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Bell Aerospace TEXTRON

Bell Aerospace Textron
Division of Textron, Inc.

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September 25, 1990

Mr. Paul R. Counterman
Director, Bureau of Hazardous Waste
Facility Permitting
Division of Hazardous Substance Regulation
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NYSDEC
50 Wolf Road
Albany, NY 12233

Dear Mr. Counterman:

Please find enclosed the Neutralization Pond Project Draft Technical Review and Preliminary Analysis of Remedial Alternatives for Bell Aerospace Textron.

If you may have any questions regarding this report, please feel free to call me.

Very truly yours,

Brian D. Smith

Brian D. Smith
Divisional Environmental
Coordinator

BDS/bam

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Golder Associates Inc.
CONSULTING ENGINEERS

NEUTRALIZATION POND PROJECT
DRAFT
TECHNICAL REVIEW
AND
PRELIMINARY ANALYSIS
OF
REMEDIAL ALTERNATIVES

BELL AEROSPACE TEXTRON
WHEATFIELD PLANT
NIAGARA, NEW YORK

Submitted to:

Bell Aerospace Textron
2221 Niagara Falls Boulevard
Niagara, New York

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September 1990

Project No.: 893-6262

Golder Associates Inc.
CONSULTING ENGINEERS

September 18, 1990 Project No.: 883-6262

Bell Aerospace Textron
2221 Niagara Falls Boulevard
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Attn: Mr. Brian Smith

RE: NEUTRALIZATION POND PROJECT, DRAFT TECHNICAL REVIEW AND ANALYSIS OF REMEDIAL ALTERNATIVES

Gentlemen:

Please find enclosed the Draft Technical Review of Remedial Alternatives report.

If you have any questions, please call. Thank you for this opportunity to be of service.

Very truly yours,

GOLDER ASSOCIATES, INC.

Richard King

Richard C. F. King, P. Eng.
Associate

Enclosures

RCFK/kmf
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1.0 INTRODUCTION

A RCRA Facility Investigation (RFI) and Corrective Measures Study are being conducted at the Bell Aerospace Textron (BAT) Wheatfield Plant in the Town of Wheatfield, New York. The purpose of the investigation has been to:

1. Determine the nature and extent of organic compounds released from the Neutralization Pond Solid Waste Management Unit (SWMU). These compounds, which are predominantly chlorinated solvents, are known to occur in the overburden adjacent to the Neutralization Pond, in a Dense Non Aqueous Phase Liquid (DNAPL) plume and an associated dissolved phase plume within the upper bedrock;
2. Assess potential risks to public health; and,
3. Develop and evaluate possible and appropriate remedial action alternatives.

Previous reports prepared for BAT have discussed site history, site characteristics, and site and regional geology and hydrogeology and the nature and extent of groundwater contamination. Potentially applicable remedial technologies have now been identified and are reviewed in this report.

The following technical review and analysis briefly describes the results of past site investigations, (see Bibliography) identifies and evaluates applicable remedial technologies, and assembles a list of potential remedial alternatives. The Corrective Measures Study phase of this project will include a detailed evaluation of potential remedial alternatives in accordance with criteria specified in Resource Conservation And Recovery Act (RCRA) guidance document prepared by the United States Environmental Protection Agency (USEPA).

1.1 Purpose

The purpose of this report is to identify and review potential remedial action alternatives that will mitigate the organic solvents within the overburden and the DNAPL and dissolved-phase plumes within the Zone 1 aquifer. This review is being performed so that New York State Department of Environmental Conservation (NYSDEC) and USEPA can conduct a preliminary review and evaluation of the concepts proposed for remedial action.

The procedure, used herein, for evaluating applicable remedial technologies is in general accordance with EPA's Guidance for Conducting Remedial Investigations and Feasibility Studies under the Comprehensive Environmental Response Compensation and Liabilities Act (CERCLA), Interim Final, October 1988. While BAT has not yet completed a review of the proposed corrective action regulations published in Vol. 55 No. 145, Part II 55FR 30798 July 27, 1990, it appears that the proposed corrective action regulations are conceptually similar to the RI/FS process in the NCP. This report provides a qualitative analysis of the identified remedial options based upon engineering feasibility and potential effectiveness.

