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April 2, 1984
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E. I. duPont de Nemours & Co., Inc.
Niagara Plant
P. O. Box 787
Niagara Falls, New York 14302

Attention: Mr. Timothy D. Van Domelen

PHASE I REMEDIATION STUDIES
NIAGARA PLANT
NIAGARA FALLS, NEW YORK

Gentlemen:

We are pleased to present herein our report of our Phase I Remediation Studies conducted for the Niagara Plant site, Niagara Falls, New York. The objectives of this study and an outline of the scope of work were defined in our letter dated March 14, 1984, entitled "Supplemental Investigations and Remedial Program". Phase I Remediation Studies were conducted to compile the available remediation techniques and to evaluate the technical feasibility, environmental effectiveness, impact on site operations and associated costs of these techniques.

This report was prepared utilizing the presently available data in order to comply with the schedule of submittals developed by DuPont. The data base utilized for the preparation of these studies is presented in our Geohydrologic Investigations Report of December 23, 1983, our Manmade Passageways Investigation Report of February 17, 1984, our Geophysical Investigations Draft Report of March 15, 1984 and our Remediation Investigations via Recovery Wells Report of March 20, 1984. It is noted that additional studies are planned to further define the geohydrologic properties of the overburden and bedrock water bearing zones.

This report was originally prepared as a draft report dated March 23, 1984 to be utilized for your review and as the basis for our meeting of March 27, 1984. After receipt of your input, the report was revised as appropriate.

We sincerely appreciate the opportunity of providing these services to you on this project. If you have any questions, please contact us.

Very truly yours,

WOODWARD-CLYDE CONSULTANTS

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PHASE I REMEDIATION STUDIES
NIAGARA PLANT
NIAGARA FALLS, NEW YORK

Submitted to:

E. I. DUPONT DE NEMOURS & CO., INC.

Niagara Falls, New York

Prepared by:

WOODWARD-CLYDE CONSULTANTS

Plymouth Meeting, Pennsylvania

EXECUTIVE SUMMARY

A Phase I Remediation Study was conducted to identify and evaluate available remediation techniques that would be applicable to the DuPont Niagara Plant site. This report presents our findings as to the technical feasibility, environmental effectiveness, site specific applicability and cost effectiveness of the these alternatives. The alternatives evaluated for this study included excavation and disposal, vertical and horizontal barriers, pumping wells, drain tile collection systems, solidification, soil flushing, bioreclamation and water treatment.

Geohydrologic information used to assess the alternative techniques was obtained from the four studies previously conducted for the DuPont Niagara Plant site by Woodward-Clyde Consultants. Results of those studies indicated the location, migration direction, type and concentration of chemical contaminants at the site. It was concluded that the contamination was generally associated with plant process areas. Five general areas of the Niagara Plant site were identified and were recommended to be included in the initial remedial program. They include:

- Solvent process area B-81-84
- B-403 polyglycol area
- West Plant Maintenance area
- B-44 NaCN product area
- HCN incinerator area.

Specific conclusions regarding remediation of these five areas were developed based on results of the evaluation of the remedial alternatives as presented in Table 1. In each case, it was first recommended to remediate the source of contamination. Remediation of the source could include excavation of contaminated soils and waste, bioreclamation of contaminated soil, flushing of contaminated soils with solvents, collection by pumping wells or drain tiles and treatment of the leachate. In every case, as the source is removed groundwater quality in the vicinity will improve. The following discusses the alternative which appears most promising at this point in time. Note that all alternatives will receive additional consideration in Phase II studies.

The volatile organic plume located near the solvent process area can be mitigated using a combination of soil flushing and hydraulic barriers. A groundwater purge/recovery well or wells can be located near the intersection of Alundum and DuPont Roads. Pumping would create a hydraulic sink area in which contaminants will flow. A series of collection points can also be stationed along the Adams Avenue sewer and the contaminated groundwater collected and treated. Induced water flow from Gill Creek will serve as the solvent to flush contaminants from the soil source area. Additional leaching can be accomplished through the placement of surface slow rate irrigation lines.

Collected leachate can be treated using above ground biological activated carbon systems or liquid phase carbon adsorption systems.

The C-2 groundwater contamination located in the B-403 polyglycol area can also be remediated using a hydraulic barrier. A drain tile collection system along DuPont Road can intercept groundwater flow to the northeast. A barrier wall may be added along Adams Avenue to further prevent off-site migration, if required.

Barium contamination associated with the West Plant maintenance area will be controlled by excavating and removing highly contaminated source areas and placement of a liner/cap to mitigate further leaching of contaminants into the groundwater.

Cyanide contamination near the B-44 NaCN product area can be remediated by excavation of highly contaminated source areas or flushing soil contaminants via an injection system. Leachate produced during the flushing operation can be collected via a hydraulic system.

Cyanide contamination associated with the HCN incinerator area can be removed by excavation or limited soil flushing.

TABLE 1
REMEDIATION TECHNIQUE VS TREATMENT AREA MATRIX

	Remediation Areas in Order of Priority				
Techniques	B-81-84	B-403	West Plant Maintenance Area	B-44	HCN Incinerator
Excavation & Disposal	Possible	Possible	Practical	Practical	Practical
Passive Containment Techniques	Possible	Possible	Practical	Possible	Possible
Active Containment Techniques	Practical	Practical	Not Applicable	Not Applicable	Not Applicable
Solidification	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Flushing	Practical	Possible	Not Applicable	Possible	Possible
Bioreclamation of Contaminated Groundwater	Possible	Possible	Not Applicable	Not Applicable	Not Applicable
Conventional Treatment of Groundwater	Practical	Practical	Not Applicable	Possible	Possible

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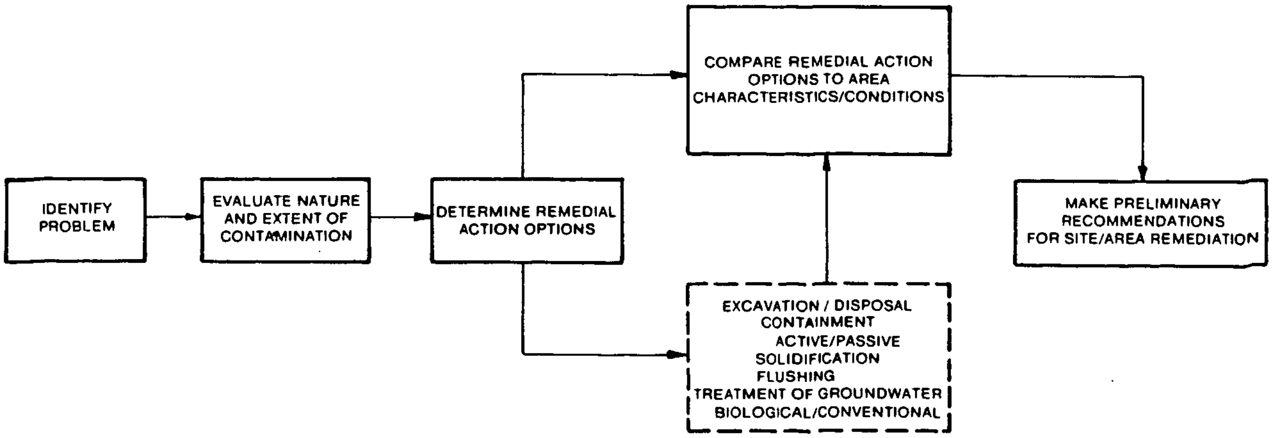
INTRODUCTION

In order to implement a remedial action program for the Niagara Plant, it is first necessary to define the overall approach and strategy for these studies. Hence, the investigatory work has been divided into two areas; (1) geohydrologic investigations and (2) remedial investigations. The geohydrologic investigations are in progress and our report of Phase I Remediation Studies is presented herein. The project strategy that has been established is to actively pursue remediation of the "source" while concurrently conducting any necessary supplemental geohydrologic investigations. The remediation investigations are, therefore, presently focused upon cleaning up the source (or sources) located within the overburden, although consideration of cleanup of the bedrock is also presented herein. Hence, at the time the remediation of the sources in the overburden is ongoing or complete, the data required to assess the need for additional remediation of the groundwater within the bedrock will be available. The following report presents our Phase I remediation studies.

The purpose of the remediation program is to remove, contain and/or neutralize the contaminant sources, such that the remediation program will function for a finite period of time. It is noted that pollutants at the site are present as both solubilized and non-aqueous phase liquids. Remediation of the bedrock will not be fully considered at this time, although the impact of the proposed source remediation upon the bedrock must be evaluated. The studies described herein were completed consistent with the phased approach to the project which initially requires remediation of the source. A remedial action selection flow chart is presented below.



PROJECT DESCRIPTION

An investigation was undertaken at the DuPont Niagara Plant site to evaluate the presence and movement of suspect chemical contaminants in the overburden and bedrock groundwater flow regimes. As described in our December 23, 1983 report, groundwater in the area of the DuPont Niagara Plant site is encountered in both the unconsolidated overburden soils and the underlying rock. The source of the groundwater recharge for the overburden in the vicinity of the Niagara Plant site is from direct infiltration of precipitation. The source of the groundwater recharge in the underlying Lockport formation is from induced infiltration from the Niagara River and to a lesser extent from leakage downward from the overlying overburden groundwater flow regime. Groundwater flow through the overlying overburden in the west plant site area (west of Gill Creek) discharges toward Gill Creek and the Niagara River and groundwater in the east Plant site area (east of Gill Creek) flows toward the northeast. By contrast, flow in the underlying fractured rock is from the Niagara River toward the Olin production wells northwest of the site and from the Niagara River toward an unidentified groundwater discharge area to the northeast of the site.

As part of the investigation, chemical analyses were performed on groundwater samples obtained from monitoring wells. Based upon field reports during well installation and groundwater sampling, as well as specific analytical results compared to solubility limits, it was concluded that non-aqueous phase fluid does exist at selected locations throughout the plant site. Further, the relative distribution of volatile compounds was compared with locations of previous processes and events on the plant site resulting in a correlation between the process/event areas and the concentrations of the individual compounds.

Potential migration of contaminants at the DuPont Niagara Plant site was evaluated during our study. Because of the presence of two liquid phases, the transport process is complex and governed by a number of factors, including groundwater flow movement and geologic structure. Based upon the data available regarding contaminant concentrations and groundwater flow direction and quantity, the total volatile organic chlorocarbon loading to the Niagara River was estimated to be approximately 100 pounds per day, with approximately 50 percent of this arriving at the Niagara River, via pumpage from the Olin production well. These data were utilized to form the basis for evaluation of remedial alternatives described herein.

EXCAVATION AND DISPOSAL

This alternative consists of excavation, transport and disposal of materials and consideration of stabilization of the cut slopes and erosion/groundwater control. Consistent with the project strategy of remediating the "source", excavation of overburden materials are of primary concern. The extent of excavation could range from a mass excavation of the plant site overburden to limited excavation of specific areas.

Since site conditions such as plant operation, building and utility line congestion preclude the use of mass excavation techniques, this section will address techniques suitable for limited area excavation. It is noted, however, that if mass excavation were feasible, the cost associated with complete removal and replacement of the plant site overburden materials would exceed $15,000,000. Dewatering and treatment of the pumped water and disposal of excavated materials in a secure landfill would be an additional cost.

LIMITED AREA EXCAVATION: Deep vertical excavation in confined areas where space is limited may be accomplished using a clam shell (crane/clam shell bucket arrangement) and/or caisson drilling rig (either crane or truck mounted auger drilling attachment) equipment. Both units can be used to excavate above and below the groundwater table. Casing or sheathing of the excavation to increase the stability of the vertical or near vertical side walls may be required. Both units can excavate a variety of soil materials. Moreover, the caisson drill rig unit can be used to a limited extent for rock excavation. Each unit is limited to relatively low production rates.

Trenching or relatively long narrow shallow excavation can be accomplished by using a backhoe or pull shovel. These units are variations of the power shovel differing in that the excavation proceeds toward rather than away from the machine. The backhoe has good mobility and is capable of excavating a variety of soils as well as broken or soft rock. The bucket size and machine capacity allow this unit to expand its capability to include excavation of relatively large confined areas. A less versatile variation of the backhoe is the Gradall. In general, this unit is limited to excavation of small quantities over large areas where production is measured in square feet rather than cubic yards. It also lacks the power and depth of reach and is used primarily for grading.

HYDRAULIC DREDGING: It is doubtful that substantial thicknesses of stream bed sediments have accumulated in Gill Creek since the 1981 clean-up which involved extensive excavation and removal of fill materials underlying the creek. However, no determination of sediment thickness has been made, nor have any sediment samples been collected for chemical analysis. If sediments are found to be contaminated in Gill Creek, hydraulic dredging for contaminated sediment removal should be considered.

To determine if hydraulic dredging is an appropriate remedial technique for use at the plant site the following factors should be evaluated: (1) quantity of sediment present and severity of sediment contamination; (2) magnitude of contaminant contribution or potential contribution to Niagara River from this source; (3) turbulence and subsequent contaminant release to the river caused by dredging operations; and (4) other remediation alternatives which could involve Gill Creek and preclude hydraulic dredging; for example, large-scale overburden removal. It is noted that should hydraulic dredging be selected as a remediation approach, the implementation of this technique would be timed such that it complements other activities/remedial techniques.

Hydraulic dredging involves the pumping of a solids/water slurry from the bed of a surface water body and typically is performed from a floating platform or barge, although a portable land-based system has application if access and coverage are not limiting factors. Because of the limited width and depth of Gill Creek, the latter method would likely be most applicable.

There are two basic types of pumping mechanisms associated with dredging operations. Centrifugal pumping systems utilize a submersible pump specially designed to chop and cut heavy, viscous materials as pump suction occurs. The other is a cutterhead pipeline system which involves a mechanical cutting assembly with suction applied from the surface. Because a portable land-based system is applicable at the site, the cutterhead pipeline system would be employed.

The sediment slurry would be pumped from the creek bottom to one or more lined settling basins equipped with underdrains. The suspended solids would settle out, and the supernatant either drained off or pumped out. Some dewatering of the sediment would also occur through flow into the underdrains. Samples of both the supernatant and fluid collected from the underdrains would be collected and analyzed to determine if these fluids should be treated as a hazardous waste. Upon completion of the dredging operation and dewatering of the accumulated sediment, these materials would be removed from the basins by conventional excavation methods for appropriate disposal.

TRANSPORTATION OF EXCAVATED MATERIALS

In general terms, transportation of excavated materials describes the movement of these materials from the source to some remote location. Over-the-road hauling uses public highways with the haul units (trucks) designed with various restrictions associated with use on public roadways such as height, weight and width. Public relations is an important consideration for over-the-road hauling. Spilling and tracking of contaminated soils off-site via hauling unit tires and undercarriage, and routing are a few of the items that need to be considered. To improve travel time, routing should avoid residential areas or areas where heavy traffic is possible. Ultimately, synchronization of the hauling and loading operation is required to optimize the productivity of the excavation system.

ANALYSIS OF EXCAVATION ALTERNATIVE

The excavation method considered most applicable for plant site remediation would be limited area excavation techniques which include the use of clam shell/caisson drill rigs for deeper vertical excavation and the hydraulic backhoe for areally larger or trench-type excavations. Although the use of this equipment is associated with low to moderate production rates, respectively, the degree of control relating to the excavated material and final disposition of those materials is good. Further, this type of equipment could also be used for any future plant site construction and in conjunction with other remedial action techniques, such as constructing slurry cutoff walls, leachate collection trenches or recovery wells. Of the available options the hydraulic backhoe is the most versatile. It is capable of excavating to depths of about 30 feet while maintaining moderate production rates. It has good mobility and good control regarding the loading of trucks. Examination of subsurface data presented in previous investigations indicates that most, if not all, of the overburden materials encountered to date at the plant site can be excavated using the backhoe.

The use of excavation as the primary remediation method may be applicable in the following areas, (1) removal of overburden containing cyanides in the vicinity of well clusters of 8 and 16 (See Plate 1), (2) removal of overburden materials containing C-2 compounds in the vicinity of well clusters 8 and 13, and (3) removal of overburden materials containing barium salts in the vicinity of utility well 10 and the west plant maintenance area. Excavation in the area near wells 8 and 16 are extremely limited due to the presence of buildings and underground utilities. In the vicinity of the well cluster 13, only a limited excavation could be attempted to remove materials contaminated with C-2 compounds. Excavation could best be accomplished using a backhoe. The excavated materials could be loaded into trucks with gasketed tail gates. The loaded trucks would travel off-site for appropriate disposal of the excavated material at a secure landfill. Control measures would be required to eliminate spillage, leakage and tracking of contaminated soils on and off the site by haul units. This would necessitate the use of wash down areas at both the source and destination points. Imported replacement fill could consist of crushed stone, shot rock or other materials that require little or no compactive effort, thus avoiding the necessity of dewatering to accomplish backfill compaction.

In the vicinity of utility well 10, the extent of barium salts contamination with depth is not well defined at this time. If the affected depth is above the groundwater table, the use of a frontend loader and/or combination of loader/bulldozer may be applicable. The use of the frontend loader/bulldozer would increase the production rate with only minimal increase in effort to prevent tracking of contaminated soil through and off-site. If the extent of contaminants is below the groundwater table the use of the backhoe would be necessary for excavation below the groundwater table. The excavated material could be hauled off-site to a secure landfill in haul units as previously described. Backfill of the excavated area below the groundwater table should consist of imported crushed stone, shot rock or other similar material that requires little or no compactive effort to achieve a stabilized area for planned future use. Above the groundwater table, backfill should consist of readily compactable materials as the area may continue to be used as the weathering area for current plant operations. This compacted material should consist of a clay material capable of limiting the vertical penetration of future possible contaminants. Alternatively, a more granular material can be used to bring the area to a site grade. Final grade would then be established to promote drainage in combination with surface sealing to inhibit downward contaminant migration. Runoff control, such as drainage ditches and collection basins would be an integral part of this alternative.

