Investigation and Hydraulic Containment of Chemical Migration: Four Landfills in Niagara Falls

Cleaning up hazardous waste sites is a complex process that requires extensive and flexible site study, and remedy assessment and implementation.

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INEXPENSIVE hydroelectric power has attracted industry to Niagara Falls, New York, since the late 1800s. In addition, large chemical manufacturing firms have operated plants in Niagara Falls for most of this century. Throughout that period, the disposal of chemical wastes by shallow land burial has been common practice. As a result, numerous hazardous waste landfills are located in the Niagara Falls area (see Figure 1).

Following media attention given to Love Canal in the late 1970s and the enactment of the Superfund program in 1979, considerable resources have been expended to identify and contain chemical migration from uncontrolled hazardous waste sites. Responses to environmental contamination problems generally proceed in three overlapping phases consisting of: remedial investigation (RI); assessment of remedies, sometimes referred to as a feasibility study (FS); and implementation of the selected remedy.

Remedial investigation objectives include: site characterization; determination of the nature, extent and rate of chemical migration; assessment of impacts on public health, welfare and the environment; and acquisition of data necessary to conduct the FS. During the drafting of the FS, alternative remedies are developed and evaluated, usually on the basis of technical effectiveness, feasibility and cost. The FS cost/benefit analysis culminates in the selection and design of a remedy. Implementation of a remedy and a long-term monitoring

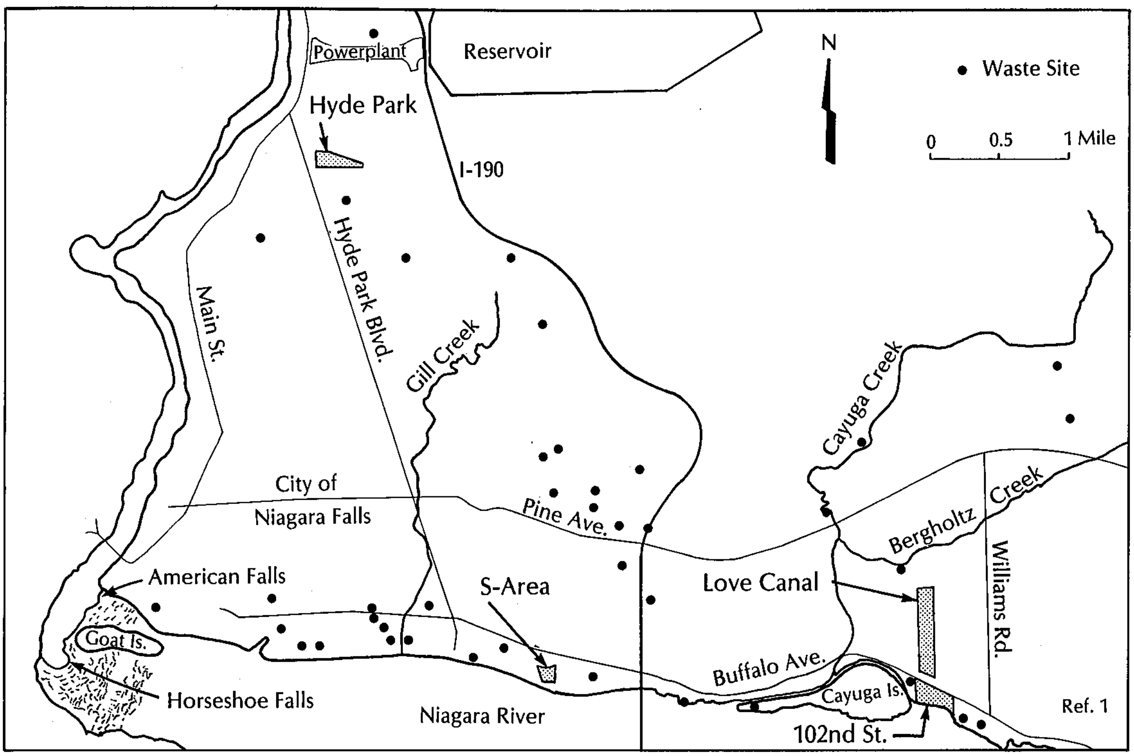

FIGURE 1. Locations of waste disposal sites in Niagara Falls.

program usually follow the RI/FS. However, due to the uncertainties associated with each response phase, the remedial process is typically iterative whereby additional studies and actions are undertaken as a better understanding of actual site conditions is achieved.

Remedial investigations have been conducted at several landfills in Niagara Falls and corrective actions have been taken at a few of these sites. Each phase of the remedial process has proven to be time-consuming and costly, in part, due to the varied and complex conditions that exist at these sites. Nevertheless, an overlying consistency in purpose and procedure has emerged during the ten years of investigation and clean-up of chemical migration from landfills in Niagara Falls. Remedial investigation surveys and containment remedies used and proposed for the Love Canal, S-Area, Hyde Park and 102nd Street landfills exemplify the state-of-the-art in managing uncontrolled hazardous waste sites.

Disposal Operations

Hooker Chemicals & Plastics Corporation (which is now known as Occidental Chemical Corporation and is referred to here as OCC) buried chemical wastes at the Love Canal, 102nd Street, S-Area and Hyde Park landfills between 1942 and 1975. The Olin Chemical Corporation also used the eastern portion of the 102nd Street site for waste disposal during that period. Estimated quantities of different types of wastes buried at each site are given in Table 1. Although not listed in Table 1, of particular concern is the presence of 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (2, 3, 7, 8-TCDD), a highly toxic byproduct of 2, 4, 5-trichlorophenol production. An estimated 0.66 to 1.65 tons of TCDD isomers were buried at Hyde Park alone.[3]

Love Canal was excavated in the 1890s to enable the generation of hydroelectric power for the development of a "model" manufacturing city. Excavation of the proposed 6 to 7 mile long canal had barely begun, with approximately 3,000 feet dug just north of the upper Niagara River, when the project failed in 1896. Prior to its use for waste disposal, the abandoned canal was approximately 3,000 feet

TABLE 1

Estimated Quantities & Types of Buried Wastes

Type of Waste or Category	Estimated Quantity (Tons) Love Canal	Hyde Park	S-Area	102nd St.
Chlorobenzenes	2,000	16,500	19,900	—
Benzylchlorides	2,400	3,400	1,600	—
Benzoylchlorides	800	6,200	3,300	—
Thionyl Chloride	500	—	4,100	—
Trichlorophenol	200	3,300	200	—
Liquid Disulfides, MCT, and Chlorotoluenes	700	2,600	2,200	—
Misc. Chlorinations	1,000	1,600	400	—
Metal Chlorides	400	100	900	—
Misc. Acid Chlorides	400	1,200	400	—
BHC Cake Incl. Lindane	6,900	2,000	—	300
Dodecyl Mercaptans, Chlorides & Misc. Org. Sulphur Compounds	2,400	4,500	600	—
Sulfides/Sulfhydrates	2,000	6,600	4,200	—
C-56 & Derivatives	—	5,600	17,400	—
Thiodan	—	1,000	700	—
HET Acid	—	2,100	500	—
Na Hypophosphite Mud	—	1,000	—	20,000
BTFs & Derivatives	—	8,500	—	—
Dechlorane	—	200	—	—
Calcium Fluoride	—	400	—	—
Mercury Brine Sludge	—	100	—	—
Inorganic Phosphorus	—	100	—	1,300
Organic Phosphorus	—	4,400	200	LT 100
Phenol Tars	—	—	800	—
Brine Sludge & Gypsum	—	—	—	53,200
Tetrachlorobenzene	—	—	—	2,327
BHC, Trichlorophenol, Trichlorobenzene, & Benzene	—	—	—	2,000
Na Chlorite Black Cake	—	—	—	18,673
Graphite	—	—	—	742
Lime Sludge	—	—	—	22,978
Brine Sludge	—	—	—	67,186
Miscellaneous	2,000	7,300	5,700	2,200
Estimated Total	22,000	80,000	63,000	200,000

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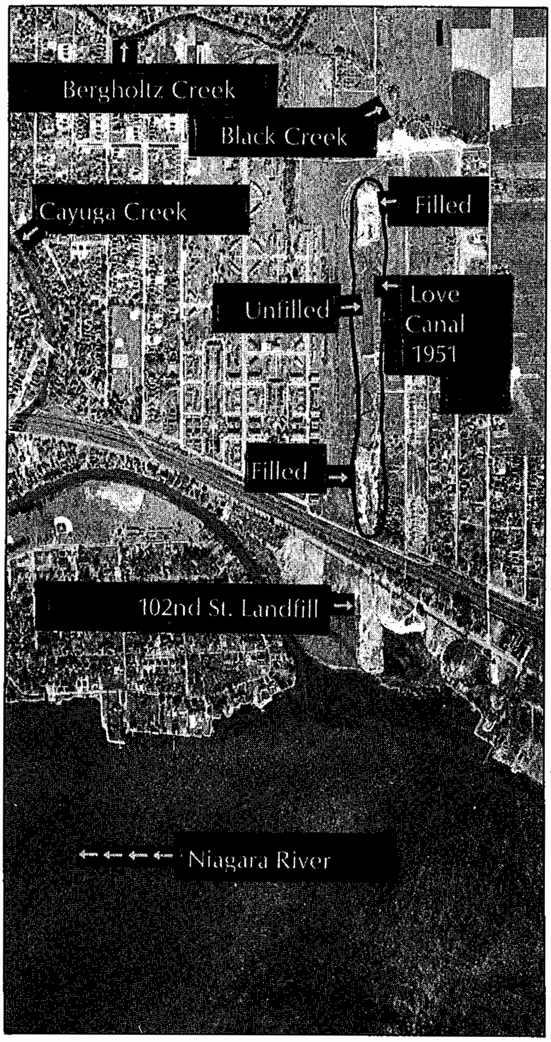


FIGURE 2. Aerial photo taken on 10/14/51 showing the Love Canal and 102nd St. landfills.

long, 40 to 100 feet wide, and 8 to 15 feet deep. OCC both widened and deepened portions of the canal, and excavated pits outside of the canal to bury approximately 22,000 tons of chemical wastes between 1942 and 1953 (see Figure 2).

The 102nd Street landfill is adjacent to the upper Niagara River just south of Love Canal (see Figure 2). OCC disposed of approximately 77,000 tons of wastes on the western 15.6 acres of the 22-acre site from about 1943 to 1971. During a similar time period, Olin dumped an estimated 66,000 tons of wastes on its eastern portion. Ten to 15 feet of wastes were deposited on top of the site's low-lying land, raising the ground surface up to the grade of Buffalo Avenue to the north. The landfill was closed in 1971 when the U.S. Army Corps of Engineers ordered the companies to construct a bulkhead to prevent the erosion of wastes into the river.

Directly west of the water treatment plant for the city of Niagara Falls, the S-Area property was partially reclaimed from the Niagara River by dumping various fill materials between 1938 and 1947. Following purchase of the property in 1947, OCC buried an estimated 63,100 tons of liquid and solid chemical wastes in 15- to 18-foot deep parallel trenches at the 8-acre S-Area site prior to 1961. Some liquid wastes were buried in tank cars. Major disposal operations at S-Area were curtailed when OCC implemented a thermal destruction process for many of their wastes in 1961. Two lagoons at S-Area are currently used to dispose of calcium fluoride sludge.

The Hyde Park landfill is 2,000 feet east of the deep gorge formed by the Niagara River downstream from Niagara Falls. OCC began using Hyde Park in 1953 for the disposal of chemical wastes previously buried at Love Canal. Up until about 1975, OCC dumped an estimated 80,000 tons of liquid and solid chemical wastes in pits and trenches at that 15-acre site.

Large quantities of relatively insoluble organic chemicals were buried at these sites. As a result, chemicals exist in the subsurface as solids, dissolved in water and as non-aqueous phase liquids (NAPL). Dissolved chemicals migrate with groundwater flow, although their velocity may be retarded by adsorption and biodegradation. The movement of NAPL, which may be composed of one or more chemicals, is complicated by several additional factors, including its density, viscosity and wettability. NAPL either floats on the water or sinks depending on its specific gravity. Dense NAPL may migrate downdip atop a confining layer in a direction other than that of the groundwater flow. The potential velocity of NAPL flow is inversely related to its viscosity. NAPL wettability determines whether the porous media will be preferentially wetted by it or by groundwater.

