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LOVE CANAL HYDROGEOLOGIC EVALUATION

REPORT TO
NIAGARA RIVER STEERING COMMITTEE
ONTARIO MINISTRY OF THE ENVIRONMENT

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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 this report is to provide the Ministry of the Environment with an independent technical review and interpretation of the hydrogeologic conditions at the Love Canal waste disposal site. It is hoped that this report can be used to assist in the understanding of past and present hydrogeologic conditions and the final development of satisfactory remedial measures for the area.

DATA INTERPRETATION

The data utilized for preparation of this report have been obtained from a number of sources. Attempts have been made to identify source documents via frequent referencing.

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

- Where data from various sources are conflicting, for instance well locations, attempts have been made to clarify the discrepancies. In general, data from the United States Environmental Protection Agency (USEPA) 1980 monitoring program have been used most extensively.

- 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 for some of the contoured figures that there is limited data and that the validity of developing contours from the limited data may be questioned. The general patterns established by the contouring are useful, however, in developing an overall hydrogeologic interpretation.

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1.0 BACKGROUND

Love Canal, a former waste disposal site of the Hooker Chemicals and Plastics Corporation (HCPC), is located in the eastern portion of the City of Niagara Falls, New York (Figure 1). More precisely, the Canal and its right of way are situated between 97th Street on the west and 99th Street on the east (Figure 2). Colvin Boulevard forms the northern boundary of the site with Frontier Avenue located on the southern extremity. Read and Wheatfield Avenues are parallel to Colvin Boulevard dividing the Canal property into northern, central and southern sections as illustrated in Figure 2.

In response to resident complaints, the first of several federal and state sampling programs in the Love Canal vicinity was initiated in the fall of 1976. Partially as a result of these studies the site was declared a threat to the public health and subsequently a presidential state of emergency order was issued for the Love Canal area. This was followed by evacuation of over 2000 residents from the Canal area, and implementation of remedial measures directed at containing the migration of contaminants and collection of those contaminants which had seeped from the Canal.

The proximity of Love Canal to the Niagara River, an international boundary waterway, has resulted in concern by Canadian governmental and regulatory agencies. The following report has been prepared to provide hydrogeologic technical support to the Ontario Ministry of the Environment's evaluation of the possible effects of the Love Canal on Niagara River water quality.

1.1 History of Love Canal

The Canal first came into existence in the 1890's for the purpose of diverting water from the Niagara River for use in electrical power generation. Various attempts at completing the Canal were unsuccessful and the project was abandoned by 1910. For the next 30 years, the Canal was virtually unaltered. Aerial photographs taken in 1938 indicate that the Canal was open and contained some water (USEPA, 1982). In 1942, Hooker began using the site for the disposal of chemical process wastes. Hooker discontinued dumping into the Canal in 1952 and a large portion of the Canal remained unfilled (Hooker, 1979a). The approximate boundary of the excavated Canal is outlined on Figure 2.

Subsequent to waste disposal operations, a series of activities at the site gradually led to migration of chemicals away from the immediate Canal site. The Love Canal property was acquired in 1953 by the Niagara Falls Board of Education. The construction of a school on 99th Street (see Figure 2) was completed in 1955. The school was constructed without a basement but with a drain system surrounding the foundation. The drain system was later connected to a storm sewer on 99th Street. In 1958, the City of Niagara Falls constructed a sanitary sewer through the site at a depth of about 10 feet along the proposed Wheatfield Avenue. A storm sewer was installed under Read Avenue in 1960. This sewer was connected from a catch basin located east of the Canal and flowed westerly to a trunk sewer located under 99th Street. Zuesse (1981) also reports the presence of a privately installed catch basin which was installed by a 97th Street homeowner.

In 1968, the State of New York Department of Transportation (NYS DOT) encountered buried chemical wastes while relocating Frontier Avenue across the southern portion of the Canal. At NYS DOT's request, Hooker agreed to remove 40 truckloads of wastes and soil from the area in which wastes were encountered (USEPA, 1982). Also at this time (1968), a storm sewer was installed under the new Frontier Avenue location.

The years of 1975 and 1976 recorded much higher than average precipitation. In the fall of 1976, a number of problems were reported by Love Canal area residents. These included surfacing of drums and the presence of highly contaminated water (visually apparent) which ponded on the ground surface. The volatilized chemicals and the chemical fumes originating from sewer manholes were cited by residents as contributing to both discomfort and illness. Oily residues accumulated in some basement sumps and there was physical evidence of chemical infiltration through the foundation walls of some houses located adjacent to the Canal (USEPA, 1982).

During late 1978 and early 1979, a barrier drain system was constructed parallel to, and on both sides of, the southern portion of the Canal. The barrier drain system was constructed by excavating a trench 12 to 15 feet deep, installing perforated tiles one foot above the trench bottom, and covering the tiles with 2 feet of uniformly sized gravel and backfilling the trench with sand (USEPA, 1982). Leachate collected was treated at an on-site facility. In 1979, the barrier drain system was extended to include the southern boundary and the central and northern portions of the Canal area. In the northern portions, the barrier drain system was installed at up to 18 feet deep. In addition, lateral drains were constructed between the perimeter drain system and the former Canal. A clay cap was installed over the Canal area to minimize infiltration and the release of volatile organics.

In 1980, USEPA was directed to conduct a comprehensive environmental monitoring study at Love Canal. The results of this study have been published in USEPA (1982).

1.2 Waste Disposal Operations

Hooker commenced disposal of chemical process wastes into the Canal in 1942 under an agreement with the Niagara Power and Development Corporation. The exact extent of the Canal when Hooker began its disposal operations is uncertain. USEPA (1982) state that according to newspaper reports, the Canal was intended to be 80 feet wide at the top, 40 feet wide at the base and 30 feet deep. Hooker (1979a) reported that the Canal was approximately 60 feet wide and 3,000 feet long with the southern most edge of the site located about ¼ mile north of the Niagara River. Hooker began its landfill operations at the north end of the site and by 1946 had moved to the south end (Hooker, 1979a). The southern portion of the original excavation was not as wide as the northern section and consequently Hooker enlarged the southern section of the Canal both in width and depth.

The Canal was filled with water when Hooker began disposing of wastes. Hooker states that the disposal operation consisted of sectioning off portions of the Canal by constructing dams across the Canal using the originally excavated material and later using fly ash brought from its Niagara Falls plant. Hooker (1979a) indicates that the drummed wastes were deposited into these sections after the water had been removed. Aerial photographs taken throughout the period of active waste disposal support Hooker's claim that they constructed dikes across the Canal before disposing of their wastes. After placing the wastes within these cells, Hooker states that they were covered with excavated material and subsequently compacted (Hooker, 1979a). Hooker also stated that a minimum of 4 feet of clay was placed over the fill (Zuesse, 1981).

During the period of active chemical waste disposal from 1942 until 1952, Hooker estimates it disposed of 21,800 tons of various chemical wastes. Table 1 presents an inventory of the wastes disposed of in the Canal. This information was abstracted from Hooker correspondence (Hooker, 1978) and reported in Interagency Task Force on Hazardous Wastes (1979) and in Hooker (1979b). Hooker states that this information was obtained using (or estimating when unavailable) production tonnage figures and estimating a residue factor for the process being used. In presenting the estimates, Hooker (1978) noted that the tabulation was based on a very limited amount of documented information and stated "...the results of calculations should not be construed to have a high degree of accuracy. They should only be interpreted as our best efforts to describe what might have occurred in the distant past."

In addition to Hooker wastes, it is stated that the city of Niagara Falls used the Canal for the disposal of municipal refuse as early as 1953 (Hooker, 1979a). USEPA (1982) and Calspan (1977) indicate that municipal solid wastes were disposed mainly in the portion of the Canal bounded by Read and Wheatfield Avenues. Disposal of drummed chemical wastes was mainly in the northern half of the northern Canal section and the southern half of the southern Canal section. Further, Calspan (1977) found from questioning local residents that "...pits were later dug as deep as 35 feet about 1957 in 3 locations between Wheatfield Avenue and Frontier Avenue and filled with drums". Zuesse (1981) states that, according to New York State officials, federal agencies also disposed of toxic chemical wastes at the Canal during and after World War II.

2.0 GEOLOGY

2.1 Regional Geology

2.1.1 Overburden

The geology in the Niagara Falls area consists of several units of unconsolidated glacial deposits overlying Paleozoic sedimentary bedrock. A series of silts, clays, and glacial till is encountered throughout the Niagara Region. The lacustrine silt and clay are glacial lake sediments, deposited over the glacial till. The depths of the unconsolidated deposits to the south of the Niagara Escarpment, a major geologic control in the area, vary from 5 to 15 feet according to Johnston (1964). However, depths up to 42.6 feet have been encountered in the Love Canal area (JRB Associates, 1981).

The glacial till is a relatively unstratified drift directly overlying the bedrock. JRB Associates (1981) state that the till is composed of "a reddish brown firm silty clay matrix, surrounding rounded and subrounded gravel and cobbles of dolomite, shale, and igneous and metamorphic rock fragments. In a few areas, the matrix of till is sandy clay. In other areas, the till is underlain by a gravel-free, reddish brown, firm, silty clay".

The glaciolacustrine deposits of clay, silt and some fine sand overlying the till were laid down by glacial lakes Dana and Tonawanda. Deposits due to Lake Dana were laid down directly over the glacial till. These deposits consist of very plastic, very sticky, wet, soft, silty clay to clay which is reddish in colour and is derived from bedrock deposits to the north. These deposits tend to be very fine grained and also contain varves.

Overlying Lake Dana deposits are sediments laid down by Lake Tonawanda. These deposits are reddish brown to gray in colour and are somewhat coarser in texture than the underlying layer. Lake Tonawanda deposits are described as firm, varved, moist, silty-clay to clay. Some vertical dessication cracks have been noted in Lake Tonawanda deposits.

Clayey silt and silty sand are encountered in variable depths above the Lake Tonawanda deposits. Random occurrence of sand lenses has also been reported within this stratigraphic zone. Sand lenses were reported to be neither extensive in area or thickness (USEPA, 1982).

Topography can be described as smooth and undulating with little relief except for the Niagara Escarpment and the Niagara River Gorge. Some relief is also provided by local creeks and tributaries to the Niagara River.

2.1.2 Bedrock

The bedrock encountered in the Niagara Falls area is Paleozoic sedimentary bedrock dipping to the south at roughly 30 feet per mile or 0.3° (Johnston, 1964). Cross sections through the bedrock formations are shown in Figures 3 and 4. The uppermost formation in the bedrock sequence is the Lockport Dolomite. Also present in the Lockport formation are intermittent layers of limestone and shaly dolomite. Vugs (cavities), fractures and secondary mineral deposits are common. Five distinct zones within the Lockport Dolomite 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 (¼ 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.

In general, the thickness of the Lockport beneath the City of Niagara Falls varies from about 140 feet in the south along the Niagara River to 100 feet in the north near the power storage reservoir (Johnston, 1964)(see Figure 1 for plan of area). However, thicknesses can vary regionally from 20 feet along the Escarpment to 180 feet near Love Canal (JRB Associates, 1981).

The Rochester Shale formation, part of the Clinton Group, immediately underlies the Lockport Dolomite. Johnston (1964) 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).

2.2 Local (Love Canal) Geology

2.2.1 Overburden

A total of 178 monitoring wells, for which geologic logs are available, were installed during the 1980 environmental monitoring study conducted at Love Canal (JRB Associates, 1981). Of these, 89 were in the overburden (A-wells), 85 were in the shallow bedrock (B-wells) and 4 were in the deep bedrock (C-wells). Several wells were also constructed as medium-depth bedrock wells (D-wells) by drilling B-wells an additional 40 feet in depth. The borehole and well locations with JRB Associates (1981) designations are shown in Figure 5. For cross referencing, the JRB Associates (1981) and corresponding USEPA (1982) site location designations are given in Table 2.

Topography in the Love Canal region is relatively smooth (Figure 6) with some relief adjacent to local creeks and the Niagara River. Black and Bergholtz Creeks flow in a westerly direction just north of the Canal area (see Figure 2). Bergholtz Creek flows into Cayuga Creek which flows southerly to the Little Niagara River. These creeks and the Niagara River control all surface water drainage in the local Canal vicinity. The land surface elevation is about 573 to 575 feet above mean sea level* (see Figure 6) on the Love Canal property, and several feet higher at the peak of the present clay cover constructed during remedial measures activities in 1978-1979.

The overburden materials in the Love Canal vicinity can be classified, from bottom to top, as: (1) till unit, (2) clay unit and (3) thin upper layer of fill and more permeable

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*All elevations shown on figures in this report refer to mean sea level minus 500 feet.

glacially-derived materials. The thicknesses of each of these units are shown contoured on Figures , 8 and 9 with the total overburden thickness shown in Figure 10. The stratigraphic interpretations shown in these figures are based on the borehole logs for the B-wells.

The overburden deposits are about 33 feet in thickness for the northern and central portions of the Love Canal property and 36 to 39 feet in thickness for the southern portion (Figure 10). Calspan (1977) found, from questioning local residents, that the Canal varied from about 10 to 35 feet in depth. JRB Associates (1981) estimated the Canal's depth at 40 feet. It should be noted however, that some uncertainty remains regarding both the originally excavated depth and the southern extent of the Canal. It is possible, therefore, that the overburden materials may have been close to or fully breached during the excavation of the Canal.

The glacial till in the vicinity of Love Canal varies from 0 to 23.8 feet in thickness (see Figure 7). At the Canal itself, the till is roughly 14 feet thick in the north decreasing to 4 or 5 feet around Read Avenue and then increasing to 18 feet for most of the area south of Wheatfield avenue. The till is essentially that which is encountered on a regional scale consisting of "reddish brown, silty clay containing from 20 to 60 percent gravel and some cobbles" (JRB Associates, 1981). Variations were noted in colour and texture.

The glaciolacustrine deposits overlying the till consist of 0 to 31 feet of silty clay (see Figure 8). The silty clay immediately overlying the till was deposited by glacial Lake Dana. This stratigraphic zone is similar to that found regionally. Overlying the Lake Dana silty clay is another silty clay attributed to Lake Tonawanda. This silty clay is 3 to 8 feet in thickness and mostly reddish-brown with dark greyish-brown, greyish-brown and yellowish-brown patches observed. Borehole logs by JRB Associates (1981) seldom differentiate between Lake Dana and Lake Tonawanda deposits. Sandy clay zones were also encountered in the glaciolacustine deposits.

Dessication cracks have been observed to depths of several feet throughout the Canal area (Clement Associates, 1980). Conestoga-Rovers & Associates (1978a) noted "It was observed during the excavation of the upper 10 feet of soil, that the soil was interlaced with a network of pores which were the result of decayed organic matter such as root systems and a fracture network which is the result of weathering on the clay soil." JRB Associates (1981) did not observe any dessication cracks in samples they described. They noted that the cracks may have been obscured in the split-spoon samples because of the mechanics of the sampling procedure.

Various layers of silty sand and clayey silt, as described in the previous section, overlie the Lake Tonawanda silty clay and appear to be derived locally although construction debris and industrial waste are also present. Industrial wastes encountered include coarse-grained carbon wastes and a black tar-like substance found mainly in the 93rd Street schoolyard (JRB Associates, 1981). The thickness of the silty sand and clayey silt layer ranges from 0 to 20 feet but is generally about 5 feet (see Figure 9). Since there are no boreholes located within the confines of the excavated canal, it is impossible to determine fill thicknesses within the region of the chemical waste disposals. The variable composition of this uppermost unit is due in part to the effect of the past activities of excavations and residential development in the Love Canal area.

Several swales or surficial drainage channels, many which are filled- in, have been identified in the Love Canal area (see Figure 11). These swales are considered, in general, to have been filled with somewhat more permeable materials than the surrounding deposits.

Sand or loamy sand lenses have been identified throughout the entire overburden thickness (JRB Associates, 1981). These deposits are reported to be small, discontinuous features that are scattered throughout the Canal area. These lenses provide localized zones of relatively high hydraulic conductivity.

2.2.2 Bedrock

Bedrock conditions beneath the Love Canal vicinity are typical of those found on a regional scale. The upper surface of the Lockport Formation is relatively smooth and slopes gently to the south (Figure 12). The bedrock surface elevation is about 540 feet above mean sea level beneath the northern and middle portions of the Canal property and 537 feet beneath the southern portion. The thickness of the Lockport in the Canal area is reported by JRB Associates (1981) to range from 162 to 178 feet. Drill cores were recovered from 4 wells (42C, 56C, 72C and 86C) drilled throughout the entire depth of the Lockport Dolomite. The borehole logs (JRB Associates, 1981) indicated that "all cores contained numerous shaley or carbonaceous partings throughout their entire length with some mineralized partings of calcium and gypsum". Vugs or cavities from fractions of an inch to several inches in size were identified in many boreholes. The borehole drilled for well 56B was reported to contain 60% vugs.

3.0 HYDROGEOLOGY

Ground water flow in the Niagara area occurs through both the glacial deposits and the bedrock. In the unconsolidated glacial deposits, water is able to flow, in general, through the pores or interstices between the individual grains. However, some vertical dessication cracks, which would allow relatively easy water movement, have been observed in the Lake Tonawanda deposits but have not been found in any of the other stratigraphic zones. In the bedrock, compaction and cementation has reduced the size of the intergranular pore spaces, restricting flow through them. Flow of ground water in the Lockport Dolomite and underlying sedimentary strata 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 ground water 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 Overburden

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 the rates of regional ground water movement in the overburden. 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 ground water 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.

Ground water 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 1) 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 average water level is at an elevation of 645 feet based on USLS datum. 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.

In general, ground water flow in the upper Lockport Dolomite is to the south towards the Niagara River for the eastern portion of the city of Niagara Falls, New York region, and to the north or north-west away from the River for the western portion of the city upstream of the Falls. The Niagara River is a source of bedrock recharge along some of the River's reach upstream of the Falls, such as at S-area (GTC, 1982a) located a distance of approximately 4 miles west of Love Canal. In many areas the river bottom remains covered by glacial sediments and these along with any accumulated bottom sediments impede either direct recharge to the bedrock or discharge from the bedrock to the Niagara River. 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. There are no reported heavily pumped wells such as these near Love Canal.

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, 1982b) 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.

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 excerpted 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 1). 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 ground water flow system is uncertain since a comprehensive water level measurement program has not been undertaken since completion of the Niagara River Power Project. However, it is known that water present in the drains may enter the conduits through a one-way weir type structure once piezometric levels exceed a certain pre-determined value.

Also, 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 along the Niagara River, 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 significance of the PASNY conduits to the Love Canal vicinity lies in the observation that ground water flow system in the Lockport Dolomite changes from towards the Niagara River at the Love Canal site to away from the River at approximately the PASNY intakes.

3.2 Local (Love Canal) Hydrogeology

As a consequence of past studies, the hydrogeological regime at Love Canal has been subdivided into 5 different zones. From uppermost to lowermost, they are:

(1) Shallow System - fill, silty sand and clay loam
  - seasonally saturated/unsaturated

(2) Confining Material - clay and till overlying the Lockport Dolomite

(3) Upper Lockport Dolomite
  - main aquifer located in upper 10-15 feet of formation
  - horizontal bedding joints that are areally extensive
  - significant vertical fracturing present

(4) Lower Lockport Dolomite
  - lower part of formation (maximum 165 feet thick)
  - bedding joints are the primary ground water conveyance mechanism

(5) Rochester Shale

3.2.1 Overburden

3.2.1a Overburden Properties

Hydraulic testing was conducted in the various stratigraphic zones in the overburden ground water flow regime. The testing site was located west of the Canal in a relatively undisturbed area on 92nd Street (see Figure 2). Field tests were conducted by JRB Associates under the direction of USEPA and GCA and were analyzed by GeoTrans.

A cluster of 4 test wells completed at 4 different elevations within the overburden deposits were used for hydraulic conductivity determinations. The results

indicated that all zones of overburden materials present at the cluster well test site had relatively low hydraulic conductivities. These hydraulic conductivities and those from other sources are summarized in Table 3. The upper well at the test site was slotted both in the upper clay and in the surface loam materials and therefore its bulk hydraulic conductivity has not been included in the table.
As discussed previously, the presence of fractures in the upper clay has been identified. The secondary permeability provided by a fracture network, if interconnected, could be several orders of magnitude larger than that for intergranular flow through intact clay. This higher permeability coupled with a much lower effective porosity (i.e. fracture porosity) could result in high transport velocities both horizontally and vertically. Since JRB Associates (1981) note that the rate of water level recovery after pumping in some overburden wells is much greater than expected for the types of material (i.e. clay) present, it is likely the presence of fractures in the upper clay is widespread in the Love Canal vicinity. The relatively impermeable deeper clay and till, in which fractures have not been noted, directly overlie the bedrock and serve to impede the vertical movement of ground water between the overburden and Lockport Dolomite.

A number of investigations have been conducted for the purpose of obtaining samples of subsurface materials, obtaining water level data, characterizing hydraulic parameters and collecting ground water samples for chemical analysis. In the course of reviewing these investigations it became apparent that 3 different time periods were present for which the overburden hydrogeological conditions at Love Canal were substantially different. Consequently, the discussion of Love Canal overburden hydrogeology has been further broken down into the following periods:

(1) Period of Active Waste Disposal (1942-1952)
(2) Period Following Active Waste Disposal (1952-1978)
(3) Period During and Following Implementation of Remedial Measures (1978-1982)

3.2.1b Period of Active Waste Disposal (1942-1952)

The probable bounds of the shallow ground water flow regime to the north are Black Creek and Bergholtz Creek, both of which flow from east to west (see Figure 2). Black Creek flows into Bergholtz Creek which enters Cayuga Creek north-west of Love Canal. Cayuga Creek, the probable western boundary of the shallow flow regime, flows essentially south to its confluence with the Little Niagara River which continues westward separating Cayuga Island from the mainland. The Little Niagara enters the Niagara River at the west tip of Cayuga Island (see Figure 1). There is no clear eastern hydrologic boundary within the study area.

Natural overland run-off was historically poor near Love Canal with run-off ponding in topographic lows during rainy periods. These low lying areas are located to the southeast and southwest of the Canal (USEPA, 1982). A number of swales are present in the Love Canal area which were thought to act as preferential paths for overland run-off. These swales were identified through interpretation of historical aerial photographs. The location of the swales as noted in Clement Associates (1980) is shown in Figure 11. The impact of these swales on the subsurface flow regime is uncertain.

The swales may have provided a path for migration of contaminated water originating in the Canal, depending on the waste disposal method outlined previously. It has been established that dykes were constructed across the Canal and wastes deposited on a cell-by-cell basis. Hooker (1979a) reported that the water was evacuated from the individual cells before wastes were dumped. If, however, water was left in the cells, and wastes were disposed under these conditions, the active cells could have represented a ground water mound, resulting in ground water flowing away from the Canal within the more permeable swale deposits.

The hydraulic head in the overburden deposits in the Niagara Falls area is generally higher than that present in the Lockport Dolomite, resulting in a downward hydraulic gradient. Although actual water level data is not available for this time period, this flow configuration is considered to be the most probable as it is observed on a regional scale.

The Canal excavation is reported to be as deep as 30 to 40 feet while the total depth of unconsolidated deposits as interpreted from the JRB Associates (1981) borehole logs range from 33 to 39 feet on the Love Canal property. Consequently, the deposits between the bottom of the excavation and the Lockport Dolomite may be quite thin or even absent in some areas. This situation, plus the downward hydraulic gradient, could result in direct access of overburden ground water to the upper zone of the Lockport Dolomite.

Randomly occurring sand lenses have also been identified in the upper clayey silt and silty sand zone of the Love Canal stratigraphy. However, these sand lenses have been found to be limited in areal extent and thickness.

In summary, sand lenses, dessication cracks, swales and overland flow are all possible pathways of higher ground water and surface water movement during and subsequent to the period of active waste disposal. Most of these pathways are highly selective and likely discontinuous in nature. The shallow ground water flow pattern during the 1942-1952 period was, in general, controlled by the presence of the Canal excavation and by the variations in topography and permeabilities of the overburden materials.

3.2.1c Period Following Active Waste Disposal (1952-1978)

During the period following active use of the Love Canal as a chemical waste dispoal site many factors affected the local shallow hydrogeology. When Hooker ceased waste disposal in 1952, they placed a cap over the entire site using excavated material (Hooker, 1979a). With residential development in the mid 1950's to early 1970's, and the construction of a school on 99th Street in 1955, many surficial and shallow subsurface changes were made with the potential to significantly alter the shallow ground water flow system and contaminant migration pathways.

Several sewers were installed during this period, which penetrated the Love Canal excavation. The location of the storm sewers is shown in Figure 13. Most sewers in close proximity to Love Canal are thought to be buried roughly 10 feet deep, which is below the previous water table at most locations. Some discrepancy exists as to whether or not the storm sewer under Read Avenue and the sanitary sewer under Wheatfield Avenue have the granular bedding specified in their construction drawings (USEPA, 1982). However, it seems relatively certain that a gravel bedding material is in place around the storm sewer constructed in 1968 under Frontier Avenue. The presence of a granular backfill is a significant factor in determining the hydrogeological impact of the sewers. If gravel bedding is present, it will act as a high hydraulic conductivity conduit capable of transmitting ground water and contaminants at a much higher velocity than in the surrounding media. If gravel is not present, and if the sewers do not have significant infiltration or exfiltration, then it is likely that the presence of the sewers will not have a pronounced effect on the local flow system.

It has been reported that the clay cap over the Canal had been breached at several locations for the purpose of grading. Hooker (1980) noted that the School Board approved the removal of 3000 cubic yards of fill on January 21, 1954 and 10,000 cubic yards on August 18, 1955. These actions likely resulted in a significant increase in infiltration on the Love Canal property.

Calspan (1977) report from their investigation that "...field observations show that the direction of surface and shallow ground water flow is in a northeast to southwest direction towards the Niagara River from about Read Avenue which includes about two-thirds of the site. From about Read Avenue, north the direction of surface water and shallow groundwater movement is towards the northwest."

Additional factors which may have altered ground water flow patterns during this period include:

(1) paving of roads and driveways which will reduce infiltration;
(2) construction of houses which will, if roof drains are connected to storm sewers, cause decreased infiltration in localized areas;
(3) construction of other utilities through the Canal such as gas mains and water mains which may also provide seepage routes from the Canal;
(4) installation of a catch basin in the backyard of a house on 97th Street;
(5) grading in developed areas including filling in swales and low lying zones essentially altering surface and subsurface drainage paths. Higher permeability soils may have been used for fill providing higher velocity migration paths for ground water and contaminants.

3.2.1d Period During and Following Implementation of Remedial Measures (1978-1982)

The implementation of remedial measures at Love Canal commenced in 1978 and is continuing. A series of different actions designed to reduce or eliminate the spread of contamination into the area surrounding the Love Canal property have been undertaken by various agencies.

Remedial action began in October, 1978 with the installation of a barrier drain along the east and west sides of the south section of the Canal (see Figure 14). This construction phase was completed in February, 1979. The barrier drain, intended to intercept shallow lateral ground water flow, consists of a trench which is 15 to 25 feet deep and 4 feet wide (Clement Associates, 1980). A French drain was installed with an 8 inch diameter perforated clay tile drain centered in 2 feet of uniformly sized gravel which is overlain to the surface with sand. Lateral trenches filled with sand were dug perpendicular to the barrier drain in the direction of the Canal. The tile drain is graded towards a series of manholes and deep wells where the leachate is collected, treated at an on site treatment facility and discharged into the city sewer system. Further remedial actions were taken between June and December 1979 which involved extending the barrier drain to the central and northern Canal sections and along the southern boundary of the Canal (Figure 14).

A clay cap was installed over the extire Canal area following completion of the barrier drain collection system. The purpose of the cap was to reduce infiltration of precipitation and losses of volatile organics. The thickness of the clay cap varies from 3 feet at its apex tapering to 1 foot on either side.

Following the remedial measures taken in 1978 and 1979, the conditions and stratigraphy at Love Canal, along with characterizing parameters, were summarized by GeoTrans (1981) as the following:

(1) "Clay cap; 3 feet thick; hydraulic conductivity is 10^{-7}cm/s or 3.28 x 10^{-9}ft/s (Conestoga-Rovers & Associates, 1978b)";

(2) "Barrier drain; gradient is 0.5%, hydraulic conductivity is 10^{-3}cm/s or 3.28 x 10^{-5} ft/s (Glaubinger, et al., 1979)";

(3) "Silty sand and silt fill; approximately 12 feet thick; hydraulic conductivity is greater than or equal to 10^{-5}cm/s or 3.28 x 10^{-7}ft/s (Fred C. Hart Associates, Inc., 1978)";

(4) "Hard clay, transition clay, soft clay; 11 feet thick; hydraulic conductivity is 10^{-8} to 10^{-9}cm/s or 3.28 x 10^{-10} to 3.28 x 10^{-11}ft/s (Leonard et al., 1977)";

(5) "Glacial till; 15 feet thick; hydraulic conductivity is probably similar to that of clays (Glaubinger et al., 1979)";

(6) "Lockport Dolomite; approximately 100-150 feet thick; transmissivity is approximately 3.5 x 10^{-3}ft^2/s (Johnston, 1964)".