2.0 SITE BACKGROUND

Brief descriptions of BAT's Wheatfield Plant, its history, and regulatory setting are presented in this section. Detailed descriptions of previous investigations, geology, hydrogeology, and groundwater quality are presented in previous site investigation reports listed in the bibliography to this report.

2.1 Site Location and Description

The Neutralization Pond which is now closed (see Section 2.2), is located at BAT's Wheatfield Plant (See Figure 1). This facility is at the southeast corner of the Niagara Falls International Airport in the Town of Wheatfield, Niagara County, New York and is within the Niagara River drainage basin.

This section of Niagara County (see Figure 1) is nearly level with a very gentle southward slope. Much of the area in the vicinity of the closed Neutralization Pond is occupied by BAT buildings, paved roads or paved parking areas. The area north and west of the Pond consists largely of open grassed surfaces and the Niagara Falls International Airport paved runway and taxiway system.

To the east and south of the BAT Wheatfield Plant, the ground is composed of a clay plain that slopes gently southwards toward the Niagara River. Two creeks cross this clay plain from east to west; Bergholtz Creek and Sawyer Creek (see Figures 1 and 2).

Other structures in the immediate vicinity of the Neutralization Pond include the Rocket Test Cell buildings, administrative office buildings, and the Helicopter Blade

Bonding Building.1 These areas are bounded to the north by a Carborundum Abrasives Company plant and to the east by Walmore Road (see Figure 2).

2.2 Site History

BAT's Wheatfield Plant includes several areas which are either known or suspected to have managed hazardous wastes or hazardous waste constituents. The focus of this study is the identification of remediate alternatives for the chlorinated solvent plume (see Section 2.3) which was generated by leakage of solvents from the Neutralization Pond that was operated at the site between circa 1948 until 1984. This Pond, which is now closed, has been identified as the original source of chlorinated organic solvents (DNAPL) and dissolved-phase plumes detected within the overburden and underlying dolostone bedrock.

The Neutralization Pond was excavated within the overburden which comprises clayey silts, silty clays, and glacial till. The Pond received liquid wastes from the Rocket Test Cells and other areas of the Plant. Those liquid wastes probably included (Frontier Technology 1988) one or more of the following constituents:

Nitrogen tetroxide
Hydrazine
Monomethyl hydrazine
u-Dimethyl hydrazine
Sodium hydroxide
Potassium hydroxide
Isopropyl alcohol
Methylene chloride
Trichloroethylene
1,2-trans-dichloroethylene
Acetone
Polychlorinated Biphenols
Polycyclic Aromatic Hydrocarbons

---

1 Rocket Test Cell facilities are owned by ARC and are located at the plant site pursuant to a ground lease between BAT and ARC.

Pursuant to a NYSDEC consent order the Neutralization Pond was closed in 1987 by excavation to bedrock, and backfilling and capping with a clayey soil. A report regarding this closure was completed in 1988 (Frontier Technology 1988).

An initial report regarding the hydrogeologic conditions in the vicinity of the Pond was completed by Goldberg-Zoino and Associates, Inc. in 1982 (Goldberg Zoino 1982).

The hydrogeological conditions, including overburden geology, bedrock geology, and groundwater flow were discussed in a Golder Associates Phase I and II Interim Hydrogeological Report dated May 1987 (Golder 1987). The identification of chlorinated solvents in the groundwater both onsite and offsite was discussed in Golder Associates Phase III and IV Interim Reports dated July 1988 (Golder 1988) and August 1989 (Golder 1989), respectively. Additional offsite plume definition work (Phase V) has recently been completed and will be described in the RFI report currently being completed. Sections 2.3 and 2.4 provide summaries of the geology, hydrogeology and detected compounds associated with the site.

2.3 Summary of Geology and Hydrology

The overburden at the site is composed of low permeability glaciolacustrine silty clays overlying glacial till. These strata are about 18 feet thick at the Neutralization Pond. They thicken, to about 30 feet, at Jagow Road which is about one mile south of the Pond. The overburden is underlain by Zone 1 dolostone.

The Zone 1 dolostone is thinly bedded, relatively permeable and about 10 feet to 15 feet thick. Bedding planes within Zone 1 and particularly at the contact with the underlying

Zone 2 dolostone (the A Marker Bed) have been weathered out by partial dissolution of gypsum seams.

Beneath the Zone 1 bedrock an 8-foot thick confining layer of massive Zone 2 dolostone exists. This unit is considered to be an aquitard.