The presence and transport of NAPL is of particular concern for several reasons. Unlike dissolved chemicals with aqueous concentrations in the ppb and ppm range, NAPL is undiluted. NAPL migration provides a transport mechanism for toxic hydrophobic chemicals like TCDD and a moving source for continued chemical dissolution in groundwater. Off-site loadings and the complexity and costs of site assessment and remediation may be greatly increased where mobile NAPL is present.

Problem Recognition

Up until the 1970s, relatively little consideration was given to the potential for subsurface chemical transport during or after the waste disposal process. However, events at Love Canal beginning in about 1976 generated substantial interest regarding the environmental fate of landfilled chemicals among regulatory agencies, chemical companies and the public.

The development of a very high water table in the 1970s, due in part to heavy precipitation, exacerbated a number of existing problems at Love Canal. Conditions of concern included:

- subsidence of the landfill surface and exposure of drums;
- ponding of contaminated surface water in backyards adjacent to the landfill;
- the presence of unpleasant chemical odors that were cited by residents as a cause of discomfort and illness;
- chemical migration into basements adjacent to the landfill; and
- chemical migration into and through the local sewer system.

As a result of these and related problems, several health emergencies were ordered by the New York State Health Commissioner in 1978, and a State-of-Emergency at Love Canal was declared twice by President Carter, one in 1978 and again in 1980. Chemicals seeping to the surface at Love Canal prompted the start of numerous remedial investigations at landfills in the Niagara Falls area. Since 1976, extensive environmental studies have been conducted at the Love Canal, S-Area, Hyde Park and 102nd Street hazardous waste sites. Continued remedial investigations are currently in progress at all of these sites.

Remedial Investigations

Environmental sampling surveys are the primary means used to date to evaluate the nature, extent, mass and rate of chemical migration at hazardous wastes sites. Media studied have included groundwater, soil, sewer water and sediment, air, and biota. Surveys to define the extent of contamination generally proceed outward from the source and downward through the subsurface to beyond the limits of migration. The rate of off-site chemical transport has been estimated by multiplying calculated fluxes of groundwater and/or surface water across site boundaries by the chemical concentration in samples taken at the boundaries. Additional data are collected and analyses are performed to assess hydrogeologic conditions, pathways and mechanisms of migration and exposure, and associated risks.

Love Canal. Extensive remedial investigations at Love Canal have been funded by the city, state and federal governments. During these studies, thousands of environmental samples were chemically analyzed and hydrogeologic conditions were characterized by data from hundreds of wells and borings, hydraulic tests, water-level surveys, geophysical surveys and computer modeling.

Approximately 30 to 40 feet of unconsolidated sediments overlie the Lockport Dolomite bedrock in the Love Canal area (see Figure 3). The Lockport Dolomite forms a fractured bedrock aquifer of regional extent. In the vicinity of Love Canal, the Lockport Dolomite is approximately 180 feet thick and has numerous water-yielding fractures in the upper 30 feet. Below the Lockport Dolomite is the Rochester Shale, a regional aquitard that is approximately 60 feet thick in the Niagara Falls area. From the ground surface down, the overburden consists of layers of fill, silty sand, fractured hard silty clay, soft silty clay and glacial till as shown in Figure 3.

Water-level measurements made prior to the completion of a leachate collection system in 1979 indicated that a groundwater mound

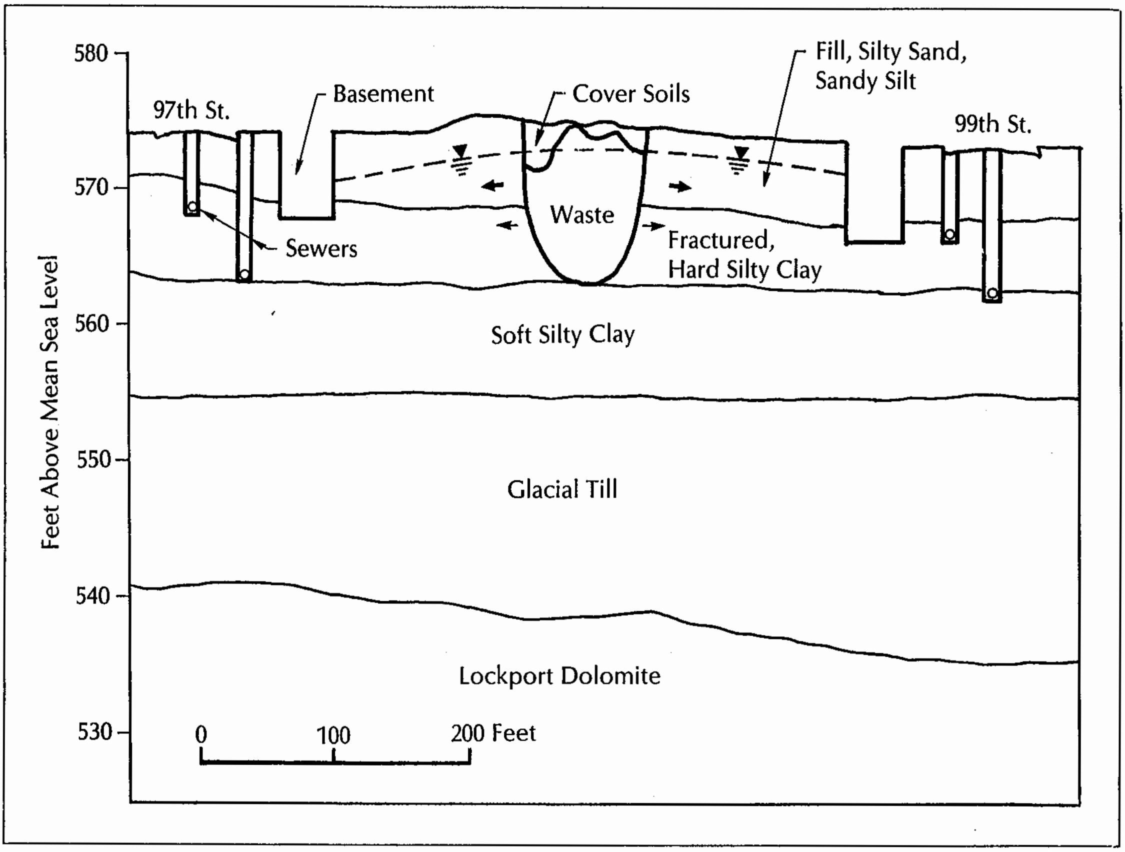


FIGURE 3. A schematic geologic cross-section through Love Canal showing the water-table mound that was found prior to remediation efforts.

had developed at the site, resulting in the radial flow of groundwater from the landfill through the overburden and downward toward bedrock. These early studies also revealed the presence of Love Canal chemicals at the landfill surface, in soils and groundwater near the site, in basement sumps of adjacent homes, in storm sewers leading to local creeks and the Niagara River, and in air samples.

These findings, combined with preliminary indications of health problems, including greater than statistical norms for spontaneous abortions and low-birthweight infants in the canal area, prompted the state and federal governments to declare an emergency at the site in August 1978. This state of emergency included the evacuation of 236 families from the first two rings of homes around the landfill (see Figure 4), closure of the 99th Street School, implementation of a site containment plan for the southern section of Love Canal and the commencement of additional investigations.

Some of the remedial studies performed in 1978 and 1979 were undertaken to aid in the construction of the leachate collection system surrounding the landfill. As part of these studies, soil borings were drilled every 10 to 20 feet along the proposed leachate collection drain line to examine subsurface conditions. These borings identified the presence of dense NAPL in the fractured silty clay layer along much of the drain line, resulting in a decision to lower the barrier drain system to beneath this layer.

Other investigative activities attempted to determine the extent of chemical migration in soils, sewers, basement sumps, creeks and indoor air. Environmental samples were taken at hundreds of locations between 93rd and 103rd Streets for chemical analysis by the New York Department of Health (NYSDOH).

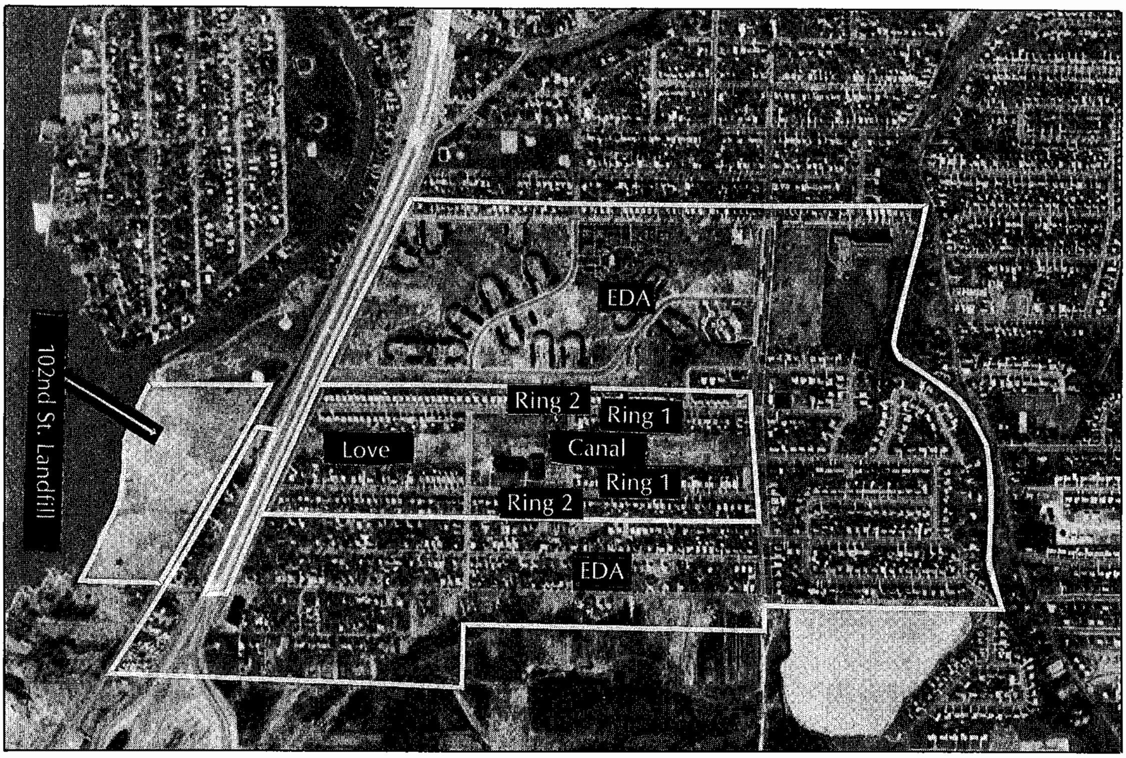


FIGURE 4. Aerial photo taken in 1976 showing the first two rings of homes around Love Canal and the 1980 Emergency Declaration Area (EDA).

NYSDOH investigators later noted that extensive chemical migration through overburden soils appeared to be limited to the Ring 1 area, except to the south of Love Canal.[4]

Chemical migration appears to have been influenced, in part, by the presence of basement sump drains and sewer lines around the landfill. Subsurface investigations revealed that most local sewer trenches had been backfilled with a mix of native materials rather than with sand or gravel. As a result, the backfill may have cut off portions of the relatively permeable shallow soil layers.[5] Additionally, these sewers lie below the water table and may have created a hydraulic sink, capturing groundwater and chemicals. Love Canal chemicals were also pumped directly from Ring 1 basement sumps into the storm sewer system. Once in the storm sewers, chemicals were routed to outfalls at Black Creek and Niagara River. Analyses of sewer water and sediment, and creek sediment, substantiate this transport pathway.