In summary, the use of land based excavation techniques appear to have limited use as a primary approach to site remediation. The backhoe would be the most versatile piece of excavation equipment and may also be used in combination with the frontend loader/bulldozer as dictated by site conditions. Limited land-based excavation techniques in the areas discussed above would likely not completely eliminate any one source of contaminants from the site area although excavation of hot spots would reduce total contaminant loading to the environment. The use of the excavation technique would most probably be used in conjunction with the installation and construction of other remedial systems.

PASSIVE CONTAINMENT TECHNIQUES

Consideration was given to the use of passive in-situ containment techniques that could be utilized at the Niagara Plant site to minimize/eliminate the off-site movement of sources of contaminants within the overburden materials. The passive in-situ containment techniques considered include the use of vertical barriers to horizontal flow and horizontal barriers to vertical flow. The passive techniques considered do not require ongoing energy input. The vertical barriers to horizontal flow considered herein include the following:

- Slurry trench cutoff walls of soil-bentonite (S/B) and cement-bentonite (C/B)

- Grout, cement and/or chemical
- Steel sheet piling
- Vibrating-beam thin cutoff walls

The horizontal barriers to vertical flow considered herein include the following:

- Grout, cement and/or chemical
- Bacteriological grouts

Each of the above barriers will be discussed with regard to the techniques and their applicability to site specific use at the Niagara Plant.

VERTICAL BARRIERS

Vertical barriers used at the site to control the movement of contaminants in the overburden would be installed in such a manner as to minimize/eliminate contaminant transport in a horizontal direction. The following paragraphs will discuss the various vertical barriers considered.

SOIL-BENTONITE: The feasibility of the soil-bentonite, (S/B), slurry trench cutoff wall must be evaluated from both a constructibility and performance perspective. The method of constructing a soil-bentonite slurry trench cutoff wall is well documented(1,2). A trench is excavated below the ground surface and trench stability is maintained by utilizing a slurry of bentonite and water. This slurry maintains the trench stability in much the same way as drilling mud maintains borehole stability and is designed to have certain density, viscosity and filtrate loss properties. Properly prepared, slurry will allow for the formation of a filter cake along the walls of the trench and thus, results in a computed factor of safety for trench stability which is greater than 1. Once the trench is excavated, it is necessary to backfill the slurry filled trench. For the plant site,

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(1) Xanthakos, P., "Slurry Walls," McGraw-Hill Book Company, New York, 1979, 622 pp.

(2) Evans, J.C., and H.Y. Fang, "Geotechnical Aspects of the Design and Construction of Waste Containment Systems," Proceed. of the 3rd Natl. Conf. on Mgmt. of-Uncontrolled Haz. Waste Sites, Washington, D.C., 1982, 175-182.

it probably will be necessary to import borrow material for use as a backfill component. The backfill typically consists of a matrix of soil material which is mixed with bentonite-water slurry and controlled on the basis of slump. Backfill is mixed to a consistency of high slump concrete, and then placed in the trench utilizing care to achieve uniform mixing of the backfill and to avoid entrapment of pockets of pure bentonite-water slurry. A schematic of excavating and backfilling procedures is shown on Plate 2.

The geotechnical and subsurface data available indicate that a S/B slurry trench cutoff wall could be constructed at the Niagara Plant site. However, excessive slurry loss could occur in areas of shot rock and possibly through unknown utility trenches. In all areas where the trench encounters old foundations, there could be excavation difficulties including excessive slurry loss. When the slurry level in the trench drops, the potential for trench instability is increased. It is concluded that construction of an S/B slurry trench cutoff wall on the site is technically feasible, provided considerations are made for potential problems as noted herein.

The behavior of the S/B slurry trench cutoff wall must be evaluated in terms of both short- and long-term performance. In the short-term, it is expected that the S/B cutoff wall would act as an effective vertical barrier to horizontal groundwater flow. It is believed that an effective S/B cutoff wall may be achieved having a net average coefficient of permeability of approximately 1×10^{-6} cm/sec, utilizing on-site and imported materials for the soil-bentonite backfill.

The long-term performance of the S/B cutoff wall must also be considered. Factors affecting the long-term performance would include the impact of the contaminants upon the performance and durability of the cutoff wall. Based upon the results of our examination of the groundwater and the water quality testing, it is concluded that the groundwater as presently characterized could be expected to alter (increase) the permeability of the completed S/B cutoff wall. It would be necessary, therefore, to document the magnitude of the permeability increase by long-term permeability tests during final design studies. It would be necessary to conduct long-term laboratory permeability tests using contaminated site groundwater as the permeant to determine the impact of the soil/water interaction upon the S/B wall integrity and the magnitude of such deterioration.

Preliminary considerations of the S/B slurry wall indicate that the barrier wall should be a minimum of 30 inches thick and have a permeability of 1 x 10^{-6} cm/sec or less. It is anticipated that the key-in for the barrier wall would be into the top of the dolomite bedrock. Final design would have to verify that these dimensions are consistent with the design concept.

The specifications for the S/B slurry wall would include slurry viscosity, slurry density, depth of trench, verticality, continuity, cleaning of the trench bottom, backfill gradation and slope of the soil-bentonite backfill. The frequency of testing for the above mentioned items should be a function of the size of the project but needs to be done at least on a daily basis. It is also important to include observation, documentation and quality assurance by a representative of the owner to determine that the end product is as specified. Testing procedures to assure the design intent of these specifications is well documented.

CEMENT-BENTONITE: The feasibility of the cement-bentonite (C/B) slurry trench cutoff wall was also considered from both a constructibility and a performance perspective. The method of constructing a cement-bentonite slurry trench is also well documented. A trench is excavated below the ground surface and trench stability is maintained by utilizing a slurry of bentonite, cement and water. This slurry maintains the trench stability in much the same manner as drilling mud maintains borehole stability. Bentonite-cement-water slurry is designed to have certain density, viscosity and filtrate loss properties. Once the trench is excavated, the cement bentonite slurry cures to form a clay-like trench backfill. Thus, there is no need to mix a specific backfill for the trench. At the end of one excavation day, the excavation continues the next day by removing a small amount of the solidified cement-bentonite backfill, thus assuring continuity of the C/B wall.

The geotechnical and subsurface data available indicate that a C/B slurry trench cutoff wall could be constructed. However, excessive slurry loss may occur in areas of shot rock and possibly through unknown utility trenches. In all areas when the trench encounters old foundations, there could be difficulties in digging and the potential for excessive loss of slurry. If the slurry level in the trench drops, the potential for trench instability is increased, but it is believed that slurry loss could be controlled.

Construction of a C/B slurry trench cutoff wall on the site is feasible, provided that special considerations are made for limited potential problem areas noted herein. It is noted that in areas where there is increased loss of slurry, additives could possibly be added that would accelerate the set of the C/B slurry and reduce the C/B loss.

The performance of the C/B slurry trench cutoff wall must also be examined in both the short- and long-term. In the short-term, it is expected that the C/B cutoff wall would act as a vertical barrier to horizontal groundwater flow. It is concluded that an effective C/B cutoff wall may be achieved having a net average coefficient of permeability of between 1 X 10^{-4} and 1 X 10^{-5} cm/sec.

The long-term performance of the C/B cutoff wall was also considered for this study. Factors affecting the long-term performance would include the impact of the contaminants upon the permeability and durability of the cutoff wall. Based upon the results of our examination of the groundwater and the water quality testing, it is concluded that the groundwater as presently characterized could significantly alter (increase) the permeability of the completed C/B cutoff wall. It would be necessary, however, to document this property change by long-term permeability tests during final design studies.

It is anticipated that the key-in for the barrier wall would be into the dolomite bedrock. Preliminary consideration of the C/B slurry wall indicates that the barrier wall should be a minimum of 30 inches thick and have a permeabilty of between 1 X 10^{-4} and 1 x 10^{-5} cm/sec or less. Final design would have to verify that these dimensions are consistent with the design concept.

The specifications for the C/B slurry wall should include slurry viscosity, slurry density, depth of trench, verticality, continuity, percent bentonite, type of cement and percent cement. The frequency of testing for the above mentioned items should be a function of the size of the project, but needs to be done at least on a daily basis. It is also important to include observation, documentation and quality assurance by a representative of the owner to determine that the end product is as specified.

GROUT: The feasibility of using a grout to construct a relatively impermeable vertical barrier to minimize/eliminate the horizontal movement of contaminants at the site was considered. The grout would be injected in holes drilled along two primary rows that would form the inner and outer limit of the grout curtain. The amount of grout injected would be controlled by the set time and viscosity of the grout utilized. The primary holes would set the limit of the barrier and the pumping of secondary or tertiary holes would be conducted to complete the wall.

The use of various types of grout would need to be evaluated to take into account the compatibility of the chemical compounds in the site groundwater with the available types of grout as these chemical compounds may inhibit the desired reactions internal to the various grout types. This would represent the reconstitution of representative samples of soil, grouting the samples under controlled laboratory conditions and the permeating of the sample with the site specific contaminants. A change in the permeability would indicate the suitability or lack of suitability of the grout with respect to the contaminants present. Further, the effect of the groundwater chemistry upon the construction properties of the grout, such as viscosity and density would also require evaluation. It is noted that it is more difficult to verify the continuity of a grout curtain than a slurry trench cutoff wall.

SHEET PILING: A steel sheet piling system would consist of steel sheet piles with interlocks. The pilings are interlocked and driven sequentially to provide a vertical barrier to horizontal flow of contaminants. The sheet piles rely on the interlock to provide for continuity and alignment. The sheet piling can be driven with either conventional air or diesel hammers or vibratory hammers. The failure of interlocks due to obstructions, boulders, shot rock, etc. could cause the sheet piling to lose its effectiveness. Further, the presence of boulders in the subsurface could limit the drivability of the sheet pile. It is concluded that steel sheet piling is not a technically feasible alternative vertical barrier.

VIBRATED BEAM SLURRY WALL: The vibrated beam slurry wall is constructed by driving a wide-flange beam to the desired depth of the containment wall and injecting a grout as the beam is being withdrawn. The grout fills the void created by driving the wide flange beam and forms the containment wall. The beam is typically driven utilizing a vibrating hammer with the beam being moved incrementally along the alignment (allowing for overlap with the preceeding drive location). This procedure is repeated for the desired plan dimension of wall.

This system has reportedly been used up to depths of 100 feet. The continuity of this system relies upon the fact that the sequential driving of the beam does not deviate significantly to cause "holes" or "windows" in the wall. This deviation could be caused by the beam being deflected by a boulder or cobble. The grout used in the system must also be compatible with the contaminants and designed so it will not be flushed out by the hydraulic gradient across the wall. It is concluded that this technique is not technically feasible for the Niagara Plant site due to the presence of boulders in the subsurface.

HORIZONTAL BARRIER

Horizontal barriers could be used at the site to control the movement of contaminants in a vertical direction below the overburden. The following sections will discuss the various horizontal barriers considered.

GROUT: The use of grout for a horizontal barrier at the site could be utilized to minimize the vertical movement of contaminants. To evaluate the usefulness of a horizontal barrier at the site, the continuity of the various zones (B,C,D, etc.) would have to be evaluated. If the continuity of a particular zone were established, a grout could be injected around the perimeter to initially close off the zone to horizontal migration. After establishing a perimeter barrier in the selected zone(s), grouting would proceed in a systematic method on a predetermined internal grid array. The continuity of such a horizontal barrier cannot be well defined. However, a series of confirmation borings can be drilled to establish a statistical degree of relative effectiveness for the horizontal barrier placed. Alternatively, pump testing could verify the barrier effectiveness. These drill holes can also be utilized to make up for deficiencies in the barrier. The grouting operation of the selected zone(s) would result in at least partial penetration in the vertical fractures present in the bedrock.

The compatibility of the grout system selected would need to be evaluated based upon the types of contaminants and concentrations that would be expected to come in contact with the barrier. Among the types of grouts that should be considered are the suspended grout and the chemical grout. The suspended grouts, which contain finely divided particulate matter suspended in water, would include cement or cement/bentonite with filler material if needed. Filler materials could include flyash and/or sand. Dry bentonite is typically mixed with water on-site at rates ranging from 5 to 25 percent by dry weight. At those ratios, the bentonite will absorb large amounts of water and form a gel. The chemical grouts behave as Newtonian fluids, which have controlled viscosity and set times. Among the chemical grouts, the most widely used are the silicate-based. The silicate-based grouts are composed of a sodium silicate base, a reactant, an accelerator and water. The concentration of sodium silicate and the accelerator in the grout would control the set/gel time, from a few seconds to many minutes. This gel time will control how far the grout would travel. Long term laboratory testing would be required to evaluate the compatibility of the chemical grout with the site groundwater.

The effectiveness of a grouting type is a function of size and quantity of the interconnected voids within the medium being grouted. Suspension grouts are generally used in sealing voids in materials with rather high permeabilities. The smallest voids that can effectively be penetrated using a suspension grout is about three times the mean size of the suspended material. Silicate based chemical grout, with no suspended material, can have various viscosities, thus can effectively flow through the treated medium similar to that of the site water. Field studies have shown that this type of chemical grout has a practical lower limit of permeating a medium to fine sand. Presented on Plate 3 is a chart showing various grout types and applicability to various soil types.

BACTERIOLOGICAL CURTAIN: Design of a horizontal barrier utilizing bacteria introduced in a life supporting medium requires essentially the same basic data used for design of the conventionally grouted horizontal barrier (see pages 31-48 for additional discussion of bioremediation). These data include, but are not limited to, continuity and permeability of the selected zone in which the bacteria are to be introduced. The basic concept of establishing a biological barrier is to introduce a bacteriologically "seeded" fluid food source into the selected zone(s) that encourages rapid proliferation of the biomass resulting in a corresponding reduction of permeability of the treated zone(s). A sensitivity study of the relationship of the biomass to the contaminants present in the treated zone(s) should be conducted to determine if such a system would produce the desired results.

The biological barrier is created by a living biomass accumulation and the short- and long-term effectiveness of the barrier must be examined and evaluated with respect to the time requirements necessary to establish the horizontal barriers. As this method is somewhat experimental in nature, quantitative data are not available to estimate its effectiveness with regard to decreasing permeability. In addition, the extent of aerial coverage can only be qualitatively evaluated. Such variables as discontinuity of the treated zone(s) and changes in the environment can adversely affect the effectiveness of this type of horizontal barrier.

The compatibility of the bacteria with the contaminants present would need to be studied. The expected life of the horizontal barrier with regard to the available food supply and the potential for reintroducing a life supporting medium at a later date to keep the bacteria barrier present would also need investigation. The length of time that the barrier would be effective is partly dependent on the time until deterioration of the bacterial carcasses impeding flow.

APPLICABILITY OF PASSIVE CONTAINMENT TECHNIQUES

The applicability of passive containment techniques to the Niagara Plant site will be discussed in the following subsections.

VERTICAL WALLS: The use of S/B slurry walls at the Niagara Plant site will probably be effective in the areas when the material at the site are predominately natural or fill soil. The use of the slurry wall (S/B) in areas of shot rock may be very difficult due to the loss of fluid (slurry) into the surrounding high permeability materials. The use of the slurry wall (S/B) would also require considerable area for mixing of backfill and disposal of the excavated material. It is most probable that the excavated material would be disposed of concurrent with the arrival and mixing of imported material for backfill. The compatibility of the slurry wall (S/B) needs to be evaluated with the groundwater contaminants to see the effect on the permeability with regard to the contaminants.

The use of a C/B slurry wall at the plant site would probably be effective in most areas of the site. However the permeability of the C/B wall will likely be approximately 10^{-5} cm/sec and the compatibility of the C/B with contaminant would need to be studied with regard to permeability. Further, it must be determined whether or not the C/B wall will "set" in the chemical environment that exists. It is possible that if the C/B wall goes through areas of high permeability (shot rock), it will be necessary to add accelerators to the C/B mix to control the rate of loss of the fluid during excavation. Moreover, those portions of the wall may require re-excavation. Alternatively a bulk filler material such as flyash may be added to the C/B mix to reduce the rate of loss of C/B fluid. A third alternative utilizing chemical grout with short setting time as an admix to the C/B mix may decrease the rate of C/B fluid loss.

The use of grout at the plant site for a vertical barrier will probably not be very effective in the overburden materials. The control of the grout to create a relatively impervious barrier will be difficult due to the hetergeneous nature of the overburden material.

The use of steel sheet piling at the plant site for a vertical barrier will probably not be technically feasible. The overburden through which the sheet piling would be driven is so variable that the interlocks would probably not stay engaged, resulting in the creation of windows that would increase the permeability. The interlocks themselves are not water tight and would leak until effectively sealed by soil fines transported by fluid flow through the wall, or unless the interlocks were grouted shut. Further, no assurance of sheet pile drivability can be made.

The use of a vibrated beam slurry wall is considered to be technically not feasible. Problems of not being able to fill the void created by the beam in very porous material would be expected. There is also the probability that continuity cannot be maintained due to obstructions encountered by the driven beam. Further, it is likely that full penetration of the beam could not be obtained.

In conclusion, it is viewed that the slurry wall (C/B or S/B) would be the most attractive alternative for a vertical barrier to horizontal flow. The potential application locations are described in a subsequent section of this report.

HORIZONTAL WALLS: The effectiveness of a grouted horizontal barrier in the bedrock to contain contaminants on site is difficult to assess. With the fractures in both the horizontal and vertical orientation, it will be necessary to do extensive grouting and testing to show that an effective barrier has been achieved. Due to the more experimental nature of biologically induced barriers it is not recommended for use at the site as a primary method of containment. However, a field pilot study may be conducted to determine its applicability for use over a limited area. Horizontal barriers as the primary means of containment are not considered to be appropriate. However, the use of horizontal barriers in conjunction with an active system may be a viable approach and will be subsequently discussed.