Beneath these two strata the 20 feet to 25 feet thick Zone 3 dolostone unit also forms an aquifer. Additional dolostone layers exist beneath these strata to a depth below surface of about 200 feet. The dolostones overlie the Rochester shale.

All these strata dip southwards very gently, as do the bedrock surface and ground surface.

Groundwater flow in the area between the BAT facilities and Jagow Road is generally southwards in the overburden and Zone 1 dolostone units. Locally, hydraulic gradients, between the overburden and Zone 1 bedrock strata, are influenced by the presence of sewer trenches in the overburden and bedrock. Prior to completing a pump test at the site in December 1989, it was considered that the sewer systems, located in the overburden adjacent to the east side of the BAT facility, caused upward gradients within the Zone 1 dolostone. This condition is now known to depend on the presence of storm runoff, or non-contact cooling water, from the rocket test cells in the ditch along Walmore Road. Water in this ditch can flow into the sewer trench backfill and hydraulically connect with the Zone 1 bedrock aquifer causing downward gradients.

To the south of Niagara Road, the hydraulic gradients appear to be downward between the overburden and the Zone 1 bedrock and between the upper and lower levels of Zone 1 bedrock.

2.4 Groundwater Chemistry

A series of hydrogeology studies completed at BAT's Wheatfield Plant have provided information regarding the extent and nature of chlorinated solvent contamination in groundwater and the overburden. Although one continuous plume, the groundwater plume is discussed herein as four plumes for convenience. These plumes which are considered to have originated at the now closed Neutralization Pond are:

1. A plume containing organic solvents within an area of overburden around the Neutralization Pond;
2. A Dense Non-Aqueous Phase Liquid (DNAPL) plume in the Zone 1 aquifer (uppermost bedrock strata) stretching about 750 feet to the southeast of the Neutralization Pond;
3. A plume containing dissolved solvents extending about 5,000 feet to the southeast of the Pond, roughly pear shaped, about 3,000 feet to 4,000 feet wide, also in the Zone 1 bedrock stratum; and,
4. A dissolved phase plume of limited extent in the Zone 3 bedrock stratum, beneath the DNAPL plume.

The locations of the Wheatfield Plant and the currently defined extent of the Zone 1 DNAPL, Zone 1 dissolved phase plume, and the overburden plume are shown in Figures 1 and 2.

Available groundwater chemistry data indicate that the Zone 2 dolostone stratum has prevented downward migration of DNAPL and restricted downward migration of the dissolved-phase solvent plume. A very limited dissolved phase plume of relatively low concentration is present in the Zone 3 dolostone strata directly beneath the Zone 1 DNAPL plume.

The DNAPL is predominantly composed of trichloroethylene (96 percent to 99 percent) with varying amounts of methylene chloride and acetone. Polycyclic aromatic hydrocarbon (PAH) compounds and polychlorinated biphenol (PCB) compounds have also been detected in the DNAPL plume. Table 1 provides a listing of compounds detected in the dissolved phase plume. This listing will be updated using the results of the full round sampling event when completed.

The DNAPL plume extends southeastwards from the Neutralization Pond for about 750 feet. It is about 150 feet wide and predominantly located at the base of Zone 1. In the vicinity of the Pond, which was the original source of the plume, DNAPL occurs above the base of the Zone 1 unit. With the closure of the Pond, any driving force, in the form of residual DNAPL in the base of the Pond, has been removed. Without a driving force, the DNAPL plume has probably stopped moving.

The dissolved-phase plume, which extends southwards from the Pond, is pear shaped, 5,000 feet long, and widens to about 4,000 feet. Based on the results of monitoring well sampling and analyses between the Fourth Quarter 1988 and the Third Quarter 1989, a series of compound concentration contours have been developed. These contour maps are provided in Figures 3 through 6 as follows:

Figure 3 - Methylene Chloride
Figure 4 - Trichloroethylene
Figure 5 - 1,2-Trans-Dichloroethylene
Figure 6 - Vinyl Chloride

It must be recognized that the constituent concentration values used to define these contours are based on sampling events from different time periods. The contours will be re-evaluated using the results of the recently completed (August 1990) full round sampling event which will include all the monitoring wells installed for the studies completed at the site.