In early 1980, several investigations were initiated to better define the presence of Love Canal chemicals in storm and sanitary sewers and in Black Creek. At this same time, a pilot study funded by the Environmental Protection Agency (EPA) was being conducted to examine chromosomes sampled from 36 Love Canal residents. Preliminary results of the pilot study suggesting that 11 of the 36 residents had chromosomal abnormalities was made public on May 19, 1980. Two days later, President Carter declared the existence of a second State-of-Emergency at Love Canal. This order was issued out of concern that Love Canal chemicals were contaminating adjacent residential areas and subjecting residents to increased health risks.[6] This declaration prompted the relocation of residents from the Emergency Declaration Area (EDA) shown in Figure 3, and the commencement of the EPA's multimedia environmental monitoring study that occurred between August and October 1980.

A major objective of the EPA's multimedia environmental study was to determine the

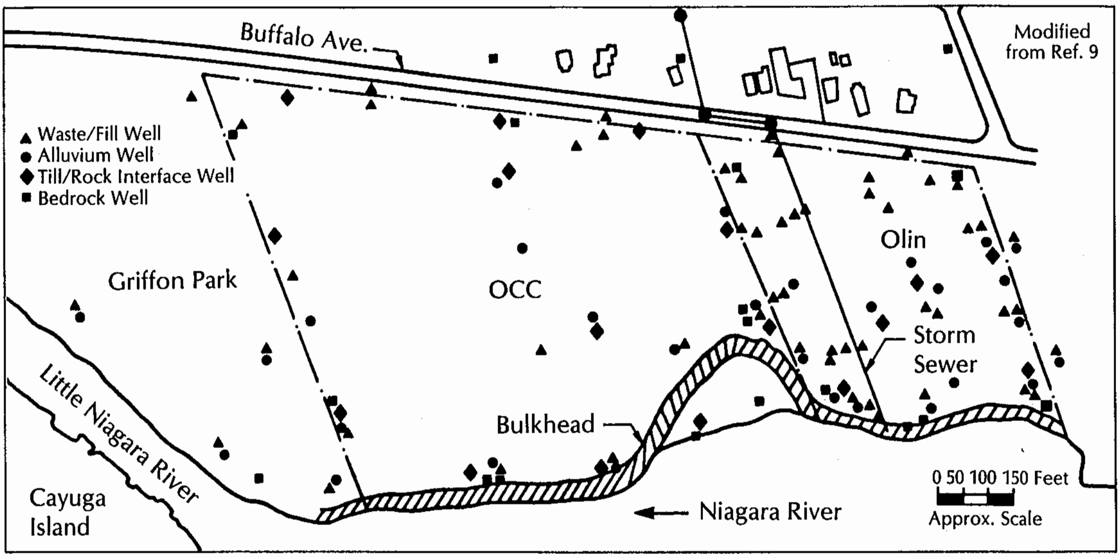


FIGURE 5. Locations of monitoring wells at the 102nd St. landfill.

nature and extent of chemical contamination in the EDA. Chemical analyses were performed on thousands of environmental samples. After more than one year of data analysis, the EPA concluded in 1982 that there was no evidence of soil or groundwater contamination attributable to Love Canal beyond the Ring 1 area and that except for residual contamination of certain local storm sewers and creeks, "...there was no compelling evidence that the environmental quality of the Declaration Area was significantly different from control sites or other areas throughout the United States."[6]

The U.S. Department of Health and Human Services (HHS) decided, on the basis of the EPA study and other data, that the EDA could be rehabilitated if residual contamination in storm sewers and creeks was removed and if adequate safeguards were maintained to prevent the future leakage of chemicals from Love Canal.[7] Both the EPA study and the HHS habitability assessment were met with criticism from various groups, including the Office of Technology Assessment of Congress (OTA). The principal finding of an OTA study was that more investigation was needed to determine whether or not the EDA could be safely rehabilitated.[8]

Several additional investigations followed the OTA study to evaluate the extent of chemical contamination in the EDA. In 1983, nearly 1,000 aqueous and sediment samples were analyzed to identify the extent of contamination requiring clean up in Love Canal area storm and sanitary sewers, and creeks, as well as the Niagara River. Soil borings were also conducted in 1983 to examine soil and chemical conditions along the alignment of a then-proposed concrete cutoff wall to encircle the Ring 1 area. Numerous monitoring wells were installed for a long-term monitoring network in 1985 and 1986, and an extensive soil survey in the EDA was conducted under the direction of an interagency Technical Review Committee (TRC) to provide input to the final decision on habitability that is expected this year or in 1988.

Numerous investigations were conducted at Love Canal between 1977 and late 1986. The main objectives of these studies were to define the nature and extent of chemical contamination and to guide clean up efforts. The duration of the RI process at Love Canal reflects the difficulties involved where chemicals have migrated through a complex environment within a residential community.

102nd Street Landfill. Remedial investigation of the 102nd Street landfill commenced in the late 1970s in the wake of Love Canal publicity. OCC and Olin hired consultants to undertake hydrogeologic evaluations of their respective

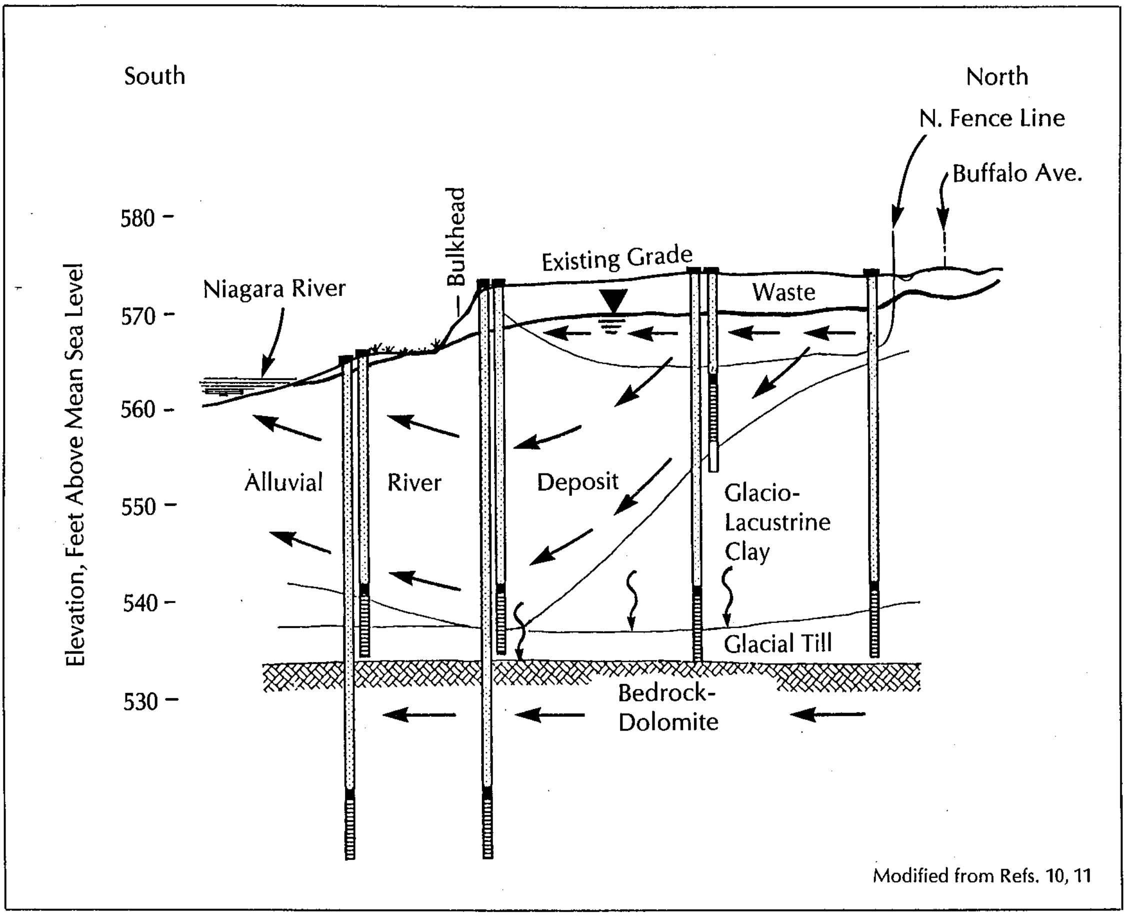


FIGURE 6. A north-south cross-section of the 102nd St. landfill with interpreted groundwater flow directions.

properties (see Figure 5). Between 1977 and 1980, approximately 75 monitoring wells were installed at the site to assess subsurface conditions, the groundwater flow field and chemical loadings to the Niagara River. Surveys were also conducted to examine the migration of chemicals into and through a 42-inch storm sewer buried on the Olin property and to examine the presence of chemicals in river sediments.

Geologic strata encountered at the site differ from those found at Love Canal due to erosion and sedimentation by the Niagara River. As shown in Figure 6, the Lockport Dolomite is overlain sequentially by glacial till, soft silty clay, river alluvium and fill materials. The river eroded the soft silty clay in the southern portion of the site and replaced it with silt, sand and gravel alluvium that coarsens with depth and pinches out near the northern site boundary.

A conceptual model of groundwater flow and chemical transport was developed by consultants for the chemical companies prior to 1984 based on hydraulic tests, water-level monitoring, chemical analyses and geologic conditions encountered at the site. This model indicated that groundwater flows laterally toward the Niagara River through the relatively permeable layers of waste, alluvium and bedrock. A downward component of flow is also apparent from the waste into the alluvium and through the clay-till aquitard to the bedrock aquifer. South of the bulkhead, groundwater presumably flows upward and discharges to the river.

A water balance developed by consultants for the chemical companies for the site is

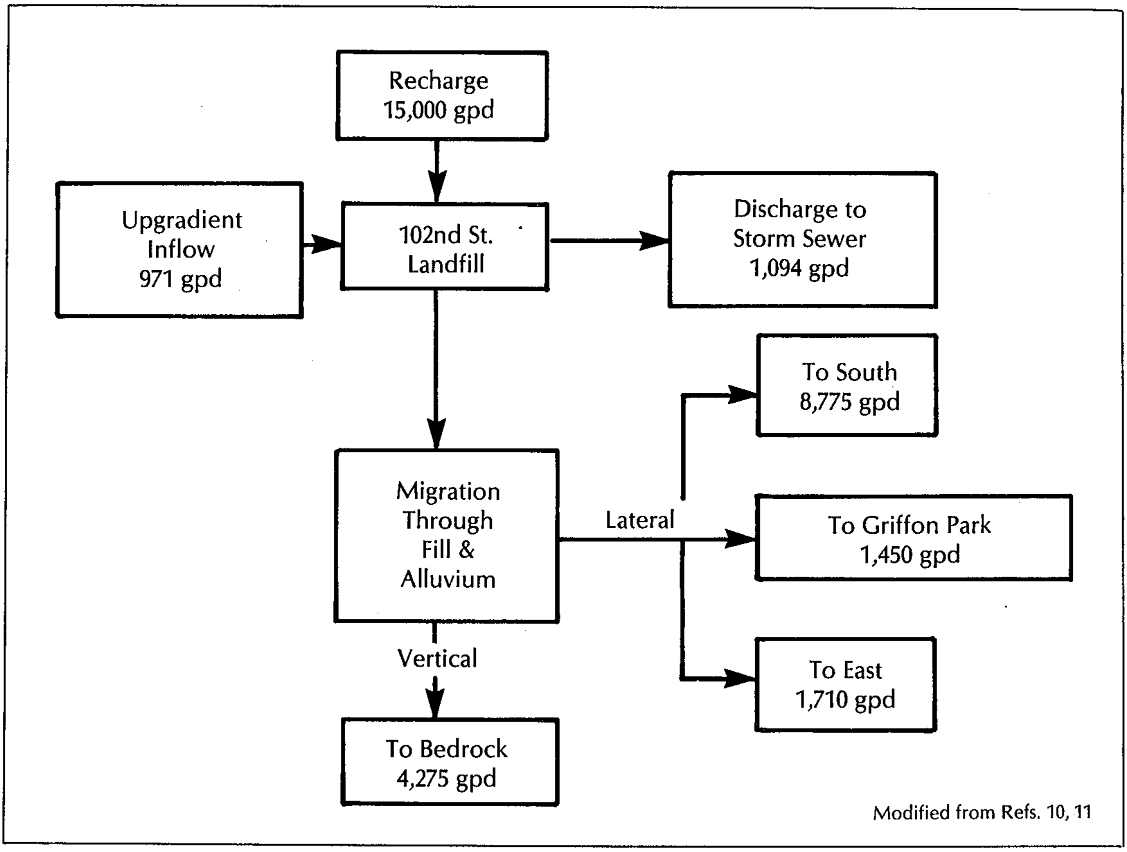


FIGURE 7. Water balance developed for the 102nd St. landfill.

illustrated in Figure 7. As shown in the figure, an estimated average 15,971 gallons of water per day (94 percent of which is thought to be derived from direct recharge to the landfill) leach through the wastes and flow off-site.