ACTIVE CONTAINMENT TECHNIQUES

The purpose of active containment techniques is to establish a hydraulic barrier which control the migration of groundwater and isolates contaminated groundwater from the regional groundwater flow regime. Hydraulic barriers can be formed by the purging of groundwater from or the injection of water into the formation. Pumping from the groundwater regime results in the development of a depression in the water table and subsequent flow toward the purge location. Injection of water into the groundwater regime results in the development of a mound in the water table and subsequent flow away from the injection location. Both methods will result in the development of a groundwater divide which isolates an area of the groundwater regime.

The design of a hydraulic barrier can incorporate the application of pumping wells, tile drains or seepage basins. These systems can be used individually or in conjunction with one another. At the plant site, the use of pumping wells and/or tile drain type systems are considered applicable. Hydraulic barriers are typically installed in the up gradient and/or down gradient area of the groundwater regime. Hydraulic barriers in the up gradient area are installed to prevent the influx of uncontaminated groundwater into the contaminated area. Hydraulic barriers in the down gradient areas of the groundwater regime are installed to prevent the further migration of contaminated groundwater.

The overburden groundwater in the plant site is divided into the west and east plant site areas, which are separated by Gill Creek. In the west plant area, the Niagara River, Gill Creek and the west boundary of the site are essentially in the down gradient directions. In the east plant area, the Niagara River and Gill Creek form the up gradient boundaries and the north and east plant perimeter form the down gradient boundaries. The flow in the overburden is shown on Plate 4. Localized deviation of the general hydraulic gradient contours occur near utility lines.

PUMPING WELLS

The principle hydraulic information for the overburden that is necessary for the design of an effective barrier includes:

- hydraulic conductivity,
- thickness of the sediments,
- variations in lithology that control groundwater flow,
- location of utilities that influence groundwater flow,
- hydraulic connection with groundwater recharge boundaries, such as the Niagara River and Gill Creek, and
- the hydraulic connection between the overburden and bedrock groundwater regimes.

The design of a hydraulic barrier would incorporate the aformentioned criteria so that the pumping wells are located such that the radius of influence of each well overlap. The overlapping influence results in an effective barrier to groundwater flow across the line of wells. In the plant site, the location of a hydraulic barrier in the down gradient areas, previously discussed, would result in the containment of contaminated groundwater on-site. However, downward vertical leakage of water to the bedrock groundwater regime could occur, depending upon the head differences between the A- and the B-Zones.

The application of a pumping/injection well hydraulic barrier is limited by several factors including:

- the number of wells necessary to form the barrier,
- the constraints placed upon the location by plant activities, of the wells and ancillary plumbing,

- the volume of water injected or that would be pumped and treated, and
- the cost and maintenance of the system.

For example, the number of wells (pumping or injection) is partially a function of the overburden permeability. In areas characterized by low permeability, more wells would be necessary pumping at low volumes while in areas characterized by high permeabilities, fewer wells pumping at higher rates would be necessary. In addition, a hydraulic barrier created by pumping would not prevent downward vertical migration of groundwater unless the hydraulic potential (head) in the overburden was lower than that of the underlying bedrock; thus resulting in an induced upward hydraulic gradient in the overburden groundwater regime. Use of an injection scheme to create a hydraulic barrier would locally increase the downward migration of groundwater.

The advantages of a hydraulic barrier include:

- ability to contain the off-site migration of contaminants in the overburden,
- purged groundwater can be used in conjunction with a treatment scheme to remove contaminants,
- ability to contain highly contaminated groundwater, and
- ability of the system to be incorporated with a flushing/treatment scheme to expedite the time required to remediate the overburden.

Note, the second and fourth items will be discussed further in subsequent sections.

The effectiveness of a hydraulic barrier can be enhanced by the incorporation of other remediation techniques, such as physical containment barriers discussed earlier. In the plant site area, low permeability physical barriers in selected areas would limit the volume of pumpage required, while infiltration from sewer lines increases the pumpage volume. Creating a horizontal barrier by grouting or other technique in the upper section of bedrock would reduce vertical leakage and the potential for migration of contaminants, particularly non-aqueous phase liquids.

DRAIN TILE COLLECTION SYSTEMS

The objective of a drain tile collection system is to lower the groundwater level along a line. The drain tile acts as a line sink. Tile drains can be constructed using standard construction techniques or existing utilities may be used if they can be demonstrated or altered to act as a line sink. Many of the limitations, advantages and disadvantages of a drain tile system are similar to those of pumping wells. Others are listed below.

Advantages of a drain tile system include:

- accessibility to the overburden along its entire length,
- reduced maintenance and operation cost,
- interception of perched water zones,
- reduced ancillary plumbing, and
- greater efficiency in collection of non-aqueous phase liquid.

Disadvantages of the drain tile system include:

- interference of active plant process during placement of drain,
- cannot be selectively pumped to collect groundwater from specific areas that are contaminated to a greater degree.

The purge well drain tile collection system remediation can be enhanced by the use of injection wells.

Advantages of injection wells include:

- flushing of solublized contaminants from overburden,
- increased mobilization of non-aqueous phase liquids for purge well collection,
- maximization of flushing rate, and
- use in conjunction with either purge wells or tile drains.

Disadvantages of injection wells include:

- lack of directional control,
- increased vertical hydraulic potential (head) between the overburden and bedrock, and
- additional construction/maintenance cost.

In summary, the collection of contaminated groundwater can be performed using purge wells and a drain tile collection system. These systems can be designed in conjunction with physical barriers to reduce pumpage and to establish a hydraulic barrier to prevent the further migration of contaminants. The removal of groundwater for treatment can be accomplished in conjunction with the formation of a hydraulic barrier. The specific areas where hydraulic controls are considered to be appropriate are discussed in a subsequent section of this report.

APPLICABILITY OF ACTIVE CONTAINMENT TECHNIQUES

Active containment techniques can be utilized either singularly or in conjunction with other remediation techniques. For example, a pumping and collection system (i.e., pump/well and drain tile) would become an integral part of any soil flushing scheme. The applicability of active containment systems to specific areas is discussed below.

In the Solvent Process Area, the manmade passageway along Adams Avenue may be used as a collection system. If it is determined that this system is not inducing a sufficient gradient, then a drain tile system may be required to enhance contaminant migration. In conjunction with this collection system, a series of pumping locations (i.e. manholes) could be constructed to facilitate transport of the contaminated groundwater for treatment. In addition a groundwater purge well can be located near the intersection of Alundum and DuPont Roads to prevent further contamination of Gill Creek.

In the B-403 polyglyco area, contaminant migration can be controlled by constructing a drain tile collection system along DuPont Road. To be an effective interceptor, the invert of this tile drain system would have to extend into the underlying rock. Again, several pumping locations (i.e. manholes) can be constructed along this system to facilitate transport of the contaminated groundwater for treatment. The number and location of these pumping manholes will be determined as part of the Phase II study.

For both the B-44 NaCN product area and the HCN incinerator area, a soil flushing scheme could be implemented. In the case of the B-44 NaCN product area, the manmade passageway along Adams Avenue alone or in conjunction with a drain tile could serve as the collection system. Most contaminants bypassing this collection system will ultimately be intercepted by the cone of depression formed by the Olin production well.

For the HCN incinerator area, the hydraulic conductivity of the overburden materials in this area must first be determined before implementing any hydraulic techniques, thus other alternatives will need to be considered.

SOLIDIFICATION AND SOIL FLUSHING

In this section, two remediation techniques will be described; solidification and soil flushing. These techniques involve detoxification of a contaminated solid, semi-solid or liquid material. At the DuPont Niagara Plant site, these remediation techniques would be applied to areas of the site identified as containing high concentrations of soil and groundwater contamination. These techniques might include, but would not be limited to, cleanup of soils and/or groundwater at the following areas:

- DuPont related volatile organic contamination at the B-81-84 solvent (trichloroethylene, tetrachloroethylene) processes area (well cluster 14) and B-64 solvent (methylene chloride and chloroform) area (well cluster 15)

- Cyanide contamination near the HCN incinerator (well cluster 8) and B-44 NaCN product building (well cluster 16).

- Barium contamination near the former Cyanide weathering area (well clusters 4 and 6 and utility well 10)

- Copper contamination near the cyanide weathering area (well clusters 4 and 6) and B-107 landfill (well cluster 1).

Contaminated soils are presently being leached by precipitation events at the site which contribute to contamination of the groundwater flow system. Therefore, remediation techniques which directly address the soil contamination also indirectly improve the groundwater quality by detoxifying this continual source.

SOLIDIFICATION

Solidification, stabilization, chemical fixation and/or encapsulation are all terms that are used to describe the remedial technique which combines a waste material (often a liquid or semi-solid) with another substance to chemically and/or physically bind the waste to limit the solubility and toxicity, and improve handling and physical characteristics. Solidification and stabilization are two terms often used interchangeably. However, solidification usually implies that the resultant waste has been physically manipulated to render a harmless end product, while in the case of stabilization the end product may be physically unchanged. Chemical fixation is a somewhat outdated term that describes the process whereby chemicals are applied to a hazardous material to destroy or stabilize the waste. Encapsulation, often referred to as surface encapsulation, involves the physical enclosure of a waste material with an impermeable "jacket" that will prevent leaching of toxic contaminants.

Solidification techniques are typically categorized by the type of fixation material that is added to the waste material during the solidification process. These categories include the following:

- cement-based processes,

- pozzolanic processes (lime),

- thermoplastic techniques,
- organic polymer techniques,
- surface encapsulation techniques (jacketing),
- self-cementing techniques,
- glassification.

In the cement-based processes, Portland cement is mixed with the waste to produce a solid consisting of a dense calcium-silicate matrix composed of thin, interfaced fibrals. This technique is particularly well suited for waste containing metals. Addition of the cement creates a high pH which then converts many metals to insoluable hydroxides or carbonates. However, certain types of wastes such as salts of zinc, copper, lead, maganese, and tin; organic materials; and silt, clay or lignite may act to delay the setting and curing times. The costs of these technologies are generally low, as compared to other solidification processes, but the final volume of the product can be high.

Pozzolanic or lime-base processes are techniques which utilize the reaction of lime with fine grain siliceous material and water. The end product is similar to that produced by the cement-based process (i.e. concrete-like solid). This technique is typically used to solidify wastes at a plant which produces flyash which can then be used as the siliceous additive. Wastes to be solidified by this technique must be stable at a high pH. The advantages and disadvantages of this technique are similar to those listed above for cement-based techniques.

Thermoplastic solidification of wastes was first developed for disposal of radioactive material. In processing such wastes, the waste is dried, heated and then mixed with asphalt using a twin screw extruder. Volume reductions, desireable in nuclear wastes processing, were achieved by drying the waste. This type of treatment is characterized by high machinery cost, low throughput rates, compatability with a wide range of waste types and ease of operation cleanup. However, thermoplastic solidification cannot be used with organic solvents, iron and alluminum salts, strong oxidizers, anhydrous salts and wastes that are susceptable to alteration by heat.

Organic polymer solidification is accomplished by adding polymers along with a catalyst to the waste material which results in the formation of a solid mass. Urea-formaldehyde, vinyl ester-styrene and polyester are organic polymers that are typically used. Again this technique requires special equipment due to the very corrosive nature of the catalyst.

In the surface encapsulation technique, an impervious jacket of polyethylene or thermoplastic is molded around the waste. The wastes most often encapsulated are dewatered waste sludges, corroded or damaged containerized wastes or solidified hazardous wastes. Advantages of this alternative are that wastes are impervious to both physical and chemical destruction. However this technique is not feasible for large volumes of wastes because of the high costs and energy requirements associated with this technique.

Wastes that are typically utilized in the self-cementing solidification technique are flue gas cleaning or desulfurization sludges that contain a large amount of calcium sulfate or sulfite. This process is similar to the cement-based solidification process described above. A small portion of the waste material, approximately 8 to 10% by weight, are calcined to form a cement. This product is then reintroduced into the waste sludge along with materials to adjust the moisture content, such as flyash. This technique is limited to sludges with high sulfate or sulfite contents.

The glassification technique involves combining the waste material with molten glass at temperatures exceeding 1350° centigrade. The material is then cooled, which results in a solid stable mass. This technique is very expensive and has not been applied to non-radioactive wastes at the present time.

The wastes which are the best candidates for solidification are wastes occuring in aqueous solution or suspension, or sludges that contain high concentrations of heavy metals or inorganic salts. In general, these wastes do not exist at the Niagara Plant site. In the areas previously mentioned, contaminated soils containing free liquid (groundwater) could theoretically be removed, stabilized or encapsulated, and placed back into the ground. However, this does not appear to be a cost effective alternative. It is therefore concluded that the solidification processes described herein have little applicability for the remediation of the Niagara Plant site.

SOIL FLUSHING

Soil flushing (solution mining) is a remedial technique which involves solubilizing waste constituents from a contaminated medium and collecting and treating the leachate. The most common example of this technique is the application of water, the solvent, to a contaminated soil area via injection wells, subsurface injection lines, leaching basin or an above ground sprinkler system, and then collecting the resultant leachate via groundwater purge wells, french or tile drains or collection trenches and sumps. Basically, this remedial method changes the hazardous waste from a solid waste (i.e. contaminated soil) into a liquid waste (i.e. collected leachate). The cost of treating the wastewater plus the cost of associated introduction and collection vehicles, (i.e. wells, trenches etc.) is likely less than the cost of treating the solid waste by excavation or solidification and therefore this method is a viable alternative to be further considered herein for site remediation.

Although water is the solvent most often utilized, solutions containing acids (sulfuric, nitric, phosphoric, hydrochloric and carbonic) can be used to disolve basic metal salts (hydroxides, oxides and carbonates). In addition, sodium hydroxide may be used to disolve certain metals, organic sulfur compounds and phenols. Surfactants (detergents) have also been widely used to disolve oil and grease from petroleum refinery sludges.

Complexing and chelating agents (i.e. ammonia, nitric acid, EDTA) can be added to a solution to elutriate heavy metals. Metallic ions (usually iron, copper, manganese and zinc) that are bound to soil particles, will combine with these agents which then can be removed with collection of the leachate. All the above described solvents have specific applicability. Introduction of the incorrect solvent could result in a leachate that is more toxic or hazardous than the initial waste material. Each contaminant to potentially be eluted and solvents potentially to be applied have to be assessed on a case by case basis to ascertain the characteristics of the resultant leachate.

Due to the wide range of known and possibly unknown chemical compounds located in the soils at the Niagara Plant site, evaluation of all potential combinations of chemical compounds, solvents and resultant leachate would be a formidable task. The obvious alternative would be to select water as the solvent. Surfactants could also be added at a later time and after the appropriate studies. A natural leaching system is already on-going at the site (i.e. rainfall flushing contaminated soils). In addition, sampling and water quality analyses of the monitoring wells provide a record of what type of resultant leachate can be expected from a soil flushing system.

Before a soil flushing system is implemented, it is important to realize that some of the waste constituents will not be readily solubilized into the water. These compounds can generally be grouped as the non-aqueous phase liquids and contaminants that are strongly adsorbed to soil surfaces. At the beginning of the soil flushing program organic compounds and other compounds "loosely" adsorbed to soil surfaces will be flushed from the soils and be removed during collection of the leachate. Initially this will result in higher contaminant concentrations in the groundwater. After flushing is continued for a period of time, desorption processes will reach an equilibrium and the contaminant concentrations in the groundwater will begin to decline. At this point, the non-aqueous phase liquids will begin to disolve into the groundwater system because of the newly established concentration gradient. Removal of contaminants that are tightly bound to soil surfaces will not be accomplished by a flushing system. However, because of their strong adsorption, they likewise would not be expected to affect groundwater quality.

There are several advantages to utilizing a soil flushing system. In general, the cost of flushing, collecting and treating the leachate is lower than most other source remediation techniques, such as excavation. In addition, excavation of hazardous waste soils can create health and safety hazards.

As a disadvantage, soil flushing will initially increase the contaminant concentrations in the groundwater and increase the volume of wastewater that has to be treated. In addition, it is critical that all the leachate be collected and treated, to prohibit introduction of contaminants into other areas resulting from such conditions as downward vertical migration.

Before a soil flushing system is implemented several laboratory and field testing techniques can be employed to assess the suitability of the site soils and associated contaminants to the soil flushing technique. The laboratory techniques include batch testing and soil column studies, and the field tests include vertical permeability and infiltration tests.

SOIL BATCH TESTS: Soil batch or adsorption tests are similar to the soil column tests (discussed in the subsequent section) as they measure the ability of specific chemicals to be desorbed from soil particles. In soil batch tests, uncontaminated soils similar to those to be flushed are spiked with predetermined concentrations of chemicals. Each soil sample (approximately 10 grams) is placed in a centrifuge tube along with a measured quantity of deionized water. The tubes are shaken for approximately 8 hours, and then centrifuged for one hour. The resultant liquid is analyzed for the chemical compounds of interest and discarded. Each tube is then refilled with deionized water and the procedure repeated. Desorption isotherms can then be developed indicating the quantity of water needed to flush chemicals from the soil particles. This technique is utilized when a quick general flushing evaluation is needed. Soil column testing is preferable because centrifuging of the soil samples does not closely model the field soil flushing remedial system.

SOIL COLUMN STUDIES: Soil column or laboratory leaching studies are conducted to evaluate the feasibility of utilizing a flushing system at a particular site. Contaminants, such as those found at the Niagara Plant Site, are adsorbed onto soil particle surfaces and are dissolved in water that is tightly held within small soil pores. Introduction of large quantities of water (or treated groundwater) would serve to hasten the ongoing slow percolation of contaminants through the soil profile. A simulation of the flushing process can be performed in the laboratory, by allowing deionized water to flow through columns of soil. In this artificial situation, the time (extrapolated from water volume) needed to desorb the majority of the contaminants from the soil surfaces can be measured.