The major organic chemical components of the dissolved phase plume, in the vicinity of the DNAPL plume, are trichloroethylene (TCE), methylene chloride and acetone. Away from the DNAPL plume the relative concentrations of compounds such as 1,2-trans-dichloroethylene and vinyl chloride tend to increase. This may be due to elevated detection limits for some of the analytes near the DNAPL plume, retardation, advection, adsorption and dispersion effects, changes in source chemistry, and/or anaerobic biodegradation of TCE, etc., to daughter products such as 1,2-trans dichloroethylene and vinyl chloride. This issue will be discussed in more detail by the RFI report.

Present information indicates that the Zone 1 dissolved phase plume south of Bergholtz Creek is located within the lower half of the Zone 1 stratum.

The Zone 3 dissolved phase plume is considered to be of limited extent and probably contained within the BAT property. Reported concentrations vary from 3,000 ug/l - 11,000 ug/l total solvents in well 87-13(3), located southeast of the Neutralization Pond, to nondetectable in well 89-2(3), located about 1,000 feet to the southeast. It should be noted that remediation of Zone 3 has not been addressed directly by this report. It is possible that remediation of Zone 3 may well occur due to remediation of Zone 1 as upward gradients move water slowly from the Zone

3 aquifer to the Zone 1 aquifer. Should remediation of Zone 3 be required, it is essential that downward gradients not be induced between contaminated sections of Zone 1 and Zone 3.

3.0 REGULATORY SETTING

3.1 Current Situation

BAT entered into a Consent Agreement with the NYSDEC (Case No. RCRA 85-010-9, Index No. 051485) to close the former Rocket Neutralization Pond at the Wheatfield, New York facility. A closure plan was submitted in July 1985 and the final plan was approved on October 8, 1986. The closure included excavation of the Neutralization Pond and backfilling and capping with clay-type material and seeding with grass. A report titled "Summary of Closure Activities and Closure Certification of Former Rocket Neutralization Pond" (Frontier Technical 1987) was submitted to BAT and NYSDEC in June 1988 and was subsequently approved by NYSDEC.

Since BAT could not complete a "clean" closure of the Neutralization Pond because of the groundwater contamination, BAT is still required to obtain a 6NYCRR Part 373-2 and HSWA Post-Closure Permit for the unit.

4.0 POTENTIAL REMEDIAL ALTERNATIVES

4.1 General

The criteria for identifying and reviewing remedial technologies and remedial alternatives are discussed in this Section. The potentially applicable remedial technologies have been qualitatively evaluated on the basis of engineering feasibility and probable effectiveness.

Alternatives that are not feasible from an engineering viewpoint for the given site conditions or do not reliably address the problem will not be considered further. Similarly, alternatives that do not effectively protect public health and the environment or have adverse effects with little environmental benefit, and those alternatives that far exceed the costs of other potential alternatives but which do not provide either substantially greater benefits, or are less technically reliable (e.g., grout curtains around dissolved phase plume), will not be considered further.

4.2 Remedial Action Objectives

Remedial action objectives will be determined by reference to all applicable statutory and regulatory requirements. In general, corrective action requirements are set out in Sections 3004 (u) and (v) of the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), and Subpart F of 40 CFR Part 264. In addition, USEPA is in the process of promulgating corrective action standards as required by RCRA Section 3004 (u).

For the purposes of this report, remedial alternatives are evaluated on the basis of demonstrated or expected levels of treatment. Those with higher levels of demonstrated or expected remediation will be evaluated further. Those alternatives which do not have significant demonstrated or expected levels of treatment will not be evaluated further.

As part of the Corrective Measures Study for this site, specific remedial action objectives will be proposed and the pre-reviewed remedial alternatives will be evaluated again with respect to such remedial action objectives along with other appropriate factors.

4.2.1 General Goals

For the purpose of this report, the greatest risk of exposure will be assumed to be from the organic solvent plume within the overburden and the DNAPL and dissolved-phase plumes within the Zone 1 groundwater. To provide an overview of current knowledge regarding remediation of DNAPL, Stanley Feenstra, of Applied Groundwater Research, was requested to complete a review of known technologies for DNAPL cleanup. This review is presented in Appendix A.