Groundwater that flows to the river environment and to properties east and west of the landfill is contaminated. For example, the distribution of total organic halogens (TOX) in overburden groundwater detected in 1986 is shown in Figure 8. Chemicals leaking into the buried storm sewer on Olin's property are discharged directly to the river.

The significance of chemical migration from the 102nd Street landfill was discussed by company and government representatives in 1984. After approximately six months of sporadic negotiations, an agreement was reached on a RI work plan to be undertaken by the companies to better define the nature, extent and rate of chemical transport, and to provide additional data necessary for remedial design. Field work began in September 1985 and will probably conclude in late this year or early next year.

The condition of the storm sewer and the potential for chemical transport through its bedding/backfill are being studied. A video inspection of the sewer was made in 1986. Eight wells completed into the bedding/backfill are being used to facilitate an assessment of transport through this media based on hydraulic tests and chemical analyses.

River sediments adjacent to the site have been shown to be contaminated by prior investigations. Additional samples are being taken along nine vectors offshore from the landfill to better define the presence of chemicals in these sediments. Similarly, another survey is being conducted to determine the extent of chemicals in surficial soils to the east, north and west of the landfill. Samples will be taken for analysis along 20 vectors radiating out from the site until clean

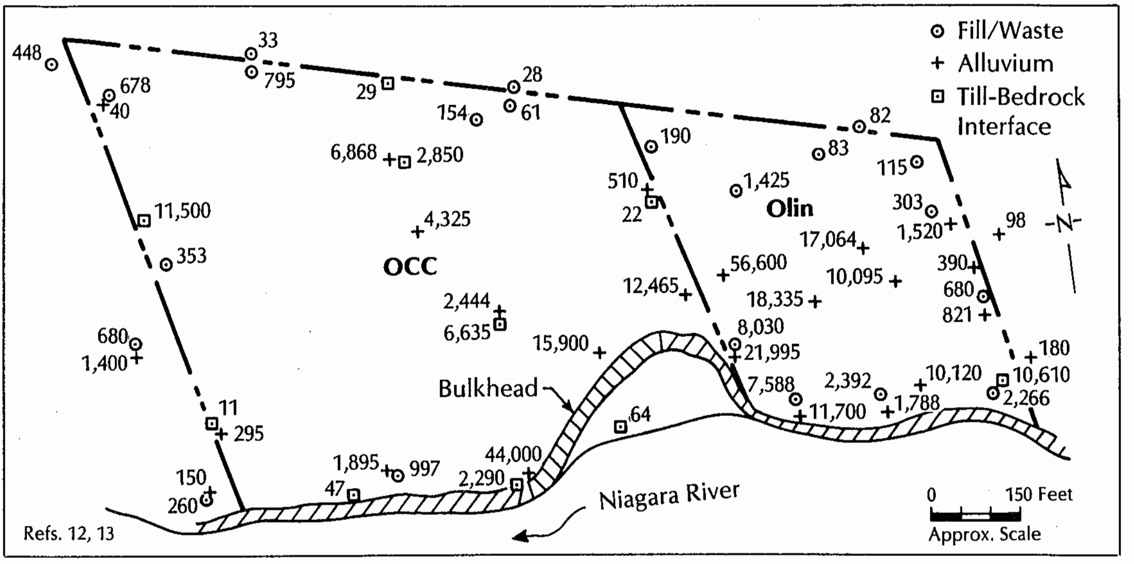


FIGURE 8. Distribution of TOX in ppb detected in overburden groundwater at the 102nd St. landfill in 1986.

soils or predetermined sampling barriers are met.

Approximately 40 new wells have been constructed since 1985. Most of these wells have been installed to the waste or alluvium along the site boundaries or off-site (see Figure 5). Eight new wells have been drilled into the Lockport Dolomite, including three that extend to the top of the underlying Rochester Shale. These new wells and some of the older wells are being used to monitor water levels and groundwater quality during the remainder of the RI.

Comprehensive chemical analyses of water samples from ten wells installed in the waste layer were used to help develop a site indicator list. Water sampled from approximately 80 wells was analyzed for general parameters to provide a snapshot of the spatial distribution of chemicals in the groundwater and to help select approximately 25 boundary wells for an extended monthly survey. Chemical analyses are also being performed on water samples taken from groundwater seeps located at the base of the bulkhead bordering the landfill. NAPL samples encountered during the field program are being analyzed to determine their chemical composition, density and viscosity. The goal of these surveys is to permit a more accurate determination of the rate and extent of off-site chemical migration through time and space.

S-Area. Drinking water for the city of Niagara Falls is conveyed from the Niagara River through tunnels cut into the Lockport Dolomite to a water treatment plant adjacent to the S-Area landfill (see Figure 9). The discovery of contaminated sludge in one of these tunnels in 1978 aroused concern that chemicals leaking from S-Area were entering the tunnel and polluting the city's water supply. Following the discovery of the problem, a series of remedial investigations funded primarily by OCC were begun to assess the nature and extent of chemical migration from the S-Area site.

Numerous wells and borings were installed between 1979 and 1982 to characterize site geology, groundwater flow directions and rates, and the distribution of chemicals in the subsurface. Monitoring well locations and a generalized cross-section depicting site conditions are shown in Figures 9 and 10, respectively.

Approximately 10 to 30 feet of relatively permeable, non-uniform fill and sand overlie an aquitard composed of silty clay and glacial till beneath the S-Area site. The clay-till aquitard, which ranges in thickness up to 18 feet in the northern portion of the site, is

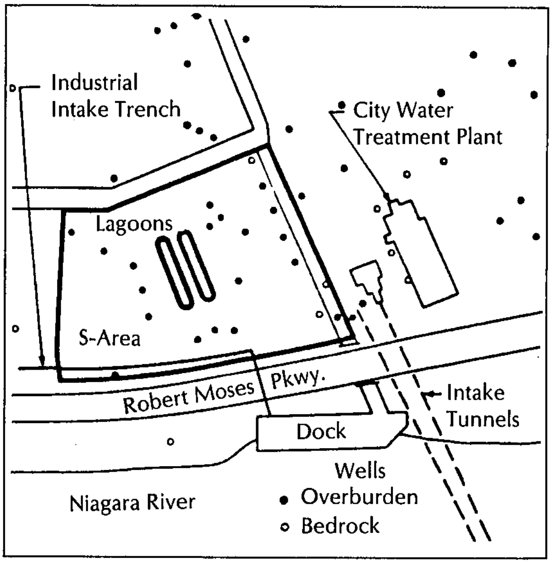


FIGURE 9. Locations of monitoring wells and water intake tunnels in the vicinity of the S-Area landfill.

absent in a small area south of the S-Area lagoons. Beneath the overburden, the highly-fractured upper 15 feet of the Lockport Dolomite form an aquifer of regional extent. The Lockport Dolomite is less fractured below this upper zone, has a total thickness of about 125 feet and is underlain by the Rochester Shale.

The groundwater flow systems beneath S-Area can be idealized as consisting of two aquifers with predominantly lateral flow that are separated by an aquitard through which flow is predominantly vertical. The aquifers are the overburden fill and sand, and the upper Lockport Dolomite. Most groundwater in the fill and sand aquifer flows south towards the Niagara River at an estimated velocity of 5 to 10 ft/month. To a lesser extent, however, shallow groundwater moves in all directions away from the site because of the development of a water table mound beneath the two lagoons. Groundwater in the Lockport Dolomite flows southeast to northwest away from the Niagara River. The potentiometric surface in the bedrock is generally several feet below the water table, indicating that flow through the clay-till aquitard is downward. A water-table low is present above where the clay-till aquitard is absent, suggesting a direct hydraulic connection between the two flow zones at this location.

Chemicals that were components and reaction products of the wastes deposited at S-Area have been found in the subsurface below and adjacent to the landfill. General evidence of existing contamination at the site is depicted in Figure 11 showing the distribution of TOX measured in overburden groundwater.

S-Area chemicals have migrated to their present locations either by dissolution in groundwater or by movement of dense NAPL. Existing contamination in the overburden aquifer generally reflects chemical transport by groundwater flow in all directions away from the site. Dense NAPL tends to sink through the fill-sand layer and move downslope on the surface of the clay-till aquitard. In addition to having a low permeability that would retard NAPL movement, the aquitard is preferentially wetted by water rather than NAPL. As a consequence, the water-saturated clay-till does not permit NAPL penetration except under extreme hydraulic gradients. The direction of probable NAPL migration establishes the potential for NAPL migration to the water treatment plant property, and the potential for NAPL migration down through aquitard discontinuities into the bedrock. Aquitard discontinuities include the area where the clay and till are absent, as well as potential manmade pathways such as power tower foundations.

The distribution of chemicals in the Lockport Dolomite suggests combined transport by groundwater flow and NAPL movement. Relatively high TOX concentrations are found in bedrock downgradient (northwest) of S-Area. High levels of TOX observed south of the site are probably the result of NAPL migration downslope on bedding planes in the Lockport Dolomite. NAPL can migrate counter to the groundwater flow direction on very gentle slopes. Consequently, the expected lateral direction of NAPL migration in the bedrock is toward the south. NAPL can also move through fractures in the bedrock, but the extent of downward migration has not yet been determined.