Basically, the leaching study is performed by collecting several soil samples (using split spoon or shelby tube samplers) that are representative of the proposed leaching area. A portion of the sample is retained for physical testing (grain size analyses, porosity), a portion is placed into sample containers for "before testing" analyses, and the remainder of the sample is packed into glass columns. A typical leaching study laboratory configuation is shown on Plate 5.

Deionized water is introduced at the soil surface and leachate collected at the bottom. The leachate volume is measured and recorded. From this data, pore volumes (i.e. volume of the soil column occupied by soil pores) and flow rates can be determined. Leachate samples are collected at predetermined pore volumes. These leachate samples are analyzed for chemical compounds of interest (i.e. the compounds which are to be flushed from the soil during the remedial program). The number of pore volumes passed through the soil column can be directly related to equivalent years of leaching. This calculation is based on the known volume of contaminated soil to be flushed, the measured porosity and the flushing rate (gallons per minute).

As pore volume samples are collected and analyzed results can be plotted to indicate when the flushing process will be completed (See Plate 6). In addition, at the completion of the leaching study, leached column soils are analyzed to assess the quantity of residual contamination remaining on soil particles.

FIELD TESTING: In addition to obtaining information about the chemical desorptive mechanisms of the contaminated soil, it is important to assess the physical hydraulic constraints of the proposed flushing system. This usually involves conducting field vertical permeability, infiltration or pump tests.

There are several techniques that are commonly used to measure infiltration/vertical permeability. All the tests involve introducing water to the soil area and measuring the time it takes to infiltrate into the soil. These tests include 1) flooding basins, 2) double ring infiltrometer, 3) sprinkler infiltrometers, 4) air entry permeameters, and 5) pump-in tests. The type of test program implemented would depend on the type of vehicle to be used for introduction and collection in the flushing system.

The results of the infiltration permeability tests are typically plotted on a graph with infiltration/permeability rate (inches/hour) versus time (hours). This curve will drop sharply at the beginning of the test, and flatten out after an equilibrium condition is reached. This equilibrium rate is then used to calculate hydraulic loading of the system. Because of the wide variety of soil textural types located at the site, it would be essential that field testing of this type be conducted prior to final recommendation of soil flushing as an alternative.

In summary, the use of soil flushing technology (in conjunction with hydraulic controls) appear to be a technically feasible and environmentally attractive alternative. Further, it appears that the use of water will provide the most economical environmentally sound solvent for soil flushing.

BIORECLAMATION OF CONTAMINATED GROUNDWATER

Presented in this section is a discussion of the feasibility of using biological techniques for remediation of contaminated groundwater contained in the overburden material (A-Zone). The major potential advantages of bioreclamation are that it is comparatively inexpensive as compared to other reclamation techniques and it converts hazardous materials to nontoxic end products. The key is to determine if the organics are degradable and if potential toxicants are present at adversely high levels.

REQUIREMENTS FOR BACTERIAL GROWTH

Before directly assessing the feasibility of biological reclamation of the contaminated groundwater, it is useful to develop a "checklist" of requirements for bacterial growth that will provide the framework for the evaluation. If existing conditions meet or can be made to meet these requirements, bioreclamation will be technically feasible.

CARBON AND ENERGY SOURCE: There must be a biodegradable organic compound present to sustain bacterial growth. The pollutant itself may be biodegradable and serve as the carbon and energy sources. Pollutants may also be transformed to nontoxic end products by processes called secondary utilization and cometabolism. Here, another organic serves as the primary energy source for growth while pollutants are transformed without contributing significantly to bacterial energy production or growth. The primary energy source may already be present in the contaminated water or it may need to be added.

In general, contaminants must be dissolved in the water for bacteria to accomplish biotransformation. However, this does not mean that so-called "non-aqueous phase liquid" contaminants cannot be degraded. As long as there is an aqueous-second phase interface, bacteria can act on the second-phase materials dissolved in the water. Since solubility in water is an equilibrium, as non-aqueous phase liquid contaminants are removed from aqueous solution by bacteria, more of the non-aqueous phase liquid dissolves in water and the reaction continues. It has been shown that biotransformation rates can be increased by increasing the interfacial area between the non-aqueous phase liquid and water.

ELECTRON ACCEPTOR (NATURE OF THE ENVIRONMENT): The importance of the electron acceptor is manifested by the difference in susceptibility of pollutants to biotransformation (conversions to end products) in different environments. In aerobic environments, oxygen is the electron acceptor, in anoxic environments it is nitrate, and in anaerobic environments carbon dioxide or reduced organics (mostly acetic acid) serve as electron acceptors. For example, most chlorinated benzenes are degradable aerobically but not under anoxic or anaerobic conditions. Some chlorinated aliphatics (like chloroform) are degradable anaerobically but not aerobically. At the present time, very few hazardous pollutants have been shown to be degradable under anoxic conditions. Thus it is imperative to know the nature of the electron acceptor to determine if bioreclamation is feasible.

If oxygen is to be the electron acceptor, it will have to be added either above or below ground. Aeration can be a significant operational expense. To maximize hazardous pollutant biotransformation, it is recommended that nitrate not serve as the electron acceptor. It may be beneficial to create an anaerobic environment to enhance bioreclamation. This will be discussed in more detail in a subsequent section.

MACRONUTRIENTS: There must be sufficient nitrogen, phosphorus, and sulfur (anaerobic requirement for sulfur is greater than aerobic requirement) to insure these nutrients do not limit biotransformation of pollutants. Nitrogen can be present as ammonia, nitrite, nitrate, or some forms of organic nitrogen (e.g., amino acids). Phosphorus is generally needed as orthophosphate, with sulfur as sulfate for aerobic environments and sulfide for anaerobic environments. Analysis of contaminated A-Zone water for these substances is required; at this time it is not known if the groundwater contains sufficient levels of these nutrients. If they are not present in sufficient quantity (5-10 mg/l range, typically), they must be added for bioreclamation to be feasible.

MICRONUTRIENTS: Trace metals (potassium, iron, molybdenum, zinc, etc.) are the major concern here and are needed in the 0.01 to 5 mg/l range. These nutrients should be present in sufficient quantities, although addition of iron (and nickel, if anaerobic) may prove helpful. While some trace organics (amino acids, vitamins) may be beneficial, they very rarely need to be added.

PROPER pH: As long as pH is in the range of 6.5 to 8.5, biological activity won't be significantly affected. Since total organic levels are reasonably low, a moderate level of alkalinity (25-75 mg/l as $CaCO_3$) should provide sufficient protection against pH decreases.

TEMPERATURE: Biological reaction rates increase with increasing temperature. Temperature may be very critical for anaerobic environments: 30-35°C is generally considered to be optimal. However, anaerobic biotransformations will take place at 15-25°C providing sufficent time is provided. Aerobic biotransformations will not be temperature-limited as long as the termperature is 20°C or greater. Biotransformations will occur at lower temperatures, but more time will be required.

ABSENCE OF TOXIC MATERIALS: Whether a material is toxic or not is a function of the nature of the material, its concentration, and the ability of microorganisms to acclimate to its presence. The keys to acclimation are providing a proper mix of bacteria and sufficient time for the bacteria to acclimate. Organic pollutants that are initially toxic may become primary carbon and energy sources or secondary substrates given sufficient time - usually called lag time. Other pollutants such as heavy metals cannot serve as food sources but bacteria can acclimate to reasonably high concentrations (greater than 100 mg/l) under the right conditions.

An additional concern is the effect of combinations of various toxicants. Combinations can be synergistic (worse than summed individual effects) or antagonistic (less severe than summed individual effects). Since the number of combinations is infinite, possible synergism or antagonism must be evaluated on a case-by-case basis.

ADEQUATE CONTACT: To ensure efficient biotransformation, there must be efficient and adequate contact between the contaminated water and the bacteria.

With above-ground treatment, this means sufficient mixing with suspended-growth reactors (water and bacteria homogeneously mixed) and uniform flow distribution with attached-growth reactors (bacteria attached to some surface). With below-ground treatement, adequate contact is much less straightforward. Either bacteria, contaminants, and nutrients must be uniformly distributed throughout the subsurface using a series of injection wells, or contaminated water must be "forced" to uniformly flow through (presumably by pumping) a zone (e.g., a trench) containing the bacteria. Obviously, control of biotransformation is much easier with above-ground methods; however, below-ground methods may be cheaper if uniform contact can be created.

SUFFICIENT TIME: Perhaps the most important key to efficient bioreclamation is providing adequate time for the bacteria to effect the biotransformation. Specifically, sufficient bacterial retention time (SRT) (to be distinguished from liquid or hydraulic retention time (HRT)) is required. Pollutant removal rate can be expressed as the mass of pollutant removed per day per mass of bacteria. The larger the bacterial mass, the greater the biotransformation rate. In addition, keeping the bacteria around longer maximizes the potential for acclimation to resistant organics and potential toxicants. Thus, the take-home message for bioreclamation of contaminated groundwaters is to keep all the bacteria you grow.

With above-ground treatment, SRT is provided by tank volume and biomass recycle via sedimentation, in suspended-growth reactors and by attachment to surfaces in attached-growth reactors. The key to economic biotransformation is providing large SRT's (high efficiency) at low HRT's (capital cost). Attached-growth systems offer significant advantages here.

In-situ treatment offers the potential of the long SRT values needed for acclimation and efficient biotransformation. Since the soil provides the surface, attached growth will occur. The main problem here would be ensuring adequate contact as described above.

With the above-described "checklist" as a basis, the feasibility of bioreclamation can be evaluated once the nature of the contaminants is known.

COMPOUNDS PRESENT

In order to determine the applicability of bioreclamation it is imperative to know the nature and concentrations of the contaminants present. A comprehensive testing program was conducted at the Niagara Plant site and results were presented in detail in the December 23, 1983 report. Relevant data will be summarized here.

A complete analysis for priority pollutants was conducted. Many compounds were detected; however, for purposes of determining the feasibility of bioreclamation, only those present in significant concentrations need to be reviewed. After initial sampling was completed, it was decided to monitor in detail only those contaminants present in the highest concentrations. These were, for the most part, volatile, chorinated organics, BHC's, PCB's, and selected heavy metals. Total organic carbon (TOC) and total dissolved solids were also measured.

The volatile organics of interest (also called "indicator" organics) are:

Chloroform (CF - $CHCl_3$)

Trans 1,2-dichloroethylene (DCE - $C_2H_2Cl_2$)

Methylene Chloride (MC - CH_2Cl_2)

1,1,2,2-Tetrachloroethane (TECEA - $C_2H_2Cl_4$)

Tetrachloroethylene (TECE - C_2Cl_4)

Trichloroethylene (TCE - C_2HCl_3)

Vinyl Chloride (VC - C_2H_3Cl)

Benzene (B - C_6H_6)

Chlorobenzene (CB - C_6H_5Cl)

In order to get an idea of the contribution of these organics, it is useful to compare the measure total organic carbon (TOC) with the organic carbon contained in these nine organics. This can be done by multiplying the measured concentration of the organic by the fraction of carbon contained in the organic. For example, chloroform (CF) contains 10 percent carbon (12/(12+1+3(35.5))). If the measured concentration of chlorofrom is 100 mg/l, the organic carbon content of that chloroform is 10 mg/l. This calculated organic carbon contribution can then be summed for the nine organics as follows:

$$\begin{aligned} \mathrm{SUM} = {} & f_1\mathrm{CF} + f_2\mathrm{DCE} + f_3\mathrm{MC} + f_4\mathrm{TECEA} + f_5\mathrm{TECE} + f_6\mathrm{TCE} \\ & + f_7\mathrm{VC} + f_8\mathrm{B} + f_9\mathrm{CB} \end{aligned}$$

where f_1 is the fraction of carbon in CF, f_2 is the fraction of carbon in DCE, and so on.

Comparison of SUM with measured TOC will indicate not only the fraction of TOC represented by these nine contaminants, but also the availability of other organics as sources of carbon and energy for bacterial growth (TOC - SUM). Also, the higher SUM, the more severe the contamination. These data are presented in Table 2 for all the A-Zone wells for June, July, September, and October, 1983 samplings.

It is evident that there is a wide range of contamination from the nine contaminants at the various wells; SUM varied from a high of 165.4 mg/l at Well 21 in June to lows of 0 mg/l at Wells 7 and 17 for July, September, and October. TOC values varied from a high of 720 mg/l, typical of a medium-strength industrial waste, at Well 8 in July to 4.5 mg/l, typical of a moderately polluted river, at Wells 12 and 17 in October. Comparison of SUM and TOC showed that in some cases the nine contaminants made up almost all (and in some cases, more than all, due to possible analytical error) of the TOC. Examples of this are: Well 1 in June, July, and October and Wells 13 and 14 for all three months. In other cases the TOC was much greater than SUM (e.g., Wells 8, 9, and 16 for all three months).

Consider the following general, arbitrary characterizations of the contamination:

SUM greater than 5 is HIGH TOC greater than 30 is HIGH

SUM = 0.1 - 5 is MODERATE TOC = 5 - 30 is MODERATE
SUM less than 0.1 is LOW TOC less than 5 is LOW

Using these categories and recognizing that a total of 59 samples were taken from A-Zone wells during the four-month period, 34% had HIGH SUMs, 33% were MODERATE and 33% were LOW. There were 33% HIGH TOC's, while 62% were MODERATE and 5% were LOW.

The relevance of this data to bioreclamation is that high SUMs may be toxic and will require significant acclimation (lag) times. LOW TOC's will support very little, if any, biological growth if this material is to serve as a primary energy source for secondary utilization of SUM compounds and other organic contaminants present in lower concentrations. MODERATE to HIGH TOC's are required to support the substantial bacterial growth required for secondary utilization of SUM contaminants. Of course, some SUM contaminants may be used as primary energy sources given sufficient acclimation time. Thus, to a certain degree SUM and TOC may have to be matched and mixed, or an exogenous primary substrate (e.g., glucose or acetate) may have to be added, increasing the operational cost of bioreclamation.

Table 3 lists other compounds that have been detected at levels above 10 ppb in A-Zone wells along with the range of concentrations measured. Many of these compounds are biodegradable, strippable, or adsorbable and as such are not expected to cause major problems with bioreclamation. The main concern is the degradability of the nine contaminants described above.

Other components of potential significance include BHC's, PCB's, heavy metals, and cyanides. Examination of the data presented in the December 23, 1983 report show that the BHC's, PCB's, and heavy metals are never present in concentrations high enough to cause a significant effect on biological activity. It is even possible that the BHC's and PCB's can be biotransformed through secondary utilization provided an acclimated culture can be developed.

Cyanides are present at potentially high levels (greater than 1 mg/l) only in isolated cases as listed in Table 4. Bacteria can acclimate to and biotransform relatively high concentrations of cyanide (10 - 40 mg/l). Thus, these levels shouldn't cause problems, with the possible exception of Well 8. However, it is expected that the composite water quality will be bioreclamated, so cyanide levels will be decreased through dilution.

OVERALL POTENTIAL FOR BIORECLAMATION

The feasibility of bioreclamation of A-Zone water can now be addressed by discussing the biodegradability and toxicity of specific contaminants, the potential for synergism and antagonism of the mixture of components, and the importance of other environmental factors.

BIODEGRADABILITY AND TOXICITY OF SPECIFIC CONTAMINANTS: Table 5 summarizes the available knowledge concerning the biodegradability and toxicity of the nine SUM contaminants and other compounds of interest. Also noted is the environment in which biotransformation was observed. From this data, it is evident that anoxic conditions (nitrate as the electron acceptor) could not be used for bioreclamation at the Niagara Plant site. It has been reported that, in general, chlorinated aliphatics (CF, DCE, MC, TECEA, TECE, TCE, VC) are biotransformed under anaerobic conditions but not aerobically, while chlorinated aromatics are degraded aerobically but not anaerobically. However, it should be pointed out that some chlorinated aliphatics have been reportedly degraded under aerobic conditions (MC, DCE, TECE). From these reports it is not clear whether the mechanism for removal was biodegradation, stripping via aeration, or adsorption onto organic solids.

The next issue to be addressed is the concentrations at which these contaminants become toxic. As described previously, there may be significant difference between the concentration causing inhibition to unacclimated bacteria and the concentration to which the bacteria can ultimately acclimate. For example, 0.5 mg/l chloroform is toxic to unacclimated anaerobic bacteria. However, these organisms can ultimately acclimate to at least 40 mg/l given sufficient time. Data in Table 6 represent the best available information on levels of SUM components that can be biotransformed. It must be emphasized that the upper limits are not firmly established and further experience may find that higher concentations can be tolerated and/or biotransformed. As noted, data for some constituents are not available.

From the data available in the literature, it is apparent that there definitely is potential for bioreclamation of the contaminated A-Zone water. Most organic contaminants are biotransformable given the right conditions. Data presented in Table 2 indicated that the five highest SUM values were 165, 81.9, 61.7, 57.3, and 56.3 mg/l (as carbon), indicating potential for acclimation and biotransformation. The key is the ability to establish the "correct" conditions.

POTENTIAL FOR SYNERGISM AND ANTAGONISM: With a mixture of many contaminants as is the case here, the potential exists for synergism (making potential toxicity more severe) or antagonism (making toxicity less severe). Although an individual contaminant may be biotransformable at a given concentration, when combined with another contaminant, it may become toxic. For example, if the maximum tolerable CF concentration was 50 mg/l and that for MC was 20 mg/l when the compounds where present individually, they would be synergistic if, when combined, the maximum tolerable concentrations descreased to 20 and 10 mg/l, respectively. All the contaminants listed in Table 4, the heavy metals, and cyanides may also contribute to synergism or antagonism. In addition, organics not measured by specific analysis may also contribute. Since the number of possible combinations is infinite, the only way to evaluate a given mixture is to test its degradability in the laboratory.