Additional changes made during the 1978-1979 remedial measures include:

(1) The removal of storm sewer leads on:

(i) Read Avenue between 97th Street and a catch basin located halfway between 97th and 99th Streets;

  (ii) Wheatfield Avenue between 97th Street and a catch basin located 170 feet east of 97th Street;

  (iii) Wheatfield Avenue between 99th Street and a catch basin located 170 feet west of 99th Street.

(2) Removal of the french drain system surrounding the 99th Street school;

(3) Removal of the privately installed catch basin at a home on 97th Street, as well as tile drains originating on several lots along 99th Street.

A total of 26 standpipes (depth of 13 feet) and 11 piezometers (depth of 13 to 59 feet) were installed adjacent to the Canal in November, 1978 by Conestoga Rovers and Associates. Clement Associates (1980) state that "Preliminary hydrogeological data (collected from November 1978 through November 1979) indicated very inconsistent changes in the level of the water table in various portions of the Canal". These inconsistencies were no doubt caused by areal variations in infiltration caused by the remedial construction activities and variations in subsurface drainage patterns caused by the barrier drain system. Water levels taken in the standpipes on November 13, 1979 are indicated in Figure 15. These water table elevations are, in general, in the range of 568 to 571 feet above mean sea level. For comparison to the overburden water levels, one bedrock well also measured at this time is shown on Figure 15 with a piezometric level of 563.5 feet. These water table and piezometric level data, although perhaps affected by remedial measures activities, suggest that a significant downward hydraulic gradient existed in November, 1979. One notable exception is the overburden water level in a standpipe on the west side of the southern section of the Canal property with a water level of 564.4 feet. This water level is similar to the piezometric level of 563.5 of a nearby bedrock piezometer. The overburden and bedrock may be hydraulically connected in this area, or this standpipe may be well connected to the barrier drain system.

Following the remedial activities of 1978-1979, a major environmental monitoring program was initiated by the USEPA. The overburden ground water monitoring system consisted of a total of 89 wells, installed in 1980. The sampling intervals for the wells are given in Appendix I and the well installation and monitoring dates are listed in Appendix II (data obtained from JRB Associates, 1981). The water table elevations reported by JRB Associates (1981) and plotted in USEPA (1982) for the overburden wells are shown in Figure 16.

In general, water levels were taken between one and three weeks after the wells were sampled. The wells were sampled by purging and allowing water levels to recover, at which time samples were removed. The water levels show a great variability, making a quantitative assessment of shallow ground water flow patterns impossible. The inconsistent water table elevations may simply be due to the fact that insufficient time was allowed for complete recovery of the water levels. It takes several weeks for water level recovery in a piezometer located in material with a hydraulic conductivity of 10^{-8} cm/s. Although water levels from piezometers in the more permeable materials are likely correct, the levels from the less permeable zones are probably not correctly represented by the measurements shown on Figure 16. For instance, well 78A shows a water level of 560.6, which is several feet lower than even the underlying Lockport Dolomite wells. There is the possibility that 78A is responding through a sand lens connection to the barrier drains. In any case, there is considerable uncertainty in the overburden water levels which can be reduced by a more detailed monitoring program.

The zone of influence of the barrier drain is uncertain. Clement Associates (1980) indicated that a maximum zone of influence can be conservatively estimated at 50 feet. In comparison, GeoTrans (1981) estimated, using a numerical modeling analysis, that the zone of influence would extend 1800 feet back from the trench for materials having a hydraulic conductivity of 9×10^{-5} cm/s and 180 feet for materials having a hydraulic conductivity of 9×10^{-7} cm/s.

It is difficult to assign a "representative" hydraulic conductivity to heterogeneous material such as the "general shallow system", which includes clay, till, swales, sand lenses, utility trench backfill, etc. However, it is possible to determine the effectiveness and extent of influence of the barrier drain system with a sufficiently detailed ground water monitoring program. The existing ground water monitoring system shows some indication of the extent of influence and an attempt has been made on Figure 16 to estimate the location of the flow divide caused by the barrier drain. The zone of influence in October, 1980 of the barrier drain appears to be of the order of 500 feet. The location of the divide is quite subjective and does not explain several anomalous water levels. A more detailed monitoring system specifically designed to determine the extent of the influence of the drains is necessary before it can be established with certainty that the drains are operating effectively.

3.2.2 Lockport Dolomite

Since remedial work commenced in 1978, an extensive monitoring network has been installed in the bedrock. JRB Associates were responsible for the installation of 89 bedrock monitoring wells in the Love Canal vicinity during 1980. Of these wells, the majority were completed in the upper 5 feet of the Lockport formation with four (42-C, 56-C, 72-C and

86-C) penetrating the entire Lockport formation until the Rochester Shale formation was encountered and three (3 -D, 71-D and 80-D) penetrating the Lockport to depths ranging from 40 to 90 feet. The sampling intervals for the bedrock wells are tabulated in Appendix I and the installation and monitoring dates are listed in Appendix II.

The Lockport Dolomite hydrogeologic system in the Love Canal vicinity is essentially the same as that observed on a regional scale by Johnston (1964). Three pumping tests were conducted in the Lockport Dolomite by JRB Associates (1981). The first 2 tests at wells 56-C and 72-C were conducted for the purpose of obtaining data for a more extensive third test in well 72-C. Data from the tests were analyzed by GeoTrans (1981). For the 22 hour discharge test at well 72-C, GeoTrans reported an average transmissivity of 0.015 ft^2/s and storage coefficient of 0.00015.

Purging the bedrock wells for sampling generally involved pumping several hundred gallons of water. In contrast to the overburden wells, the bedrock wells have apparently responded quickly to the purging activities as evidenced by the consistency of the piezometric levels in the Love Canal vicinity (Figure 17). Piezometric levels indicate a general southwest trend in flow direction towards the Niagara River.

4.0 MIGRATION OF CONTAMINANTS

4.1 Nature of the Contaminants

4.1.1 Monitoring Programs

The largest and most extensive contaminant monitoring program conducted at the Love Canal area was that coordinated by the USEPA in 1980. Based on the analyses of leachate and air samples collected prior to the initiation of the field sampling program, together with the results of previous monitoring studies as well as the approximate inventory of the Canal as supplied by Hooker, USEPA compiled two lists of targeted substances. The first of these lists comprised approximately 150 organic and inorganic substances, the concentrations of which were to be determined for water/soil/sediment/biota samples, while the second list was made up of approximately 50 substances for air samples. USEPA further states that these substances were selected because they were most abundant in the source, prevalent in the environment and of toxicological significance. The contaminants comprising the first list are pertinent to this study and have therefore been presented in Table 4.

The water/soil/sediment/biota samples which were taken as part of the monitoring program were routinely analysed for the targeted substances. Analysis results are not reported for all the designated sampling locations. The data base presented in USEPA (1982) includes the statement that "...only those substances which were determined in each sample are included in the listing in order to conserve space."

Other sampling program results have been reported for Love Canal in addition to that given by USEPA (1982). JRB Associates (1981) report well sampling results for both total organic carbon and total organic halogens as well as for pH and specific conductance. This data has been assessed in the latter sections of this chapter.

4.1.2 Migration Properties of Organic Contaminants

The rate at which chemical contaminants migrate in a ground water system is a function of many parameters. Some of these are particular to a given site (such as permeability and porosity) while some are characteristic of the contaminant itself. For example, the solubility of a contaminant in water may be a controlling factor (together with the flow rate through the site) in the amount of the contaminant which will enter the ground water system. The form in which these materials were disposed (e.g. liquid or solid) and the barriers surrounding these wastes (e.g. drums) affect the leach rate of the contaminants. Solubilities are important in establishing an upper bound on the amount of material capable of dissolving in the ground water. This is especially significant for contaminants possessing low solubilities, i.e. those which are likely to be solubility limited. Non-aqueous phase transport (i.e. movement of contaminants which are liquid in form but not dissolved in ground water) may also occur.

A property useful to describe contaminant migration through a ground water system is the sorption capability. Kenaga and Goring (1980) suggest that the octanol-water partition coefficient (K_{ow}) and possibly the water solubility are reasonable preliminary indicators of the potential for sorption of nonionic organic compounds by soils or sediments. Typically, the ability of an organic substance to sorb onto a soil mass is expressed either in terms of a retardation coefficient (R) or a soil sorption coefficient (K_{oc}). Basically, the retardation factor represents the ratio of the velocity of ground water to the velocity of the contaminant through the system. Soil sorption coefficients (K_{OC}) represent the concentration of chemical sorbed by the soil, expressed on a soil organic carbon basis divided by the concentration of the chemical in the water. Soil sorption coefficients can be useful in explaining observed contamination concentrations and distributions. Contaminants possessing high soil sorption coefficient values will typically exhibit higher relative concentrations in soil and sediment samples while water concentrations will tend to be low. Also contaminants with higher retardation factors will tend to migrate shorter distances in a given time period.

Other parameters which could potentially influence observed contamination levels in the field include the volatility and biodegradability of the chemical. Wilson et al (1981) have shown that volatilization losses from soil are usually significantly less than values reported for water. Biodegradation rates for the various organic substances are generally quite variable being highly dependent on microbial populations, aerobic or anaerobic conditions and the concentration of the source contaminant.

4.2 Areas of Observed Contamination

Evaluation of monitoring program data for sites exibiting evidence of contamination at Love Canal is divided into two areas: overburden and bedrock. Contaminant transport in the overburden flow regime is assumed to include overland flow, storm and sanitary sewer flow and flow in local streams and creeks. Contaminant migration in the bedrock is controlled by ground water movement through fractures and bedding planes inherent in the Lockport formation.

The USEPA monitoring program described earlier is the most extensive source of data on organic contaminants for both the overburden and bedrock flow system. The vast number of targeted substances considered by USEPA makes it an immense task to consider the extent and possible avenues of contamination of each individual targeted substance. The migration paths of all the contaminants should be similar from any particular location and the extent of contamination should, therefore, be directly related to the soil sorption properties of the various contaminants. A few fairly soluble organic contaminants which are relatively abundant in the Canal and which have relatively small calculated sorption coefficients were chosen for the purpose of assessing the potential pathways in the Canal area.

4.2.1 Overburden Contamination

The first contaminant selected to investigate organic contaminant migration in the overburden system was 1,4 Dichlorobenzene. Wilson et el (1981) report the water solubility of 1,4 Dichlorobenzene at 79 mg/L and present data suggesting it is somewhat less reactive (in a low organic matter sandy soil) than several other organic contaminants. In addition, Hooker states that chlorobenzenes comprised approximately 2000 tons (slightly less than 10%) of the wastes disposed at Love Canal.

Evidence of contamination due to 1,4 Dichlorobenzene is sparse and sporadic. No readily identifiable groundwater pathways of contaminant migration could be discerned from the reported concentrations. Concentrations of 1,4 Dichlorobenzene were detected in only four of the soil samples analysed while only two wells located in the overburden ground water system exhibited non-zero concentrations. Highest water concentrations of the contaminant were found in the sumps of the row of houses immediately adjacent to the Canal and ranged upwards to a maximum of 870 ppb.

Some sediment samples obtained from storm sewers and surface water drainage courses did exhibit fairly high concentrations of 1,4 Dichlorobenzene (Figure 18). The highest of these was encountered in sediment collected from a storm sewer which runs beneath Lindbergh Avenue (see Figure 2) and presumably

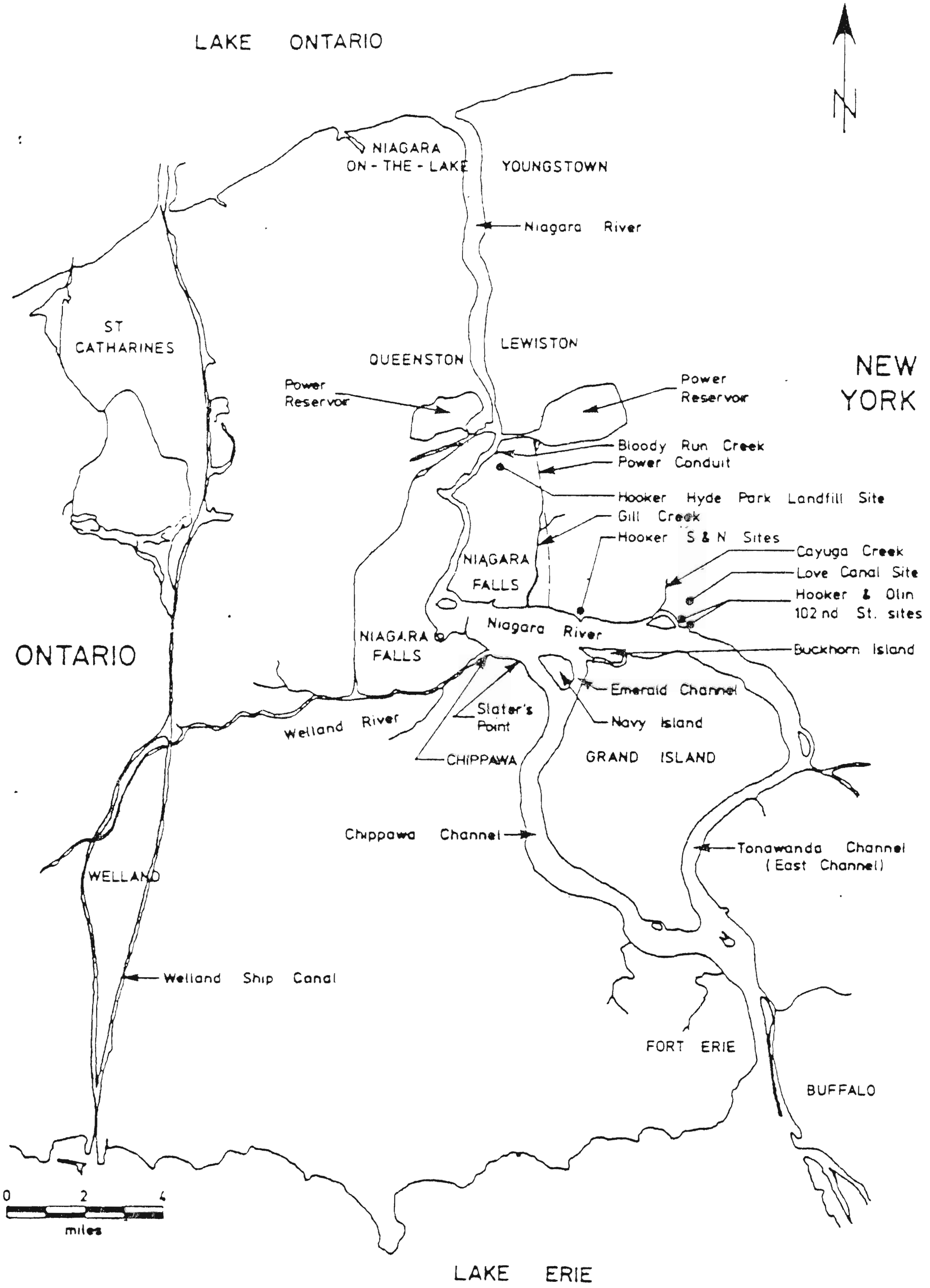

Figure 1. Plan of Niagara Falls and surrounding area.

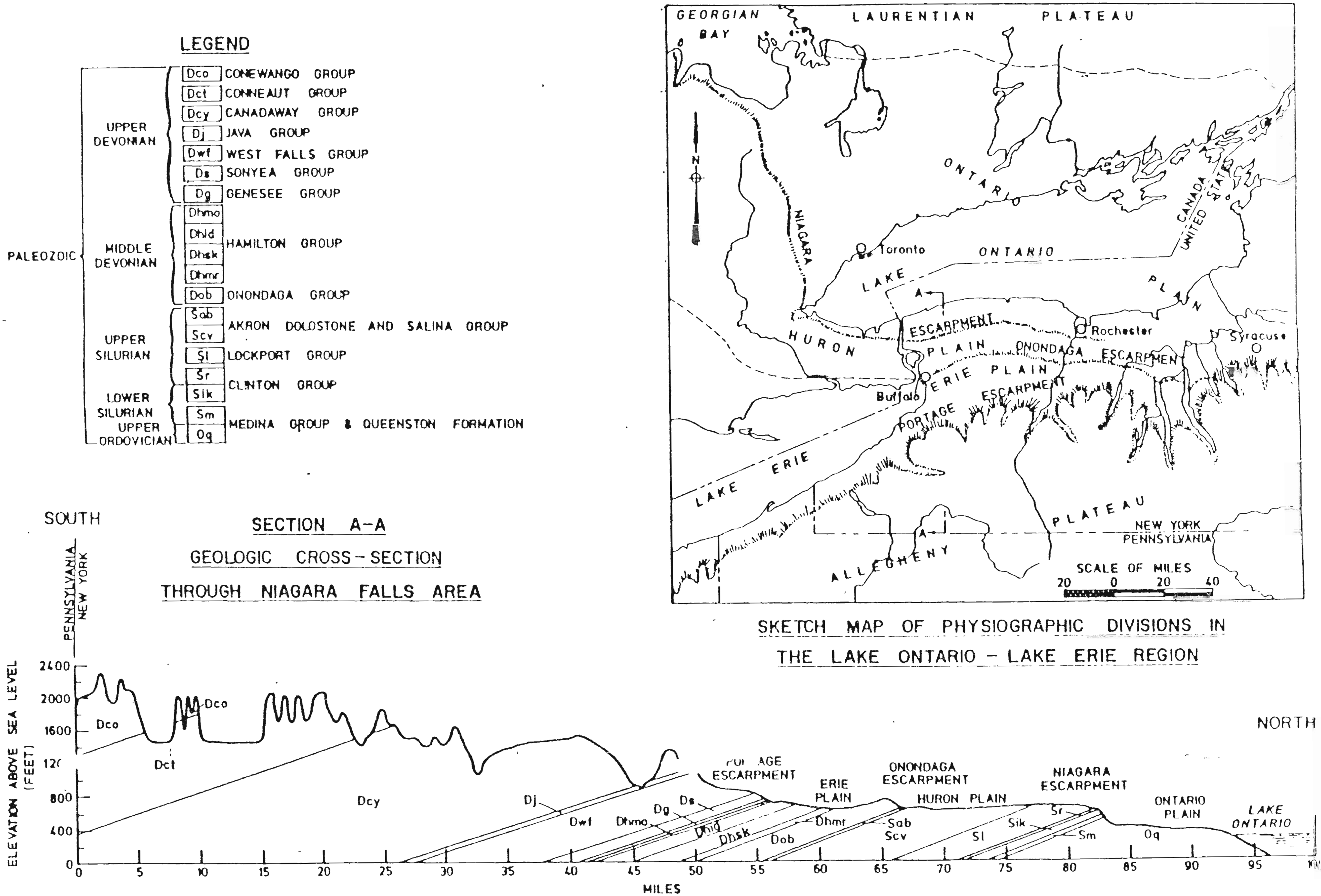

Figure 3. Regional geology of the Niagara Falls area (after American Falls International Board, 1974.)

SALINA GROUP

ISTON FORMATION

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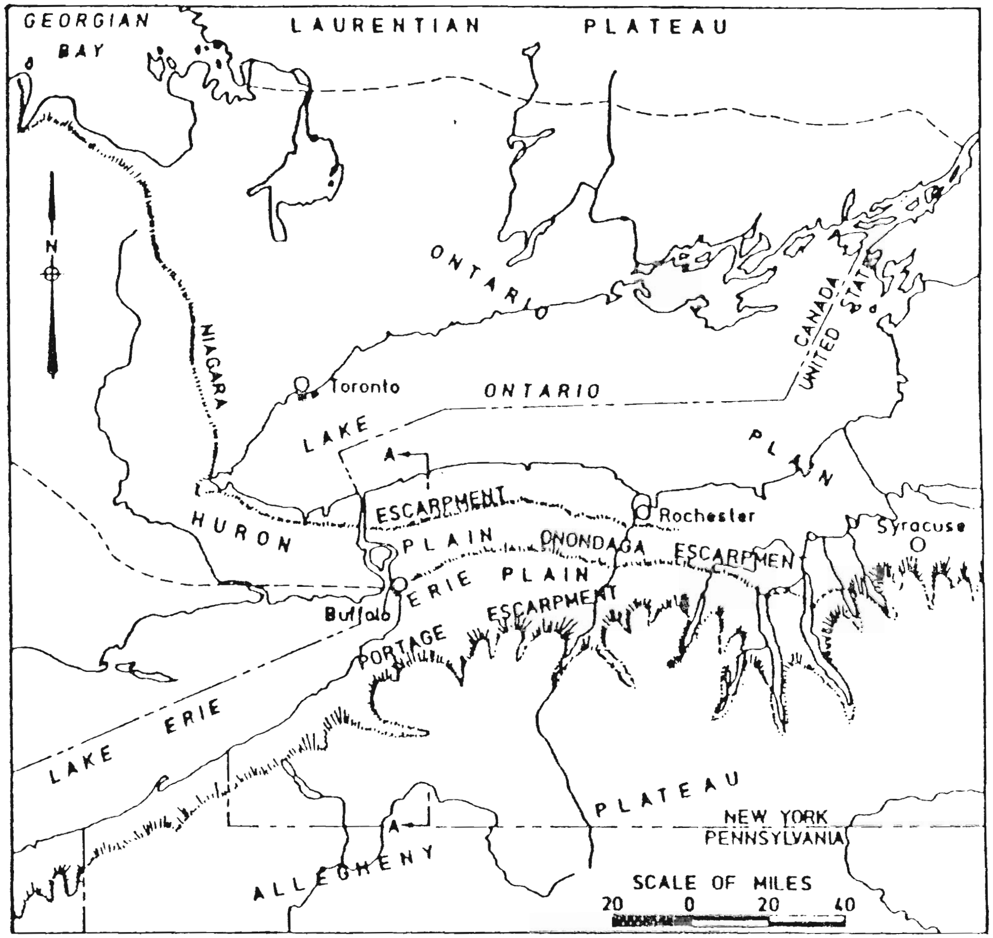
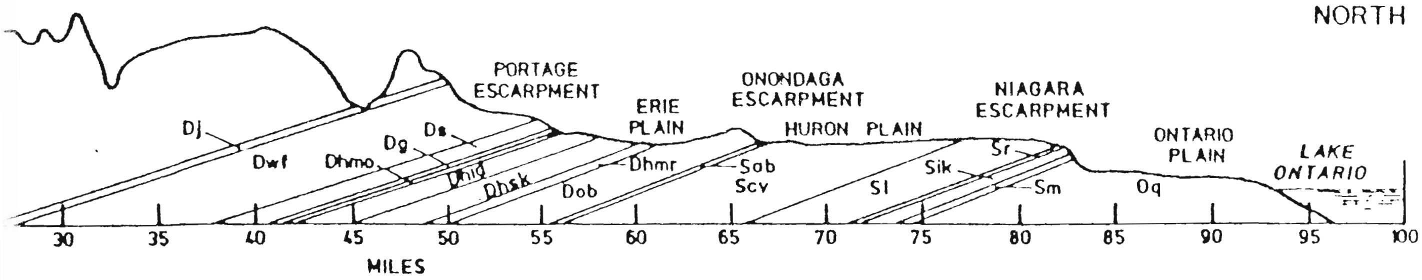
S AREA

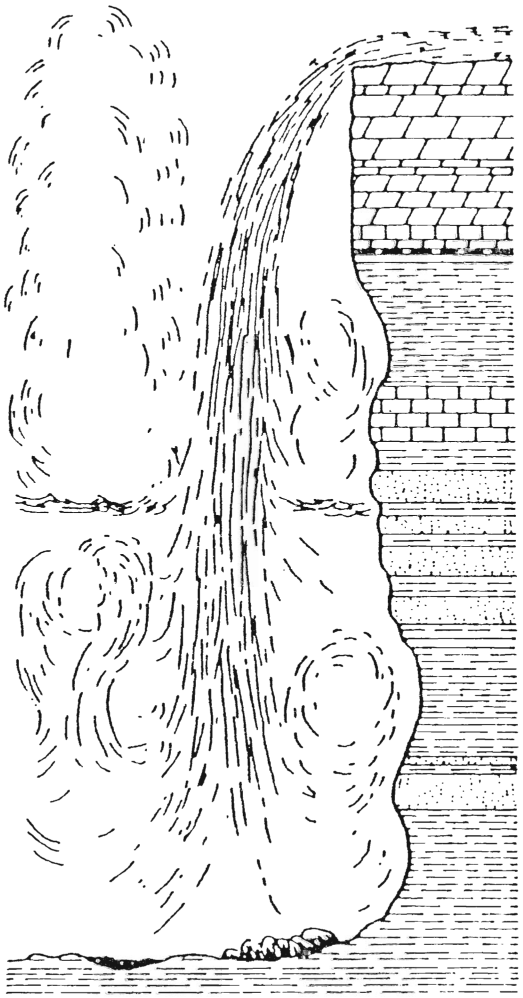


SKETCH MAP OF PHYSIOGRAPHIC DIVISIONS IN THE LAKE ONTARIO - LAKE ERIE REGION



gional geology of the Niagara Falls area (after American Falls
ternational Board, 1974.)

Figure 4. Bedrock



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)

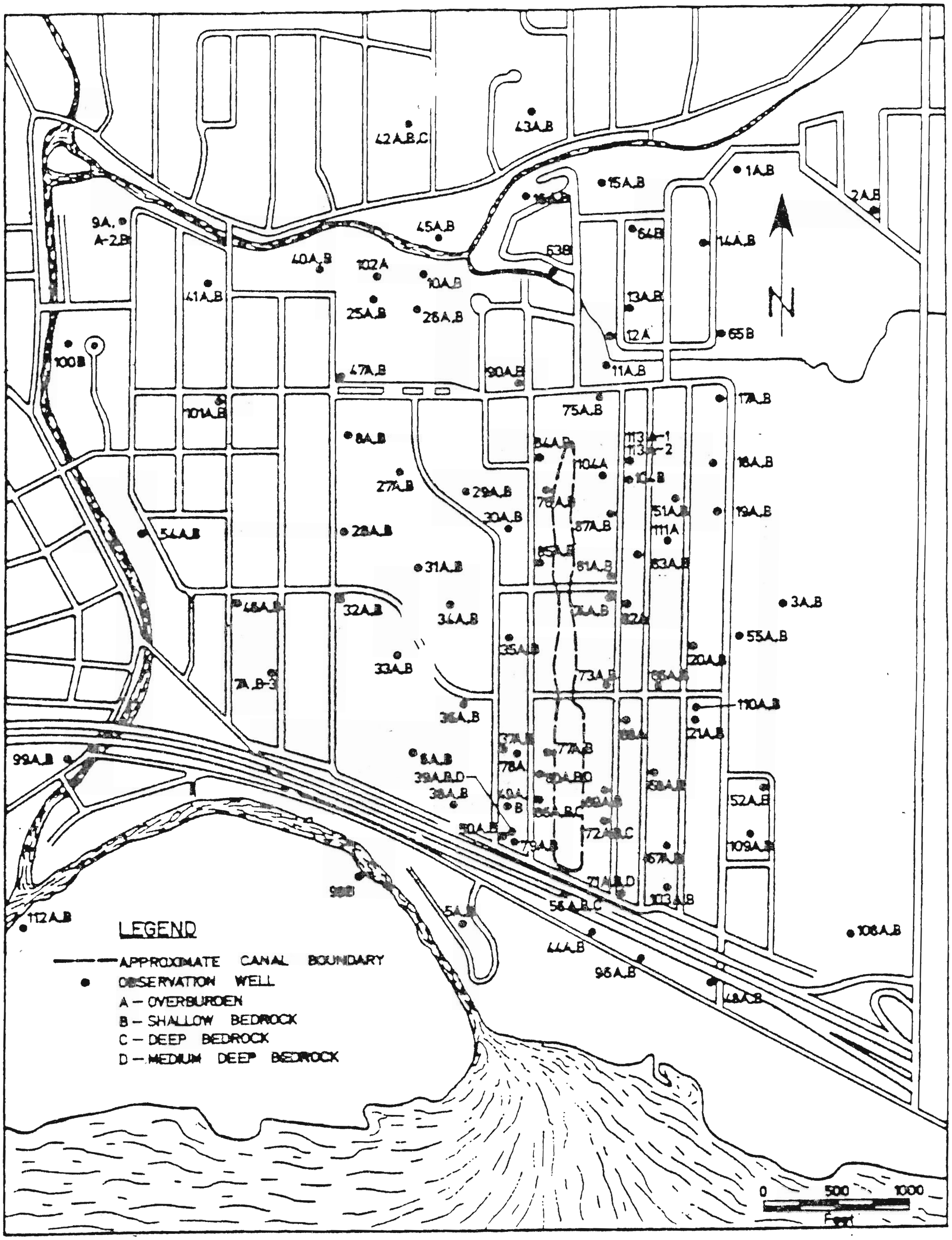


Figure 5. Well locations and designations.