Following five years of sporadic negotia-

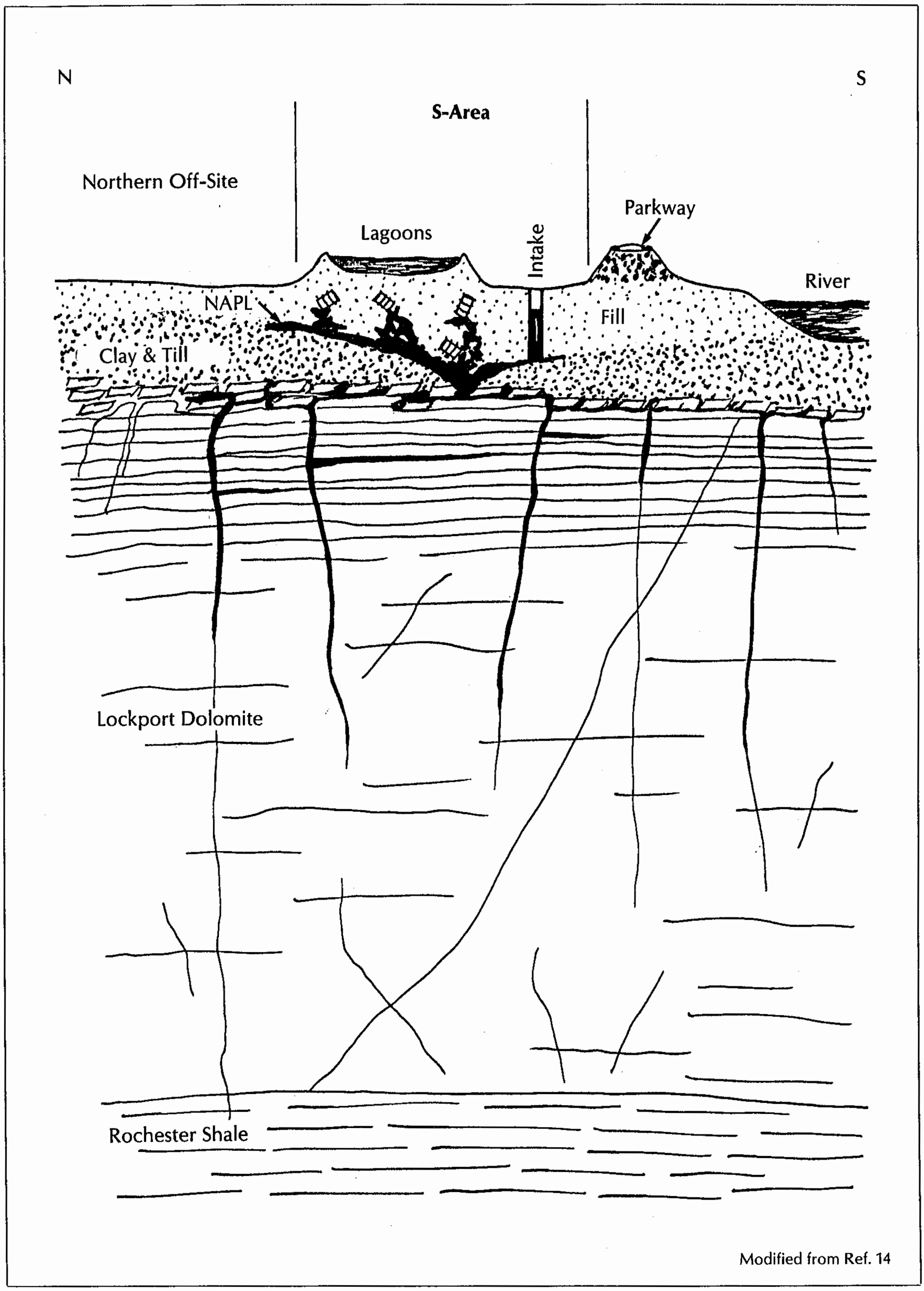


FIGURE 10. A generalized geologic cross-section at the S-Area landfill.

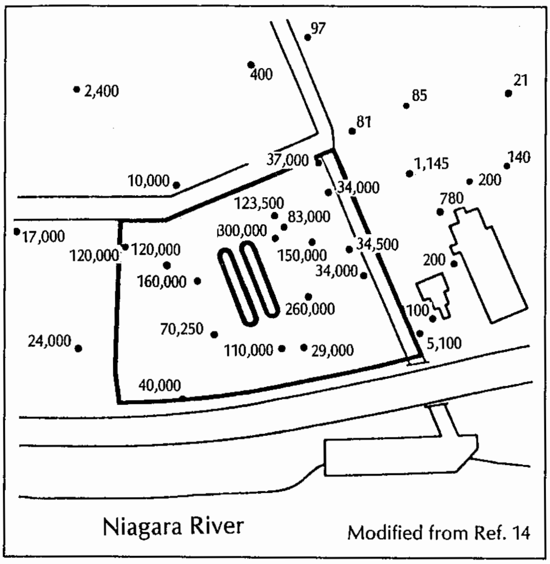


FIGURE 11. Distribution of TOX in ppb measured in overburden groundwater at the S-Area site.

tions between OCC and the city, state and federal governments, a settlement agreement was reached regarding additional investigation and the containment of buried chemicals at S-Area in April 1985. Prior to the construction of a containment system, the settlement required the completion of a surveys and studies phase that is to be conducted this year. This phase consists of numerous geologic borings and tests to more completely describe the S-Area lithology, including the thickness of the aquitard and the area of its discontinuity. Information from the drilling and testing will be analyzed using sophisticated numerical models of groundwater flow and chemical transport to further refine the containment system prior to installation.

The installation of three groups of monitoring wells will be undertaken also in the survey and study phase. Fourteen overburden wells will be drilled along the Robert Moses Parkway from east of the water treatment plant to west of S-Area (see Figure 9). These wells will be used to determine the extent of chemicals moving toward the river. Twenty-one overburden wells will be installed to further delineate the extent of contamination on the water treatment plant property. Finally, twenty wells will be drilled to the top of the Rochester Shale to determine the extent of chemical migration in the Lockport Dolomite.

Hyde Park. Groundwater studies at the Hyde Park site were initiated in 1978 when OCC installed a shallow tile drain and clay cover at the landfill. These actions were taken to reduce the volume of leachate generated at the site and to prevent Hyde Park chemicals from entering a local creek known as Bloody Run. As part of this project, monitoring wells were constructed to assess groundwater conditions at the site.

Negotiations following the filing of an EPA enforcement action in Federal District Court in December 1979, resulted in a settlement agreement with OCC. Approved by the court in April 1982, the agreement required OCC to:

- determine the extent of contamination;
- cap contaminated soils;
- collect and treat contaminated groundwater; and
- remediate contamination in Bloody Run by either capping or excavation.

OCC performed the remedial investigations required by the settlement agreement from 1982 to 1984. A major component of the RI was a drilling program designed to determine the extent of chemical contamination in the overburden and bedrock. Borings were cored and tested in 15-foot sections to the top of the Rochester Shale along ten vectors radiating out from the landfill. Groundwater samples were taken for analysis from those 15-foot sections that yielded significant amounts of water. If chemicals were present above specified levels, a new hole was drilled about 800 feet away along the vector. Some of these holes were used as observation wells during aquifer tests prior to being grouted.

As a result of the drilling programs, the local geology has become fairly well-known (see Figure 12). Approximately 15 to 30 feet of waste at the landfill are underlain by 0 to 10 feet of silty clay sediments. Beneath the overburden, the Lockport Dolomite ranges in thickness from 130 feet (200 feet southeast of the landfill) to 65 feet at the Niagara Gorge. The Lockport Dolomite overlies the Rochester

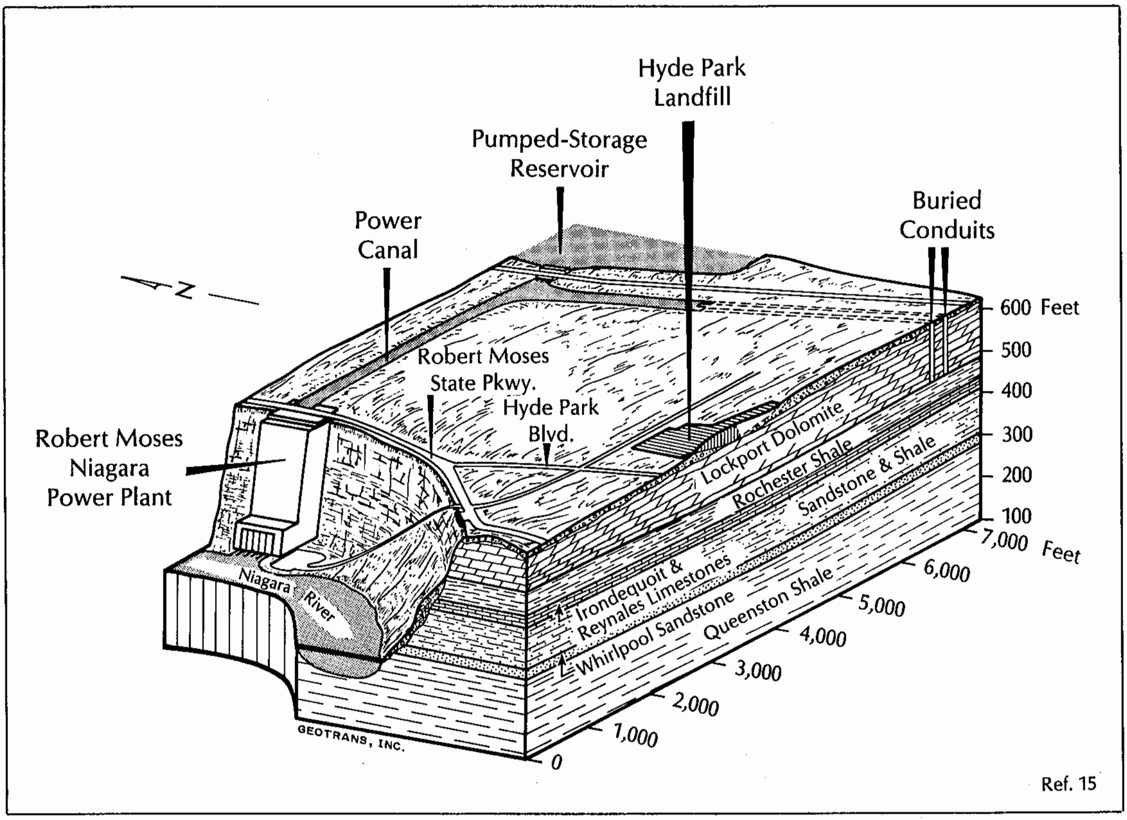


FIGURE 12. A generalized diagram showing the geologic formations and topographic features in the vicinity of the Hyde Park landfill.

Shale and several lower units in a layercake sequence.

The hydrogeology of the Hyde Park area is unique because of the Niagara River Gorge and the man-made channels associated with a nearby pump storage reservoir (see Figure 12). The Niagara Gorge (about 2,000 feet to the west), the forebay canal (about 4,000 feet to the north) and the buried conduits (about 3,000 feet to the east) control groundwater movement in the Hyde Park area.

The groundwater system can be idealized as a series of flat-lying, permeable zones sandwiched between aquitards, all of which are bounded on three sides by drains. Precipitation infiltrates the wastes and the low-permeability overburden before recharging the highly-fractured upper layer of the Lockport Dolomite. Where glacial sediments are present beneath the landfill, downward groundwater flow and chemical migration is retarded. In areas where these sediments are thin and or absent, groundwater and chemicals move freely into the underlying rock. In the permeable bedrock zones, much of the groundwater flows laterally toward the three boundaries. Between these zones, groundwater moves slowly downward to the next lower permeable layer.

Analyses of groundwater samples taken during the vector well survey revealed that contamination had migrated much further than previously thought. In fact, Hyde Park chemicals were found in seeps emanating from the Lockport Dolomite along the Niagara Gorge in July 1984. Dissolved chemical and NAPL plumes in the overburden and in the Lockport Dolomite were delineated during the RI as shown in Figure 13. Although the areal extent of contamination has been defined, the depth of chemical migration is unknown because dissolved chemicals and NAPL were observed all the way to the base of the Lockport Dolomite at many locations