OTHER FACTORS: A "checklist" of requirements for bacterial growth was presented earlier. Since the primary goal of bioreclamation is to transform hazardous organic contaminants into nonhazardous end products, conditions must be developed such that nothing else limits or interferes with this transformation. If aerobic conditions are desired, sufficent oxygen must be provided; if anaerobic conditions are desired, air must be specifically excluded. Sufficient macro and micronutrients (nitrogen, phosphorus, sulfur, iron, etc.) must be present. At the present time, it is unknown whether these nutrients are present in acceptable quantities. If they aren't, they must be added. For the most part, temperature is not expected to be a problem, while pH control may be necessary. There must be adequate contact between the contaminants, bacteria, and nutrients. Finally, sufficient time must be provided to acclimate to and biotransform the target constituents. This will be provided with proper engineering design and operation.

SUMMARY: There is definite potential for bioreclamation of contaminated A-Zone water. Individual components are biodegradable. The major questions to be addressed are:

- Will the mixture of individual contaminants reduce the biodegradability?
- Is the organic material represented by TOC - SUM (organics other than those listed in Table 6) biodegradable and in sufficient quantity to support bacterial growth (in general, more than 50 mg/l degradable TOC is desirable)?
- Are there sufficient nutrients present to support bacterial growth?

These questions can be answered by relatively simple analyses and laboratory studies. If the answer to the second and third questions is no, these compounds must be added. If the answer to the first question is yes, it will be important to determine the extent of the reduction and whether it can be compensated for. These aspects will be further discussed in the following section.

POSSIBLE MANAGEMENT ALTERNATIVES

SELECTION OF WELL AREAS TO BE TREATED: When assessing bioreclamation of A-Zone waters, an evaluation of which well areas (hereinafter denoted as wells) to treat must be made. Assuming that a significant portion of the TOC is biodegradable, it would seem advantageous to combine wells with HIGH SUMs and wells with HIGH TOC values. In that regard, it would be helpful to develop a site map showing the most contaminated wells and to rank the wells from most contaminated to cleanest. Plate 7 shows the relative contamination at each well using definitions for TOC and SUM developed previously. To rank the wells, values for SUM and TOC were averaged for the three months data, (four months for Wells 1 and 21) and listed in Table 7. For the purpose of discussion wells are used as a reference for location of contaminated areas and are not intended for use as remediation production wells. The use of data from individual wells permits the assessment of the treatability of the composite groundwater.

From these data it is apparent that not all wells may have to be treated. There are some very clean wells (e.g. 7, 12, 17), some very contaminated wells (e.g., 1, 8, 21), and some wells with LOW SUMs and HIGH TOC's (e.g., 18 & 19). Also, some areas of the site are particularly contaminated (the area bordered by Chemical Road, Adams Avenue, Gill Creek, and Niagara Parkway (Wells 1, 2, 3, 13, 14, 15, 16, 21), and the area around Wells 8 and 9). It may be that contaminants are moving from Wells 8 and 9 toward Wells 10, 11, and 12. Perhaps there will be significant advantages to treating a cluster or combination of wells. For example, if using in-situ treatment, the contaminated areas described above may be the only wells requiring treatment.

As a basis for developing the specific bioreclamation alternatives to be discussed below, it would be useful to combine various wells and calculate their average SUM and TOC values. To provide some general guidelines, biodegradable TOC levels need to be approximately 50 mg/l or above to support significant bacterial growth (settled domestic sewage contains 50-200 mg/l TOC). Thus, there may be advantages to combining HIGH TOC wells with LOW TOC wells. Since the goal is to degrade the SUM compounds, it is important that they not be present at toxic levels. Perhaps a first-cut target should be SUM levels less than 25 mg/l. The dilution provided by combining HIGH SUM/MODERATE TOC wells with LOW-MODERATE SUM/HIGH TOC wells should thus be beneficial. The groupings to be investigated are listed in Table 8 along with justification for their selection. When calculating the combined SUM and TOC levels, it was assumed that wells were combined on an equal volume basis. The resulting values are listed in Table 9.

The decision as to which combination of wells should be treated will be a function of the desired degree of reclamation (how clean is the site to be?). If above-ground treatment was employed, it would seem that a majority of the SUM contaminants would be treated with combination F (total of nine wells), and most definitely treated with combination I (14 wells). If in-situ treatment was used, treatment of combination A and combination B would address the majority of the SUM contaminants, and C would address movement from Wells 8 and 9 towards Wells 10, 11, and 12. However, Wells 18 and 19, with very high TOC levels, would not be treated. Also, the biodegradable TOC levels of combinations A, B, and C may not be sufficient to support bacterial growth. Exogenous, biodegradable carbon may have to be added.

ABOVE-GROUND BIORECLAMATION: Above-ground treatment can be aerobic or anaerobic, suspended growth or attached growth.

Aerobic vs Anaerobic Bioreclamation: It has been discussed previously that the majority of the chlorinated aliphatics can be degraded anaerobically, but some may not be biotransformed aerobically. However, those compounds not degradable aerobically may be removed by stripping (volatilization) during aeration. Thus, there may be very little difference between overall removals of the SUM components. A disadvantage of aerobic treatment is that oxygen will have to be supplied, representing a significant operational expense. Anaerobic bacteria are slower growers than aerobic bacteria and thus may require a longer SRT to accomplish equivalent removals. These longer SRT's can be obtained economically using attached-growth reactors (discussed below).

Attached vs Suspended Growth: The basic difference between these two types of reactors is that with attached-growth (AG) systems, a surface is provided for bacterial attachment (rocks, plastic, sand, granular activated carbon, aluminum or silicon oxides: media may be either static or fluidized) while with suspended-growth (SG) systems, bacteria are kept in suspension by mixing. In typical SG systems, a sedimentation basin is required following the bioreactor to settle the bacteria grown for recycle back to the bioreactor.

The key to economical, efficient bioreclamation is separation of SRT (determines process efficiency and degree of acclimation) from HRT (determines capital cost). In this regard, AG systems offer a distinct advantage with their inherent solids retention capabilities. This is particularly critical in bioreclamation of contaminated groundwaters since time required for acclimation to resistant and toxic contaminants to occur. With SG systems, SRT is provided by a large reactor plus a sedimentation tank with a recycle pump. The trade-off is basically media cost vs settling tank and recycle pumpage. It is difficult to economically obtain SRT levels much above 25-40 days with SG systems. AG systems typically give SRT values in excess of 100 days. Since AG systems can maintain higher biomass levels, they can operate at lower HRTs (e.g., 0.5-2 hrs vs 3-10 hrs for SG), the magnitude of the HRT will to a certain degree also be a function of the degradability of the organic matter. A potential advantage of aerobic SG systems is more efficient stripping of nondegradable, volatile organics.

Process efficiency for both AG anu SG systems is a function of SRT and the biodegradability of the organics. It is difficult to predict removal efficiencies without knowing rates of biodegradability. For example, in aerobic SG systems fed glucose, a readily degradable organic, 99 percent conversation can be accomplished with SRT's of 2-5 days and HRT's of 1-3 hours. However, with chlorobenzene, SRT's of greater than 50 days and HRT's of 10-24 hours may be necessary to accomplish 99 percent conversion. Again the key is acclimation. With an acclimated culture in an AG reactor, 99 percent converstion of CB may be possible in less than an hour. It is easier to develop and maintain an acclimated culture with an AG reactor. (Coincidentally, this may be why soil microbes operate efficiently - the SRT of soil bacteria may be on the order of a year). Acclimation times have been reported to vary from several weeks to several months for the various chlorinated organics. If bacteria can acclimate to the organics contained in SUM and TOC, the following efficiencies might be expected from AG and SG systems with stated operating conditions:

	HRT (hrs)	SRT (days)	% REMOVAL of SUM	% REMOVAL of TOC
AG-aerobic	0.5-2	50-200	90-99	50-80
AG-anaerobic	1-24	50-200	85-95	50-80
SG-aerobic	12-36	20-40	90-99	50-80
SG-anaerobic		Not Applicable		

It cannot be overemphasized here that the key is acclimation time. the above numbers are meaningless if acclimation does not occur. Careful, patient attention to bioreclamation principles is required to ensure acclimation. AG systems have a distinct advantage in this regard.

Combination Processes: There are many possible physical and chemical processes that may be used as pretreatment prior to bioreclamation. For examples, use of activated carbon, organic resins, and air stripping prior to biological treatment have been reported to remove substances that inhibit bioreclamation. For the sake of brevity, such combinations will not be discussed here. Only combinations that can be made to occur within the biological reactor will be considered.

During above-ground aerobic bioreclamation, volatile constituents will be stripped from the bioreactor. All SUM components are susceptible to significant stripping during aerobic treatment; however, only CF, DCE, and TECEA are reported to be stripped to any significant degree (greater than 15% removal) under actual treatment conditions. The majority of removal is reported to be via biotransportation.

Perhaps the most useful and well-tested combination process is to use granular activated carbon (GAC) as a media for an AG system (can be either aerobic or anaerobic). Such a process has been shown to work exceptionally well for treatment of phenolics and coal gasification wastewaters. It is also used to Europe to treat contaminated surface waters prior to domestic use. The advantage here is that in addition of the benefits described above for AG bioreclamation, nondegradable organics and potentially toxic substances are removed by adsorption. Biological GAC (BAC - GAC is specifically seeded with bacteria) offers an advantage over conventional GAC treatment because degradation of adsorbed organics regenerates the carbon. Thus, the need for external regeneration, which makes conventional GAC very expensive, is reduced, significantly reducing operational costs.

The BAC system works particuarly well for contaminated waters that exhibit fluctuating concentrations of organics and changes in the nature of the organics to be treated. Examination of data contained in the December 23, 1983 report shows that over a four-month period, the following variation in just the SUM contaminants for the five most contaminated wells was observed:

SUM CONTAMINANT	RANGE OF CONCENTRATION (mg/l)
CF	0-160
DCE	0-390
MC	0-140
TECEA	0-92
TECE	0-72
TCE	0.5-360
VC	0-35
B	0 (max. conc. = 6 at Well 8)
CB	0 (max. conc. = 2.2 at Well 10)

The "buffer" provided by BAC for these fluctuations should lead to very stable operation.

The question as to whether to use aerobic or anaerobic conditions is complex. Chlorinated aromatics adsorb strongly and are degraded aerobically but not anaerobically. Chlorinated aliphatics are adsorbed weakly and are degraded to a wider degree anaerobically than aerobically. Since the primary contaminants (at least for the volatile organics) at Niagara Falls are chlorinated aliphatics, it would seem that anaerobic BAC offers significant potential.

If GAC is used as the media in an AG bioreclamation system, SRT's and HRT's would be similar to those listed above. Removal efficiences will be much higher; BAC systems would typically yield "not detectable" levels for many priority pollutants. The key to process cost would be the adsorbability of the TOC, which could be determined from simple laboratory tests.

IN-SITU BIORECLAMATION: Although in-situ bioreclamation of oil spills is common, below-ground, in-situ bioreclamation of contaminated groundwaters is not. As described earlier, the major problem is nonuniformity with respect to organic content (nature and concentration), bacterial numbers, potential toxicity, nutrients, and flow. In other words, it is difficult to meet all the requirements of the "checklist", especially adequate contact. If uniformity and adequate contact could be created, at least locally, in-situ bioreclamation would be feasible. The key again is providing/developing a sufficient quantity of bacteria that are acclimated to the combination of contaminants. Conceptually there are three general "schemes" for in-situ bioreclamation:

- enhancement of existing bacteria,
- extraction/injection-recycle, and
- creation of a biologically active barrier.

Enhancement Of Existing Bacteria: In this method, nutrients and perhaps additional biodegradable organics (e.g., glucose or acetate) would be injected via a series of wells into contaminated areas to promote the growth of indigenous bacteria. The hope is that with a larger population and sufficent acclimation time, a microbial population would develop that would biotransform the pollutants at a significant rate. This process would only seem feasible if contaminated groundwater could not migrate downward away from the developing biomass. Since downward migration is definitely happening at the Niagara Plant site, this type of bioreclamation may be eliminated from further consideration. However, if downward migration is stopped this alternate may become attractive.

Extraction/Injection-Recycle: There are many possibilities under this general heading. Both aerobic and anaerobic environments could be created by selective use of aeration. The general idea would be to extract contaminated water from selected wells, combine it with necessary nutrients, acclimated bacteria (developed above ground initially and produced below ground with time), and perhaps an exogenous primary substrate in a short-detention-time reactor (small volume), and then re-inject back into the overburden. The contaminated overburden would thus serve as an AG reactor. As contaminants are removed from the water, it is expected that organics that have been adsorbed on soil (could be a significant quantity) would be desorbed and removed as treated water is recycled. In essence, this method would be somewhat analogous to land treatment of wastewater.

Groundwater Decontamination Systems, Inc. of Waldwick, New Jersey have developed a sytem somewhat similar to this. However, they advocate the use of an above-ground, SG, aerobic reactor (like an activated-sludge system) followed by a sedimentation system prior to re-injection. In addition, air is injected at selected points throughout the site to maintain aerobic conditions below ground. It would be more cost efficient to eliminate the activated-sludge reactor and settling tank and replace them with the mixing tank described above and allow the soil to be the only bioreactor. If it is deemed necessary to ensure that a portion of the overburden be aerobic, aeration could be used in the mixing basin.

Whether the proposed scheme is feasible depends upon the lag time required to develop the acclimated microbial population. Once the population is developed, the process should work. Water from cleaner wells could be added for dilution if periodic toxicity is a problem. It has been shown that most toxicity is biostatic; that is, if the toxic substance is removed or diluted, the bacteria will recover. Since the bacteria will be retained in the soil matrix, none will be lost and recovery (acclimation) will be possible. Removal efficiencies would seem to be limited only by the kinetics of the biological reaction. Reports in the literature suggest that under the proper conditions, chlorinated organics can be reduced to around 1 ppb.

Creation Of A Biologically Active Barrier: The concept of creating a biological barrier is experimental in nature. However, evaluation of existing workable in-situ treatment techniques indicates that a biological barrier would be a logical extension of existing technology. This technique would be feasible if a majority of the contaminated water flows or could be made to flow fairly uniformly in one direction. For example, since the west plant flow is partially radial toward Gill Creek and the Niagara River, a biologically active barrier in the form of a slurry trench containing acclimated bacteria, nutrients, and perhaps an exogenous carbon source could be used to intercept and treat the contaminated water. This trench would be another form of an in-situ, AG reactor. If necessary, extraction wells or collection trenches could be used downstream to collect and recycle treated water if the degree of treatment is not sufficient. Once an acclimated population of bacteria is developed in the trench, recycle may not be necessary.

In essence, groundwater could be artificially forced to flow toward the "bio-trench" by pumping, but that would be an additional expense.

In summary, all three general in-situ bioreclamation techniques would be feasible under the right conditions. Keys include stopping downward migration, developing acclimated bacteria, determining if exogenous carbon or nutrients are required, ensuring uniform distribution of injected water, and comparing projected economics with above-ground methods. Most of all, making these alternatives feasible requires patience and an understanding of the fundamentals of bacterial growth. It has been demonstrated elsewhere that in-situ bioreclamation will work if these requirements are met.

SUMMARY

From an examination of the data available describing the nature and concentration of contaminants in A-Zone water, it appears as though bioreclamation is potentially feasible. Individual contaminants present have been reported in the literature to be degradable. Definite conclusions regarding the feasibility of bioreclamation await laboratory studies assessing the biodegradability of the mixture of contaminants contained in each well and combination of wells. If acclimated bacteria cannot be developed, bioreclamation will not work without pretreatment. From the examination of available data, toxicity due to heavy metals, cyanides, BHC's or PCB's appears unlikely.

Possible management alternatives are listed in a decreasing order of potential feasibility:

- Above-ground, AG, anaerobic GAC reactor
  Above-ground, AG, aerobic GAC reactor
  In-situ extraction/injection-recycle

- Above-ground, AG, inert-media (sand, etc.) reactor

- In-Situ creation of a biologically active barrier

- In-Situ enhancement of existing bacteria
  Above-ground, SG, aerobic reactor (like Groundwater Decontamination Systems, Inc.)

Economic feasibility of these alternatives also needs to be evaluated.

Bioreclamation will most likely work at the Niagara Plant site. However, patience and an appreciation for the fundamentals of bacterial growth will be necessary. As noted in the above ranking, an above ground biological granular activated carbon system offers the most potential and would be integral with the groundwater control systems previously described.

CONVENTIONAL TREATMENT OF GROUNDWATER

The non-biological treatment of groundwater at the Niagara Plant must address the following items:

- Solids in the water - either from the individual wells or from combining waters to form precipitates in the water,
- Non-Aqueous Phase Liquids - expected to be present in some monitoring wells,
- Cyanide (found at eight locations),
- Copper and Barium, and
- Soluble organics both (a) volatiles and (b) non-volatiles

Phase I of these remediation studies consider alternatives for applicability, limitations, advantages, disadvantages and environmental effectiveness. The possibility of using facilities and utilities already present at the plant or off-site is included in this evaluation.

The five treatment items identified above will be discussed in order of occurrence.

SOLIDS IN WATER

Filtration of solids from water is an old technology that continues to change, leading to a great variety of available techniques. Two important criteria for the selection of the best techniques for a particular application are the magnitude (flow rate and concentration of solids) and the effectiveness. In a case such as this one, the selection process is complicated by the potentially hazardous nature of the solids that are being removed.

The following list of filtration techniques presents the most likely candidates for further consideration.

- Plate and Frame - This filter is best suited for high-solids applications such as processes where the filter cake is the desired product and the liquid is of minor interest. They are cumbersome and labor intensive, and considered the least likely choice for this application.

- Vacuum Pre-Coat - These filters are usually very expensive to purchase and to operate. They require a body feed or filter aid and the liquid loses its head on treatment requiring a pump station to feed water through the rest of the system. They can be effective and show a good particle size cut-off but their cost makes them an unlikely choice.