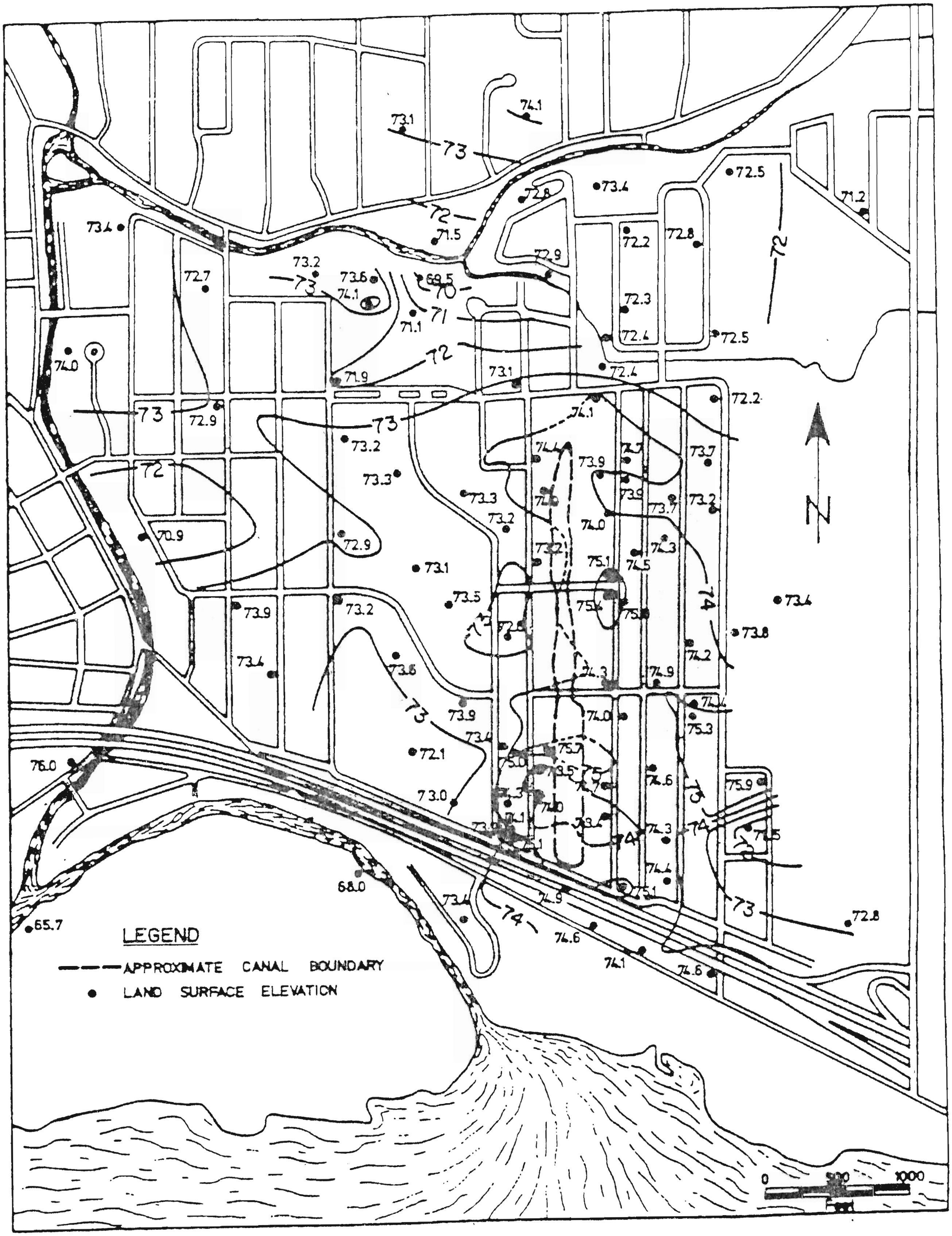


Figure 6. Surface topography in the Love Canal vicinity.

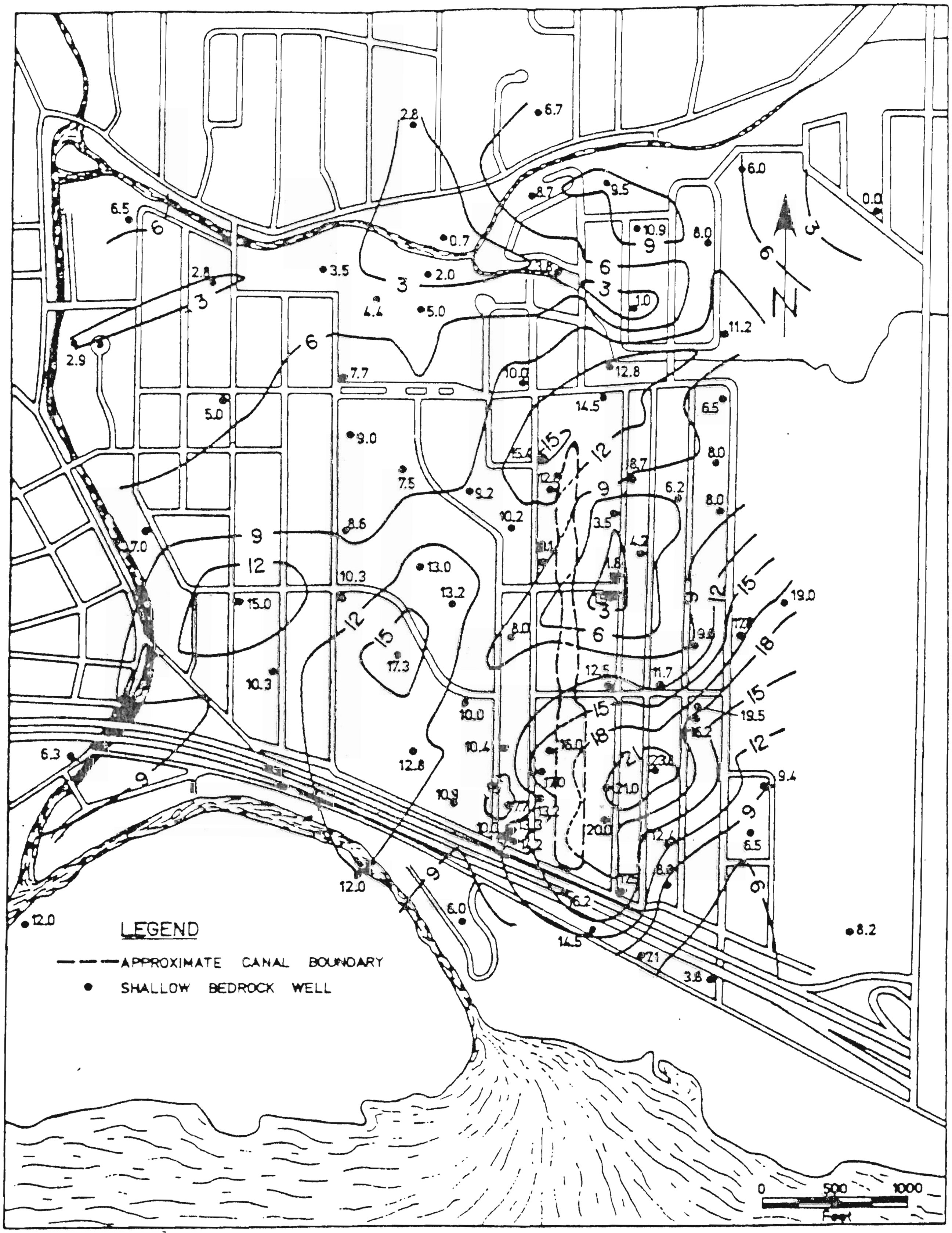


Figure 7. Contour diagram of thickness (ft) of till.

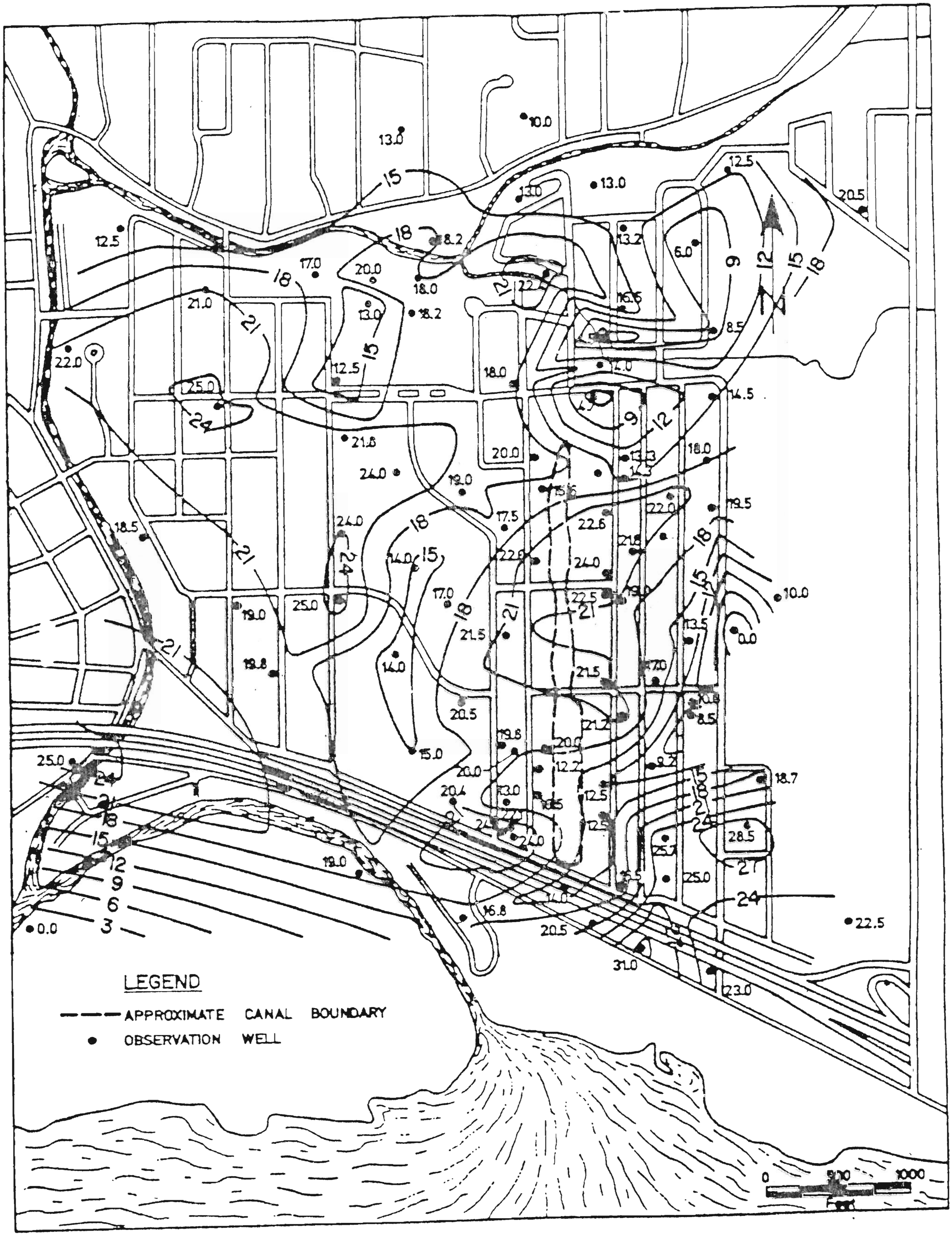


Figure 8. Contour diagram of thickness (ft) of clay.

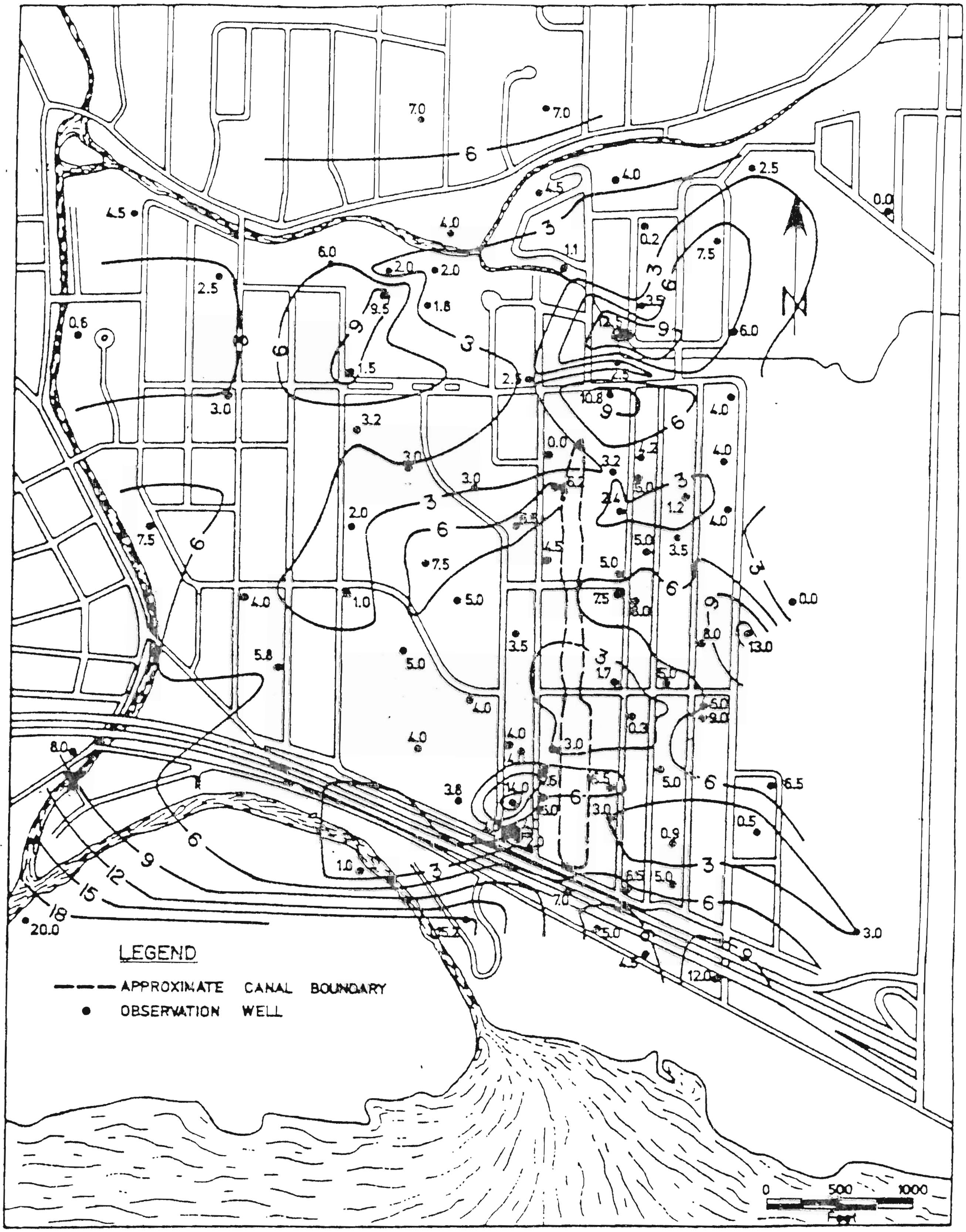


Figure 9. Contour diagram of thickness (ft) of shallow materials overlying the clay unit

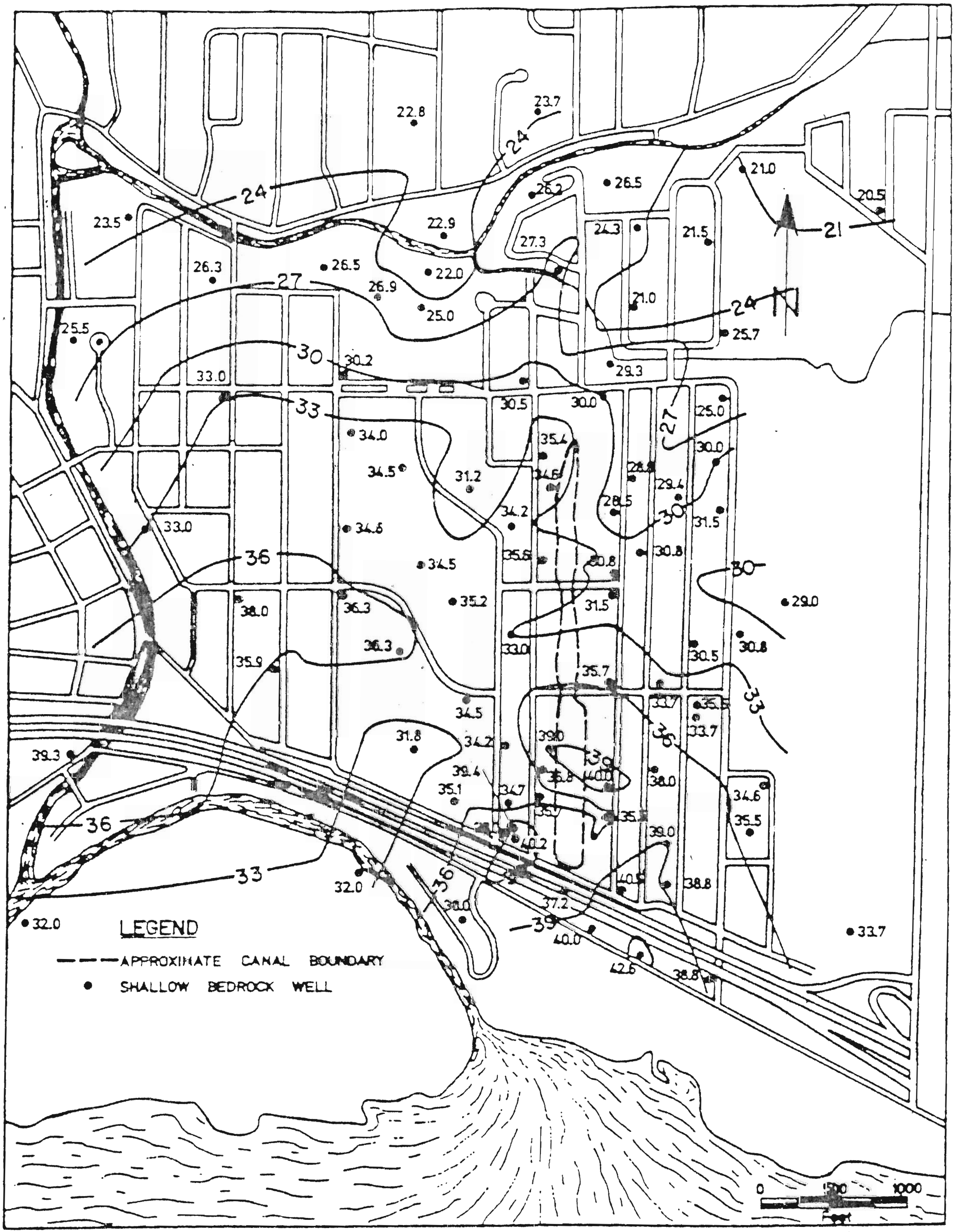


Figure 10. Contour diagram of total thickness (ft) of overburden.

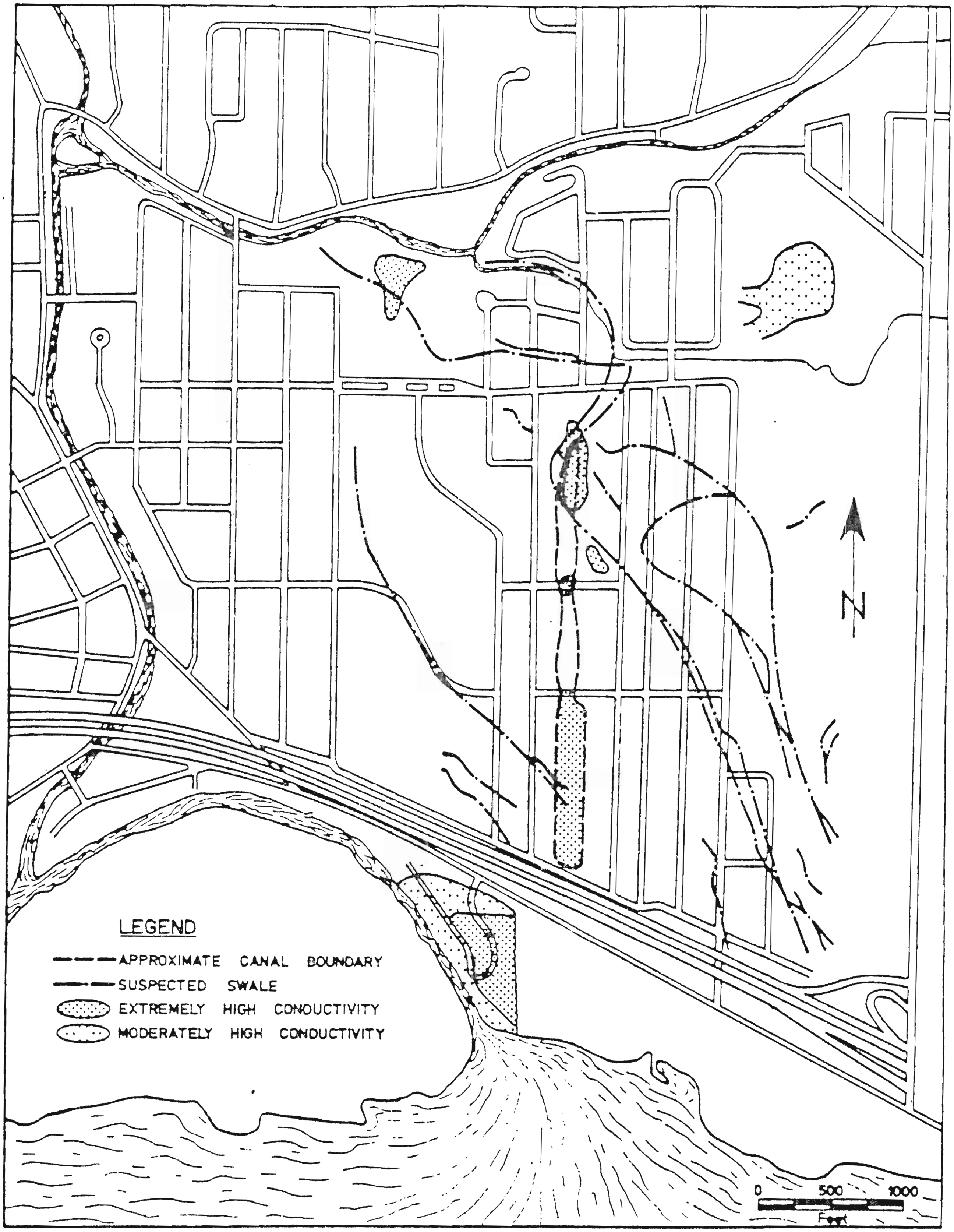


Figure 11. Major swales and areas of high electrical conductivity in Love Canal vicinity (after JRB Associates, 1981, and USEPA, 1982).

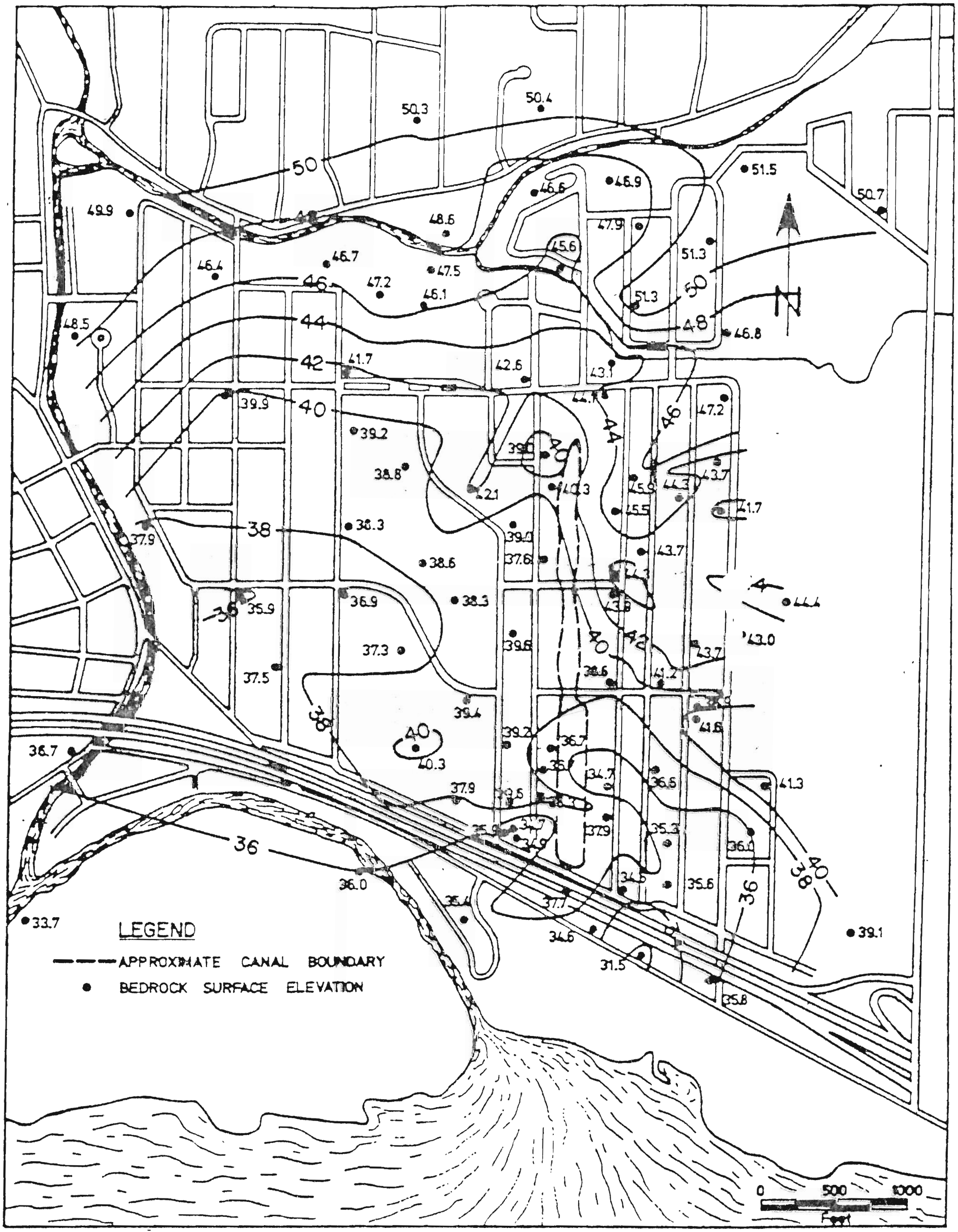


Figure 12. Topography of the upper surface of the Lockport Dolomite in the Love Canal vicinity.

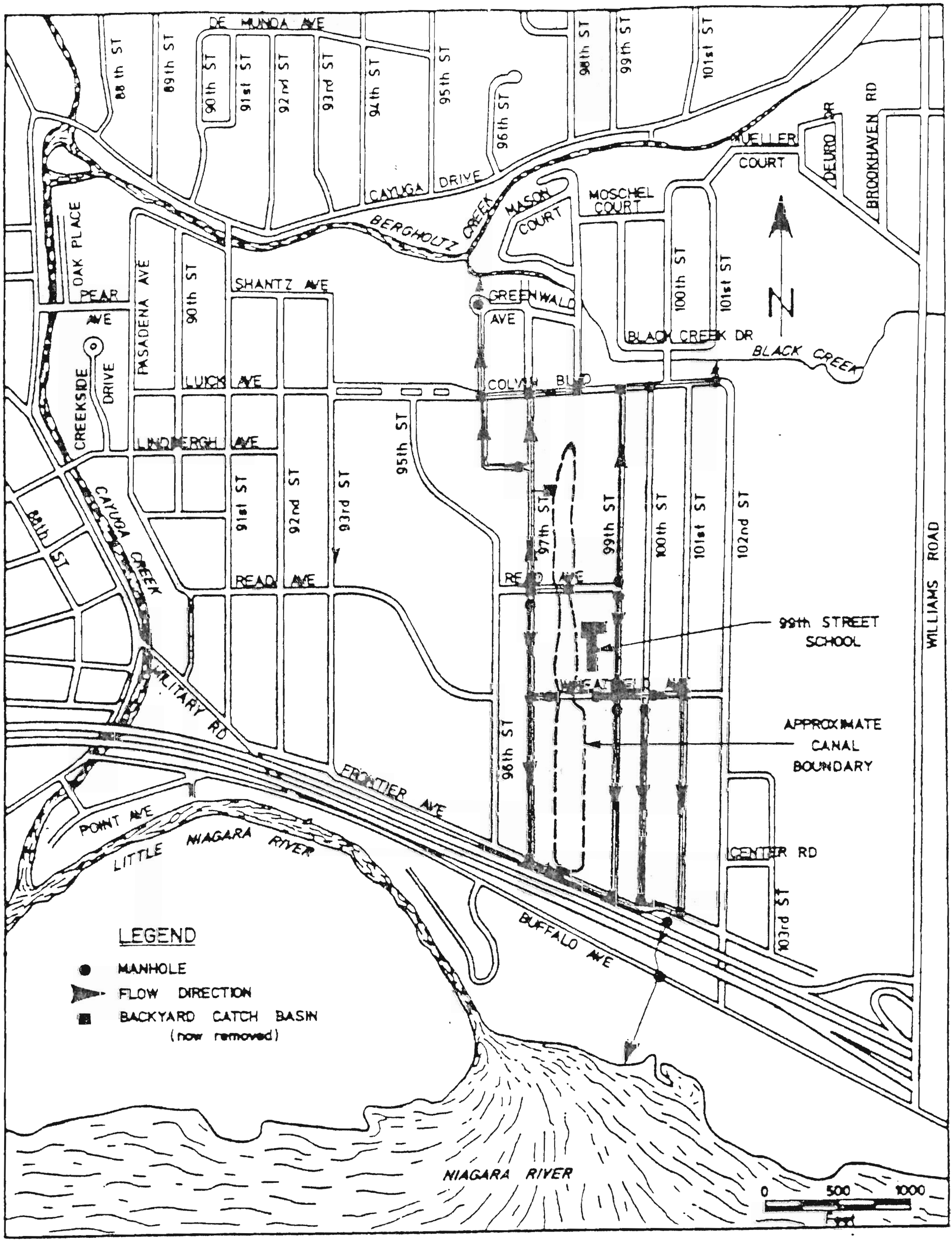


Figure 13. Location of storm sewers in the Love Canal vicinity (after USEPA, 1982).