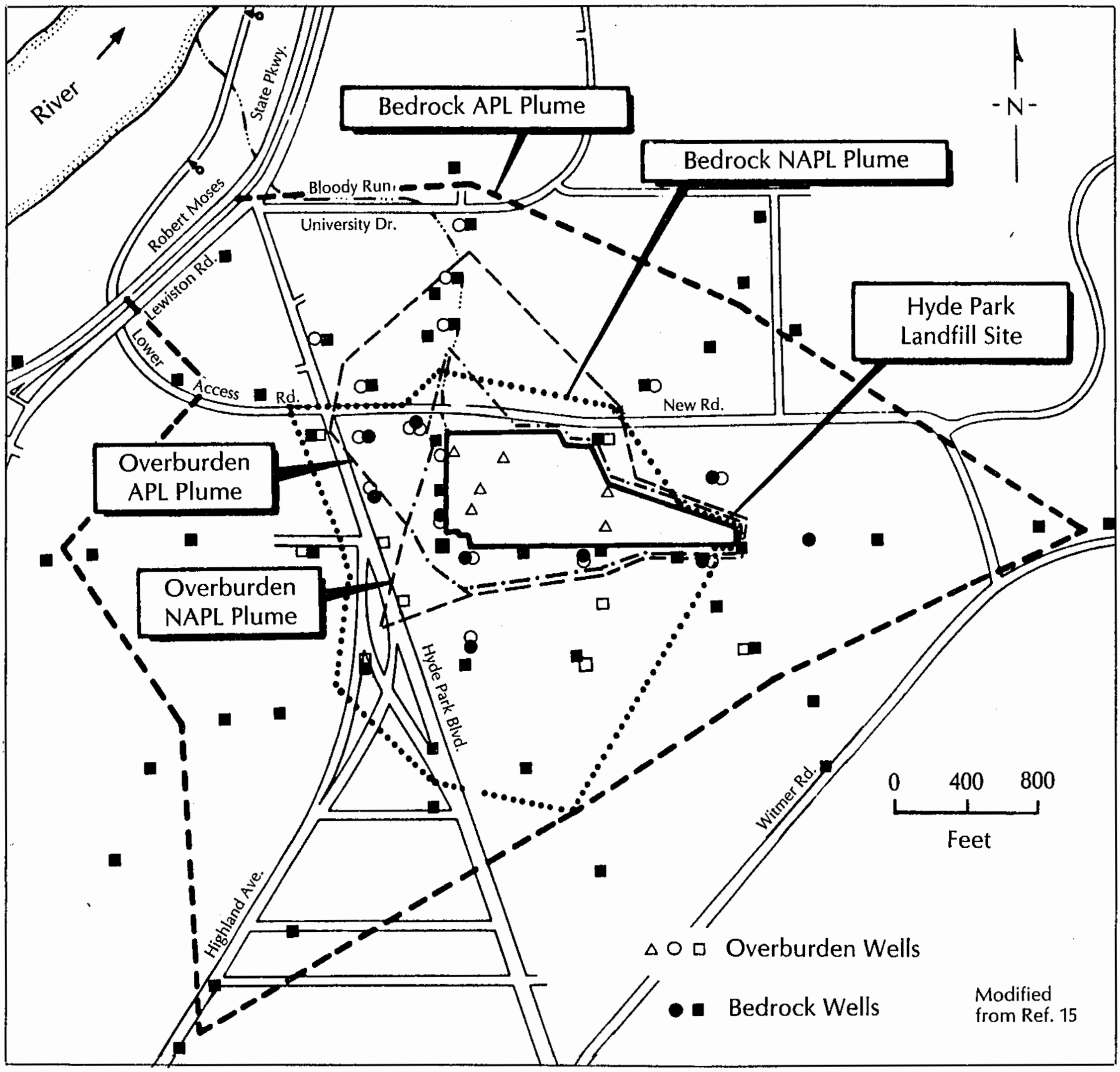
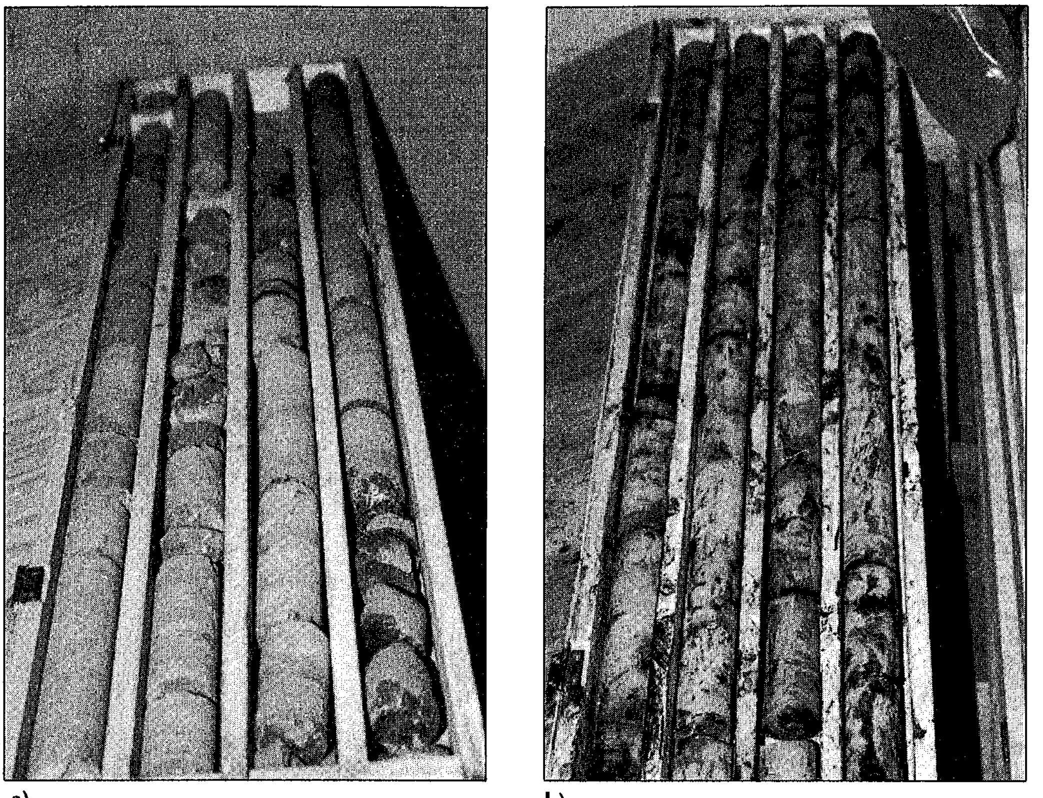


FIGURE 13. Boundaries of dissolved chemical and NAPL plumes of contaminated groundwater emanating from the Hyde Park landfill through the overburden and Lockport Dolomite.

(see Figure 14).

The distribution of chemicals in the overburden reflects the downward migration of contaminated surface runoff from the Hyde Park landfill, which is elevated relative to surrounding properties. Lateral chemical transport through the overburden has been limited because the potential for downward flow to bedrock exceeds that for outward flow through the low-permeability glacial sediments.

The contamination observed in the Lockport Dolomite reflects variations in the directions of groundwater flow that have occurred since waste disposal began at Hyde Park. Chemical analyses indicated the past migration of chemicals though the upper Lockport Dolomite in all directions. Present groundwater flow is primarily to the northwest, but the southern and eastern areas of contamination suggest that groundwater at one time moved toward those areas. Groundwater flow prior to the construction of the forebay canal and buried conduits (from 1958 to 1962) was inferred to be toward the southwest. Similarly, dewatering during the construction of these conduits could have drawn contaminated groundwater toward the east. Chemicals have



a) b)

FIGURE 14. Photos showing the absence (a) and presence (b) of NAPL on core samples of the Lockport Dolomite aquifer recovered near the Hyde Park landfill.

moved downward to the base of the Lockport Dolomite by dissolution in groundwater and by dense NAPL flow.

As part of their study submitted in 1984, OCC proposed several remedial measures for Hyde Park. Negotiations with the governments over remedial actions and additional investigations continued until October 1985, and resulted in a Stipulation on Requisite Remedial Technology. Additional investigations required by the stipulation included drilling to determine the depth of chemical migration in bedrock and extensive groundwater monitoring of the Hyde Park area.

Remediation

Remedial actions at hazardous waste sites where groundwater has been contaminated generally can be subdivided into three categories:

- excavation of wastes and contaminated soils for burial at another landfill or for incineration;
- hydraulic containment of subsurface chemicals by pumping groundwater; and
- no action or limited action, such as adding a clay cap to a landfill.

Recent analyses indicate that excavation of wastes and contaminated soils from Hyde Park and burial at a nearby permitted hazardous waste landfill would cost between $237 and $560 per cubic yard, and that excavation and incineration would cost between $900 and $3,300 per cubic yard.[16] As such, excavation with burial or incineration at any of these sites would likely cost between $100 million and $4 billion. Besides the high cost, several other negative factors are associated with the excavation option, including:

- the absence of landfills that are permitted to accept TCDD-containing wastes;
- the limited space available at permitted hazardous waste landfills nationwide;
- the perception that excavation and reburial is a shell game where the problem only shifts location; and
- the exposure risks posed by excavation, transport, reburial and/or incineration.

As a result of these considerations, the excavation of wastes and contaminated soils in Niagara Falls has not yet been judged to be cost-effective by chemical company or government officials. However, others argue that the long-term costs associated with hydraulic containment make excavation and incineration an attractive remedy.[17]

Hydraulic containment refers to control of the groundwater flow field and chemical transport by pumping. Recovery wells, sometimes augmented by injection wells, and drains are installed and pumped to modify existing hydraulic gradients in such a manner that chemicals moving off-site are captured and withdrawn for treatment. The general goal of hydraulic containment is to maintain inward hydraulic gradients toward the recovery wells or drains throughout the zone of the subsurface contamination. The effectiveness of a hydraulic containment system can be evaluated by monitoring groundwater levels to determine flow directions and by monitoring the groundwater quality to detect chemical migration. At Love Canal, S-Area and Hyde Park, the hydraulic containment option has been selected to prevent the uncontrolled chemical migration that is considered to be a threat to human health and the environment. A remedial strategy for the 102nd Street landfill has yet to be chosen.

Love Canal. Beginning in 1978, remediation at Love Canal has proceeded in phases. The main objectives have been to contain chemical migration, clean up contaminated areas and limit chemical exposure. Implemented remedies have included site evacuation, demolition of homes and a school, installation of clayey soil and synthetic covers, construction of a tile drain leachate collection system with a carbon adsorption treatment plant, severance and plugging of utility lines, construction of cutoff walls at selected locations, installation of fencing and the cleaning of sewer lines. Future remedial work is scheduled to include the cleaning of local creeks, and continued operation and maintenance of the site containment system and long-term monitoring program.

Following President Carter's Emergency Declaration of August 1978, Phase 1 of site remediation efforts occurred in the southern section of Love Canal between October 1978, and February 1979. This phase consisted of the construction of a leachate collection system and clayey soil cover. In addition, contaminated groundwater was treated using temporary facilities. The leachate collection system consisted of barrier drains that were installed parallel to the southern portion of Love Canal in the back yards of Ring 1 homes. Vitrified-clay pipe was placed in trenches that were dug 12 to 15 feet deep and 4 feet wide. The pipe was backfilled with crushed stone and sand to ground level. Leachate entering the drains flows by gravity to precast wet wells and then is pumped to holding tanks and the on-site treatment plant. In January 1979, eight lateral French drains were constructed from the main drains to the landfill to expedite the dewatering of the site prior to the installation of the clayey soil cover.

A Supplemental Health Order issued by the N.Y. State Health Commissioner in April 1979, directed that the leachate collection system be extended to the central and northern sections of Love Canal. Known as Phase 2 of the remedial program, work on these sections began in May 1979, and was completed in December 1979. As in the southern section, numerous French drain laterals were installed between the main drain lines and the landfill to promote site dewatering. During the Phase 2 construction, an examination of the barrier drain in the southern section revealed numerous pipe separations and infilling of stone. Extensive repairs of the drain system were performed between July and October of 1979. In December 1979, construction of a permanent

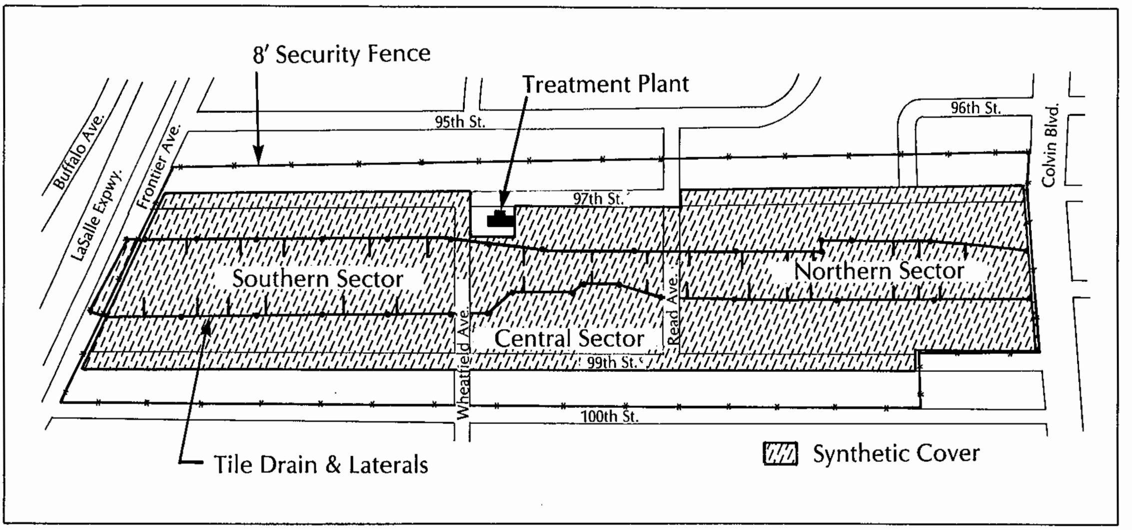


FIGURE 15. Major components of the site containment system at Love Canal.

activated-carbon treatment plant was completed and it was put into operation. Effluent from this treatment plant is discharged to the sanitary sewer system.