- Multi-Media - These filters are commonly used on municipal water treatment systems to treat low concentrations of suspended solids economically. They are reasonably effective. Solids are removed from these filters by backwashing with a high velocity water stream. This is very troublesome for a hazardous waste application. In effect the multi-media filters have acted as concentrators of the solids. Another disadvantage is the need for either shutting down during backwashing or providing parallel units to stay on-line. They are not recommended for this application.

- Cartridge - These filters are enclosed, easy to operate, have a good particle size cut-off, and are inexpensive to purchase. Their operating costs can be high if the solids loading is moderate to high. The solids disposal cost is increased because the entire cartridge is thrown away. This filter also requires a parallel set up so the system can stay up while cartridges are replaced. Depending on the solids level in site water, these filters may or may not be a good choice for further consideration.

- Bag - These filters are inexpensive to purchase and easy to operate. It may take body feed or filter aid to achieve good results with this filter, which adds to the complexity and cost, but the disposal costs will not be as high as for the cartridge filter. The control on particle size and concentration is likely satisfactory with this filter for the purpose intended here. The bag filter is recommended for further consideration.

- Static Screen - This filter is inexpensive and very easy to operate. It has reasonably good control on particle size and there is no need to shut down for solids removal. There is no filter aid making solids disposal minimal. One disadvantage is the loss of head on the water requiring a pump station to feed the rest of the system. If the nature of the solids permit, this may be the best choice for this application and is recommended for further consideration.

NON-AQUEOUS PHASE LIQUID

If groundwater extraction results in both the non-aqueous and aqueous phase liquids, a phase separation will be needed. The final selection of techniques for non-aqueous phase liquid and solids removal will depend on the exact groundwater conditions.

Two factors of particular importance for this step of the process are the densities of the non-aqueous phase liquids and their hazardous nature. The two most likely techniques available for treating this problem are a baffled tank or a coalescer.

- Baffled Tank - This device simply provides a relatively quiescent residence volume to provide the opportunity for the two phases to separate. The effectiveness of this device is somewhat questionable. If the pump feeding this tank tends to homogenize the two phases, separation may be difficult. Such tanks are relatively cheap and that is probably their main advantage.

- Coalescer - A coalescer has tubular elements that resemble cartridges in a cartridge filter. The phase separating ability of these units are much better than the simple tanks. The applicability of this technique is difficult to predict a priori and further investigations including input with the appropriate vendors is required.

The ultimate disposal of the recovered non-aqueous phase liquid from this step also deserves comment. This liquid will be a mixed non-aqueous phase liquid saturated with water. Since the plant apparently no longer has facilities for these chemicals, off-site disposal/incineration will be required.

CYANIDE

Cyanide treatment is typically accomplished through "breakpoint chlorination". This technique involves raising the pH to nine or higher and adding hypochlorite. The term comes from the fact that the process is usually controlled by measuring for residual chlorine, indicating that there is no remaining cyanide to react.

It is usually best to treat for cyanide before filtering because the pH change will often cause the formation of additional solids. The pH will probably have to be reduced once the cyanide is destroyed. This will require another step with chemical addition and the associated control.

COPPER AND BARIUM

It is not certain that separate treatment for copper and/or barium will be needed. Depending on water flow rate, cation concentrations and effluent requirements there are two likely treatment options for these parameters.

- Precipitation is very commonly used for metals problems. Copper in solution can be reduced by raising the pH with chemical addition to form the hydroxide or the carbonate. The precipitate must then be removed for disposal. Barium can be precipitated as an insoluble sulfate.

This technique is often considered and chosen. The advantages are largely economic. However, in some parts of the country, regulators are discouraging or even banning the landfilling of sludges from operations such as this. Technically the disadvantages usually center on the solids separation step since some of the precipitates are difficult to dewater.

- Ion exchange can be an effective technique for reducing cation (copper and/or barium) concentrations in water. If the effluent requirements are very stringent or the water contains chemicals capable of keeping the cations in solution (complexing or chelating agents for example), precipitation may be ineffective. In many cases such as these, ion exchange will be the only effective alternative. If however, the water contains high concentrations of non-target cations, conventional ion exchange can also be ineffective. For some cations such as copper, the resin manufacturers have used complex and chelate chemistry to develop very selective resins that can be effective in the presence of high interference.

The major disadvantages of ion exchange are the high operating costs and the handling or disposal of the spent regenerant. The high operating costs are largely related to the cost of chemicals to regenerate the resin once it is saturated with the target cation. Ion exchange has the reputation of being a "low concentration process" because of this regenerant requirement. In effect, the ion exchange process removes the target ion from the primary stream, stores it on the resin, and then releases it to the regenerant stream; the result is a concentrating of the cation into a low volume spent regenerant.

These techniques are available, but probably do not warrant significant consideration as the copper and barium are believed to be relatively tightly bound to the soil.

ORGANICS IN SOLUTION

The following discussion focuses upon those techniques that are effective, demonstrated and commercially available for organic removal from water.

It is recognized that some of the organic contaminants at this site can be effectively treated with granular activated carbon (GAC). The pesticides and phenols are the main contaminants in this group. The main reason GAC represents the only real choice for these organics is the extremely low effluent guidelines attached to these contaminants.

It is recognized that nearly all of the chlorinated C-1 and C-2 compounds at this site are poorly adsorbed on GAC. That is, the loading values for these compounds are very low. The GAC can be effective in meeting low effluent guidelines but only at the price of large carbon usage and correspondingly large costs. There is an economic incentive to remove these compounds before the water passes over the GAC. Fortunately these compounds tend to have high vapor pressures and low solubilities in water. This combination of properties suggests the use of air or stream to strip these compounds from the water. Therefore, the choices for treating the organics problem are; (a) air stripping followed by GAC, (b) air stripping with vapor phase carbon followed by GAC or (c) steam stripping followed by GAC (Distillation).

Alternative (a) is usually the cheapest of the three and can be very effective for the water phase. It does release chlorinated C-1 and C-2 compounds, some known or suspected carcinogens and benzene to the atmosphere. Depending on the scale of the discharge this may or may not be allowed.

If alternative (a) is not allowed, a choice between alternatives (b) and (c) must be made. This is not an easy choice to make. Selection of alternative (b) implies the need to make additional choices regarding the handling of vapor phase carbon. The exit air from the air stripper is a source of air pollution. The usual approach is to use a heat exchanger to increase the temperature of the exit air. The reason for this is that the high Relative Humidity in the air stream dramatically reduces the loading of VOC's on the carbon due to the competitive absorption. Heating the air as little as 10^{o}F will lower the Relative Humidity to about 50 percent. This change in the Relative Humidity will increase the VOC loading from the 3 percent to the 15-20 percent range. The heated air is then passed over the Vapor Phase Carbon and released to the atmosphere. For low loading rates (lbs of VOC/hour), the vapor phase carbon will be effective for a long while and regeneration will not be justified. At the same time, the cost of throwing the VPC away, may become higher than the cost of regeneration.

Vapor phase carbon, unlike GAC, can be regenerated by stream. Two vapor phase carbon systems are normally used - one on-line and one in regeneration or stand-by. The steam from the regeneration step goes through a total condenser. The organic phase (wet with water) is disposed of and the water phase (with dissolved VOC's) is sent back to the head of the treatment plant.

The disposal of the organic phase might be one of the following:

(a) Incincerate,

(b) Find a reclaimer interested in recovering the chmicals,

(c) Secure landfill (long-term liability problem)

(d) Condense and haul to Chambers Works,

Option (c) refers to the case where the VOC loading is "very high". Rather than use an air stripper with vapor phase carbon and steam regeneration of the carbon, it becomes attractive to use the steam directly on the groundwater stream. The overhead steam is then condensed with cooling water and the same situation as described above is accomplished with a fraction of the equipment.

The availability of steam at a plant site such as this has a strong impact on the economic comparisons discussed above. The allocated cost of utility steam can be considerably less than initiating a package unit such as available from Calgon Adsorption Service. In summary, liquid phase carbon adsorption is the best available non-biological treatment and only technology available to adequately remove the non-volatile organics to extremely low effluent levels.

SUMMARY EVALUATION OF REMEDIAL ALTERNATIVE

Results of the geohydrologic investigations conducted at the DuPont Niagara Plant site indicated the presence of elevated levels of certain chemical compounds in the groundwater flow system. Results of chemical analyses from samples collected from groundwater monitoring wells indicate that the contamination is generally associated with plant process areas. In order to effectively remediate the Niagara Plant site area, it was decided to first remediate the contaminant source areas.

There are five general areas of the Niagara Plant site that should be included in the initial remedial program. They include the following:

- Solvent process area B-81-84 (near well cluster 14) and B-64 (near well cluster 15)

- B-403 polyglycol area (near well clusters 8 and 10).

- West Plant maintenance area (near well clusters 4, 5 and 6)

- B-44 NaCN product area (near well cluster 16)

- HCN incinerator area (near well cluster 8)

In addition to the five areas listed above, an additional area located near well cluster 15 was also evaluated with respect to inorganics. This area contains elevated levels of copper (less than 10 ppm). Soil samples collected during the manmade passageways investigation contained slightly less than 1,000 ppm of copper. However, copper is not very mobile and the concentration of copper in the groundwater is two orders of magnitude lower than the concentrations measured in the soil. Therefore, this area is not considered to be a major contributor to contamination in the groundwater flow system and remediation of this source is considered to be a low priority. In addition, remedial measures proposed in nearby areas may indirectly improve the water quality in this area.

The proposed remediation techniques to be employed at each of the five above mentioned areas will be discussed separately, beginning with the remediation sites located in the west plant site area.

SOLVENT PROCESS AREA

The major area of groundwater contamination in the west plant area is the A-Zone volatile organic plume located near well clusters 14 and 15. Total concentrations of C-1 and C-2 compounds exceed 600 and 200 ppm, respectively. In addition, non-aqueous phase liquids have been observed in these wells. Remediation of this area considers application of several remedial components because of the large areal extent of the contaminant plume, the high concentrations of volatile compounds, presence of non-aqueous phase liquids and the close proximity to Gill Creek.

The flow direction in the A-Zone in this area, is to the east toward Gill Creek. Therefore, volatile contaminants in the A-Zone are slowly being discharged to Gill Creek which then discharges to the Niagara River. During calculations of Niagara River contaminant loadings, which were prepared for the geohydrologic investigation, it was estimated that 10 pounds per day were entering the Niagara River from this area. This accounts for approximately 10 percent of the total loading rate leaving the Niagara Plant site. Results of the manmade passageway investigation indicate that localized groundwater flow in the A-Zone near the sewer lines is toward the north flowing Alundum Road sewer and the west flowing Adams Avenue sewer.

In addition, two test pits were excavated to bedrock in the area just east of Building 81-84. Samples were collected at several depths throughout the soil profile and analyzed for DuPont-related volatile compounds. Results of these analyses indicate that the highest volatile organics concentrations occur directly above the bedrock, at a depth of approximately seven feet.

Remediation alternatives were considered that would utilize the existing manmade passageways to control the contaminant migration. In order to prevent further contamination of Gill Creek, the groundwater flow direction must be reversed. This can be accomplished by locating groundwater purge or recovery well(s) near the intersection of Alundum and DuPont Roads. This well, or several wells, pumping at a yet to be determined pumping rate, can create a hydraulic low or sink area. Contaminants within this newly created cone of depression, will move toward these wells and can be removed. A series of collection manholes could also be constructed along Adams Avenue so that contaminated groundwater can be collected for treatment. Further investigation will be needed to determine the actual construction and hydraulics of this collection system. For example, it may be necessary to remove material from the existing manmade passageway and add a drain tile system to enhance leachate movement and collection.

The purge well will induce flow from Gill Creek into this area. This will act as a soil flushing system and aid in remediation of the source. However, contaminants located in the unsaturated zone above the newly established groundwater table will not be affected. Therefore, it may be advantageous to place several slow rate irrigation lines directly below the soil surface in areas identified as containing high levels of volatile compounds. Construction of this flushing system could be coordinated with any planned construction in the old tank area.

At this time, it is felt that contaminant movement can be hydraulically controlled in this area and construction of a horizontal or vertical barrier are not necessary. However, it will be necessary to fully evaluate this alternative using computer modeling and field permeability testing before a final remediation system is installed.

B-403 POLYGLYCOL AREA

Results of groundwater analyses performed on samples collected from wells 8 and 10 indicate the presence of high concentrations of C-2 compounds (29 and 16 ppm, respectively).

Remediation in this area can be accomplished in much the same manner as that described for the volatile compounds in the west area. Contaminant migration can be controlled by constructing a hydraulic barrier (pumping or injection). A drain tile collection system can be constructed in the top of rock along DuPont Road. The direction of groundwater flow in the A-Zone, which is generally toward the northeast, will be altered so that it discharges into the drain tile system. The contaminated groundwater can then be removed via several manholes located along this system. The exact number and location of manholes and construction details of the drain tile system will be determined during Phase II. It is possible that some type of barrier (active/passive) may be required in the vicinity of wells 18 and 7 along Adams Avenue. This will serve to prevent off-site migration of the volatile compounds toward the northeast. This alternative will be more fully evaluated, after information obtained during installation of new monitoring wells is gathered and the flow system modeled.

WEST MAINTENANCE AREA

The west maintenance area is the former location of the cyanide weathering area and the current location for the handling of barium, sodium and calcium chlorides. Water quality analyses showed elevated levels of barium. After several soil samples are collected in this area to better define the areal extent of the barium soil contamination, it may be advantageous to excavate any highly contaminated areas. Placement of a liner/surface seal in this area is proposed, as waste will continue to be produced and placed in this area. This liner would serve to mitigate further leaching of contaminants into the groundwater. A liner/surface seal of clay or asphalt would prevent further leaching of the contaminants presently in the soil. Diversion ditches and surface wells should also be added to further prohibit infiltration by surface runoff.

This area contains a clayey overburden material and a perched water table condition. Therefore, soil flushing may not be appropriate due to low hydraulic conductivity of the clay soil. This can be better assessed after additional information about this area is obtained during the soil sampling program.

Note that the top of bedrock generally slopes toward the Niagara River in the west plant site. However, local variations in the top of rock surface have been observed elsewhere on the site and would be expected throughout the site. The potential exists for gravitational transport of the heavier than water non-aqueous phase liquids to the river. To preclude the off-site gravitational migration of these heavy non-aqueous phase liquids it may be necessary to construct a slurry trench cutoff wall along the Niagara Parkway, as shown on Plate 1.

B-44 NaCN PRODUCT AREA

Groundwater samples collected from the A-Zone in well 16 during October, 1983 indicated an elevated level of total cyanide (36 ppm). However, no soil samples have been collected and analyzed for cyanide in this area, therefore the extent of the "source area" is unknown. Soil samples should be collected in the small open area located between Buildings 44 and 48. If results of cyanide analyses indicate that soils in the area contain high concentrations of cyanide then excavation of these soils must receive further consideration. If analyses indicate moderate or low cyanide concentrations in the "suspected source area", or if excavation proves not to be feasible, then a soil flushing scheme could be implemented. As described in the report, the hydraulic properties of the soil source area would have to be evaluated prior to selection and design of a system. As there is a limited area available for flushing, an injection well may prove to be the best method for introducing the solvent to the source area.

The leachate produced during this operation will either (1) flow into the B-Zone groundwater system, which is ultimately intercepted by the cone of depression formed by the Olin production well, or (2) remain in the A-Zone groundwater flow regime and discharge into the Adams Avenue sewer. The leachate discharging into the Adams Avenue sewer could be collected at several points via manholes and then treated.

HCN INCINERATOR AREA

Groundwater samples collected from monitoring well 8 contained high concentrations of total cyanide (approximately 10 ppm). As the exact areal extent of this source is unknown, soil samples should be collected prior to determination of a remediation plan. If results of the analyses indicate high concentrations of cyanide, limited areas could be excavated. However, due to the close proximity of buildings in this area, excavation may not be a feasible alternative. In that case, a soil flushing system could be implemented. This alternative would be contingent on suitable overburden hydraulic conductivities. As this area also contains elevated levels of C-2 compounds, it is most likely that remediation of the cyanide will be accomplished during the remediation of the volatile compounds in this area.