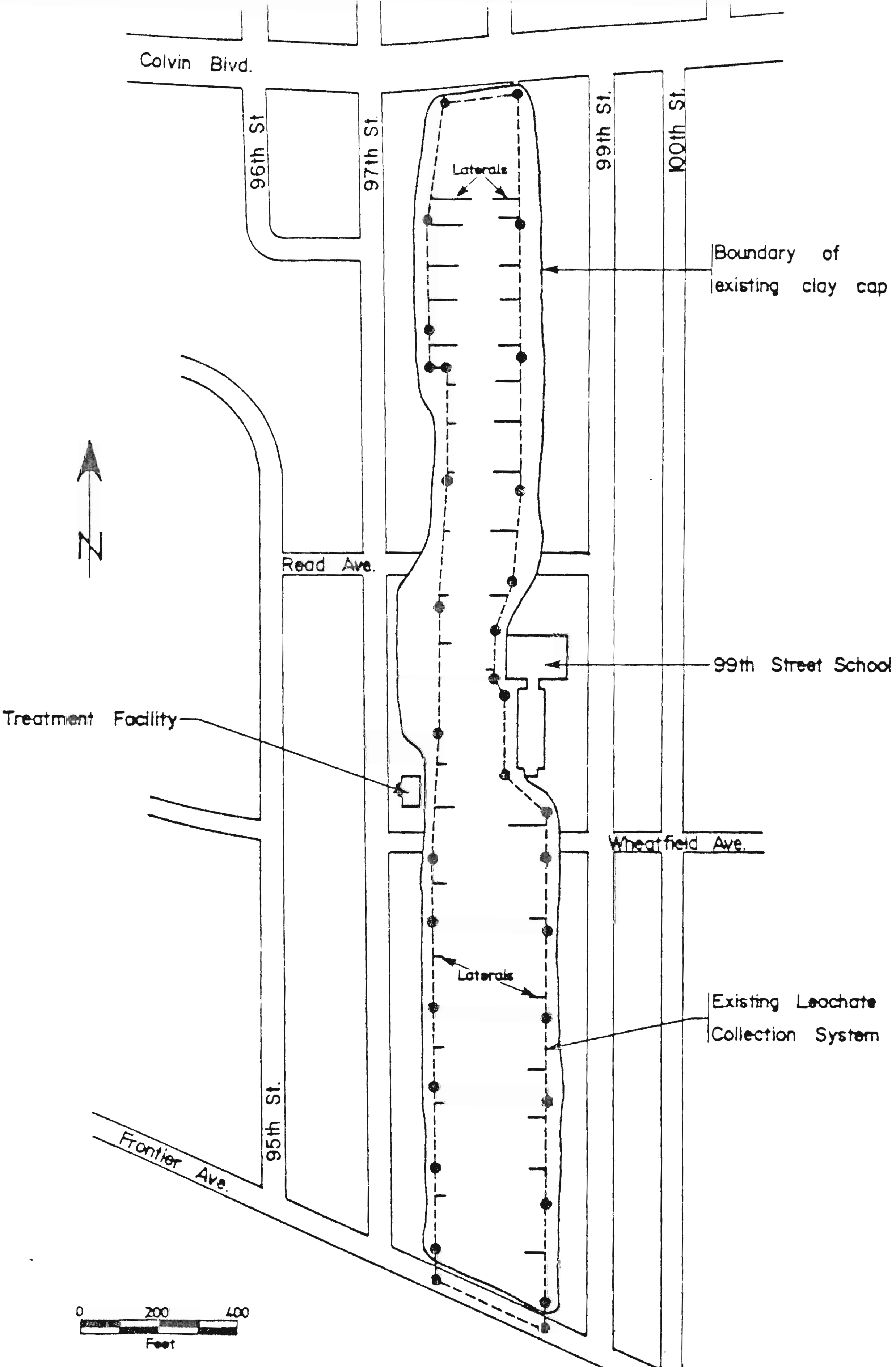


Figure 14. Location of barrier drain system and clay cap installed during 1978-1979 (after CH2M Hill, 1982).

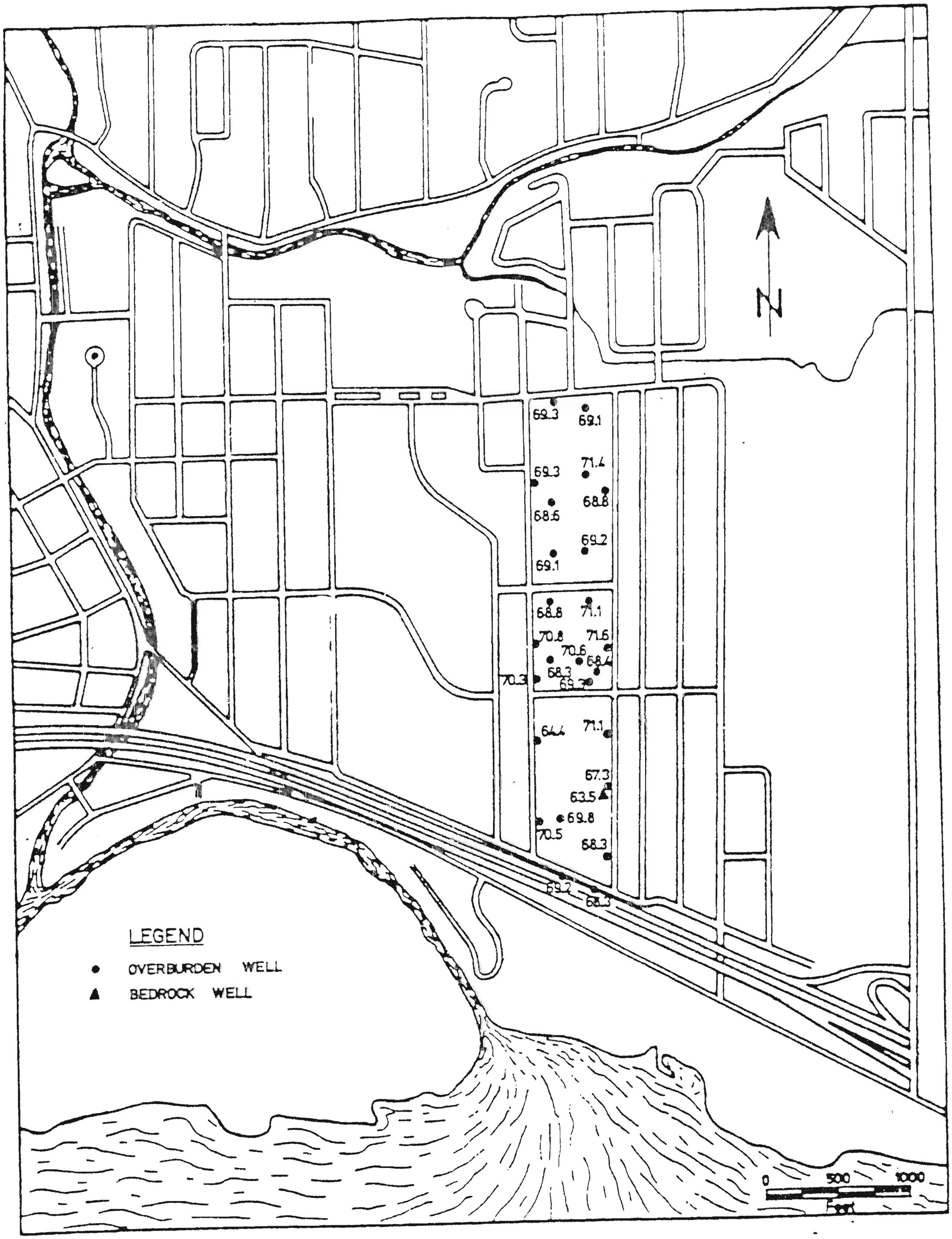


Figure 15. Overburden water table elevations on Love Canal property taken on November 13, 1979 (data from Clement Associates, 1980).

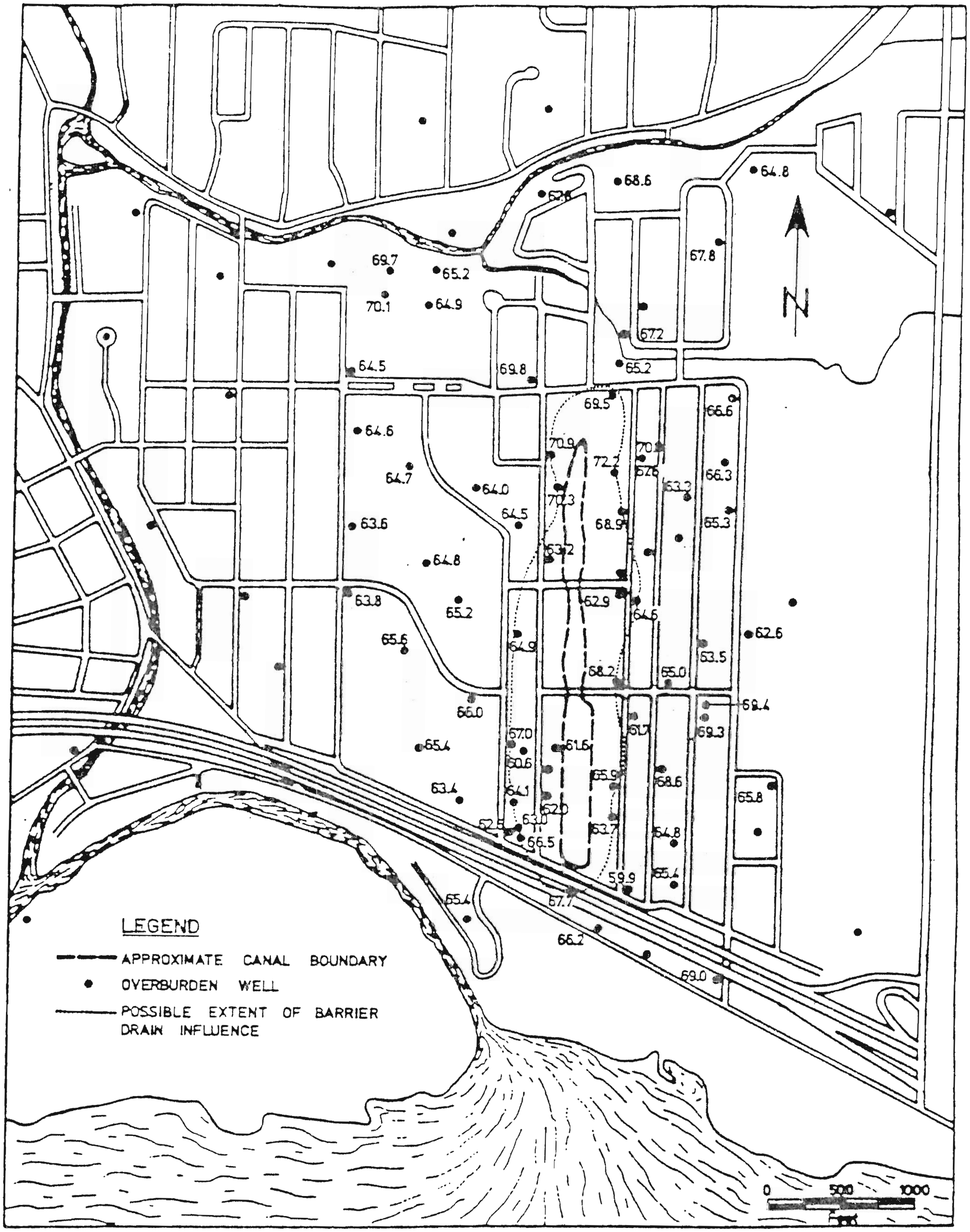


Figure 16. Overburden water table elevations for period October 22-24, 1980 (data from USEPA, 1982).

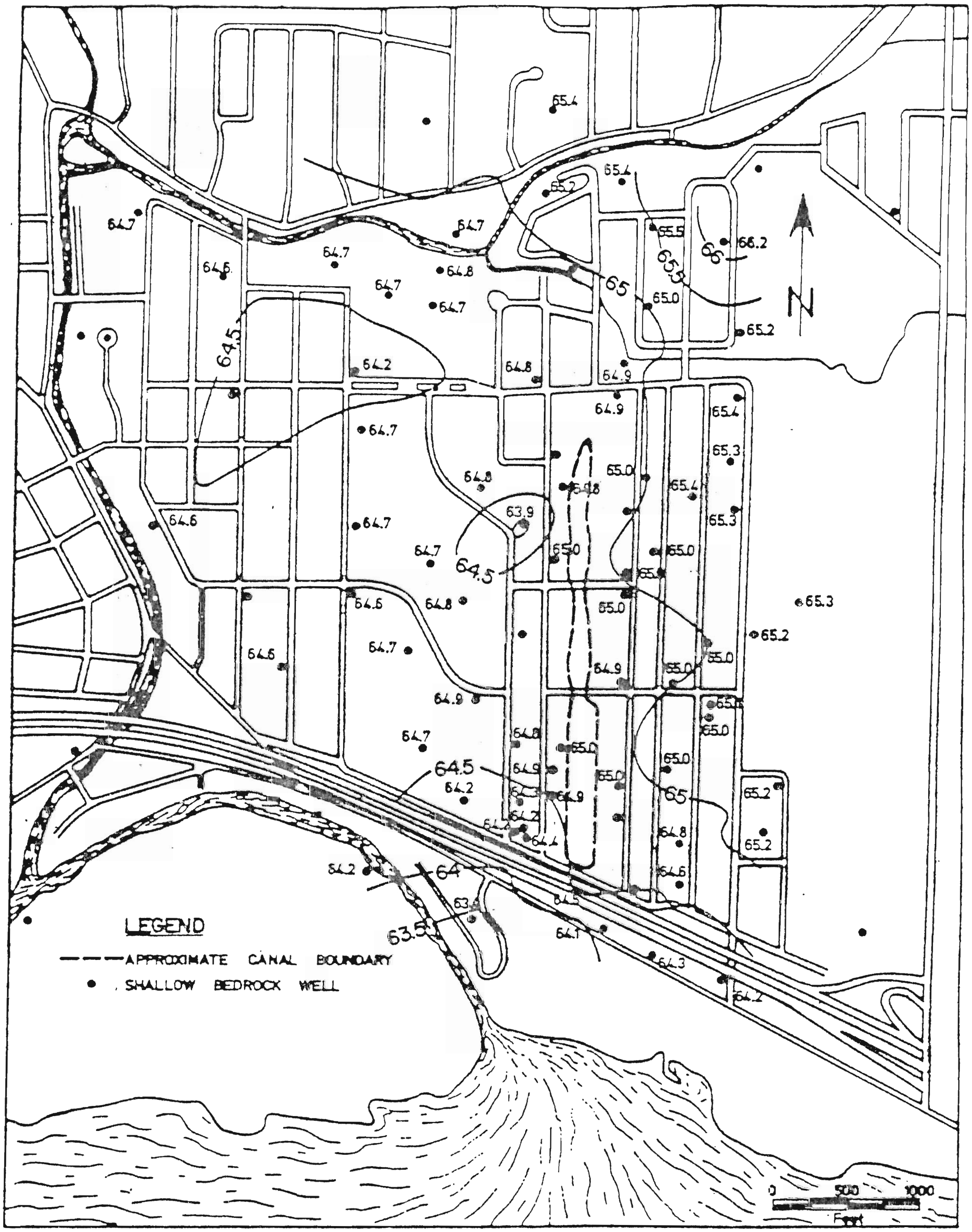


Figure 17. Piezometric elevations in upper Lockport Dolomite for period October 22-24, 1980 (data from USEPA, 1982).

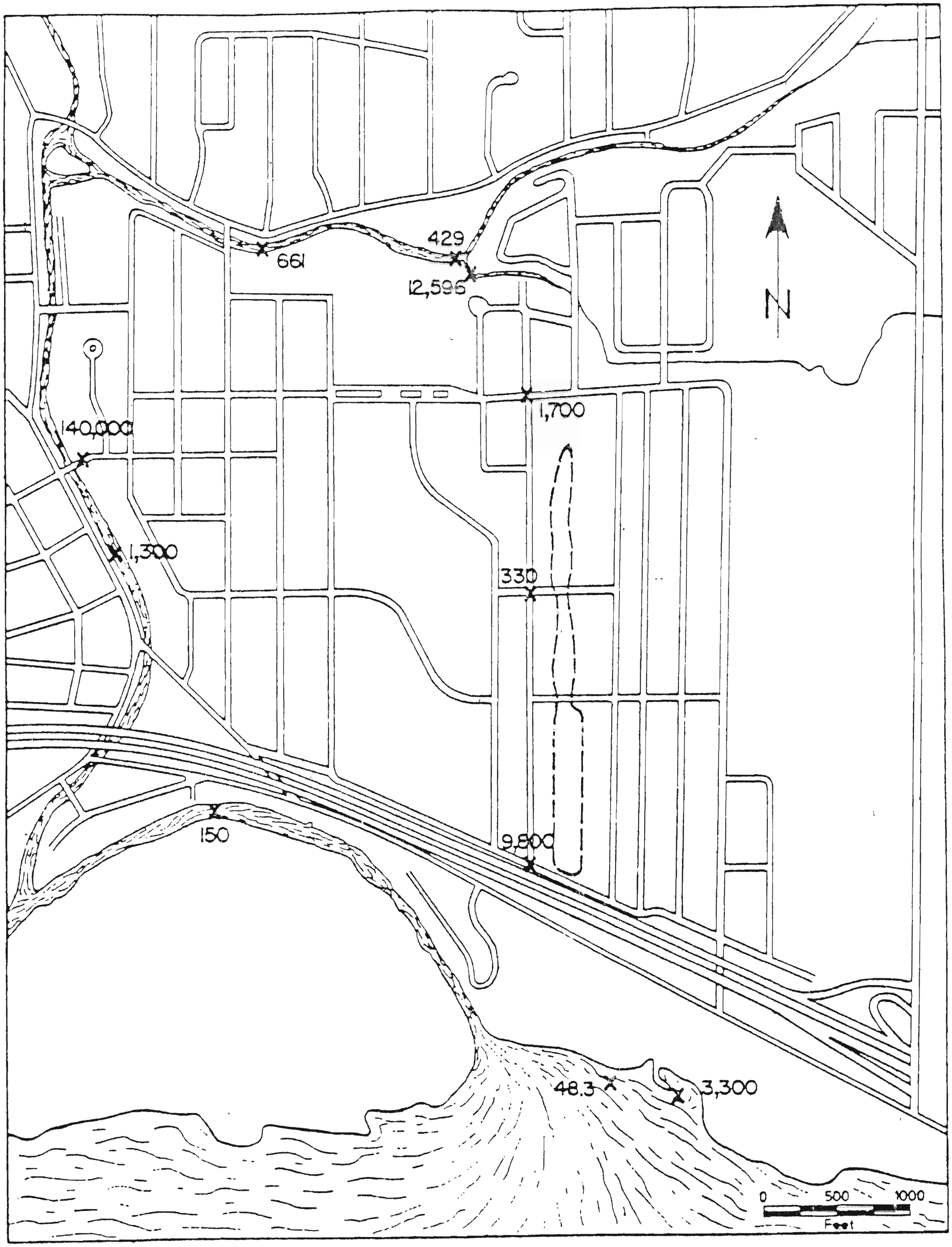


Figure 18. Concentrations (ppb) of 1,4-Dichlorobenzene in sediment samples taken from storm sewers and surface water drainage courses.

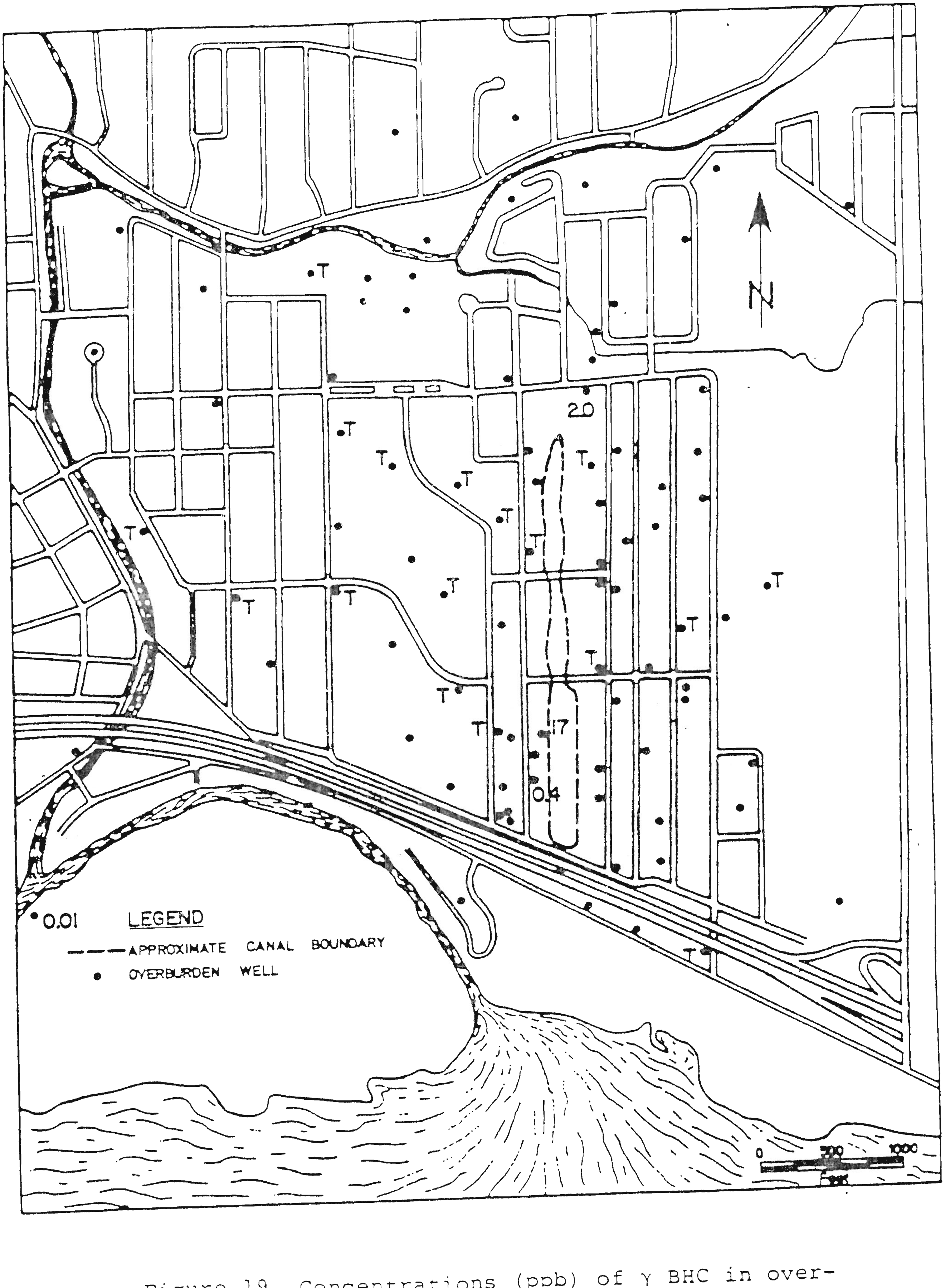


Figure 19. Concentrations (ppb) of γ BHC in overburden wells.

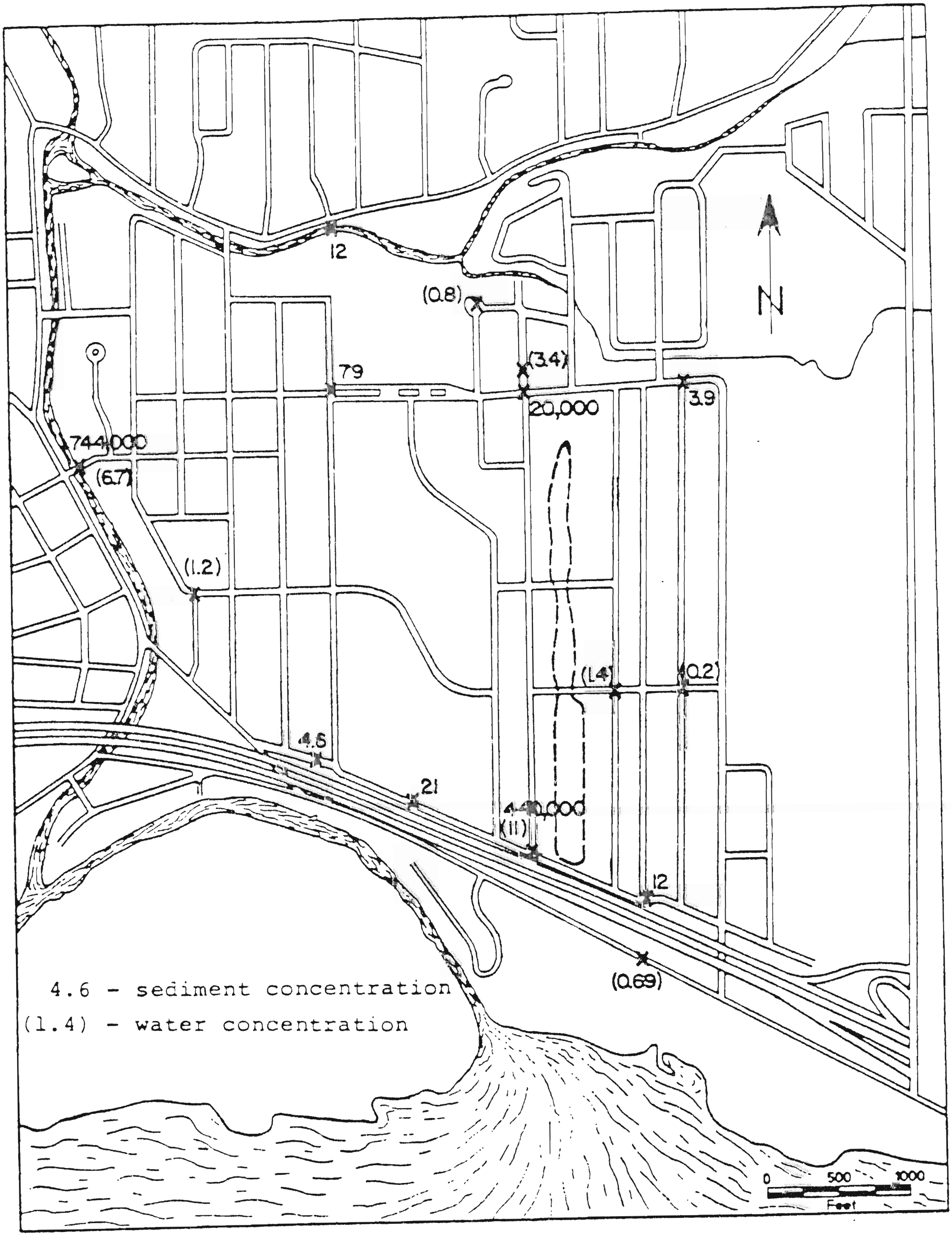


Figure 20. Concentrations (ppb) of γ BHC in storm sewer sediment and water samples.

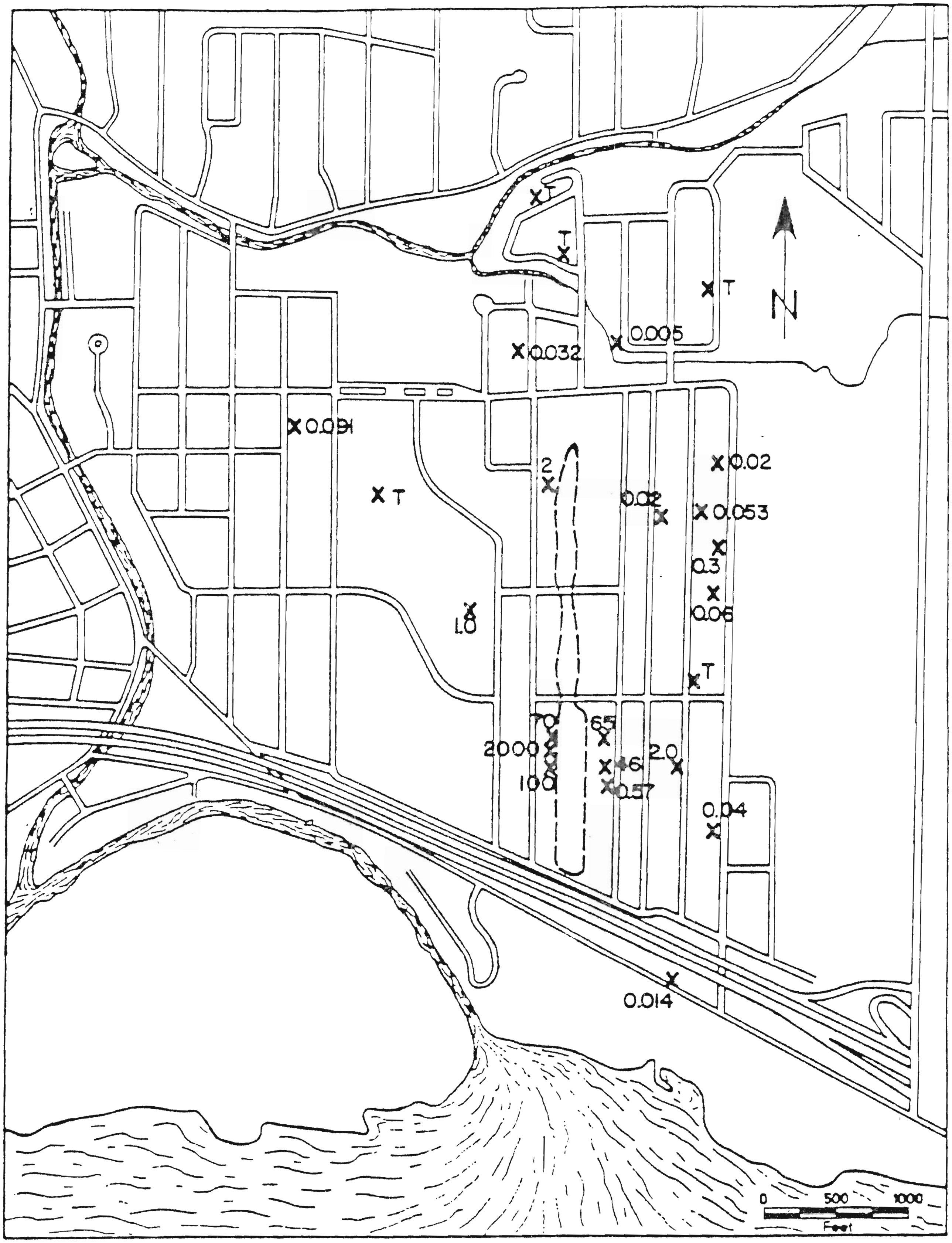


Figure 21. Concentrations (ppb) of γ BHC in sump samples.