As part of the May 1980 Emergency Declaration by the federal government, residents of the EDA became eligible for relocation at government expense. By May 1982, approximately 570 families had been relocated from the EDA. Other remedial actions included the plugging of the Wheatfield Avenue sanitary sewer in 1980 following the determination that Love Canal chemicals were migrating through this conduit, and final work on the clayey soil cover over the landfill that was completed in 1981.

Additional remedial work to improve the site containment system began in September 1982 and was completed in December 1984. This work included:

- construction of a high density polyethylene (HDPE) synthetic membrane cover over the entire ring 1 area;
- installation of drain tiles on top of the HDPE cover to divert surface runoff;
- inspection, cleaning and repair of the existing barrier drains;
- placement of concrete cutoff walls beneath seven street crossings; and
- demolition of the 99th Street School and Ring 1 and 2 homes.

A concrete cutoff wall surrounding the site was not constructed as planned because chemicals had been discovered along portions of the wall alignment. In addition, groundwater modeling performed for EPA to predict the hydraulic effects of the planned barrier wall indicated that the benefits of the wall would be minor.[19]

Clean up of contaminated storm and sanitary sewers in the Love Canal area was completed in 1986. Truck-mounted hydraulic vacuums were used to remove sediment from the sewer lines. The excavation of 15,000 cubic yards of contaminated sediments from Black and Bergholtz Creeks is scheduled to begin next year. These contaminated sediments will be stored within the Love Canal containment area.

Major components of the site containment system — including the barrier and lateral drains, the synthetic cover and the treatment plant — are shown in Figure 15. Construction of the barrier drain system and landfill covers has provided substantial environmental benefits. The clay and synthetic covers have been effective in:

- preventing surface runoff of chemicals from Love Canal;
- preventing human contact with chemicals at the surface of Love Canal;
- reducing the rate of recharge to the

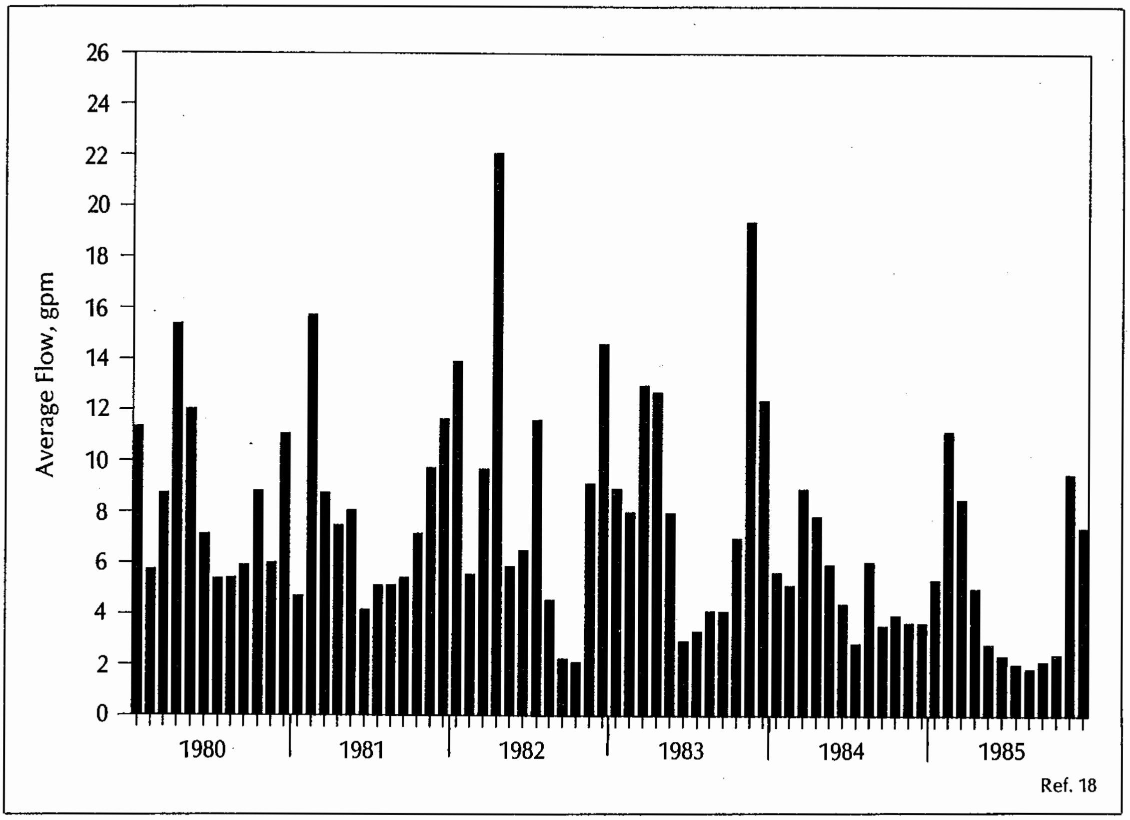


FIGURE 16. Time-averaged monthly flows to the leachate collection system at Love Canal from 1980 to 1985.

landfill; and

- improving the appearance of the site.

Construction of the barrier drain leachate collection system has:

- improved drainage at the site and kept the water table below ground surface;
- provided for the removal of hazardous chemicals from the subsurface for treatment; and
- prevented and/or reduced the prior uncontrolled migration of Love Canal chemicals through the overburden.

The hydraulic containment system at Love Canal has been operating since 1979. Monitoring data have shown that the average annual flow to the leachate collection system has declined with time (see Figure 16), particularly after the initial dewatering of the landfill and after installation of the synthetic cover in 1984. However, it has been difficult to determine the capture zone (area of inward flow) of the drain system due to the heterogeneous nature of the overburden and the flatness of the water table at the site. The recent installation of additional nested piezometers in transects perpendicular to the landfill should provide the areal and vertical direction of hydraulic head data needed to better delineate the capture zone of the drain system.[20]

102nd Street. The on-going RI was designed to provide sufficient data to determine an appropriate remedial response at the 102nd Street landfill. A variety of remedial options will be considered such as the use of wells and drains to effect hydraulic containment at the site, construction of a new landfill cover, construction of subsurface cutoff walls, insertion of a pipe sleeve in the storm sewer, clean-up and/or fixation of contaminated river sediments, and no action. A FS is not expected

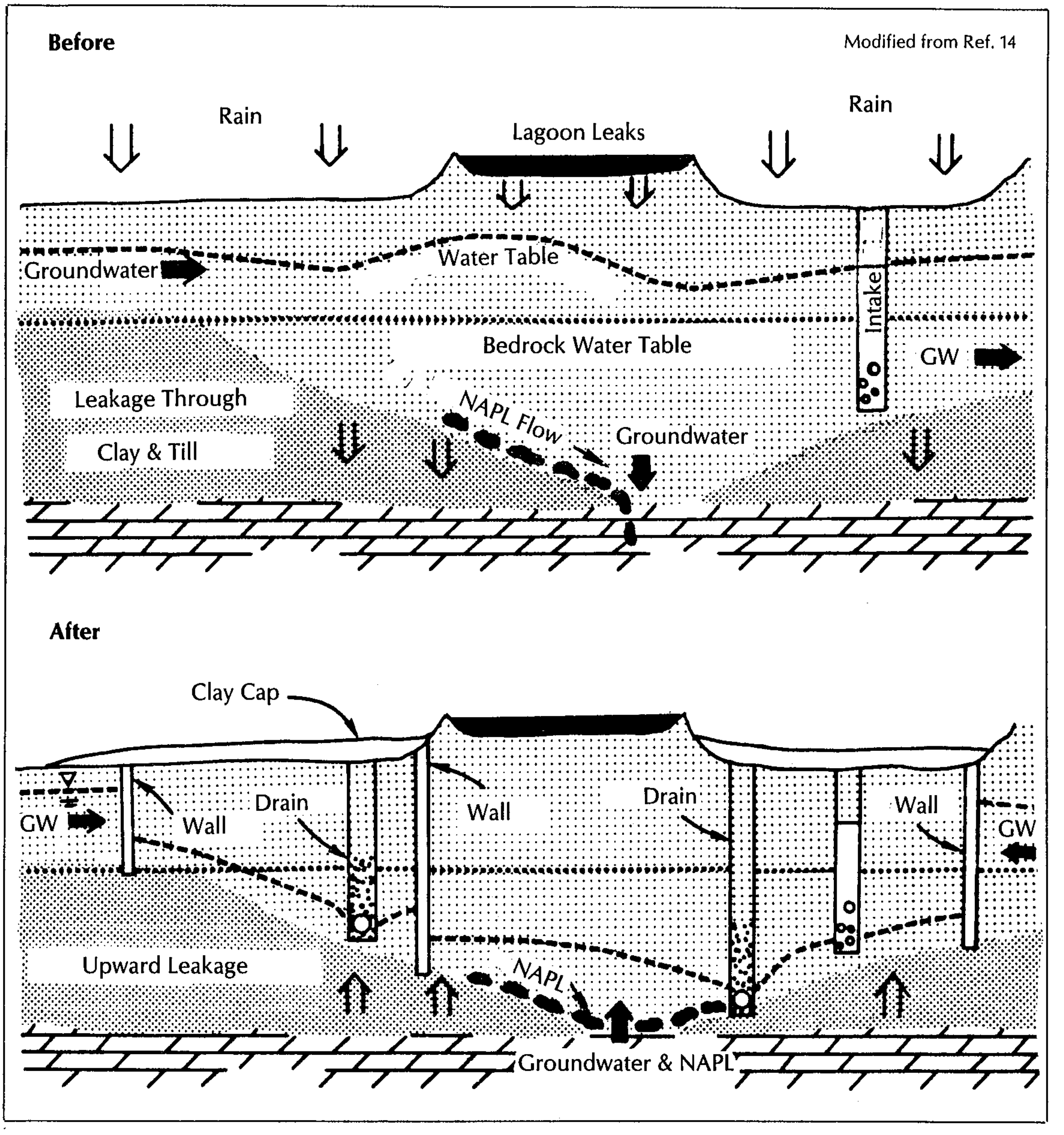


FIGURE 17. A conceptual cross-section of the hydraulic containment system to be implemented at the S-Area landfill.

at this site until next year.

S-Area. The S-Area containment system described in the OCC settlement agreement is designed to provide for the hydraulic containment of chemicals in the subsurface. Groundwater levels will be controlled to prevent NAPL and dissolved chemicals from moving to off-site areas. Hydraulic containment will be achieved by constructing a system of remedial components that include drains, barrier walls, plugs, a clay cap and a lagoon liner. Inward groundwater flow across barrier walls and plugs, and upward flow through the aquitard, will be effected by pumping from drains. Figure 17 shows a conceptual cross-section of this containment system. In the area where the aquitard is missing, the remedies must create an upward hydraulic gradient that is sufficient to cause the upward flow of dense NAPL. By achieving this goal, chemicals in the subsurface will move toward drains where they can be removed.

In addition to the containment system designed for S-Area, additional collection systems are required for an adjacent site to the north of S-Area and for the water treatment plant property.

The monitoring program described by the settlement agreement is an essential part of the overall remedial strategy. The program provides the means for collecting data and establishing performance criteria that can be used to determine if the remedial components are achieving their design objectives. If the design objectives are not being fulfilled, OCC has the responsibility to correct deficiencies, modify or repair damaged components, and implement additional remedies as needed. The specified monitoring program is comprehensive and provides redundant measures for system effectiveness.