Tables

TABLE 1
REMEDIATION TECHNIQUE VS TREATMENT AREA MATRIX

	Remediation Areas in Order of Priority				
Techniques	B-81-84	B-403	West Plant Maintenance Area	B-44	HCN Incinerator
Excavation & Disposal	Possible	Possible	Practical	Practical	Practical
Passive Containment Techniques	Possible	Possible	Practical	Possible	Possible
Active Containment Techniques	Practical	Practical	Not Applicable	Not Applicable	Not Applicable
Solidification	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Flushing	Practical	Possible	Not Applicable	Possible	Possible
Bioreclamation of Contaminated Groundwater	Possible	Possible	Not Applicable	Not Applicable	Not Applicable
Conventional Treatment of Groundwater	Practical	Practical	Not Applicable	Possible	Possible

TABLE 2

COMPARISON OF TOC(1) WITH SUM(2)

WELL	JUNE		JULY		SEPTEMBER		OCTOBER	
	SUM	TOC	SUM	TOC	SUM	TOC	SUM	TOC
1	61.7	13.0	30.7	13.0	27.9	42	21.2	12
2	-	-	8.6	5.0	10.3	5.0	2.8	15
3	-	-	1.2	9.0	1.0	7.7	0.7	9
4	-	-	0.2	18	0	26	0.1	7
5	-	-	0.5	13	0.5	9	no data	
6	-	-	0.1	26	0.1	31	0.2	5
7	-	-	0	16	0	18	0	7.8
8	-	-	7.0	720	10.2	570	11.7	460
9	-	-	0.7	420	0.8	220	0.7	100
10	-	-	0.1	12	2.7	17	6.6	14
11	-	-	0.5	9.5	0.6	18	0.5	8
12	-	-	0	14	0.1	28	0.1	4.5
13	-	-	40.4	17	26.4	20	56.3	9.3
14	-	-	57.3	22	26.4	34	19.6	11
15	-	-	2.3	10	0.4	20	81.9	22
16	-	-	1.3	41	1.8	330	1.4	150
17	-	-	0	5.2	0	17	0	4.5
18	-	-	0.1	540	0.1	54	0.1	37
19	-	-	0.1	4.8	0.1	31	0.1	30
20	no data was ever taken from Well 20							
21	165	30	17	12	11.2	70	26	53

(1) Total Organic Carbon

(2) $\mathrm{SUM} = f_1\mathrm{CF} + f_2\mathrm{DCE} + f_3\mathrm{MC} + f_4\mathrm{TECEA} + f_5\mathrm{TECE} + f_6\mathrm{TCE}$
$+ f_7\mathrm{VC} + f_8\mathrm{B} + f_9\mathrm{CB}$

TABLE 3
CONTAMINANTS FOUND IN A-ZONE GROUNDWATER AT CONCENTRATIONS GREATER THAN 10 ppb

COMPOUND	WELL NO.	CONCENTRATION (ppb)
hexachlorobutadiene	1, 14	14 - 710
hexachloroethane	1, 14	15 - 880
1,1-dichloroethane	1, 18	52 - 85
1,2-dichloroethane	1, 13	94 - 150
1,1-dichloroethylene	1, 5, 13, 14, 21	290
1,1,1-trichloroethylene	1, 5, 16	200 - 1,100
1,1,2-trichloroethylene	1, 13, 14, 21	320 - 1,200
phenol	8, 16	300
acenapthene	3	12
B-BHC	18	24
Fluorene	3	16
napthalene	3, 13, 16	13 - 100
phenanthrene	3, 16	16 - 22
indeno(1,2,3-cd)pyrene	9	10
pentachlorophenol	18	35
2,4,6-trichlorophenol	18	16
chloromethane	9	110
toluene	8, 9	52 - 900
ethylbenzene	8, 18	36

TABLE 4

ISOLATED CASES OF HIGH CYANIDE LEVELS

WELL	TOTAL CYANIDE IN mg/l		
	7/83	9/83	10/83
2			3.3
3	3.3	2.2	1.4
5		2.0	
7	1.3	8.0	1.3
8	37	30	61
9		8.2	3.5
15	9.6		3.5
16	40		36

TABLE 5

REPORTED RELATIVE BIODEGRADABILITY AND TOXICITY OF A-ZONE VOLATILE ORGANICS

	IS CONTAMINANT DEGRADABLE?			
CONTAMINANT	AEROBIC	ANAEROBIC	ANOXIC	POTENTIALLY TOXIC?
CF	NO*	YES	NO	YES
DCE	NO*	YES	NO	YES
MC	YES	YES	NO	YES
TECEA	NO*	YES	NO	YES
TECE	NO*	YES	NO	YES
TCE	NO	YES	NO	YES
VC	(?)	YES*	NO	YES
B	YES*	NO	NO	YES
CB	YES	NO	NO	YES
Phenol	YES	YES	YES	YES
Napthalene	YES	NO	NO	YES
Ethylbenzene	YES	NO	NO	YES
1,1,1-trichloroethane	NO	YES	NO	YES
1,1,2-trichloroethane	NO	YES	NO	YES
Pentachlorophenol	YES	YES	NO	YES
PCB's	YES	(?)	NO	YES

*There is still some question as to YES or NO

TABLE 6

BEST AVAILABLE DATA ON MAXIMUM LEVELS OF CONTAMINANTS THAT CAN BE TOLERATED WITHOUT SIGNIFICANT TOXICITY

CONTAMINANT	MAXIMUM TOLERABLE CONCENTRATION (mg/l) AEROBIC	ANAEROBIC
CF	500(1)	25-30
DCE	50-200(1)	greater than 0.1(2)
MC	50-200	greater than 10(2)
TECEA	50-200	greater than 0.1(2)
TECE	N/A(3)	greater than 0.1(2)
TCE	N/A(3)	greater than 0.1(2)
VC	N/A(3)	5-30
B	40-150	N/A(3)
CB	greater than 0.1(2)	N/A(3)

(1) Removal mechanism not completely understood: could be biotransformed, stripped or adsorbed

(2) Higher concentrations not tested

(3) Data not available

TABLE 7

RANKING OF WELLS

		SUM				TOC	
RANK	WELL	CONCENTRATION* mg/l	STANDARD DEVIATION* mg/l	RANK	WELL	CONCENTRATION* mg/l	STANDARD DEVIATION* mg/l
1	21	54.9	73.9	1	8	583	131
2	13	41.0	15.0	2	9	247	162
3	1	35.4	18.0	3	18	210	286
4	14	34.4	20.1	4	16	174	146
5	15	28.2	46.5	5	21	41.3	25.5
6	8	9.6	2.4	6	14	22.3	11.5
7	2	7.2	3.9	7	19	21.9	14.8
8	10	3.1	3.3	8	6	20.7	13.8
9	16	1.5	0.3	9	1	20.0	14.7
10	3	1.0	0.3	10	15	17.3	6.4
11	9	0.7	0.1	11	4	17.0	9.5
12	11	0.5	0.1	12	12	15.5	11.8
13	5	0.5	0	13	13	15.4	5.5
14	4	0.1	0.1	14	10	14.3	2.5
15	6	0.1	0.1	15	7	13.9	5.4
16	12	0.1	0.1	16	11	11.8	5.4
17	18	0.1	0	17	5	11.0	2.8
18	19	0.1	0	18	17	8.9	7.0
19	7	0	0	19	3	8.6	0.8
20	17	0	0	20	2	8.3	5.8

*Concentration and Standard Deviation in mg/l for three months data except for Wells 1 and 21 (four months)

TABLE 8

IDENTIFICATION AND JUSTIFICATION FOR VARIOUS WELL COMBINATIONS

GROUP IDENTIFICATION	WELLS* COMBINED
A	Contaminated cluster in center of site 1, 2, 3, 13, 14, 15, 16, 21
B	Two most contaminated wells on right side 8, 9
C	Contamination from 8 and 9 may be moving 8, 9, 10, 11, 12
D	Five wells with highest SUM levels 1, 13, 14, 15, 21
E	Five wells with highest TOC levels 8, 9, 16, 18, 21
F	Group D + Group E
G	Ten wells with highest SUM levels 1, 2, 3, 8, 10, 13, 14, 15, 16, 21
H	Ten wells with highest TOC levels 1, 6, 8, 9, 14, 15, 16, 18, 19, 21
I	Group G + Group H
J	All 20 wells combined

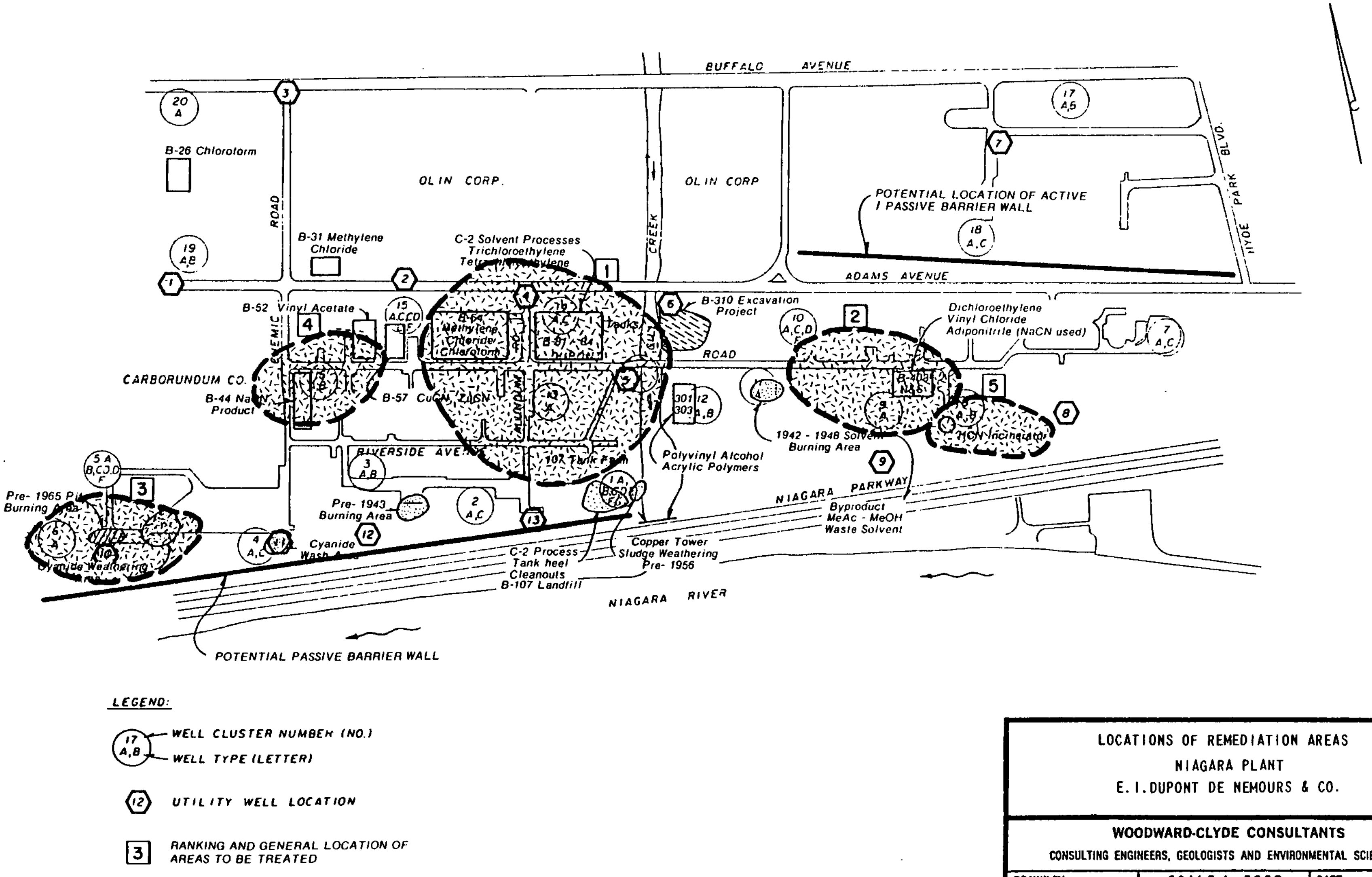
*See Plate 7

TABLE 9

VALUES OF SUM AND TOC FOR VARIOUS WELL COMBINATIONS

GROUP IDENTIFICATION	JULY		SEPTEMBER		OCTOBER		3-MO. AVERAGE	
	SUM	TOC	SUM	TOC	SUM	TOC	SUM	TOC
A	19.9	16.1	13.2	66.1	26.2	35.2	19.8	39.1
B	3.9	570	5.5	395	6.2	280	5.2	415
C	1.7	235	2.9	171	3.9	117	2.8	174
D	29.5	14.8	18.5	37.2	41.0	21.5	29.7	24.5
E	5.2	347	4.8	249	8.0	160	6.0	252
F	17.4	199	11.7	151	24.3	94.9	17.8	149
G	16.6	86.1	11.8	112	22.8	75.5	17.1	91.2
H	11.7	180	7.9	140	16.3	88	12.0	136
I	11.9	132	8.5	104	16.4	66.2	12.3	101
J	8.4	96.4	6.0	78.4	12.1	50.5	8.8	75.5

Plates

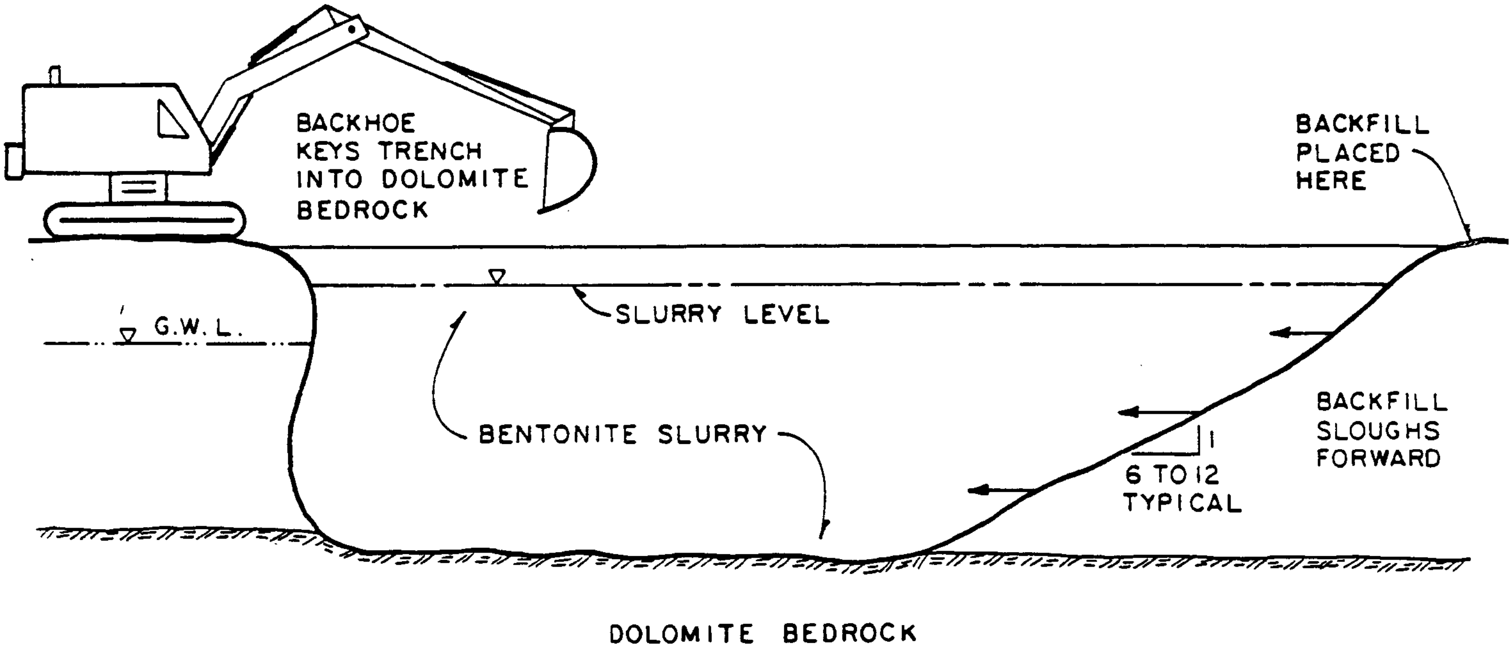


LOCATIONS OF REMEDIATION AREAS
NIAGARA PLANT
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

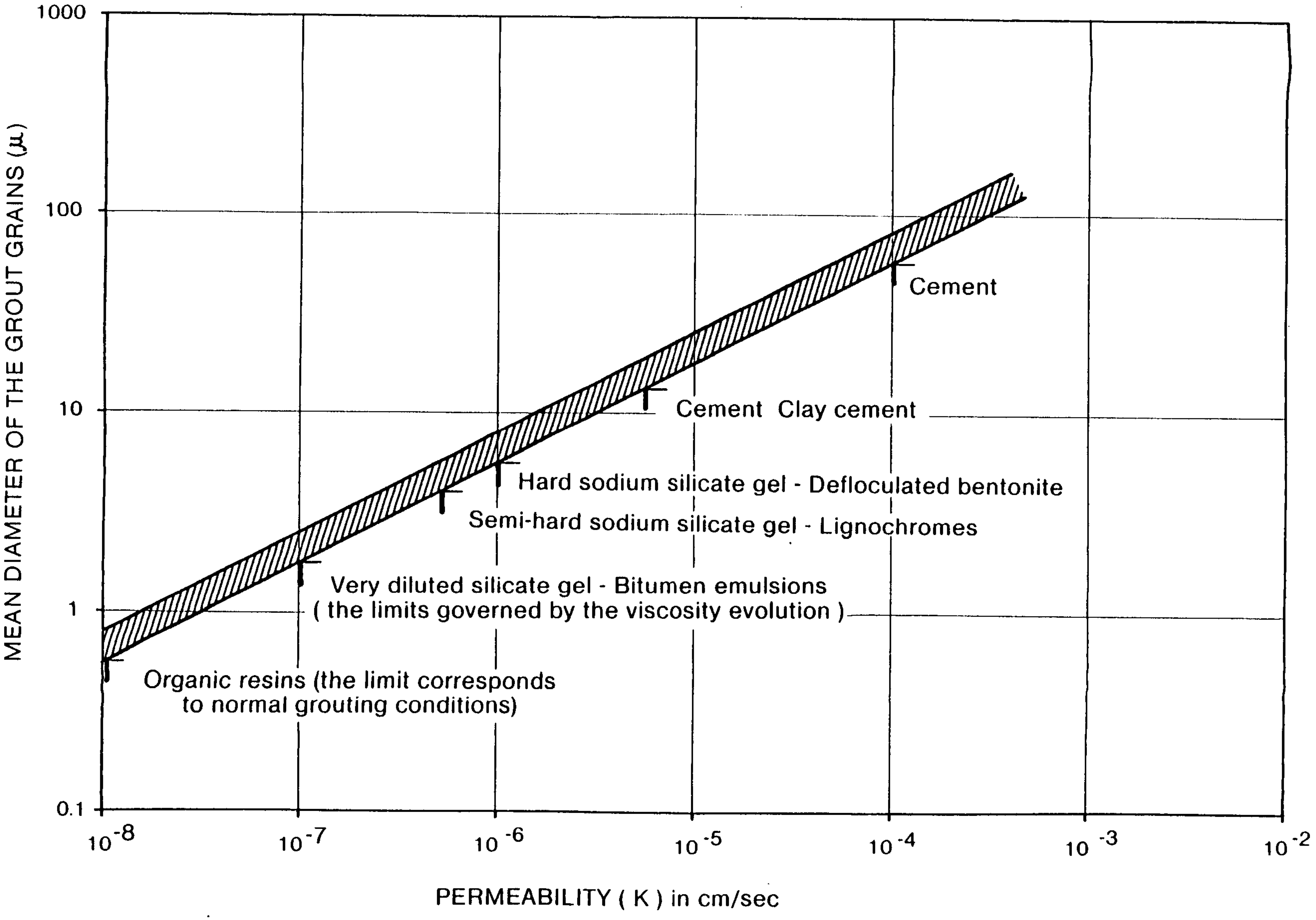
DRAWN BY: T.P.	SCALE in FEET 0 300	DATE: 3/30/84	
CHECKED: J.C.E.		JOB: 83C2236-7	