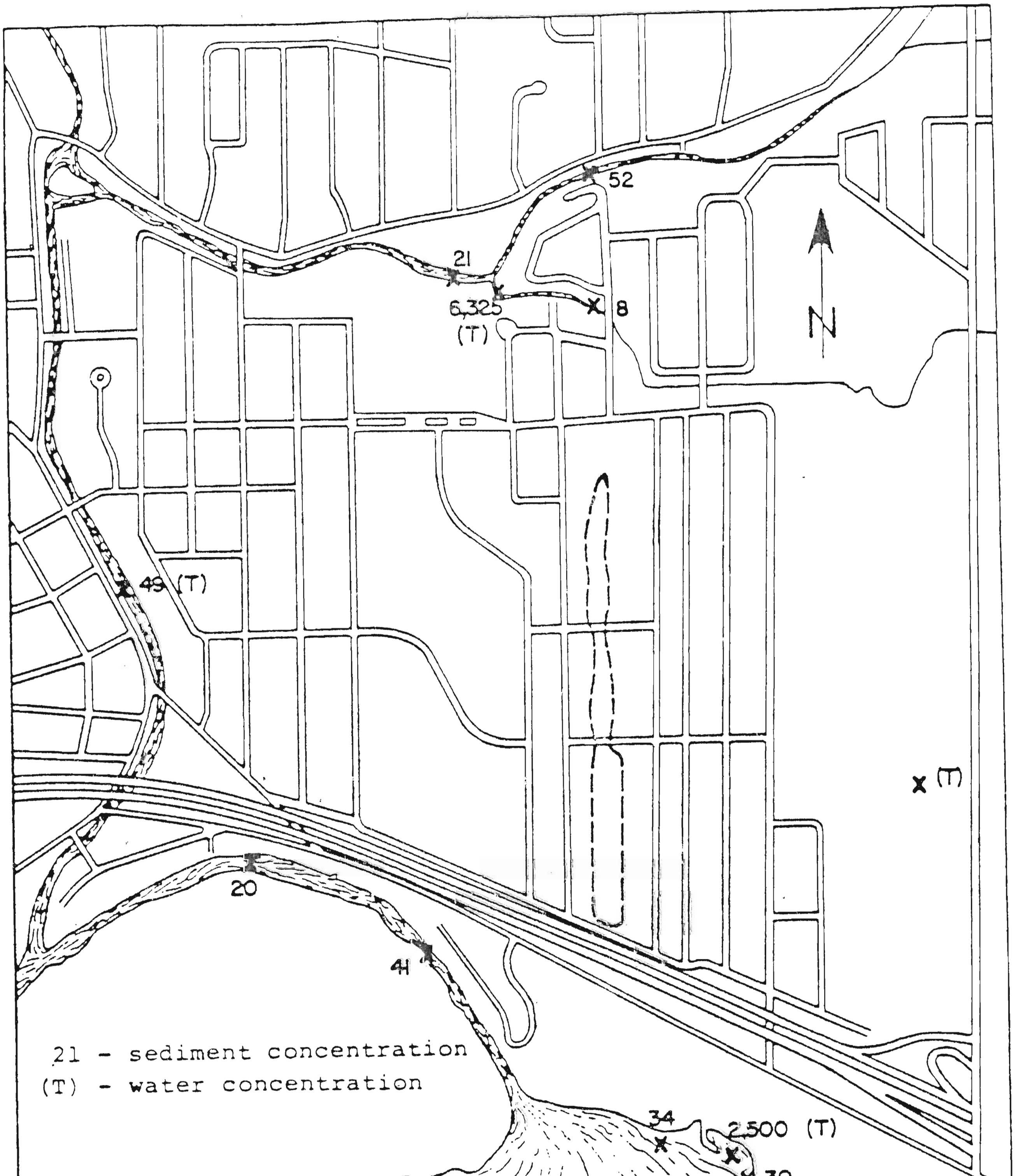


Figure 22. Concentrations (ppb) of γ BHC in surface water body sediment and water samples.

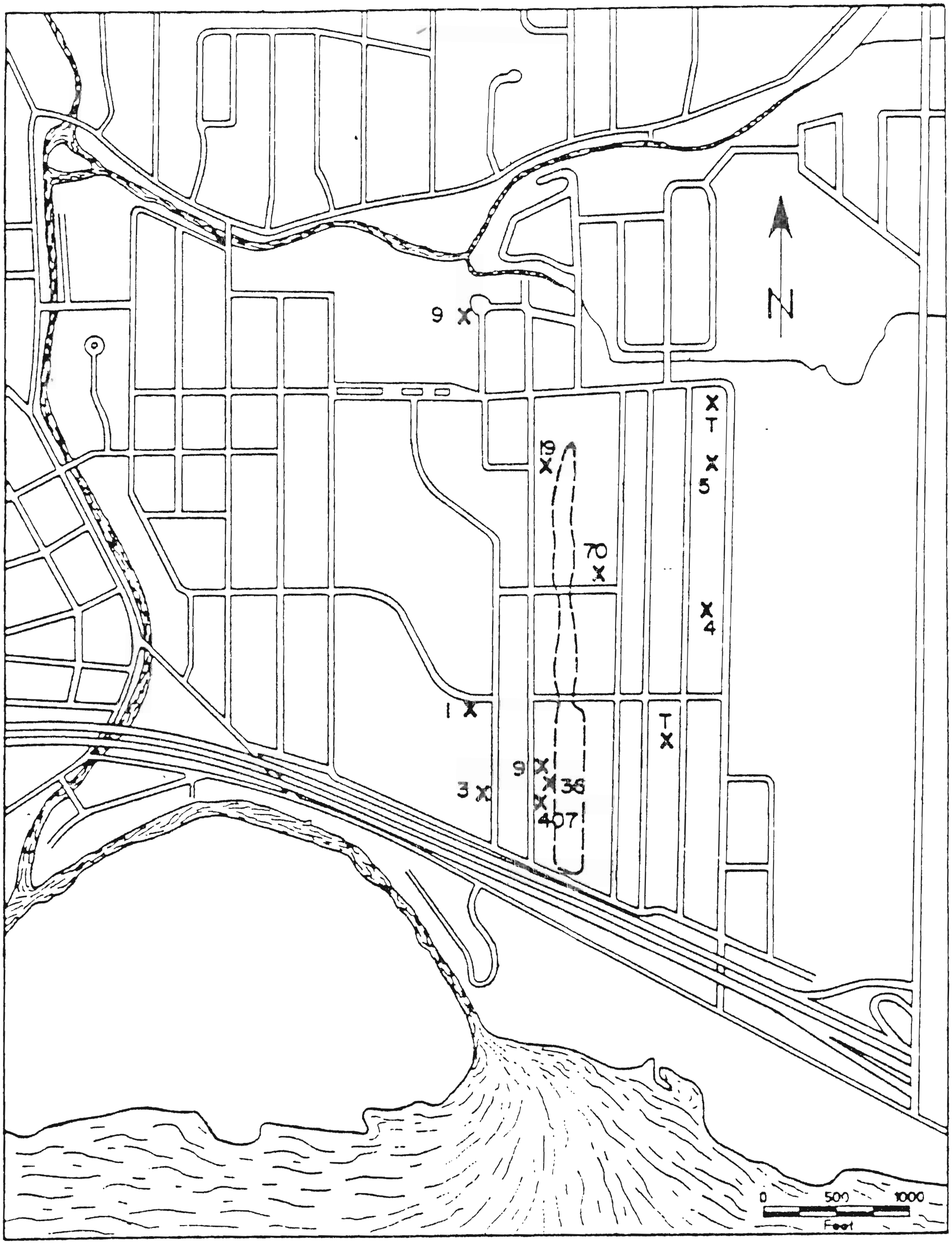


Figure 23. Concentrations (ppb) of γ BHC in soil samples.

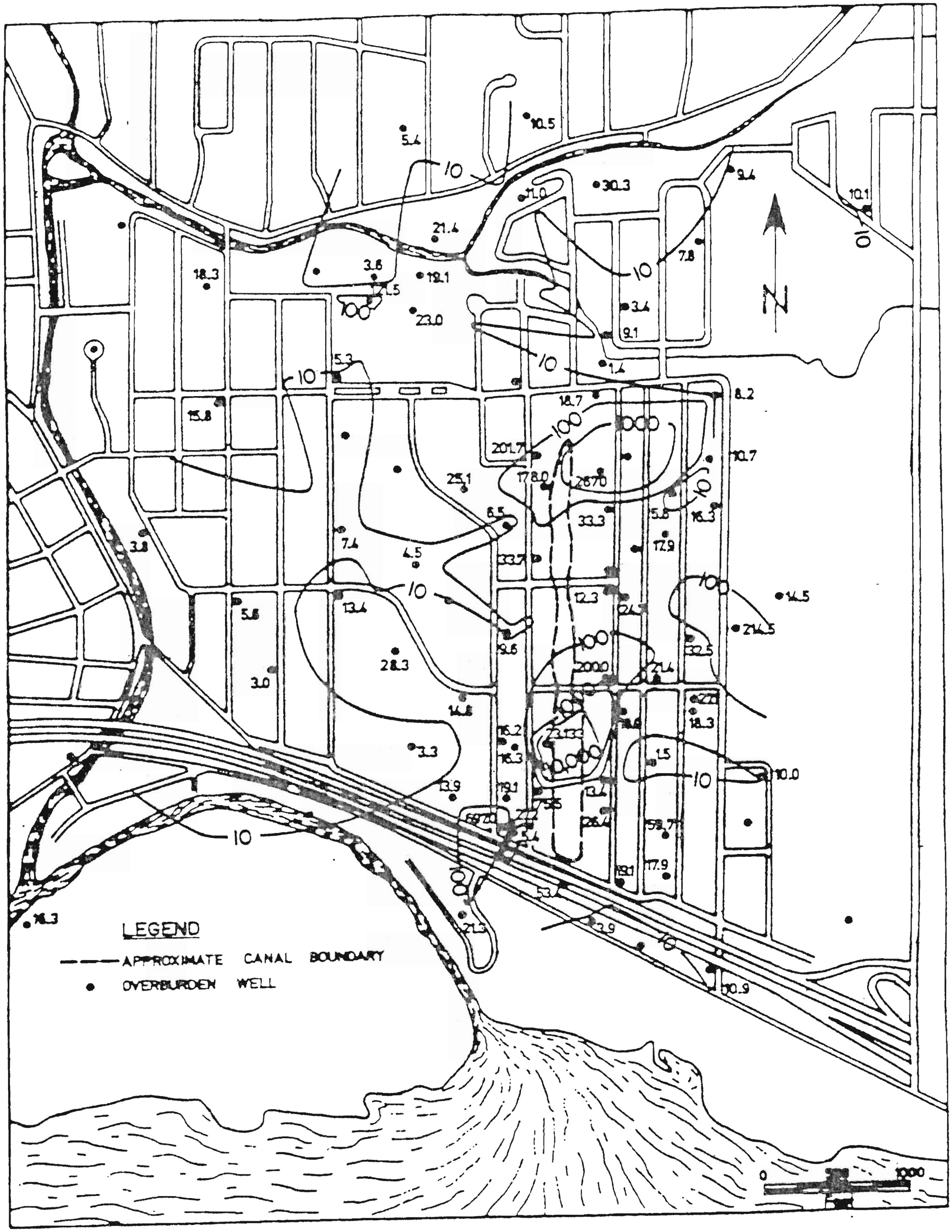


Figure 24. Concentrations (ppb) of total organic halogens in overburden wells.

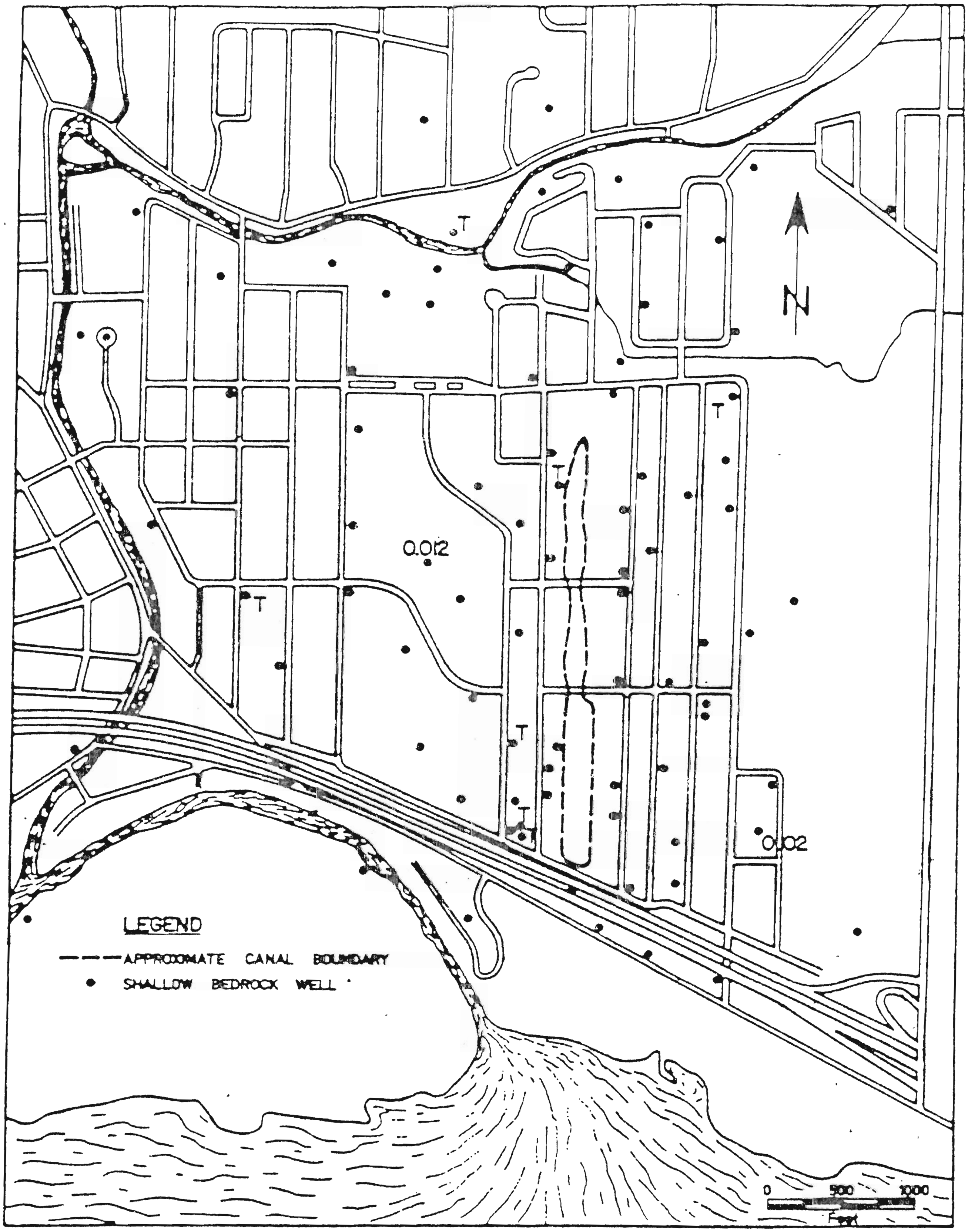


Figure 25. Concentrations (ppb) of γ BHC in Lockport Dolomite wells. (Well 4-B-2, at .015 ppb, could not be accurately located)

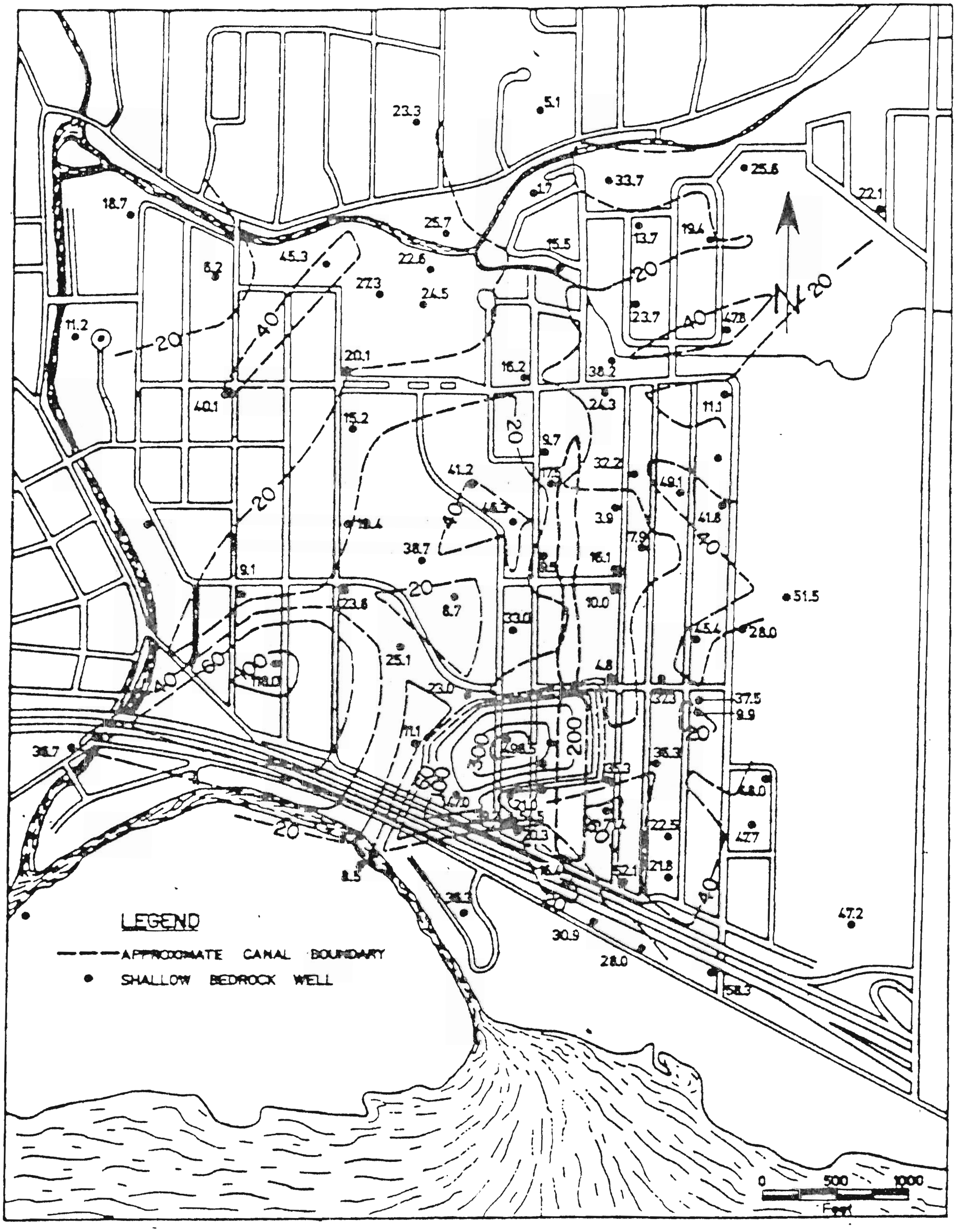
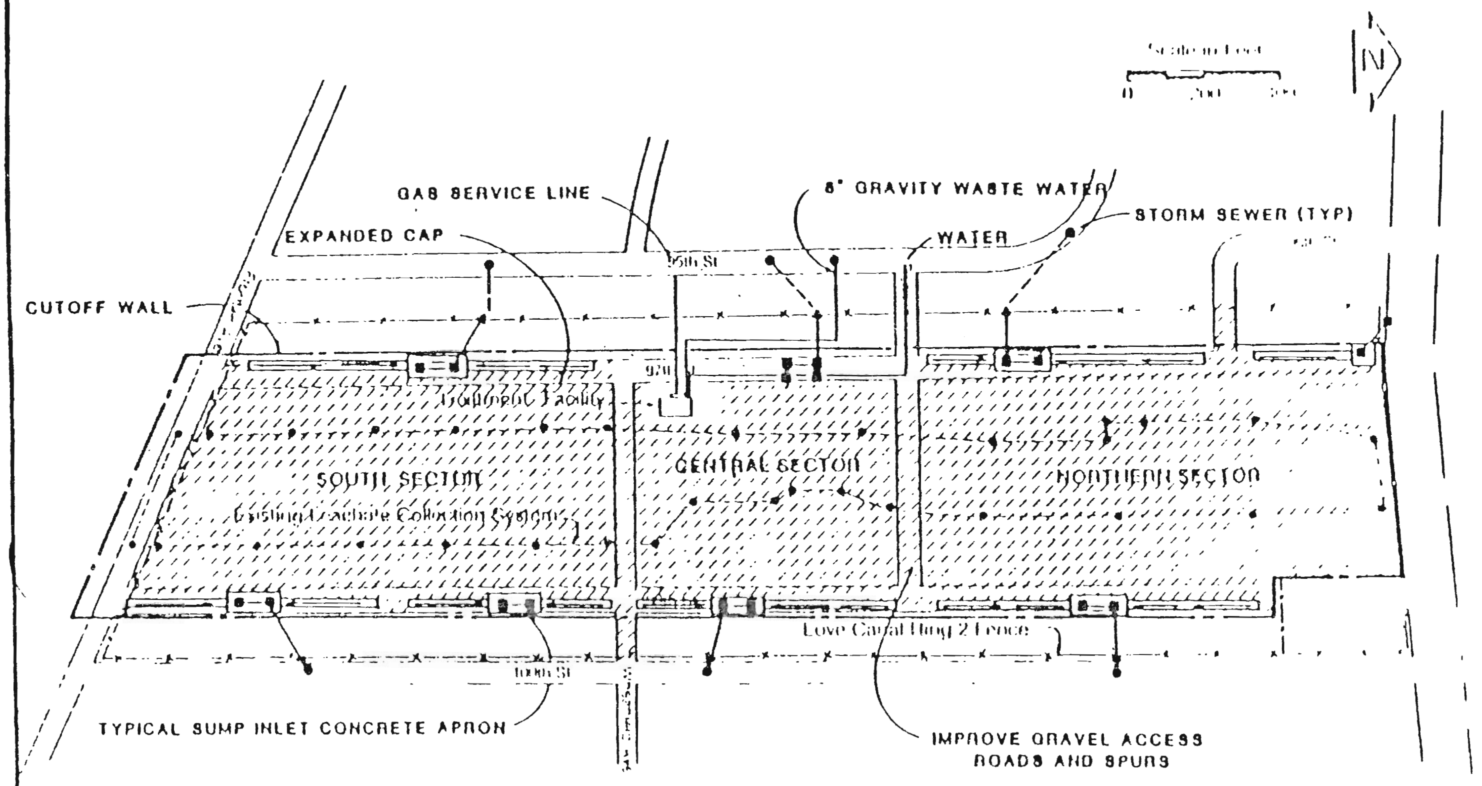
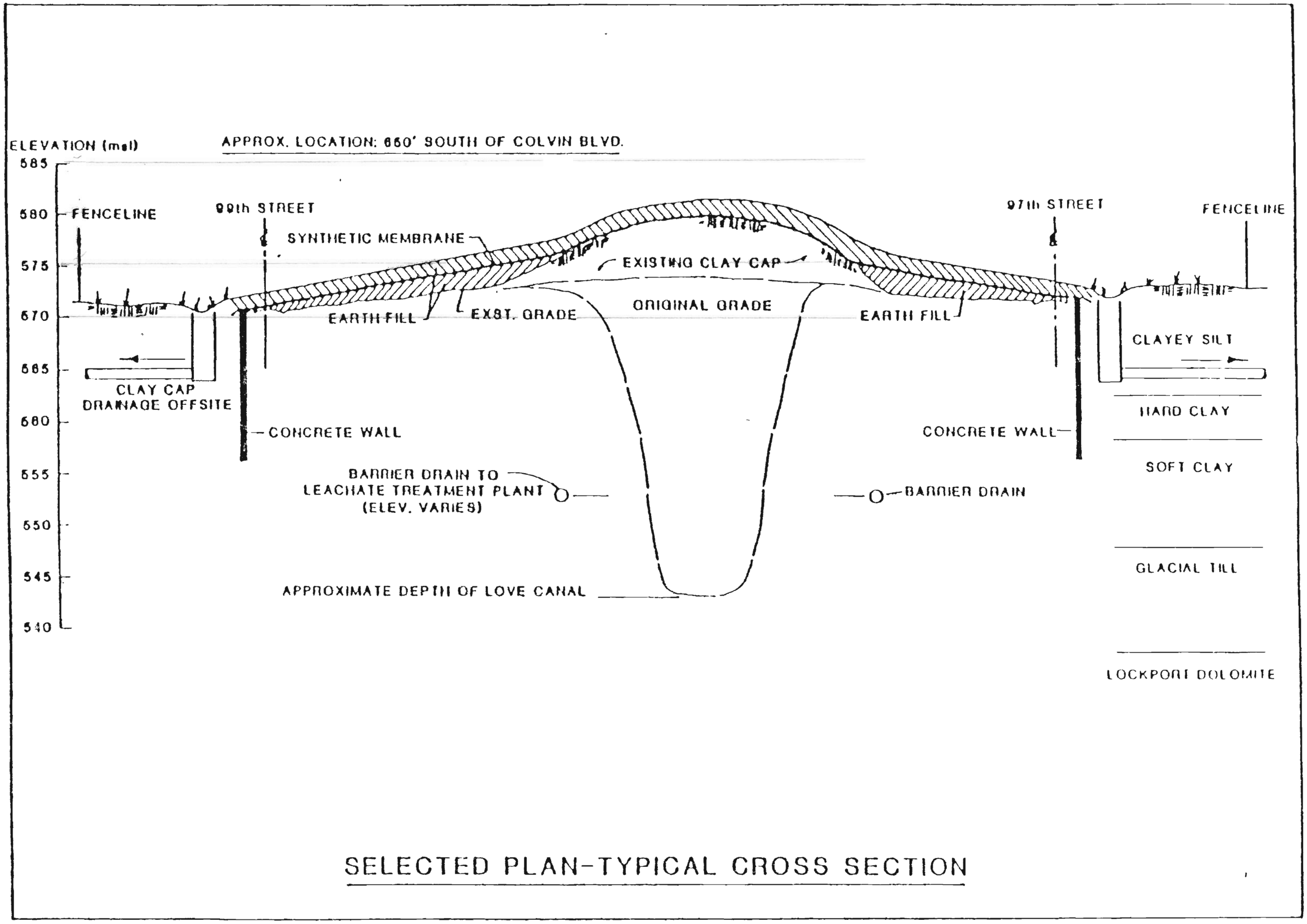


Figure 26. Concentrations (ppb) of total organic halogens in Lockport Dolomite.



PLAN VIEW OF SITE CONTAINMENT

Figure 27. Location of expanded clay cap, concrete cut off wall and other elements of the proposed Superfund remedial action (from Love Canal Superfund Presentation, August 16, 1982)



SELECTED PLAN-TYPICAL CROSS SECTION

Figure 28. Cross section showing subsurface elements of the proposed Superfund remedial action (from Love Canal Superfund Presentation, August 16, 1982)

discharges to Cayuga Creek. Concentrations of 1,4 Dichlorobenzene in this sample were of the order of 140,000 ppb. Contamination in sediments obtained from sewers was erratic. Sites possessing high 1,4 Dichlorobenzene levels were frequently located adjacent to sites which had below detectable levels. Surface water sediment samples indicated a similar erratic nature of contamination. Although some of the samples indicated fairly high levels of contamination, no consistent pattern of contamination was apparent.

