip gradient α, the hydraulic gradient i, the natural groundwater density ρ_w and the contaminant fluid density ρ_c. In the variable-density system shown in Figure VI-1, the density variation between two wells located a distance L apart is assumed to be linear. Using manometer theory, the pressure $p_{2\ell}$ and p_{2r} can be determined. For flow to occur downdip, then

$$p_{2\ell} > p_{2r}$$

where $$p_{2r} = \rho_w g \{d + (\alpha + i)L\}$$

and $$p_{2\ell} = p_1 + \Delta p_{1-2}$$

$$= \rho_c g d + \left(\frac{\rho_c + \rho_w}{2}\right) g\alpha L$$

For flow to occur downdip, then $p_{2\ell}$ must be greater than p_{2r}. From the above expressions for pressure at wells 1 and 2, one can develop the following equation in terms of the densities:

$$\rho_c > \rho_w\{1 + \left(\frac{2Li}{2d + L\alpha}\right)\}$$

The density of contaminated fluid required to cause flow downdip between a central position (hypothetical well 1) within S-Area and the edge of the Niagara River (hypothetical well 2) was calculated using the following parameter values:

$L = 570$ ft

$i = 6.6 \times 10^{-4}$ ft/ft

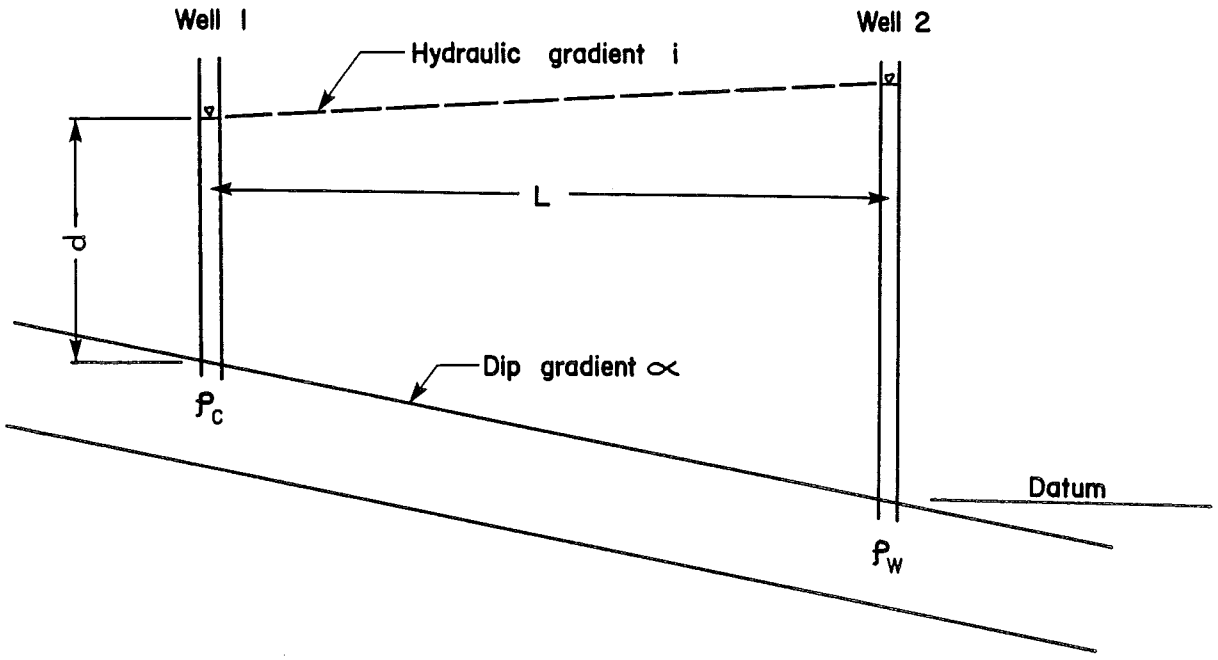
$\alpha = 30$ ft/mile or 5.68×10^{-3} ft/ft

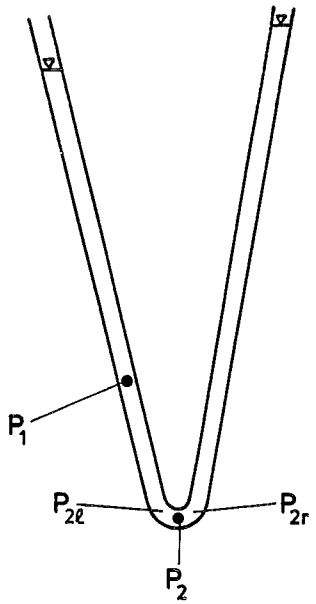
$d = 20.7$ ft (piezometric level-bedrock surface elevation)

Using the above density inequality expression:

$$\rho_c > 1.017\ \rho_w$$

Therefore under the existing conditions at S-Area, and utilizing the assumptions and parameters stated above, it can be inferred that fluids of density greater than 1.017 can migrate, along southward dipping bedding planes, against an opposing hydraulic gradient of 6.6×10^{-4} ft/ft.





EQUIVALENT
MANOMETER
SYSTEM

Figure VI-1 Hydrostatic method for assessment of flow resulting from density variations.