Water-level monitoring, tracer monitoring and chemical monitoring will be utilized to monitor the remedial system. Water-level monitoring at numerous wells will be used to substantiate the existence of upward and inward hydraulic gradients at the site. Chemical analyses will be conducted at regular intervals on groundwater samples to identify the presence of S-Area and tracer chemicals. The tracer and chemical monitoring programs will provide independent means for evaluating the effectiveness of the containment system, particularly in the bedrock.

The hydraulic containment system at S-Area will probably begin operation in about 1992. Groundwater withdrawals are planned to continue for at least 35 years unless OCC can demonstrate that the site poses no potential adverse environmental impact.

Hyde Park. The Hyde Park Stipulation requires several remedial actions. The specified remedial measures focus on source control, overburden remedies, bedrock remedies and control of seeps at the Niagara Gorge face. Design of these remedies was facilitated by the application of a series of numerical models of groundwater flow and chemical transport.

The source control program is designed to reduce the amount of chemicals migrating from the landfill into the overburden and bedrock. This reduction will be achieved by a synthetic cap to reduce recharge and by extraction wells to remove chemicals. During the prototype phase of the program, two large-diameter extraction wells are to be installed in the landfill. If a reasonable amount of NAPL can be removed with this method, an operational network of six extraction wells will be installed.

The remedial program specified for the overburden is designed to achieve the lateral containment of dissolved chemicals and NAPL and to maximize collection of NAPL. Mobile NAPL not removed from the overburden will tend to sink downward to the bedrock and will be addressed by the bedrock remedy. The overall approach of the program is to further define the boundary of the overburden NAPL plume and then install a tile drain to collect mobile NAPL. The location and depth of the drain will be determined after the overburden plume boundaries have been refined. The performance criteria for the overburden system are:

- an inward hydraulic gradient must be maintained toward the drain or downward into the bedrock; and
- there must be no expansion of the NAPL plume toward the drain or downward.

Remedial systems planned for the Lockport Dolomite are designed to contain both the NAPL and aqueous phase liquids (APL) plumes. Specific objectives of the bedrock system are to contain dissolved chemicals and NAPL within the NAPL plume, contain dissolved chemicals in an area near the gorge face designated the remediated APL plume, and eliminate the seepage of chemicals at the gorge face. However, portions of the APL plume will not be remediated. As with the source control system, a prototype system will be implemented first and later refined into an operational system. The system will use extraction and injection wells to maximize the the collection of both dissolved chemicals and NAPL. The locations of purge, injection and monitoring wells, and a schematic cross-

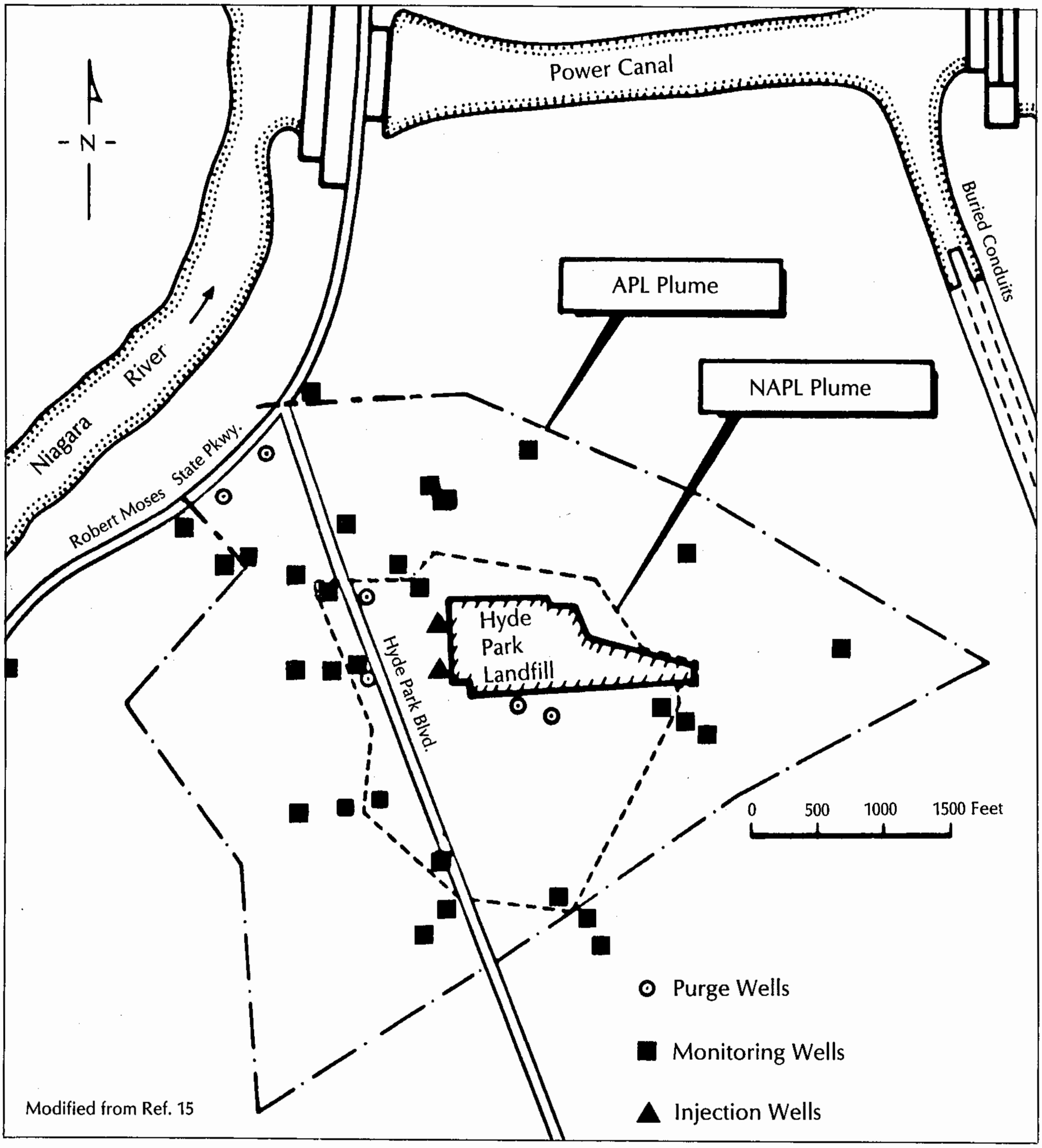


FIGURE 18. Locations of purge, injection and monitoring wells to be installed for the prototype Lockport Dolomite hydraulic containment system at the Hyde Park site.

section of the containment concept, are shown in Figures 18 and 19, respectively. The reason for adding recirculation wells to the NAPL plume containment system is to speed up the recovery of contaminants, and to maintain higher water levels for the flushing of chemicals in the upper bedrock.

The main performance criteria for the bedrock system is that an inward hydraulic gradient must be maintained at the NAPL plume boundary. In addition, the flux of certain chemicals to the Niagara River must be below specified limits. The interim flux level for 2,3,7,8-TCDD is 0.5 g/yr. This level will be modified based on a future study of TCDD in the Niagara River and Lake Ontario. The TCDD study will be jointly funded by OCC, the EPA and the state of New York.

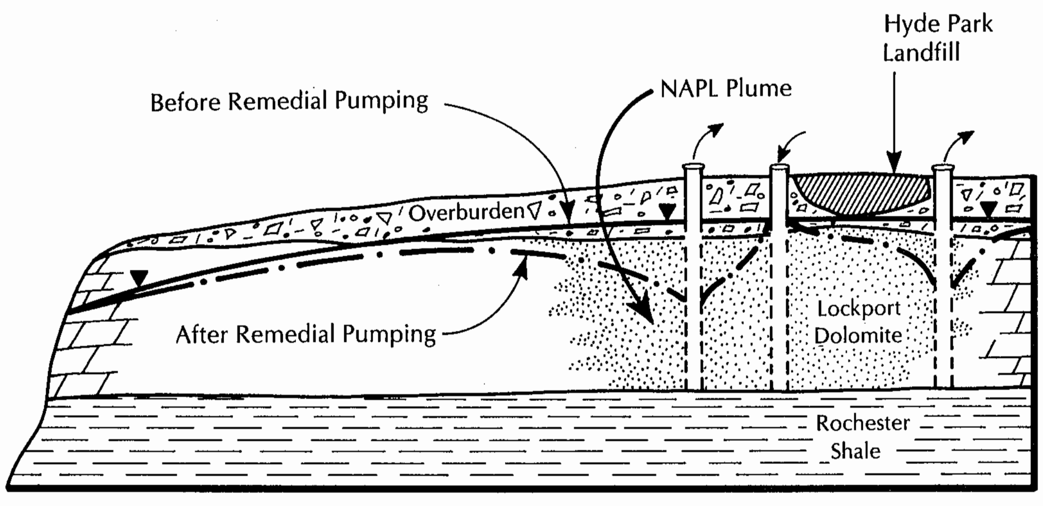


FIGURE 19. A conceptual cross-section of the Lockport Dolomite hydraulic containment system at the Hyde Park site.

The remedies described in the Stipulation include extensive monitoring programs to ensure that performance goals are achieved. If these performance criteria are not met, the system must be modified accordingly. These performance-oriented remedial actions allow flexibility in altering the remedial system as more data are obtained.

Most of the activities set forth in the Stipulation are contingent upon OCC receiving a permit to incinerate dioxin-containing wastes. It is anticipated that this permit will not be obtained prior to 1988. However, there are certain priority activities that have already begun or will be started sooner. These activities include the implementation of a community monitoring program, the Gorge Face Seep program, the APL and NAPL plume boundary refinement in the overburden, and the design of the on-site storage and treatment facility. The community monitoring program involves the measurement of water levels and analysis of groundwater and soil gas from shallow wells to address conceivable routes of groundwater migration to houses. The Gorge Face Seep program is designed to limit chemical exposure at the seeps by removing dioxin-contaminated soils, constructing a fence to prevent access, and when the incineration permit is granted, by pumping purge wells to dry up the seeps.

Costs

Over the past ten years, millions of dollars have been spent investigating the Love Canal, S-Area, Hyde Park and 102nd Street hazardous waste sites. As of December 1983, the federal government had expended approximately $45 million in studies and response actions at Love Canal.[21] The state of New York and city of Niagara Falls also have committed vast resources to the Love Canal problem. At S-Area, where the EPA spent $2 million for more than 25,000 hours of technical advice from consultants on how to remedy the site, implementation of the remedial program will take 5 to 8 years and will cost OCC approximately $36 million.[22] OCC has estimated that the remedial program at Hyde Park will cost $17 million in capital costs and $1.5 million in operating and maintenance costs in the first year.[23] Over the long term, additional costs will be incurred in the operation and maintenance of the hydraulic containment and monitoring systems at each of these sites. Costs associated with future investigation and remediation at the 102nd Street landfill are unknown.

Conclusions

Hazardous chemicals buried in Niagara Falls have migrated through a varied and complex network of environmental media from their original disposal sites during the past forty years. Since the late 1970s, a large amount of resources has been dedicated to the investigation and remediation of the uncontrolled chemical migration at several of these sites.

The characterization of the nature, extent and rate of chemical migration in the environment, particularly through the subsurface, is a complex and costly task that is subject to significant uncertainty. Therefore, the remedial investigation program should be performed in phases. In this way, later phases may be modified based on the knowledge gained from earlier phases.

The selection of an appropriate remedy is also subject to considerable uncertainty and has been the focus of lengthy negotiations. Long-term hydraulic containment of contaminated groundwater and NAPL using recovery wells and drains has been the main feature of remedies chosen for Love Canal, S-Area and Hyde Park. At each of these sites, the effectiveness of the remedy and the need for additional action will be evaluated by the operation of an extensive long-term monitoring program. A key component of a good remedial plan, therefore, is the flexibility to change the design and operation of the remedy based on review of the monitoring data.

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