Since 1,4 Dichlorobenzene did not exhibit any consistent contaminant patterns, a second relatively abundant component in the Canal, γ BHC or Lindane, was selected. The solubility of γ BHC in water is about 80 mg/L, and under similar soil conditions it should be approximately a factor of 4 more reactive than 1,4 Dichlorobenzene. However, the detection limit of the laboratory measurement for γ BHC was .004 as compared to 34 ppb for 1,4 Dichlorobenzene. Therefore γ BHC should provide a relatively sensitive pathway detection capability.

The number of ground water samples containing measurable quantities of γ BHC is much higher than those containing 1,4 Dichlorobenzene, with water quality samples from 21 overburden wells indicating the presence of γ BHC (Figure 19). The concentration is in most instances trace (T) and likely reflects the sensitivity of the method and the general background levels rather than presenting any preferred pathways in the groundwater system.

Samples of water and sediment taken from the storm sewer system (Figure 20) show that the contaminant is present although primarily in the sediment rather than the water. Samples from the storm sewer outfall on Lindbergh Avenue and the manhole at the corner of 97th Street and Frontier Avenue had sediment concentrations that were five orders of magnitude higher than water concentrations.

Sump samples contained the highest concentrations of γBHC found in any water samples. As can be seen in Figure 21, house sumps immediately adjacent to the Canal possess the highest measured levels. As was the case with 1,4 Dichlorobenzene, sediment samples from nearby surface water channels (Figure 22) exhibited fairly high concentrations of γBHC, while water samples from these same bodies contained little if any contaminant.

The results of the soil samples (maximum 6 foot depth) analysed for γBHC are presented in Figure 23. Again there is no clear contamination pattern. Given that a portion of the original clay cover was removed and used for fill and grading in the surrounding area, it is possible that many areas in the vicinity of Love Canal might exhibit soil contamination.

The concentration data for all the contaminants for overburden wells from the monitoring program reported in USEPA (1982) indicate that contamination levels are, in general, relatively low. This data has been summarized in Appendix IV for all of the organic contaminants and the highest two metal concentrations reported at each well. This data base indicates that the contaminants, in general, are either not present or are present in trace or low concentrations. For example, concentrations of individual organics and metals do not exceed 3300 ug/L and 3700 ug/L respectively.

Another data base for assessing the extent of contamination is given in JRB Associates (1981). JRB analyzed ground water samples for concentrations of total organic carbon (TOC) and total organic halogens (TOH) and measured specific conductance and pH. Results exist for the majority of wells providing the best available overall representation of contamination in the Love Canal vicinity. Of these, TOH was the only parameter which suggested a consistent pattern (Figure 24). Relatively high TOH concentrations occur at the north end of the Canal (wells 76A, 84A and 104A) and at the Canal just south of Wheatfield Avenue (wells 73A and 77A). Concentrations decrease rapidly with distance away from the areas of peak concentration suggesting that contamination is not widespread. It should be noted that Calspan (1977) found that drummed wastes were disposed of primarily in the northern and southern limits of the Canal and intermittently elsewhere. Another relatively high concentration of TOH is present at well 50A near Frontier Avenue and 96th Street.

The TOC, specific conductance and pH data, taken from JRB Associates (1981), are shown plotted in Appendix IV. The TOC concentrations (Figure IV-1) and specific conductance measurements (Figure IV-2) are erratic and do not show any consistent trend with respect to the location of the Canal. Several wells exceed the range of specific conductance (727-2240 umhos/cm) reported by Johnston (1964) for overburden wells in the Niagara Falls area, but no apparent migration pathways from the Canal are evident. The pH measurements (Figure IV-3) are generally in the range of 7 to 9 (similar to range reported by Johnston, 1964) with several values higher than 12.

4.2.2 Possible Migration Pathways in Overburden Flow System

The examination of specific organic contaminants monitored by the USEPA provided limited evidence of contamination patterns in the Love Canal area. The highest levels of contamination appear to be associated with sediment samples of either the storm sewer system or surface water bodies. It was also found that water concentrations of these contaminants were highest in the sumps of houses immediately adjacent to the Canal. One might have expected concentrations of the sump water to be similar to water from nearby overburden wells which were generally relatively low. It is conceivable that a difference in the sampling technique used for sumps versus ground water wells might account for some of the apparent discrepency between sample concentrations. The overburden wells were purged until dry followed by a recovery period prior to obtaining samples for analysis of organic and inorganic constituents (JRB Associates, 1981). In the case of volatile organics, dewatering the well and a portion of the surrounding sand pack may have actually optimized conditions for volatilization losses.

The relatively high concentrations found in storm sewer and stream sediments and water might have resulted from several possible migration pathways. It is possible that the contamination was derived from overland flow of ponded contaminants to catch basins prior to the implementation of remedial measures. However, while this method of migration might account for some of the observed concentrations downstream of catch basins, it is difficult to attribute all the observed contamination to this process. This is substantiated by the relatively high concentrations found in the sanitary sewer sample. Another possible transport mechanism is the infiltration of contaminated ground water into the sewer systems (note that the sewers were installed at about a 10 foot depth). Contaminated ground water from the Canal could have migrated to the sewer systems along preferential pathways including filled swales and buried utility/service lines. Even if the sewer was not laid upon nor backfilled with gravel, the excavation process itself may result in higher permeability material in the excavated trench. The potential for contaminated ground water to seep into a sewer, through joints or breaks in the pipe, is quite high.

Sumps located in the basements of nearby houses would tend to act as ground water sinks drawing in contaminated ground water which had migrated from the Canal. This would explain the high concentrations associated with the sumps of houses immediately adjacent to the Canal. If the pumps located in these sumps were activated fairly often then it is likely that a high percentage of the shallow contaminated ground water emanating from the

Canal was intercepted by these sumps. Consequently, the quantity of contaminated ground water capable of migrating to houses at greater distance would be less. Evidence provided by USEPA's monitoring program (USEPA, 1982) would tend to support this hypothesis. Since the sump water is discharged to the sewers, this provides an additional mechanism for the contamination of the sewer system.

Some of the erratic nature of contamination determined by USEPA's monitoring program may be attributable to another transport process. Some of the soil cover on the filled Canal was removed and used for grading nearby areas (Zuesse, 1981; Hooker, 1980). It is conceivable that the low permeability materials surrounding the Canal in conjunction with high levels of precipitation could have caused ground water mounding in the vicinity of the Canal resulting in the contamination of the soil cover with leached chemicals. The removal of this cover for the purpose of grading would therefore result in scattered areas of contamination wherever the material was used. Associated with this soil contamination would be subsequent ground water contamination from chemicals leached from the fill material.

The presence of cracks or fractures in the upper portion of the clay unit was identified during several investigations (Conestoga-Rovers & Associates, 1978a; Clement Associates, 1980). As discussed previously, there is the potential for rapid transport of ground water through a fractured hydrogeologic system. The chemical concentration data obtained with the overburden well monitoring network, however, do not indicate a well connected fracture network in the Love Canal vicinity. The significance of the fractures has likely been reduced by a combination of diffusion of chemicals into the intact clay matrix, sorption onto the fracture surfaces and into the clay matrix, and poor interconnection of the fractures.

4.2.3 Bedrock Contamination

1,4 Dichlorobenzene and γBHC were also used to investigate transport of organic contaminants in the bedrock flow system. Data obtained from USEPA (1982) indicated that migration patterns were indeterminant as only 1 non-zero well sample was obtained for 1,4 Dichlorobenzene and 9 for γBHC, of which most were trace concentrations (Figure 25).

TOH and TOC concentrations and specific conductance and pH measurements by JRB Associates (1981) were also available for the bedrock wells. TOH concentrations suggest that a contaminated zone may be present west of the canal just south of Wheatfield Avenue (Figure 26). This zone is downgradient of the Canal in the bedrock ground water flow regime. Unfortunately, the TOH data is incomplete with the wells closest to the southern end of the Canal reported as "N.A.". Also, the relatively high TOH values are not reflected in the organic and metal concentration data in Appendix III. Concentrations of TOH in wells surrounding the peak drop off quickly to background levels.

The bedrock well TOC levels (Figure IV-4 in Appendix IV) in the Canal area are comparable to background levels in the surrounding area. There are several wells, upgradient from the Canal, which report higher TOC levels. Specific conductance measurements (Figure IV-5) are erratic and suggest no apparent pattern with respect to the Canal area. They are, in general, similar to the range (335-6390 umhos/cm) reported by Johnston (1964). Many of the bedrock wells had apparently not chemically stabilized prior to sampling as evidenced by the high pH values (Figure IV-6). These high pH measurements indicate that about half of the wells had significant cement contamination. The chemical data should, therefore, be considered to be approximate, indicative only of general patterns. Considering the short time period between well installation and sampling, there exists the possiblility that some of the contamination present in the bedrock wells may have been derived from the overburden during well installation. From available information, it is not possible to determine if this is the case.

5.0 THE PROPOSED LOVE CANAL REMEDIAL ACTION PROGRAMS (1982)

5.1 Proposed Remedial Program (after CH2M Hill, 1982)

CH2M Hill, under contract to USEPA and New York State Department of Environmental Conservation (NYSDEC), was retained to complete a study aimed at containing and/or removing contamination directly attributable to past waste disposal practices at Love Canal. The scope of the project was to involve remedial measures associated with contamination problems encountered within the fenced area at Love Canal. The fenced area runs north from Frontier Avenue, south from Colvin Boulevard, east from half way between 96th and 97th Streets and west from 100th Street. Remedial plans for the area outside the fenced Canal are known to be planned (Love Canal Superfund Presentation, 1982) and are discussed in a later section. Proposed remedial actions dated April 1982 for the fenced area are scheduled for implementation late in 1983. It should be noted that these plans are not finalized and are subject to approval of various government agencies. Highlights of the remedial measures planned are outlined below as quoted from CH2M Hill (1982).

- "A continuous slurry wall will be constructed to depths ranging from 10 to 14 feet around the entire canal site. On 97th and 99th Streets, it will be constructed about 15 feet outside the curb line on the side of the road furthest from the canal. On the north end, it will be constructed just inside the fenceline along Colvin Boulevard. On the south end, it will be constructed within the Frontier Avenue right-of-way south of the road."

- "Subject to approval by the City of Niagara Falls, 97th and 99th Streets will be abandoned south of Wheatfield Avenue and north of Read Avenue. NYSDEC will coordinate approval of activities with the City."

- "An expanded clay cap will cover the site, extending from the existing clay cap to the outside edges (furthest from the cap) of the abandoned portions of 97th and 99th Streets. Around the school and the leachate treatment plant, ground surface will be contoured to ensure adequate drainage from these structures. The expanded cap will be graded to a minimum 2 percent slope from the existing cap to the roads. Grading the site will increase run off from the presently flat terrain, thereby reducing infiltration. The 15-foot strip between the slurry wall and the street, and the ground surface between the school and the treatment plant and the street will not be provided with a clay cap."

- "Water, gas, sanitary, and storm sewers entering and leaving the site will be cut off and plugged."

- "A new 6-inch potable water line will connect the leachate treatment plant to the existing water system on 95th Street to the west of the plant. A new 8-inch effluent line will connect the plant sanitary facilities to the off-site wastewater collection system on 95th Street. This line will parallel the new 6-inch water line."

- "Runoff from the site will be collected at 8 locations. Two of these will be located between Wheatfield and Read Avenues on 97th and 99th Streets. The remaining 6 locations will collect drainage from the expanded clay cap."

- "Specified existing monitor wells will be maintained while some wells, to be designated, will be plugged."

- "Telephone utility lines along Frontier Avenue may have to be relocated to facilitate slurry wall construction."

- "The storm and sanitary sewers may be cleaned to remove deposits."

- "After site activities are completed, 97th and 99th Streets between Wheatfield and Read Avenues will be repaired and sealed to restore the surface and to reduce infiltration of water through the pavement surface."

- "It is assumed that the pending NYSDOT contract will include the following elements:

  - Demolish both Ring 1 and Ring 2 homes.

  - Provide clay cap on demolished homesites within the fenced areas.

  - Remove all unnecessary utility poles and sidewalks within the fenced area. All pavements and slabs in the Ring 2 area and in roadside portions of Ring 1 will be removed. Trees will be saved where possible, to be designated during construction.

  - Provide new utility service to the existing wastewater treatment plant and school."

5.2 Proposed Remedial Program (after Love Canal Superfund Presentation, 1982)

A modified version of the remedial measures proposed by CH2M Hill was presented at the Love Canal Superfund Presentation dated August 16, 1982. Proposed actions listed below for the fenced area follow along the same lines as the CH2M Hill recommendations given in the previous section. The final disposition of these plans is unknown at this time. The site containment construction elements include (Figures 27 and 28):

- "Sever and plug all underground utilities leaving site"
- "Provide new utilities to leachate treatment plant, new storm sewers"
- "Construct concrete cutoff wall around site"
- "School demolition"
- "Remove ring 1 trees, cover unnecessary roads, provide 2% minimum site grade"
- "Cover contained site with impermeable membrane"
- "Provide 18" minimum soil cover over membrane"
- "Provide well monitoring system (later projects)"

Remedial measures under consideration for the area outside the fenced area at Love Canal include the following list of assessment type projects which are scheduled to follow construction of site containment measures discussed previously (Love Canal Superfund Presentation, 1982):

- "North storm and sanitary sewers clean-up"
- "Black and Bergholtz creeks clean-up"
- "South storm and sanitary sewers clean-up"
- "Ground water monitoring"
- "102nd street outfall sediment clean-up"
- "West storm and sanitary sewer clean-up"
- "Construction work plan and schedule report"

5.3 Discussion of Proposed Remedial Programs

In comparing the proposed remedial actions presented in sections 5.1 and 5.2, several differences are apparent. Most notably the Love Canal Superfund Presentation (1982) includes demolition of the 99th Street school, placement of a synthetic membrane over the entire Love Canal site and utilization of a concrete cutoff wall.

The synthetic membrane should further reduce infiltration, although cost/benefit arguments against the membrane can be developed if assumptions are made concerning membrane life and replacement frequency (eg. Woodward-Clyde, 1982). The concrete cutoff wall will result in reduced lateral ground water movement into or out of the Canal area, however, it may also limit the lateral extent to which the installed barrier drains are effective. If the barrier drains and other remedial measures such as the clay or membrane cap lower the water table sufficiently and the cutoff wall deflects sufficient horizontal ground water movement, the drain system may actually cease to function. However, the concrete will eventually degrade and require replacement, whereas a slurry wall should have better long term characteristics.

With the existing and proposed remedial measures, the downward hydraulic gradient from the till to the Lockport Dolomite will be reduced and possibly reversed, resulting in upward flow from the Lockport Dolomite to the till and barrier drains. This can be considered a positive feature as it should further reduce any ground water movement away from the site.

Overall, the net flow of ground water from the site (within the confines of the barrier wall) should be minimized. The severing and plugging of utility lines, enhanced overland run-off collection, demolition of buildings, and grading and repairing of roads will also act to reduce ground water flow through the immediate Love Canal area.

Migration of chemicals from the Canal in the ground water system should be minimal, providing the measures are successful. The success of the proposed remedial measures are contingent on adequate engineering methods and perpetual maintainance. There is some uncertainty regarding the possible breaching of the till cover during Canal excavation, with the resultant direct hydraulic connection between the Canal wastes and the Lockport Dolomite. More detailed monitoring of the Lockport Dolomite wells in the vicinity of the relatively high TOH values in the bedrock (Figure 26) is required. If continued and extensive contamination is present, a remedial program concerning the Lockport Dolomite ground water system will need to be developed.

The question of migration of solvents or chemicals in liquid form, but not necessarily dissolved in groundwater, has not been addressed. Many of the drums, etc. that contained the original chemicals will eventually disintegrate. As this occurs, liquids with properties different to those of water (e.g. density, viscosity) will be added to the subsurface system. An understanding of the suitability of the present and proposed remedial program for isolation and/or interception of these non-aqueous phase contaminants should be developed. The understanding could be initiated with a mathematical modeling study involving transport of non-aqueous liquids and vapor phases within water saturated and unsaturated hydrogeologic systems.

6.0 CONCLUSIONS

Evaluations of previous hydrogeologic studies and other data relevant to Love Canal have resulted in the following conclusions which are considered pertinent to Niagara River water quality. It should be noted that the ground water elevation and water quality data base, which were collected over a short time span (several months), are considered insuffient to facilitate definitive conclusions on the ground water flow patterns or the exact extent of contaminant migration. However, the following conclusions were drawn based on available information:

- It is likely that some contaminants originating in Love Canal have entered the Niagara River via its tributaries which were receiving storm sewer discharge originating in the Love Canal vicinity. The level of contaminant loading is unknown.

- The data suggest that little contamination has entered the Niagara River or its tributaries through conveyance in the overburden ground water system or Lockport Dolomite aquifer. Contamination of the overburden ground water system is generally confined to the immediate Love Canal area.

- Implemented remedial measures have reduced further migration, in the overburden ground water system, of contaminants from the Love Canal into the Niagara River or its tributaries. Some contaminated sediments still remain in local tributaries and sewers at this time. Clean up of these sediments is part of the proposed future remedial measures.

- Contaminant migration in the overburden ground water system from the Love Canal waste disposal site is believed to have been confined to several highly selective routes of relatively high hydraulic conductivity. Preferential migration pathways are considered to include dessication cracks, underground utilities, intermittent sand lenses, and swales. These selective transport pathways, plus redistribution of clay cap material for grading and fill purposes, have resulted in erratic contamination of the general Canal area.

- Interconnection of the upper Lockport Dolomite aquifer and overburden ground water system is possible but indeterminate from the available data. The interconnection would likely be a result of the original Canal excavation extending through the full depth of the clay and till to the Lockport Dolomite. Total organic halogen concentrations in the Lockport Dolomite are well above background levels in some bedrock wells which are located on the southwest side of the Canal.

7.0 RECOMMENDATIONS

The following recommendations are made for the purpose of assisting the ongoing studies and remedial action in the Love Canal area. They are based on the understanding of the hydrogeologic conditions in the Canal area developed during the course of the evaluation presented in this report.

1. The three dimensional extent and effectiveness of the installed barrier drain system should be evaluated by extending and augmenting the existing ground water monitoring network. The location and type of ground water instrumentation (eg. piezometers, wells, tensiometers) should be selected specifically for barrier drain evaluation. The barrier drain is likely the single most effective measure on site and establishing its effectiveness with considerable certainty would be extremely useful in evaluating containment.

2. Existing bedrock wells 6B, 37B, 38B, 39B, 39D, 49B, 50B, 56B, 56C, 77B, 79B, 80B, 80D, 86B, and 86C should be sampled several times over the next six to twelve months in order to clarify the Total Organic Halogen (TOH) data shown in Figure 26. If the samples show contamination in the wells, it would imply a breach of the till overlying the bedrock in the Canal as well as direct access of contaminants to the bedrock. If the contamination appears extensive and persistent, a more detailed monitoring network in the bedrock should be established and a remedial program concerning the Lockport Dolomite should be developed.

3. An understanding should be developed of the suitability of the existing and proposed remedial measures to intercept and contain non-aqueous phase contaminants. The understanding could be initiated with a conceptual and modeling study concerned with transport of non-aqueous phase liquids (solvents, dense chemicals) and vapor phases within water saturated and unsaturated hydrogeologic systems.

REFERENCES

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TABLE 1. Waste Inventory for Love Canal (after Hooker, 1978)

Waste Categories	Physical State	Total Estimated Quantity - Tons	Container
Miscellaneous acid chlorides other than benzoyl (includes acetyl, caprylyl, butyryl, nitro benzoyls)	L,S	400	D
Thionyl chloride and miscellaneous sulphur/chlorine compounds	L,S	500	D
Miscellaneous chlorinations (includes waxes, oils, napthalines, aniline)	L,S	1,000	D
Dodecyl (Lauryl, Lorol) mercaptans (DDM), chlorides and miscellaneous organic sulphur compounds	L,S	2,400	D
Trichlorophenol (TCP)	L,S	200	D
Benzoyl chlorides and benzotrichlorides	L,S	800	D
Metal chlorides	S	400	D
Liquid disulphides (LDS/LDSN/BDS) and chlorotoluenes	L	700	D
Hexachlorocyclohexane (Lindane/BHC/HG1)	S	6,900	D,C
Chlorobenzences	L,S	2,000	D,C
Benzyl chlorides (includes benzal chloride, benzyl alcohol, benzyl thiocyanate)	S	2.400	D
Sodium sulphides/sulfhydrates	S	2,100	D
Miscellaneous 10% of above		2,000	
	TOTAL	21,800	

L - liquid waste under normal conditions

S - solid waste under normal conditions

L,S - sludge or combination of liquid and solid wastes

B - bulk shipment of residues

D - drum shipment of residues

C - non-metal containers of residue

TABLE 2. Cross Reference Directory for JRB Associates (1981) Well Number to USEPA (1982) Site Code Number

JRB Well No.	EPA Site Code No.	Wells With EPA Water Quality Data	JRB Well No.	EPA Site Code No.	Wells With EPA Water Quality Data
1A,B	05030	A	32A,B	03526	A
2A,B	99550	A,B	33A,B	03513	A
3A,B	07504	A,B	34A,B	02043	A
4A,B,B-2	99558	B,B-2	35A,B	02044	A
5A,B	99559	A,B	36A,B	03515	A
6A,B	03512	A,B	37A,B	03516	A,B
7A,B	99552	A	38A,B	03517	A
8A,B	02014	A,B	39A,B,D	03518	A,B
9A,B	99556	B	40A,B	01011	A
10A,B	02025	A,B	41A,B	99551	A,B
11A,B	04520	A	42A,B	99015	A,B
12A	04512	A	43A,B	99016	A,B
13A,B	05021	A	44A,B	10039	A
14A,B	05026	A,B	45A,B	99017	A,B
15A,B	04018	A,B	46A,B	99553	A,B
16A,B	04002	A,B	47A,B	02049	A
17A,B	07015	A,B	48A,B	10040	A
18A,B	07014	A	49A,B	03524	A,B
19A,B	07019	A,B	50A,B	03525	A,B
20A,B	07020	A	51A,B	06018	A
21A,B	09015	A,B	52A,B	10041	A,B
25A,B	02027	A,B	54A,B	99554	A
26A,B	02026	A,B	55A,B	07501	A,B
27A	02037	A	56A,B	10042	A,B
28A,B	02038	A,B	63B	04037	B
29A,B	02039	A,B	64B	05018	B
30A,B	02040	A	65B	05027	B
31A,B	02041	A,B	66A,B	06011	A,B

JRB Well No.	EPA Site Code No.	Wells With EPA Water Quality Data
67A,B	08012	A
68A,B	08011	A
71A,B	11034	A,B
72A,B	11035	A,B
73A,B	11036	A,B
74A,B	11037	A
75A,B	11038	A
76A,B	11001	A,B
77A,B	11039	A,B
78A	11040	A
79A,B	11041	A,B
80A,B	11017	B
81A,B	11042	B
82A	11043	A
83A,B	11044	B
84A,B	11045	A,B
85A,B	11046	A
86A,B	11047	A
87A,B	11048	A,B
88A	11049	A
89A,B	11050	A,B
90A,B	04508	A
96A,B	10034	B
98B	99033	B
99A,B	99034	B
100B	99557	
101A,B	99555	A,B
102A	02057	A
103A,B	08020	A,B
104A,B	11054	A,B
108A,B	99560	B
109A,B	10051	B
110A,B	09019	A
111A	06019	A
112A,B	99072	A,B
113A-1, A-2	11066	A-1,A-2

Note:
1) Well 27B abandoned;
2) Wells 4A, 4B, 4B-2 could not be located;
3) No EPA data reported for well 100B.

TABLE 3. Hydraulic Conductivities of Overburden Materials

Stratum	Hydraulic Conductivity (cm/s)	Comments	References
Shallow Fill	10^{-5}		USEPA (1982)
Shallow coarser fill	1×10^{-2}	Estimated	JRB Associates (1981)
Clay	9.8×10^{-9}	Constant head test in upper portion of clay unit at 92nd Street test site	GeoTrans (1981)
Clay	3.7×10^{-8}	Slug test in lower portion of clay unit at 92nd Street test site	GeoTrans (1981)
Clay	approx. 10^{-7}	Upper portion of clay unit (3 to 8 ft thick)	USEPA (1982)
Clay	approx. 10^{-8}	Lower portion of clay unit (6 to 29 ft thick)	USEPA (1982)
Till	similar to clays		GeoTans (1981) (references source as Glaubinger et al., 1979)
Till	7.6×10^{-9}	Constant head test at 92nd Street test site	GeoTrans (1981)
Till	approx. 10^{-7}		USEPA (1982)

TABLE 4. List of Substances Monitored in Love Canal Water/Soil/Sediment/Biota (from USEPA, 1982)

Methylene chloride
Chloromethane
1,1-Dichloroethene
Bromomethane
1,1-Dichloroethane
Vinyl chloride
cis-1,2-Dichloroethene
Chloroethane
trans-1,2-Dichloroethene
Trichlorofluoromethane
Chloroform
1,2-Dichloroethane
1,2-Dichloroethene
1,1,1-Trichloroethane
Carbon tetrachloride
Bromochloromethane
Bromodichloromethane
2,3-Dichloropropene
1,2-Dichloropropane
Trichloroethene
2-Chlorophenol
3-Chlorophenol
4-Chlorophenol
2-Nitrophenol
Phenol
2,4-Dimethylphenol
2,4-Dichlorophenol
2,3,5-Trichlorophenol
2,4,6-Trichlorophenol
4-Chloro-3-methylphenol
2,4-Dinitrophenol
2-Methyl-4,6-dinitrophenol
Pentachlorophenol
trans-1,3-Dichloropropene
Benzene
Acrolein
Acrylonitrile
Dibromochloromethane
1,1,2-Trichloroethane
Bromoform
1,1,2,2-Tetrachloroethane
Benzyl chloride
o-Xylene
m-Xylene
p-Xylene
Tetrachloroethene
Toluene
2-Chlorotoluene
3-Chlorotoluene
4-Chlorotoluene
Chlorobenzene
Ethyl benzene
1,2-Dibromoethane
1,2-Diphenylhydrazine
4-Chlorophenylphenylether
2,4-Dinitrotoluene
2,4-Dichlorotoluene
Diethylphthalate
N-nitrosodiphenylamine
Hexachlorobenzene
4-Bromophenylphenylether
Phenanthrene
Anthracene
Di-n-butyl phtalate
Fluoranthene
Pyrene

4-Nitrophenol
Hexachloroethane
1,4-Dichlorobenzene
1,3-Dichlorobenzene
1,2-Dichlorobenzene
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
N-nitrosodi-n-propylamine
Hexachlorobutadiene
1,2,3-Trichlorobenzene
N-nitrosodimethylamine
1,2,4-Trichlorobenzene
1,3,5-Trichlorobenzene
Nitrobenzene
Naphthalene
Isophorone
Bis(2-chloroethoxy)methane
Hexachlorocyclopentadiene (C-56)
2-Chloronaphthalene
Acenaphthylene
Acenaphthene
Dimethylphthalate
2,6-Dinitrotoluene
Fluorene
α-BHC
β-BHC
δ-BHC
γ-BHC (Lindane)
Heptachlor
Aldrin
Mirex
Endosulfan I
Heptachlor epoxide
DDE
Endrin
Benzidine
Butylbenzylphthalate
Di(2-ethylhexyl)phthalate
Chrysene
Di-n-octylphthalate
Benzo(a)anthracene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Benzo(a)pyrene
3,3-Dichlorobenzidine
Indeno(1,2,3-dc)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
Pentachloronitrobenzene
2,4,6-Trichloroaniline
4-Chlorobenzotrifluoride
(Trifluoro-p-chlorotoluene)
1,2,3,4-Tetrachlorobenzene
1,2,4,5-Tetrachlorobenzene
Tetrachlorotoluenes (18 position isomers-ring and methyl substitution)
Endosulfan sulfate
DDD
Chlordane
DDT
Toxaphene
Aroclor 1221
Aroclor 1254
Aroclor 1016
Aroclor 1232
Aroclor 1242
Aroclor 1248
Aroclor 1260
Mercury
Nickel

Endosulfan II
Dieldrin
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Copper
Lead
Selenium
Silver
Thallium
Zinc
Fluoride
Nitrate

Note: 2,3,7,8-Tetrachlorodibenzo-p-dioxin or dioxin was quantitatively determined in a select number of samples.