PLATE 1



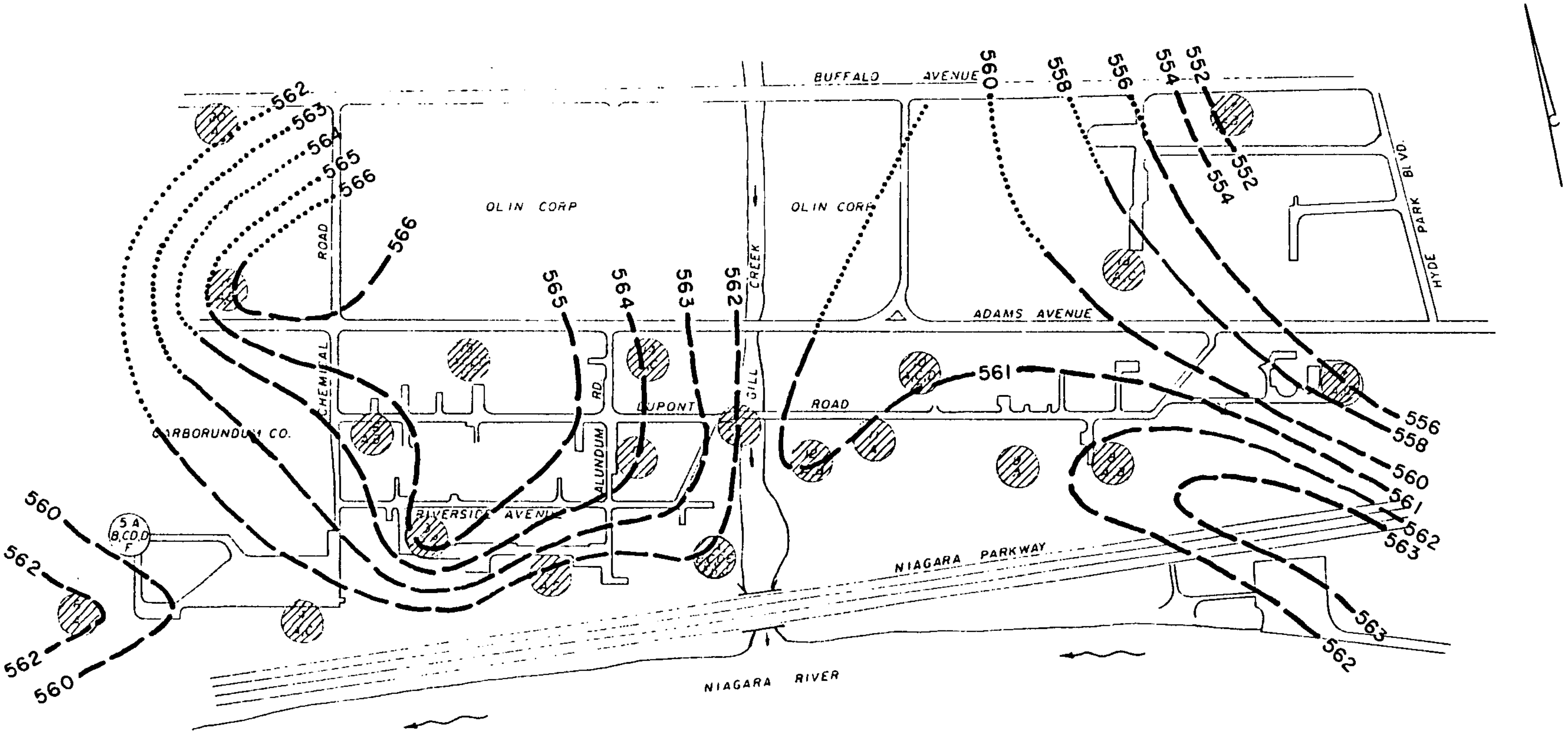
SCHEMATIC OF CUTOFF WALL CONSTRUCTION
DuPONT PLANT
NIAGARA FALLS, NEW YORK

PLATE 2



LIMIT OF INJECTABILITY OF GROUTS, BASED ON
THE PERMEABILITY OF SANDS AND GRAVELS
NIAGARA PLANT SITE
E.I. DUPONT DE NEMOURS & CO.

PLATE 3



DURING PUMPING TEST

OCTOBER 19, 1983, TIME ~ 1600

LEGEND:

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

WELL USED TO GENERATE CONTOUR MAP

561 GROUNDWATER ELEVATION

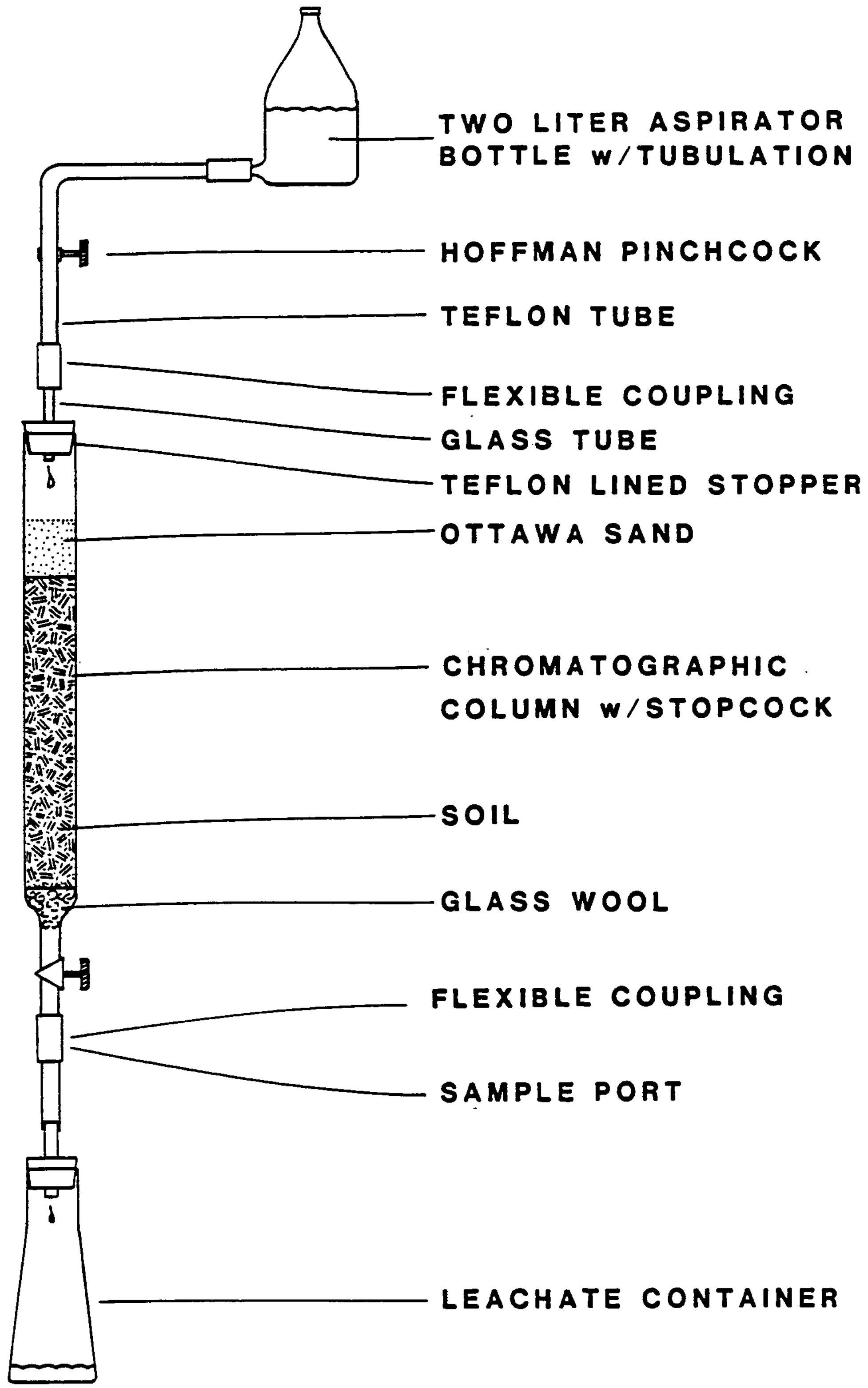
NOTE: GROUNDWATER CONTOURS HAVE BEEN INTERPOLATED BETWEEN DATA POINTS AND ACTUAL CONDITIONS CAN VARY FROM WHAT IS SHOWN.

A-ZONE GROUNDWATER CONTOURS
NIAGARA PLANT
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

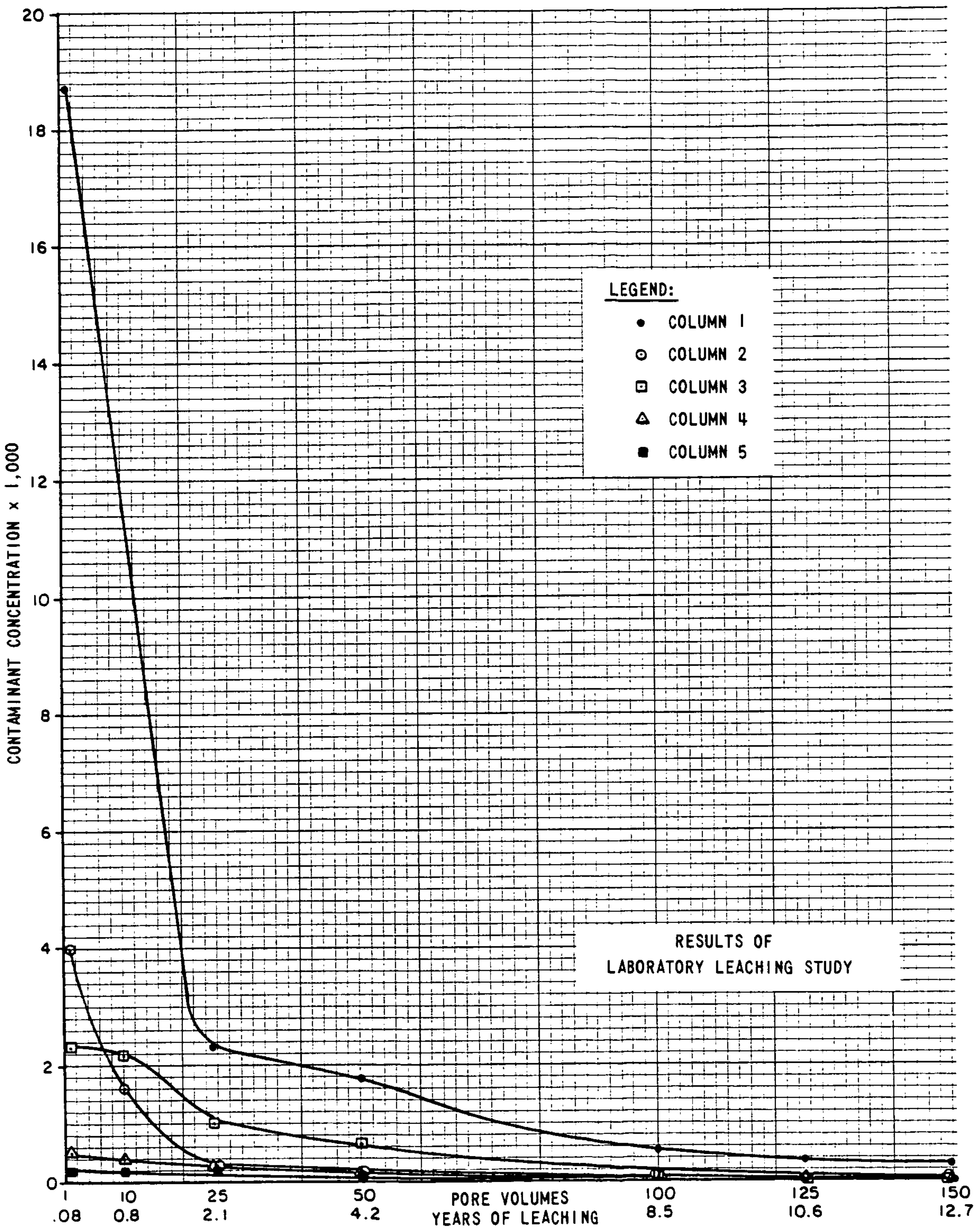
DRAWN BY: T.P.	SCALE in FEET	DATE:
CHECKED : J.C.E.	0 300	JOB : 83C2236

PLATE 4



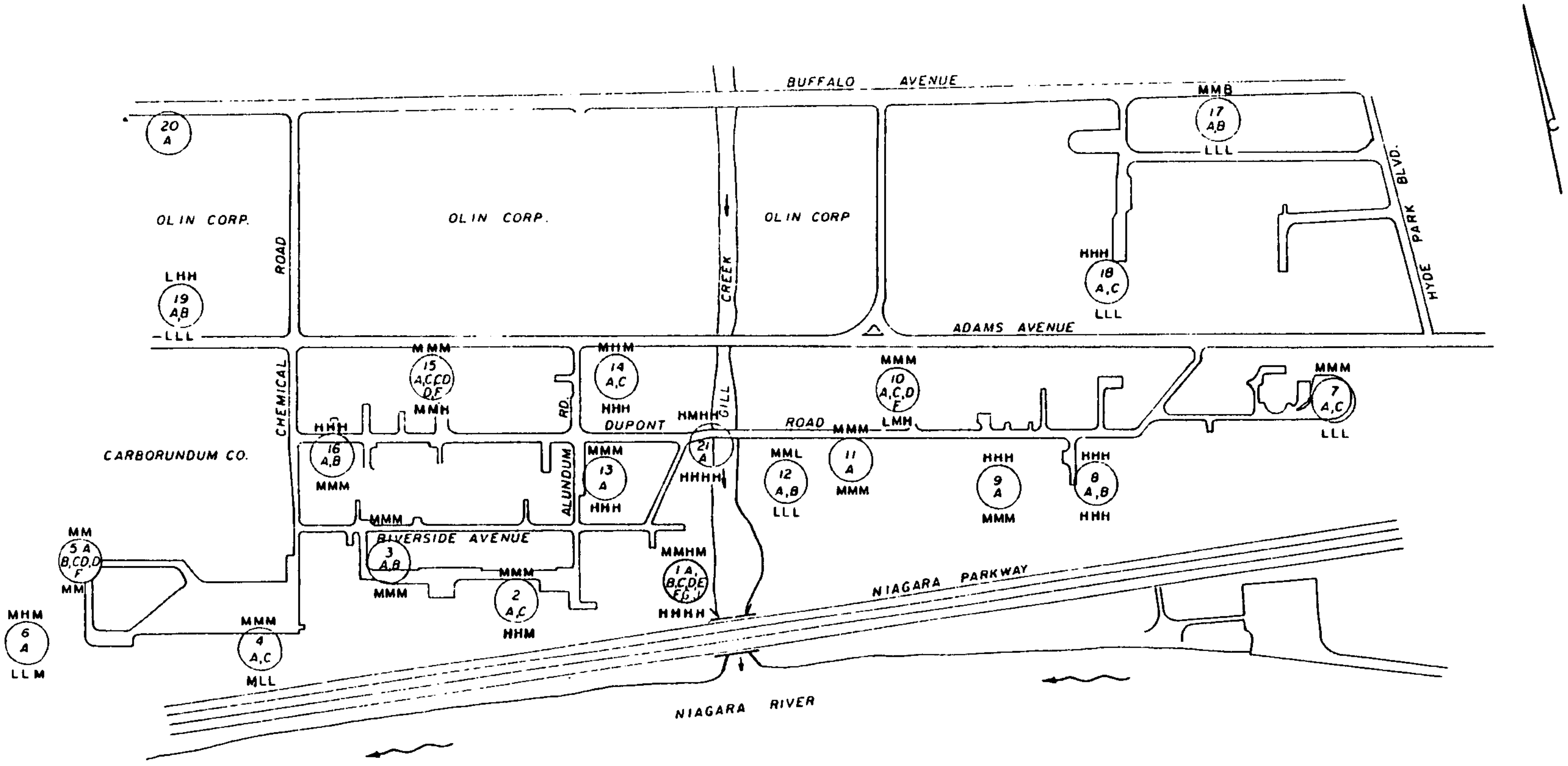
LEACHING STUDY LABORATORY CONFIGURATION
NIAGARA PLANT SITE
E.I. DUPONT DE NEMOURS & CO.

PLATE 5



TYPICAL SOIL FLUSHING DATA

PLATE 6



EXPLANATION

MMB — TOC LEVELS FOR JULY, SEPT., OCT.
17 A,B
000 — SUM LEVELS FOR JULY, SEPT., OCT.

H = HIGH
M = MODERATE
L = LOW

NOTE: WELLS 1 AND 21 ALSO HAVE DATA FOR JUNE

GENERAL LEVELS OF SUM AND TOC
AT INDIVIDUAL WELLS
NIAGARA PLANT
E. I. DUPONT DE NEMOURS & CO.

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIRONMENTAL SCIENTISTS

DRAWN BY: T.P.	SCALE in FEET 0 300	DATE: 3/22/84	
CHECKED : J.C.E.		JOB : 83C2236-7	

PLATE 7

#17