APPENDIX II

Installation and Sampling Dates (1980) for Overburden and Lockport Dolomite Wells

Note: Well installation and water level measuring dates are from JRB Associaties (1981) and water quality sampling dates are from USEPA (1982)

TABLE II-1. Installation and Sampling Dates (1980) for Overburden Wells

Well No.	Well Installation Date	Water Quality Sampling	Water Level Measuring
1A	8/27	9/23, 9/27, 9/29	10/23
2A	8/29	9/23, 9/29	no data
3A	9/3	9/23, 9/27, 10/13	no data
4A	9/5	no data	no data
5A	9/5	9/22, 9/23, 9/27	10/22
6A	9/4	9/23, 9/27	10/23
7A	9/3	9/23, 9/29	no data
8A	9/9	9/23, 9/29	10/23
9A	9/3	no data	no data
9A-2	9/5	no data	no data
10A	9/7	9/23, 9/27, 9/29	10/23
11A	9/22	10/8	10/23
12A	9/5	9/22, 9/27	10/23
13A	9/8	9/23, 9/27	10/23
14A	9/12	9/23, 9/29	10/23
15A	9/16	9/22, 9/29	10/22
16A	9/18	10/3	10/23
17A	9/13	9/24, 10/1	10/23
18A	9/11	10/17	10/23
19A	9/9	9/24	10/23
20A	9/24	10/3	10/23
21A	9/26	10/3	10/23
25A	9/9	9/23, 9/27	10/23
26A	9/8	9/23, 9/27	10/23
27A	9/11	9/24	10/23
28A	9/15	10/1	10/23
29A	9/13	9/24, 10/1	10/23
30A	9/19	10/1, 10/2	10/23
31A	9/20	10/8	10/23

Well No.	Well Installation Date	Water Quality Sampling	Water Level Measuring
32A	9/18	10/2	10/23
33A	9/20	10/8	10/23
34A	9/19	10/2	10/23
35A	9/17	10/1	10/23
36A	9/19	10/2	10/23
37A	9/16	9/22, 9/26, 9/27	10/23
38A	9/18	10/1	10/23
39A	9/17	9/22, 9/27, 10/1	10/23
40A	9/23	10/8	no data
41A	9/23	10/3	no data
42A	9/16	10/9	no data
43A	9/11	9/24	no data
44A	9/19	10/1	10/22
45A	9/19	10/1	no data
46A	9/20	10/8	no data
47A	9/17	9/24	10/23
48A	9/23	10/1	10/22
49A	9/16	9/22, 10/1	10/23
50A	9/16	9/22, 9/27, 10/1	10/23
51A	9/29	10/14	10/23
52A	9/22	10/9	10/23
54A	9/25	10/8	no data
55A	9/23	10/3	10/23
56A	9/30	10/15	10/23
66A	9/30	10/9	10/23
67A	9/27	10/9	10/23
68A	9/25	10/9	10/23
71A	9/30	10/15	10/24
72A	9/24	10/15, 10/16	10/24
73A	10/1	10/9, 10/13	10/24
74A	10/3	10/16	10/24
75A	10/6	10/13	10/24

Well No.	Well Installation Date	Water Quality Sampling	Water Level Measuring
76A	10/3	10/13	10/24
77A	10/9	10/16, 12/18	10/24
78A	10/6	10/16	10/24
79A	10/2	10/13	10/24
80A	10/6	no data	10/24
81A	10/7	no data	10/24
82A	10/3	10/12	10/24
83A	10/8	no data	10/24
84A	10/1	10/14	10/24
85A	10/3	10/13	10/24
86A	9/23	10/9	10/24
87A	10/10	10/12	10/24
88A	10/4	10/12	10/24
89A	10/2	10/15	10/24
90A	9/24	10/3	10/22
96A	10/8	no data	10/22
99A	10/14	no data	no data
101A	10/10	10/15	no data
102A	10/6	10/14, 10/17	10/23
103A	10/10	10/15	10/24
104A	10/16	10/13	10/24
108A	10/15	no data	10/23
109A	10/13	no data	10/23
110A	10/14	10/15	10/23
111A	10/15	10/14	10/23
112A	10/14	10/16	10/22
113A	10/16	12/18	10/24
114A	10/10	12/18	10/24

(113A-2)

TABLE II-2. Installation and Sampling Dates (1980) for Lockport Dolomite Wells

Well No.	Well Installation Date	Water Quality Sampling Date	Water Level Measuring Date
1B	8/27	no data	10/23
2B	8/29	9/17, 9/24	10/23
3B	9/5	9/23, 9/27	10/23
4B	9/5	9/18	no data
4B-2	9/29	10/13	10/23
5B	9/8	9/17, 9/29	10/22
6B	9/6	9/18, 9/27, 9/29	10/23
7B	9/9	no data	10/23
8B	9/8	9/18, 9/29	10/23
9B	10/10	9/17, 9/29, 10/14	10/23
10B	9/7	9/18, 9/27	10/23
11B	9/25	no data	10/23
13B	9/9	no data	10/23
14B	9/12	9/18, 9/29	10/23
15B	9/17	9/22, 9/29, 10/2	10/23
16B	9/20	10/3	10/23
17B	9/12	10/1	10/23
18B	9/10	no data	10/23
19B	9/9	9/24	10/23
20B	9/27	no data	10/23
21B	9/27	10/3	10/23
25B	9/9	9/18, 9/29	10/23
26B	9/8	9/18, 9/22, 9/27	10/23
28B	9/15	9/24	10/23
29B	9/13	9/29	10/23
30B	9/22	no data	10/23
31B	9/22	10/2	10/23
32B	9/17	no data	10/23
33B	9/1	no data	10/23
34B	9/23	no data	10/23

Well No.	Well Installation Date	Water Quality Sampling Date	Water Level Measuring Date
35B	9/17	no data	no data
36B	9/22	no data	10/23
37B	9/16	9/22, 9/27	10/23
38B	9/20	no data	10/23
39B	9/20	9/22, 9/27	10/23
40B	9/23	no data	10/23
41B	9/27	10/3	10/23
42B	9/19	10/9	10/23
43B	9/10	9/24	10/23
44B	9/23	no data	10/22
45B	9/23	10/1	10/23
46B	9/20	10/8	10/23
47B	9/16	no data	10/23
48B	9/30	no data	10/22
49B	9/17	9/22	10/23
50B	9/15	9/22, 9/27	10/23
51B	9/29	no data	10/23
52B	9/26	10/9	10/23
54B	9/25	no data	10/23
55B	9/25	10/3	10/23
56B	10/6	10/15	10/23
63B	10/11	10/14	no data
64B	10/11	10/14	10/23
65B	9/27	10/3, 10/17	10/23
66B	9/30	10/9	10/23
67B	9/27	no data	10/23
68B	9/26	no data	10/23
71B	9/30	10/15	10/24
72B	10/7	10/16	10/24
73B	10/3	10/9	10/24
74B	10/3	no data	10/24
75B	10/6	no data	10/24

Well No.	Well Installation Date	Water Quality Sampling Date	Water Level Measuring Date
76B	10/4	10/13	10/24
77B	10/9	10/15, 10/16	10/24
79B	10/2	10/13	10/24
80B	10/6	10/13	10/24
81B	10/7	10/12	10/24
83B	10/8	10/12	10/24
84B	10/1	10/14	10/24
85B	10/2	no data	10/24
86B	9/29	no data	10/24
87B	10/10	10/12	10/24
89B	10/2	10/15	10/24
90B	9/27	no data	10/23
96B	10/11	10/16	10/22
98B	10/17	10/18	10/22
99B	10/15	10/16	10/22
100B	10/13	no data	10/23
101B	10/10	10/15	10/23
103B	10/14	10/15	10/23
104B	10/13	10/13, 12/18	10/24
108B	10/16	10/17	10/23
109B	10/15	10/17	10/23
110B	10/15	no data	10/23
112B	10/14	10/16	10/22

APPENDIX III

Organic and Metal Constituent Concentrations for Overburden and Lockport Dolomite Wells

Note: Based on data from USEPA (1982)

TABLE AIII-1. Organic and Metal Constituent Concentrations for Overburden Wells

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
1A	Pesticides	B.D.	Zinc	52
	Volatiles	B.D.	Nickel	51
2A	1,1,1-Trichloroethane	4	Nickel	91
	Phenol	2	Zinc	47
	Tetrachloroethene	1		
	Anthracene	Trace		
	Phenanthrene	Trace		
	Pesticides	B.D.		
3A	Aldrin	Trace	Nickel	220
	Benzene hexachloride (alpha isomer)	Trace	Antimony	49
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Benzene	Trace		
	DDE	Trace		
	DDT	Trace		
	Heptachlor	Trace		
	Toluene	Trace		
5A	Phenol	72	Barium	500
	Aldrin	Trace	Cooper	95
	Benzene hexachloride (beta isomer)	Trace		
	Volatiles	Trace		
6A	1,1-Dichloroethene	Trace	Zinc	14
	1,1,2,2-Tetrachloroethane	Trace	Copper	8
	Anthracene	Trace		
	Benzene	Trace		
	Napthalene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
7A	Benzene hexachloride (beta isomer)	Trace	Barium	220
	Volatiles	B.D.	Zinc	130

Note: B.D. means below detection

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
8A	Benzene hexachloride (alpha isomer)	Trace	Zinc	45
	Benzene hexachloride (beta isomer)	Trace	Barium	27
	Benzne hexachloride (gamma isomer)	Trace		
	Benzene hexachloride (detla isomer)	Trace		
10A	Pesticides	B.D.	Mercury	976
	Volatiles	B.D.	Zinc	28
11A	Benzene hexachloride (alpha isomer)	Trace	Lead	65
	Benzene hexachloride (beta isomer)	Trace	Zinc	57
	Heptachlor	Trace		
	Volatiles	B.D.		
12A	Benzene	Trace	Antimony	73
	Pesticides	B.D.	Lead	49
13A	Benzene	Trace	Antimony	70
	Toluene	Trace	Barium	31
	Pesticides	B.D.		
14A	Pesticides	B.D.	Nickel	290
	Volatiles	B.D.	Zinc	74
15A	Pesticides	B.D.	Zinc	370
	Volatiles	B.D.	Nickel	100
16A	Anthracene	Trace	Barium	650
	Benzo(a)anthracene	Trace	Antimony	170
	Butylbenzylphthalate	Trace		
	Fluoranthene	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
17A	Benzene hexachloride (beta isomer)	Trace	Zinc	67
	DDT	Trace	Lead	58
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
18A	Endosulfan sulfate	0.4	no data	
	Benzene hexachloride (delta isomer)	0.24		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
19A	Pesticides	B.D.	Lead	72
	Volatiles	B.D.	Zinc	59
20A	Phenanthrene	2	Barium	320
	Acenaphtylene	Trace	Antimony	210
	Aldrin	Trace		
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Fluorene	Trace		
	Heptachlor	Trace		
	Volatiles	B.D.		
21A	Naphthalene	Trace	Antimony	140
	Volatiles	B.D.	Barium	120
25A	Pesticides	B.D.	Zinc	250
			Barium	110
26A	1,1,2,2-Tetrachloroethane	Trace	Zinc	72
			Antimony	36
	4-Chlorophenol	Trace		
	Benzene	Trace		
	Chlorobenzene	Trace		
	Chloroform	Trace		
	Ethyl benzene	Trace		
	Fluoranthene	Trace		
	Fluorene	Trace		
	Napthalene	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
27A	Benzene hexachloride-(beta isomer)	Trace	Lead	120
			Zinc	75
	Benzene hexachloride-(gamma isomer)	Trace		
	Volatiles	B.D.		
28A	Phenol	10	Lead	90
	Benzene hexachloride (alpha isomer)	Trace	Zinc	88
	Benzene hexachloride (beta isomer)	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
29A	Chloroform	2	Nickel	130
	Benzene hexachloride		Chromium	87
	(alpha isomer)	Trace		
	Benzene hexachloride			
	(beta isomer)	Trace		
	Benzene hexachloride			
	(gamma isomer)	Trace		
	Bromodichloromethane	Trace		
	Heptachlor	Trace		
30A	Benzene hexachloride		Antimony	190
	(delta isomer)	2	Zinc	84
	1,1,1-Trichloroethane	Trace		
	Benzene hexachloride			
	(alpha isomer)	Trace		
	Benzene hexachloride			
	(beta isomer)	Trace		
	Benzene hexachloride			
	(gamma isomer)	Trace		
	DDT	Trace		
	Dieldrin	Trace		
31A	Phenol	5	Zinc	580
	Benzene hexachloride		Lead	350
	(alpha isomer)	Trace		
	DDD	Trace		
	DDE	Trace		
	Heptachlor	Trace		
	Volatiles	B.D.		
32A	Toluene	37	Lead	220
	M-Xylene	18	Zinc	200
	O-Xylene	18		
	Benzene	8		
	Ethyl benzene	7		
	Acenaphtylene	Trace		
	Aldrin	Trace		
	Benzene hexachloride			
	(alpha isomer)	Trace		
	Benzene hexachloride			
	(beta isomer)	Trace		
	Benzene hexachloride			
	(gamma isomer)	Trace		
	DDT	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
33A	Benzene hexachloride		Nickel	140
	(alpha isomer)	Trace	Zinc	83
	Benzene hexachloride			
	(beta isomer)	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
	DDE	Trace		
	Fluoranthene	Trace		
	Heptachlor	Trace		
	Pyrene	Trace		
	Trichloroethene	Trace		
34A	Phenol	8	Zinc	240
	Aldrin	Trace	Lead	150
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
35A	Benzene hexachloride (alpha isomer)	Trace	Barium	570
			Antimony	280
	Benzene hexachloride (beta isomer)	Trace		
	Heptachlor	Trace		
	Volatiles	B.D.		
36A	Benzene hexachloride (alpha isomer)	Trace	Lead	110
			Zinc	75
	Benzene hexachloride (gamma isomer)	Trace		
	DDE	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
37A	Phenol	4	Zinc	7
	Aldrin	Trace	Barium	3
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Volatiles	B.D.		
38A	Phenol	17	Barium	280
	Chloroform	Trace	Antimony	260
39A	Pesticides	B.D.	Lead	67
	Volatiles	B.D.	Zinc	52
40A	Aldrin	Trace	Zinc	220
	Benzene hexachloride (alpha isomer)	Trace	Lead	130

Well No.	Organic Type	 Concentration (ug/L)	Metal Type	 Concentration (ug/L)
con't	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Fluoranthene	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
41A	2,4-Dichlorophenol	11	Barium	1500
	Butylbenzylphthalate	Trace	Antimony	550
	Pentachlorophenol	Trace		
	Phenol	Trace		
	Tetrachloroethene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
42A	Di-n-octylphthalate	150	Antimomy	100
	Pesticides	B.D.	Copper	100
	Volatiles	B.D.		
43A	Aldrin	Trace	Lead	83
	Benzene hexachloride (beta isomer)	Trace	Zinc	53
	Volatiles	B.D.		
44A	Benzene hexachloride (beta isomer)	Trace	Lead Zinc	82 81
	Volatiles	B.D.		
45A	DDT	Trace	Barium	3700
	Volatiles	B.D.	Zinc	1000
46A	Benzene hexachloride (alpha isomer)	Trace	Lead Zinc	130 76
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	DDT	Trace		
	Dieldrin	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
	Tetrachloroethene	Trace		
47A	Chloroform	1	Zinc	100
	Pesticides	B.D.	Barium	42

Well No.	Organic		Metal	
	Type	Concentration (ug/L)	Type	Concentration (ug/L)
48A	Benzene hexachloride (alpha isomer)	Trace	Barium	110
	Benzene hexachloride (beta isomer)	Trace	Antimony	93
	Benzene hexachloride (gamma isomer)	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
49A	Phenol	8	Barium	150
	Pesticides	B.D.	Nickel	25
50A	1,2-Dichloroethane	17	Zinc	70
	Phenol	12	Lead	53
	Pesticides	B.D.		
51A	Pesticides	B.D.	no data	
	Volatiles	B.D.		
52A	Pesticides	B.D.	Lead	160
	Volatiles	B.D.	Copper	76
54A	Benzene hexachloride (alpha isomer)	Trace	Mercury	70
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Fluranthene	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
	Volatiles	B.D.		
55A	Benzene hexachloride (beta isomer)	.045	Barium	330
	Benzene hexachloride (alpha isomer)	.013	Antimony	170
	Benzene	Trace		
	M-Xylene	Trace		
	P-Xylene	Trace		
	Toluene	Trace		
56A	Pesticides	B.D.	Lead	61
	Volatiles	B.D.	Zinc	48
66A	Di-n-octylphthalate	48	Lead	290
	Pesticides	B.D.	Zinc	260
	Volatiles	B.D.		

Well No.	Organic		Metal	
	Type	Concentration (ug/L)	Type	Concentration (ug/L)
67A	Chloroform	11	Barium	220
	Pesticides	B.D.	Zinc	140
68A	Pesticides	B.D.	Zinc	160
	Volatiles	B.D.	Lead	85
71A	Pesticides	B.D.	Zinc	200
	Volatiles	B.D.	Lead	170
72A	Endosulfan sulfate	.17	Zinc	250
	Benzene hexachloride (alpha isomer)	.072	Barium	85
	Benzene hexachloride (delta isomer)	.052		
	1,1-Dichloroethene	Trace		
	Diethylphthalate	Trace		
	Di-n-octylphthalate	Trace		
	Volatiles	B.D.		
73A	Benzene hexachloride (alpha isomer)	Trace	Lead Nickel	170 110
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Benzene hexachloride (delta isomer)	Trace		
	Heptachlor Epoxide	Trace		
	Pesticides	B.D.		
	Volatiles	B.D.		
74A	Chloroform	Trace	no data	
75A	Fluoranthene	120	Zinc	980
	Phenanthrene	120	Barium	780
	Pyrene	98		
	Benzo(a) anthracene	73		
	Chrysene	58		
	Benzo(k) fluoranthene	48		
	Anthracene	44		
	Benzene	30		
	Naphthalene	29		
	Fluorene	27		
	Acenaphthene	23		
	Indeno (1,2,3-cd) pyrene	18		
	Benzo(a) pyrene	17		
	Benzo (g,h,i) perylene	16		
	Dibenzo (a,h) anthracene	16		
	2,4-Dimethylphenol	2		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
con't	Benzene hexachloride (gamma isomer)	2		
	Acenaphtylene	Trace		
	Aldrin	Trace		
	Benzene hexachloride (alpha isomer)	Trace		
	Chlorobenzene	Trace		
	Heptachlor	Trace		
	Mirex	Trace		
76A	Benzene	20	Lead	62
	Chlorobenzene	2	Zinc	55
	Aldrin	Trace		
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (delta isomer)	Trace		
	Heptachlor	Trace		
77A	2,4,6-Trichlorophenol	734	no data	
	2,4-Dichlorophenol	507		
	1,1,2,2-Tetrachloroethane	500		
	3-Chlorotoluene	500		
	4-Chlorotoluene	500		
	Benzene	500		
	Chlorobenzene	500		
	Toluene	500		
	Tetrachloroethene	320		
	2-Chlorotoluene	304		
	1,4-Dichlorobenzene	190		
	Trichloroethene	157		
	1,2-Dichlorobenzene	130		
	Chloroform	80		
	Benzene hexachloride (gamma isomer)	17		
	Trans-1,2-Dichloroethene	14		
	1,1,2-Trichloroethane	11		
	Ethyl benzene	11		
	Benzene hexachloride (alpha isomer)	5		
	Phenol	3		
	M-Xylene	2		
	1,1-Dichloroethene	1		
	P-Xylene plus O-Xylene	1		
	1,1,1-Trichloroethane	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
con't	1,2,3,4-Tetrachlorobenzene	Trace		
	1,2,4-Trichlorobenzene	Trace		
	1,3,5-Trichlorobenzene	Trace		
	2-Chlorophenol	Trace		
	2,4,6-Trichloroaniline	Trace		
	4-Chlorophenol	Trace		
	Diethylphthalate	Trace		
	Naphthalene	Trace		
78A	2-Chlorotoluene	Trace	no data	
	Acrylonitrile	Trace		
	Tetrachloroethene	Trace		
79A	Mirex	2	Lead	200
	Volatiles	B.D.	Zinc	110
82A	Pesticides	B.D.	Zinc	210
	Volatiles	B.D.	Lead	88
84A	Pesticides	B.D.	Zinc	140
	Volatiles	B.D.	Lead	74
85A	Aldrin	Trace	Zinc	110
	Acenaphtylene	Trace	Lead	71
	Benzene hexachloride (gamma isomer)	Trace		
	Dieldrin	Trace		
	Fluoranthene	Trace		
	Mirex	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
	Volatiles	B.D.		
86A	Toluene	25	Nickel	79
	2-Chlorotoluene	12	Lead	60
	Benzene hexachloride (gamma isomer)	.4		
87A	Pesticides	B.D.	Zinc	150
	Volatiles	B.D.	Barium	110
88A	Pesticides	B.D.	Zinc	330
	Volatiles	B.D.	Nickel	210
89A	Volatiles	B.D.	Zinc	320
			Barium	210

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
90A	2,4-Dichlorophenol	Trace	Barium	420
	Benzene	Trace	Antimony	240
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (beta isomer)	Trace		
	Diethylphthalate	Trace		
	Ethyl benzene	Trace		
	P-Xylene	Trace		
	Phenol	Trace		
	Tetrachlorotethene	Trace		
101A	Benzene hexachloride (alpha isomer)	.2	Zinc	1700
	Volatiles	B.D.	Lead	620
102A	Di-n-octylphthalate	11	Barium	1500
	Endosulfan sulfate	Trace	Zinc	660
	Volatiles	B.D.		
103A	Pesticides	B.D.	Lead	91
			Antimony	45
104A	3-Chlorotoluene	3300	Zinc	410
	2-Chlorotoluene	2700	Lead	110
	Toluene	270		
	1,2,4-Trichlorobenzene	190		
	2,4-Dichlorotoluene	150		
	1,2,4,5-Tetrachloro-benzene	120		
	Tetrachloroethene	77		
	1,2-Dichlorobenzene	52		
	1,4-Dichlorobenzene	50		
	4-Chloro-3-methylphenol	40		
	Chlorobenzene	27		
	1,2,3,4-Tetrachloro-benzene	15		
	Benzene	8		
	M-Xylene	4		
	O-Xylene	4		
	ethyl benzene	3		
	Trichloroethene	2		
	2-Nitrophenol	Trace		
	Aldrin	Trace		
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Fluoranthene	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
con't	Heptachlor	Trace		
	Phenanthrene	Trace		
	Pyrene	Trace		
110A	Pesticides	B.D.	Zinc	100
			Nickel	74
111A	Pesticides	B.D.	Barium	1900
	Volatiles	B.D.	Zinc	1400
112A	Endosulfan sulfate	.36	Zinc	400
	Benzene hexachloride (beta isomer)	.28	Chromium	101
	Heptachlor	.2		
	Aldrin	.04		
	Benzene hexachloride (gamma isomer)	.01		
	3-Chlorotoluene	Trace		
	Diethylphthalate	Trace		
113A-1	Phenol	5	no data	
	Naphthalene	3		
	Butylbenzylphthalate	1		
	Fluorene	1		
	Phenanthrene	1		
	2-Chlorotoluene	Trace		
	2,4-Dichlorophenol	Trace		
	2,4,6-Trichlorophenol	Trace		
	Acenaphtylene	Trace		
	Volatiles	B.D.		
113A-2	Phenol	12	no data	
	Butylbenzylphthalate	4		
	Fluorene	1		
	2,3,6-Trichlorophenol	Trace		
	2,4-Dichlorophenol	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		

TABLE AIII-2. Organic and Metal Constituent Concentrations for Lockport Dolomite Wells

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
2B	Butylbenzylphthalate	7	Zinc	18
	Chlorobenzene	Trace	Barium	11
	Chloroform	Trace		
	Phenol	Trace		
	Pesticides	B.D.		
3B	Phenol	230	Barium	91
	Acenaphtylene	150	Zinc	39
	Naphthalene	12		
	Benzene	Trace		
	Chloroform	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
4B	Toluene	5.2	no data	
	M-Xylene	3.4		
	P-xylene	3.4		
	1,1,1-Trichloroethane	Trace		
	Benzene	Trace		
	Bromodichloromethane	Trace		
	Chlorobenzene	Trace		
	Chloroform	Trace		
	O-Xylene	Trace		
	Tetrachloroethene	Trace		
4-B-2	Pentachlorophenol	5	Zinc	139
	Chloroform	4	Barium	65
	Benzene hexachloride (alpha isomer)	.039		
	Benzene hexachloride (gamma isomer)	.015		
	Aldrin	Trace		
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (delta isomer)	Trace		
	DDT	Trace		
	Fluoranthene	Trace		
	Heptachlor	Trace		
	Pyrene	Trace		
	Volatiles	B.D.		

Note: B.D. means below detection

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
5B	Phenol	35	Zinc	60
	Benzene	Trace	Barium	22
	Chloroform	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
6B	1,1-Dichloroethene	Trace	Zinc	75
	4-Chlorophenol	Trace	Barium	11
	Anthracene	Trace		
	Benzene	Trace		
	Chloroform	Trace		
	Naphthalene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
8B	1,1-Dichloroethene	6		
	1,1,2-Trichloroethane	Trace		
	Benzene	Trace	Barium	1900
	Bromodichloromethane	Trace	Lead	400
	Ethyl Benzene	Trace		
	O-Xylene	Trace		
	Phenol	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
9B	Butylbenzylphthalate	7		
	Di-n-octylphthalate	7		
	1,1,-Dichloroethene	Trace	Barium	440
	Benzene	Trace	Mercury	95
	Toluene	Trace		
	Pesticides	B.D.		
	Volatiles	B.D.		
10B	Benzene	Trace		
	Toluene	Trace		
	Pesticides	B.D.	Zinc	28
			Barium	17
14B	Chloroform	6		
	Toluene	5		
	1,1-dichloroethene	Trace	Lead	45
	1,1,2,2-Tetrachloroethane	Trace	Barium	27
	Benzene	Trace		
	Ethyl Benzene	Trace		
	M-Xylene	Trace		
	O-Xylene	Trace		
	P-Xylene	Trace		
	Pesticides	B.D.		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
15B	Phenol	20	Zinc	390
	Chloroform	4	Lead	52
	Benzene hexachloride (delta isomer)	Trace		
	Pesticides	B.D.		
	Volatiles	B.D.		
16B	Chloroform	Trace	Barium	1600
	Toluene	Trace	Antimony	380
	Pesticides	B.D.		
17B	Chloroform	11	Barium	140
	Trichlorofluoromethane	10	Lead	140
	Benzene hexachloride (alpha isomer)	Trace	Zinc	140
	Benzene hexachloride (gamma isomer)	Trace		
	DDE	Trace		
	DDT	Trace		
	Heptachlor	Trace		
	Heptachlor epoxide	Trace		
19B	Phenol	20	Zinc	190
	Chloroform	10	Lead	180
	Pesticides	B.D.		
21B	Benzene hexachloride (beta isomer)	.007	Barium	3600
	Benzene	Trace	Antimony	670
	Chloroform	Trace		
25B	Chloroform	6	Lead	650
	4-Chorophenol	5	Barium	550
	Naphthalene	4		
	1,1-Dichloroethene	Trace		
	1,1,2,2-Tetrachloroethane	Trace		
	Benzene	Trace		
	O-Xylene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
26B	Acenaphtylene	55	Zinc	61
	Butylbenzylphthalate	22	Lead	47
	4-Chlorophenol	13		
	Chloroform	5.8		
	Pyrene	5		
	Naphthalene	4		
	Anthracene	Trace		

Well No.	Organic Type	Organic Concentration (ug/L)	Metal Type	Metal Concentration (ug/L)
	Benzene	Trace		
	Fluoranthene	Trace		
	Fluorene	Trace		
	N-Nitroso-di-n-propylamine	Trace		
	N-Nitrosodiphenylamine	Trace		
	O-Xylene	Trace		
	Toluene	Trace		
	Pesticides	B.D.		
28B	Benzene hexachloride (alpha isomer)	Trace	Zinc	77
			Lead	71
	Benzene hexachloride (beta isomer)	Trace		
	DDT	Trace		
	Heptachlor	Trace		
	Phenanthrene	Trace		
	Volatiles	B.D.		
29B	2,4-Dimethylphenol	53	Barium	240
	2-Chlorophenol	42	Antimony	73
	3-Chlorophenol	33		
	Phenol	33		
	2,4-Dichlorophenol	30		
	Acenaphthene	22		
	1,2-Dichlorobenzene	15		
	1,3-Dichlorobenzene	15		
	Bis(2-Chloroethoxy)-methane	14		
	N-Nitrosodiphenylamine	14		
	Chloroform	13		
	Anthracene	9		
	Toluene	6		
	Bromodichloromethane	5		
	1,1-Dichloroethene	Trace		
	1,1,2,2-Tetrachloroethane	Trace		
	1,4-Dichlorobenzene	Trace		
	2-Chlorotoluene	Trace		
	3-Chlorotoluene	Trace		
	4-Chlorotoluene	Trace		
	Benzene	Trace		
	Chlorobenzene	Trace		
	Dibromochloromethane	Trace		
	Ethyl benzene	Trace		
	M-Xylene	Trace		
	Naphthalene	Trace		
	O-Xylene	Trace		
	P-Xylene	Trace		
	Pesticides	B.D.		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
31B	Chloroform	13.33	Zinc	100
	Benzene hexachloride (alpha isomer)	.05	Barium	27
	Benzene hexachloride (delta isomer)	.018		
	Benzene hexachloride (gamma isomer)	.012		
	2,4-Dichlorotoluene	Trace		
	Chrysene	Trace		
	Phenanthrene	Trace		
	Pesticides	B.D.		
	Volatiles	B.D.		
37B	Phenol	14	Zinc	27
	Chloroform	7	Barium	14
	Benzene hexachloride (gamma isomer)	Trace		
39B	Chloroform	12.35	Barium	180
	Phenol	7	Copper	59
	Benzene hexachloride (gamma isomer)	Trace		
	Bromodichloromethane	Trace		
	Dibromochloromethane	Trace		
	Pesticides	B.D.		
41B	2,4 Dichlorophenol	15	Barium Antimony	700 120
	Chloroform	10		
	Benzene hexachloride (alpha isomer)	.006		
	2,4,6-Trichlorophenol	Trace		
	Benzene	Trace		
	Diethylphthalate	Trace		
	Naphthalene	Trace		
	Pentachlorophenol	Trace		
	Phenol	Trace		
	Tetrachloroethene	Trace		
	Toluene	Trace		
	Trans-1,2,-Dichloroethene	Trace		
42B	Pesticides	B.D.	Lead	100
	Volatiles	B.D.	Antimony	80
43B	1,1,1-Trichlorethane	3	Barium	340
	Chloroform	1.09	Zinc	160
	Diethylphthalate	.13		
	Aldrin	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
56B	Pesticides	B.D.	Cadmium	27
	Volatiles	B.D.	Zinc	18
63B	Pesticides	B.D	Amtimony	52
	Volatiles	B.D	Barium	48
64B	Toluene	13	Barium	210
	M-Xylene	11	Zinc	64
	P-Xylene	11		
	Pesticides	B.D.		
65B	3-Chlorotoluene	Trace	Barium	1400
	Bromomethane	Trace	Antimony	350
	Chloroform	Trace		
	Cyclohexane	Trace		
	Dimethyl Cyclohexane	Trace		
	Fluorene	Trace		
	M-Xylene	Trace		
	Methyl Cyclopentane	Trace		
	O-Xylene	Trace		
	P-Xylene	Trace		
	Pesticides	B.D.		
66B	Pesticides	B.D	Antimony	60
	Volatiles	B.D.	Lead	60
71B	Chlorobenzene	17	Zinc	76
	Pesticides	B.D.	Copper	13
72B	Benzene hexachloride		Zinc	52
	(alpha isomer)	Trace	Barium	51
	Chloroform	Trace		
	Toluene	Trace		
73B	Toluene	12	Antiony	120
	Pesticides	B.D.	Lead	110
76B	M-Xylene	6	Barium	240
	O-Xylene	5	Zinc	23
	Toluene	5		
	Chloroform	2		
	Ethyl benzene	2		
	Aldrin	Trace		
	Benzene hexachloride			
	(beta isomer)	Trace		
	Benzene hexachloride			
	(gamma isomer)	Trace		
	DDE	Trace		
	Mirex	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
77B	3-Chlorotoluene	35	Barium	160
	4-Chlorotoluene	35	Zinc	52
	Toluene	26		
	Pesticides	B.D.		
79B	Acrolein	50	Zinc	39
	Chloroform	5	Barium	17
	Aldrin	Trace		
	Benzene hexachloride (alpha isomer)	Trace		
	Benzene hexachloride (beta isomer)	Trace		
	Benzene hexachloride (gamma isomer)	Trace		
	Benzene hexachloride (delta isomer)	Trace		
	DDT	Trace		
	Dieldrin	Trace		
	Heptachlo	Trace		
80B	Benzene hexachloride (alpha isomer)	Trace	Zinc	99
	Benzene hexachloride (beta isomer)	Trace	Antimony	32
	Benzene hexachloride (delta isomer)	Trace		
	Mirex	Trace		
	Volatiles	B.D.		
81B	Pesticides	B.D.	Barium	34
	Volatiles	B.D.	Zinc	17
83B	Pesticides	B.D.	Barium	72
	Volatiles	B.D.	Zinc	14
84B	Pesticides	B.D.	Barium	50
			Zinc	44
87B	Pesticides	B.D.	Barium	37
	Volatiles	B.D.	Zinc	16
89B	DDT	.2	Lead	96
	Volatiles	B.D.	Zinc	75
96B	3-Chlorotoluene	62	Barium	53
	Endosulfan Sulfate	.06	Zinc	15
	Aldrin	.007		
	Bromodichloromethane	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
	Chloroform	Trace		
	Dibromochloromethane	Trace		
	M-Xylene	Trace		
	Naphthalene	Trace		
	O-Xylene	Trace		
	P-Xylene	Trace		
	Toluene	Trace		
98B	Endosulfan Sulftate	.06	Barium	33
	1,1-Dichloroethene	Trace	Zinc	7
	Di-n-octylphthalate	Trace		
99B	Endosulfan Sulfate	.15	Barium	383
	Benezene hexachloride (beta isomer)	.07	Zinc	14
	Bromomethane	Trace		
	Chloroform	Trace		
	M-Xylene	Trace		
	P-Xylene	Trace		
101B	Pesticides	B.D.	Zinc	56
	Volatiles	B.D.	Antimony	42
103B	Di-n-octylphthalate	16	Zinc	37
	Pesticides	B.D.	Barium	36
	Volatiles	B.D.		
104B	4-Nitrophenol	9	Barium	150
	Diethylphthalate	7	Zinc	20
	2-Chlorotoluene	5		
	Chloroform	5		
	3-Chlorotoluene	3		
	1,2,3,4-Tetrachlorobenzene	Trace		
	1,2,4-Trichlorobenzene	Trace		
	2-Chlorophenol	Trace		
	2,3,6-Trichlorophenol	Trace		
	2,4-Dichlorotoluene	Trace		
	Butylbenzylphthalate	Trace		
	Phenol	Trace		
	Pesticides	B.D.		
	Volatiles	B.D.		
108B	3-Chlorotoluene	Trace	Barium	36
	Bromodichloromethane	Trace	Zinc	20
	Chloroform	Trace		
	DiBromochloromethane	Trace		
	Endosulfan Sulfate	Trace		
	M-Xylene	Trace		

	Organic		Metal	
Well No.	Type	Concentration (ug/L)	Type	Concentration (ug/L)
	O-Xylene	Trace		
	P-Xylene	Trace		
109B	O-Xylene	68	Barium	105
	M-Xylene	62	Zinc	9
	P-Xylene	62		
	3-Chlorotoluene	13		
	Heptachlor epoxide	.1		
	Endosufan sulfate	.09		
	Benzene hexachloride (alpha isomer)	.04		
	Benzene hexchloride (gamma isomer)	.02		
	1,1-Dichloroethene	Trace		
	Benzene	Trace		
	Bromodichloromethane	Trace		
	Butylbenzylphthalate	Trace		
	Chlorobenzene	Trace		
	Chloroform	Trace		
	Di-n-octylphthalate	Trace		
	Tetrachloroethene	Trace		
	Toluene	Trace		
	Vinyl chloride	Trace		
112B	M-Xylene	105	Barium	51
	P-Xylene	105	Zinc	26
	O-Xylene	92		
	Toluene	16		
	3-Chlorotoluene	13		
	Benzene	Trace		
	Chlorobenzene	Trace		
	Di-n-octylphthalate	Trace		
	Endosulfan Sulfate	Trace		
	Tetrachloroethene	Trace		

APPENDIX IV

Total Organic Carbon, Specific Conductance and pH Data For Overburden and Lockport Dolomite Wells

Note: Data obtained from JRB Associates (1981)

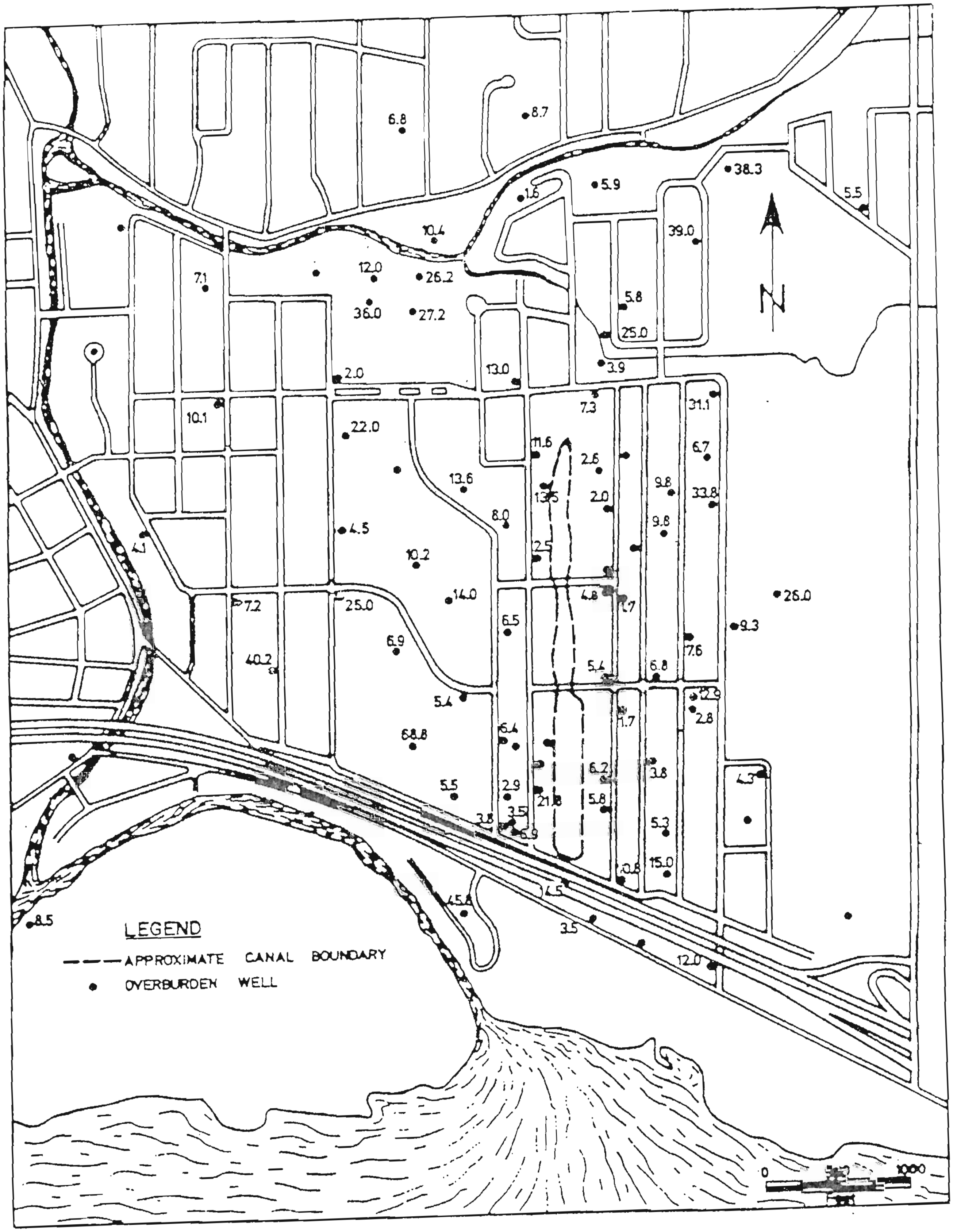

Figure IV - 1. Concentration (ppb) of total organic carbon in overburden wells.

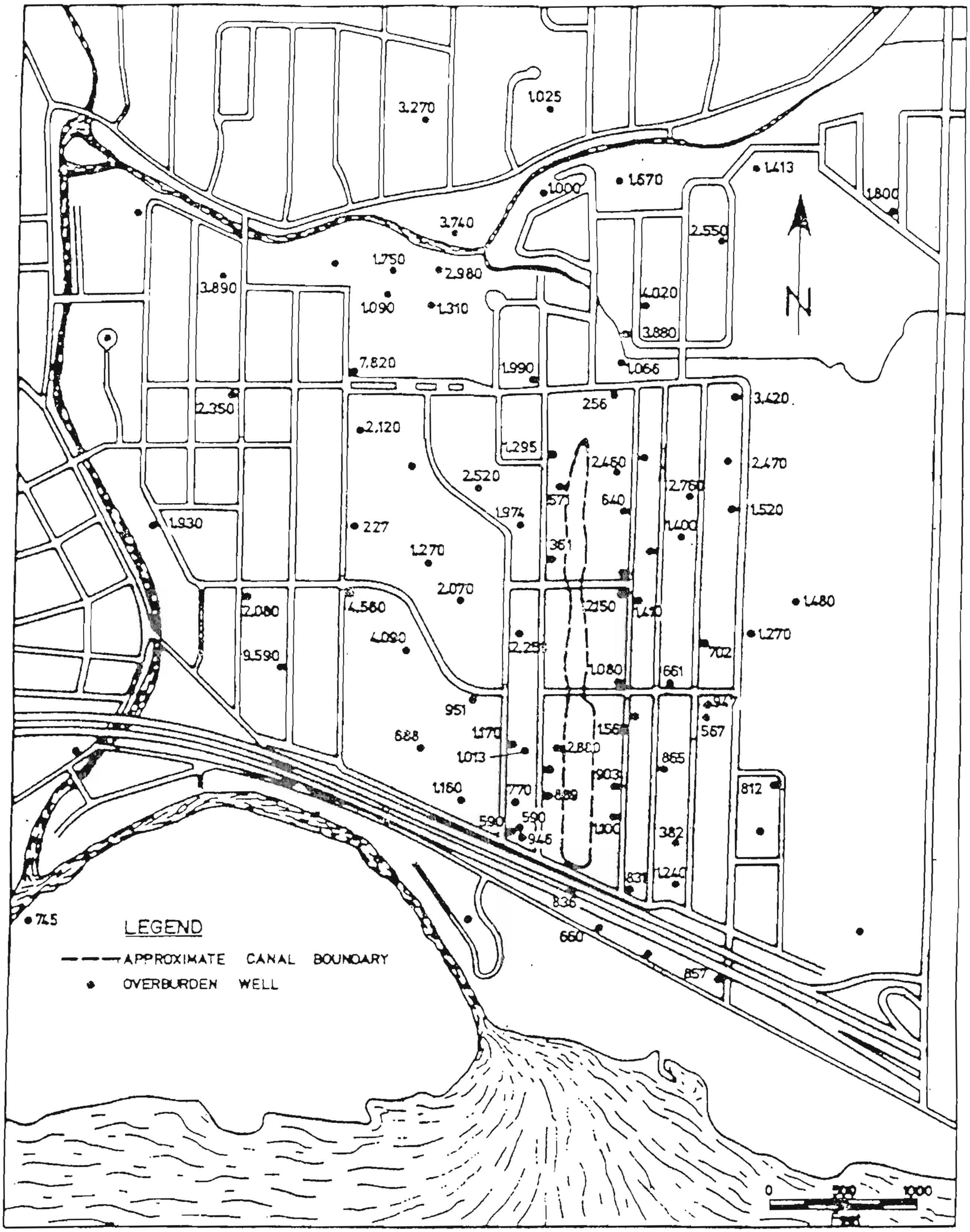

Figure IV - 2. Measurement (umhos/cm) of specific conductance in overburden wells.

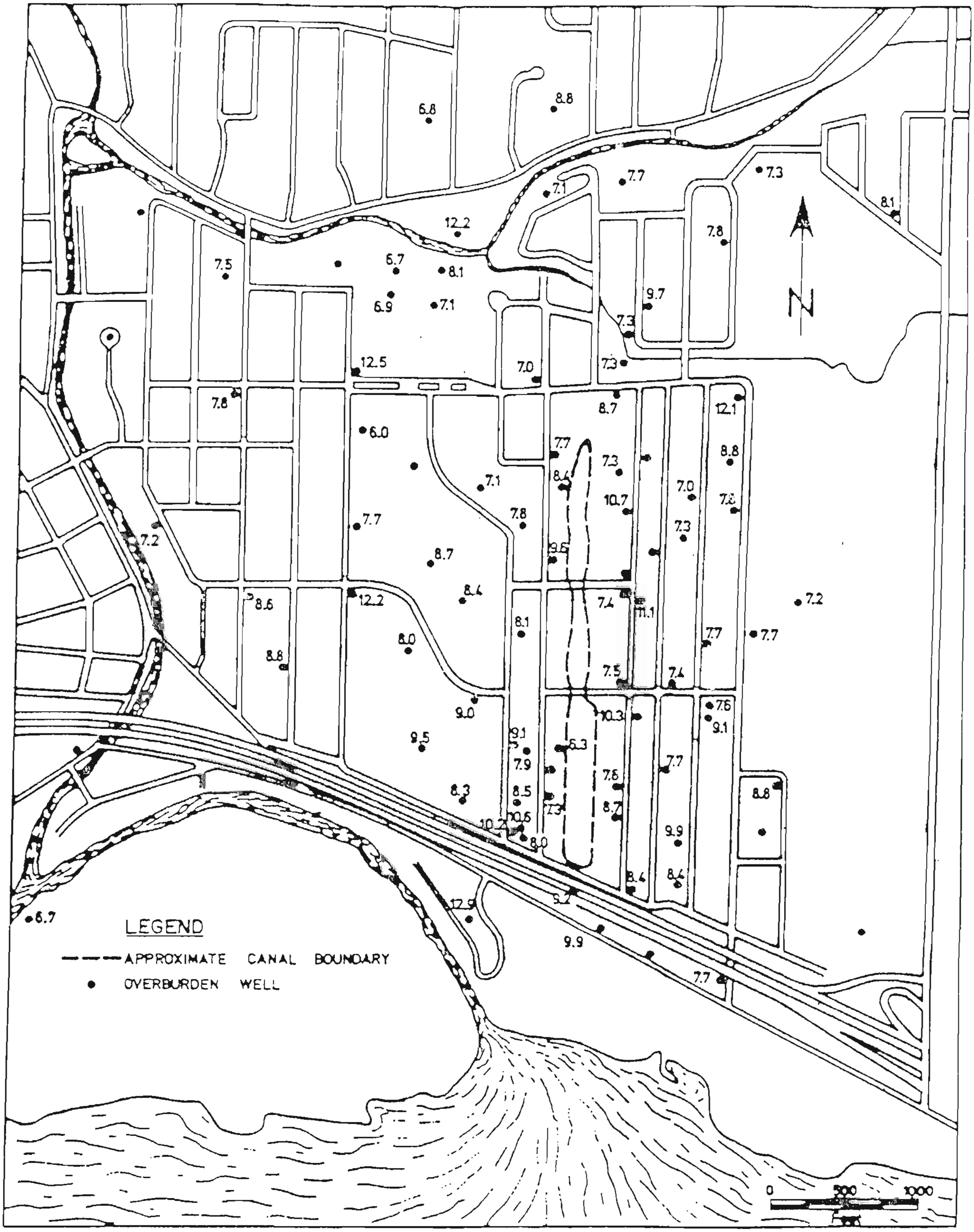

Figure IV-3. Measurement of pH in overburden wells.

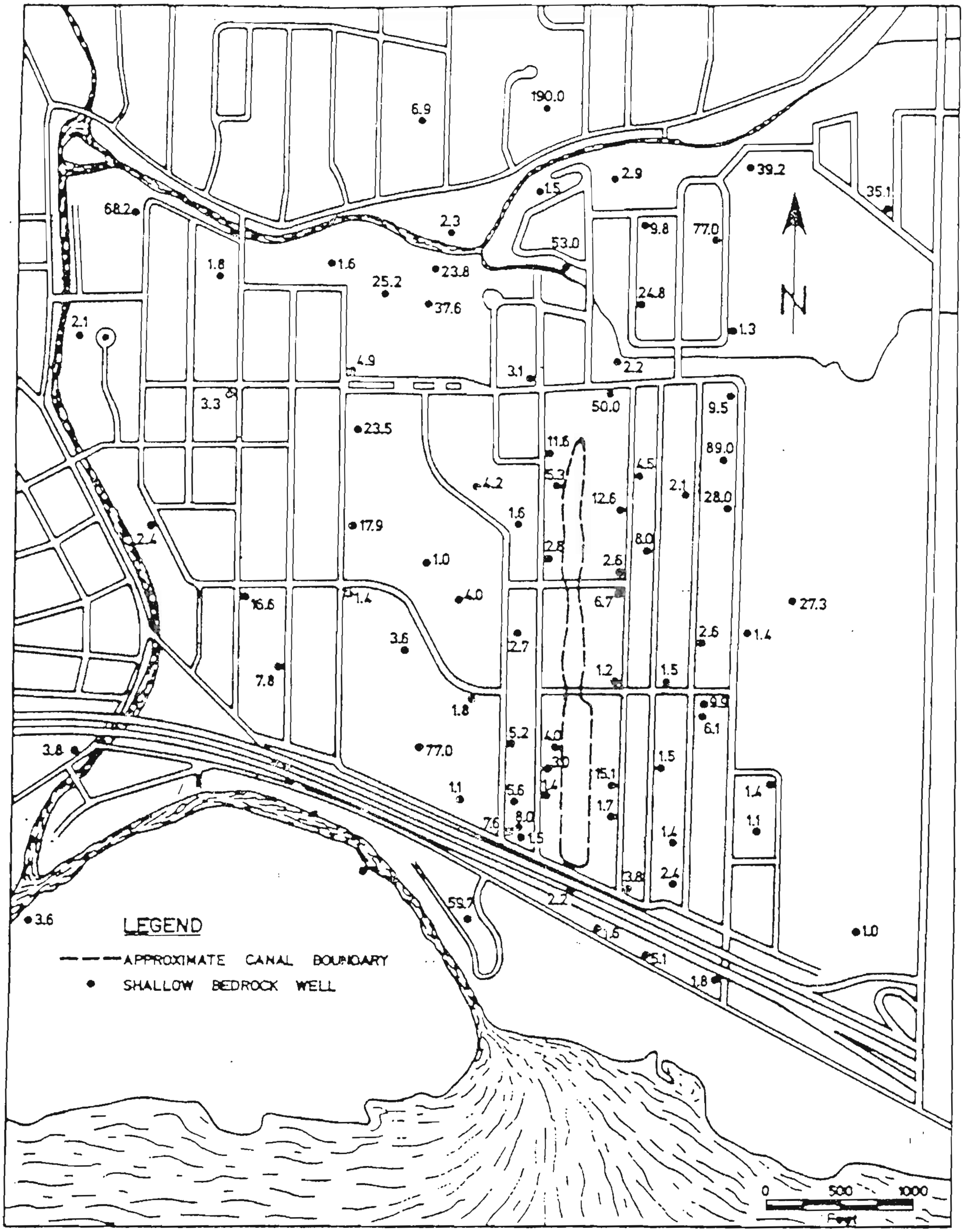

Figure IV-4. Concentration (ppb) of total organic carbon in Lockport Dolomite wells.

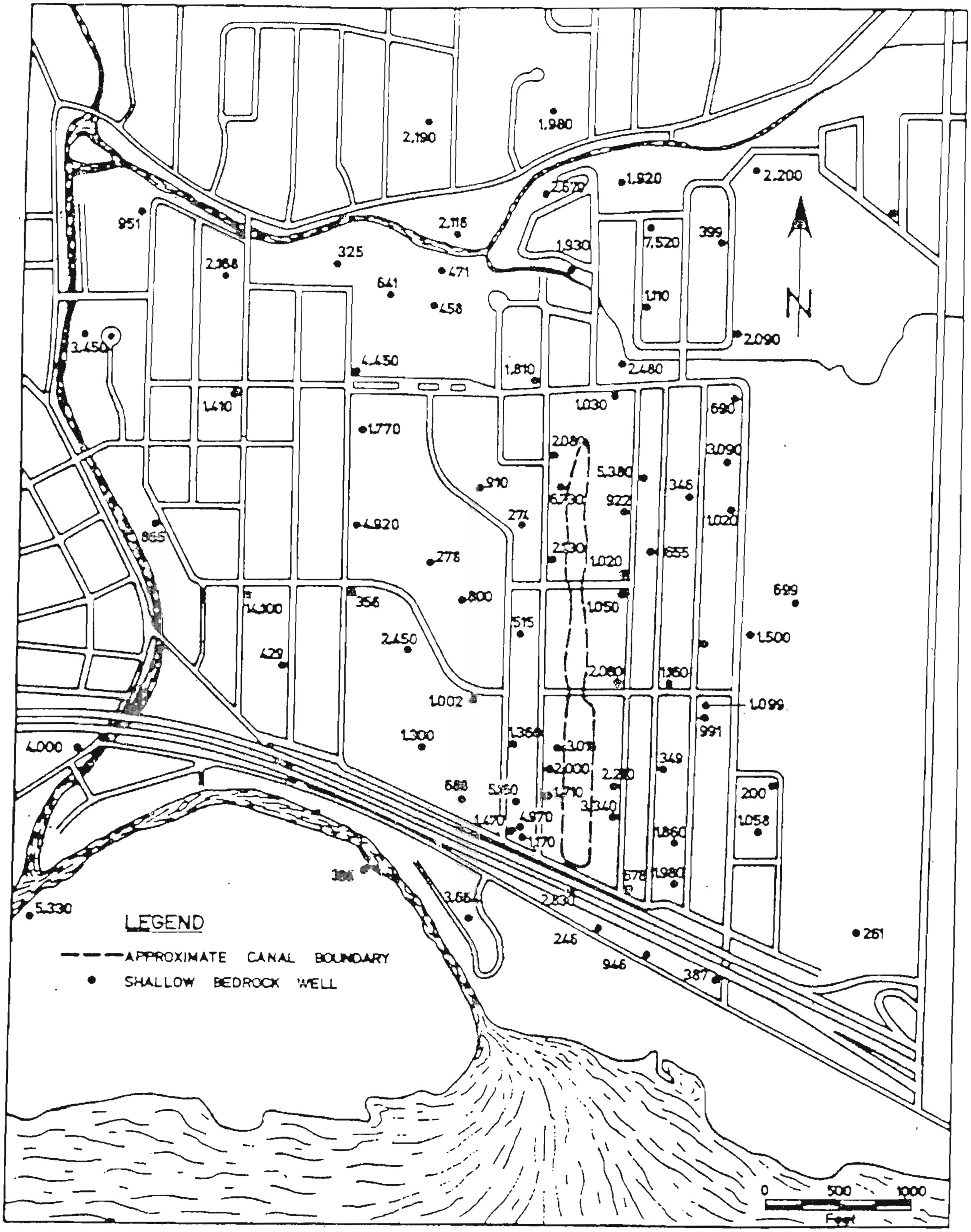

Figure IV-5. Measurement (umhos/cm) of specific conductance in Lockport Dolomite wells.

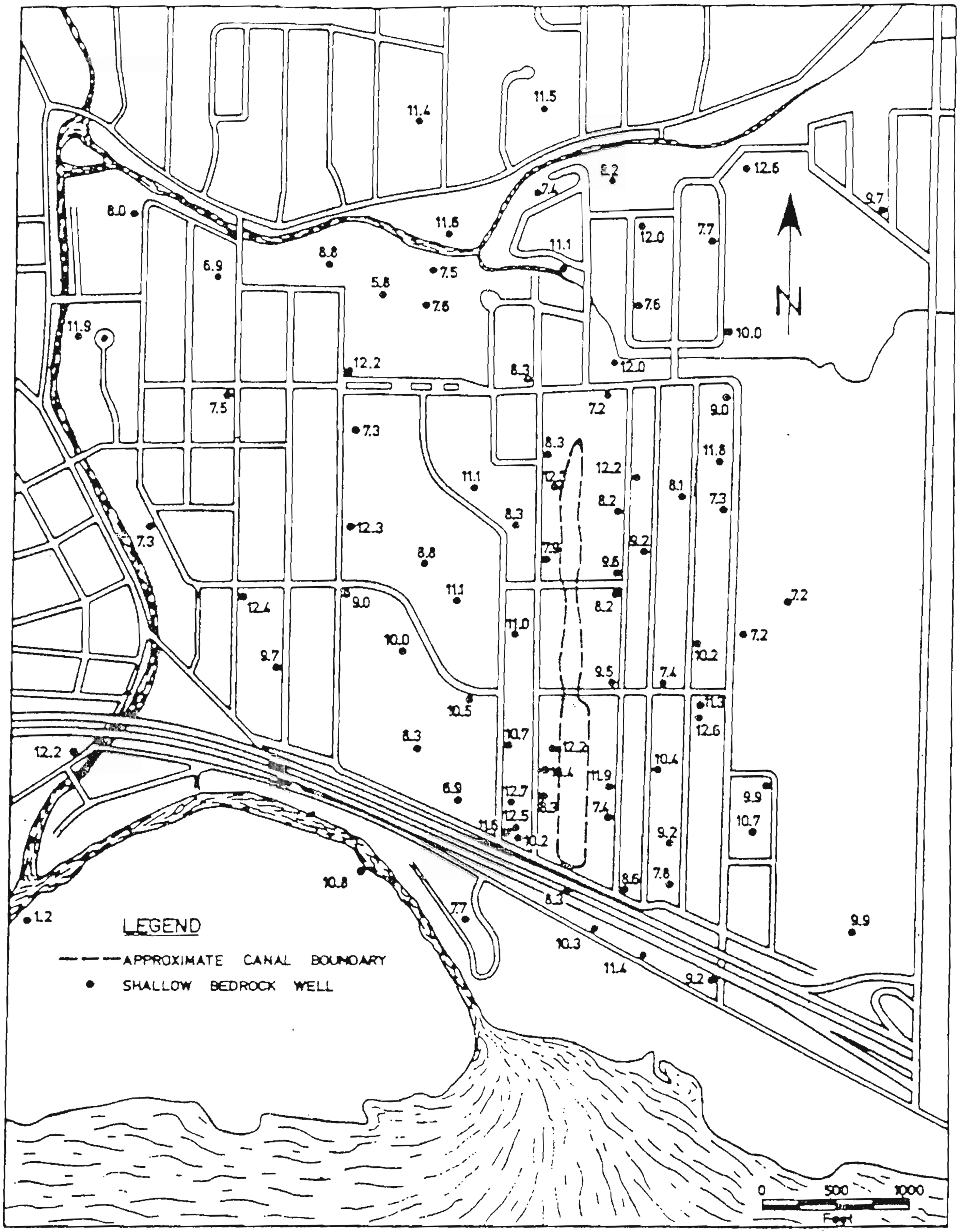

Figure IV-6. Measurement of pH in Lockport Dolomite wells.