Mr. Feenstra's review concluded that it is not now possible to completely remove DNAPL from the subsurface in much the same way as it is not possible to remove 100 percent of the oil from an oil field. Since small amounts of residual DNAPL can result in the potential for a very large dissolved phase plume to redevelop after "remediation" by partial DNAPL removal, complete removal of DNAPL is not considered to be a remedial alternative. ✓

Consequently, the following general remediation criteria have been developed to evaluate, control and/or mitigate exposure to these plumes:

1. Restrict off-property migration of organic solvents from the overburden plume;

2. Reduce the concentration of organic solvents within the overburden, especially within the vadose zone;
3. Restrict migration of the DNAPL plume;
4. Reduce the amount of the DNAPL and the DNAPL head in the Zone 1 DNAPL plume (see below);
5. Control continued development and off property migration of the Zone 1 dissolved-phase plume; and,
6. Reduce the concentration of hazardous organic compounds within the Zone 1 dissolved-phase plume both on and off BAT property to acceptable State and Federal levels.

4.2.2 Cleanup Levels

As discussed in Section 4.2, USEPA is in the process of promulgating corrective action standards as required by RCRA Section 3004 (u).

The remedial alternatives considered by this report to be potentially applicable will be reassessed during the Corrective Measures Study to determine their ability to meet the cleanup goals defined by corrective action standards.

4.3 Appropriate Remedial Actions

Appropriate remedial actions are considered to be those which will reduce the potential for migration of and exposure to, the overburden and groundwater plumes. The following actions are generally appropriate for meeting the previously discussed criteria:

1. Minimal/No Action - institutional actions and other methods for reducing exposure to onsite and offsite hazards;
2. Removal - excavate impacted materials for disposal or treatment;

3. Containment - physically isolate groundwater or DNAPL plumes to reduce migration and minimize potential exposure;

4. Extraction - withdraw groundwater or DNAPL plumes from the aquifer for disposal or treatment;

5. Treatment - destroy, degrade, transform, or immobilize hazardous compounds; and,

6. Disposal/discharge - transport, manage, or treat removed or extracted wastes at an appropriate facility.

Item 5 (treatment) can take the form of an in-situ treatment technology or form part of a remedial alternative with extraction technology. Similarly, Item 6 (disposal/discharge) forms an action after extraction and treatment technologies have been used for remediation. Table 2 provides a description of the available options and/or technologies for remediation and indicates the rationale for selection or rejection of an option. Table 2 also identifies the presently preferred remedial options. These options will be studied in more detail during the Corrective Measures Study. Brief descriptions of the remedial options are provided below. More detailed discussions regarding the potential remedial options for the DNAPL plume are provided in Appendix A.

4.3.1 Minimal/No Action

Minimal/no action technologies are those that neither treat nor remove hazardous substances, but limit the potential for contact or exposure to the contaminated plumes. Potential technologies applicable to the Neutralization Pond plumes include limiting site access with fencing and other security measures (already in existence), limiting land and groundwater use through deed restrictions, local laws or construction moratoriums (maximum depth of service trenches, etc.), and closure of privately owned groundwater wells in the vicinity of the BAT facility. These responses have been retained as potentially applicable actions since:

1. It is not considered possible to remove the overburden plume without demolition of part of the facility. This would result in the potential for exposure to workers involved in incursive activities such as trenching and maintenance of services;
2. The Zone 1 DNAPL plume cannot be entirely removed; and,
3. The remediation of the dissolved phase plumes will probably take several years, during which time there is a potential for extraction of the groundwater at offsite locations for irrigation purposes or other uses.

BAT has already completed the following steps, as interim measures, to reduce the potential for exposure:

1. Attempted to identify and locate every well on every property within an area that includes the Zone 1 dissolved phase plume;
2. Decommissioned all private, offsite wells for which permission has been obtained; and,
3. Requested that the Town of Wheatfield adopt a local law which restricts the installation of groundwater extraction wells within the plume area or within an area within which extraction wells could influence the migration of the plume.

4.3.2 Removal

Since the overburden plumes and Zone 1 DNAPL plumes act as potential sources for the Zone 1 and Zone 3 dissolved phase plumes and since these potential sources are relatively shallow (less than 30 feet below surface) the excavation of these plumes is considered as a potential remedial alternative.

4.3.2.1 Overburden Excavation

Excavation of the overburden is considered to be technically feasible by using backhoe equipment after demolition and excavation of structures (Rocket Test Cells, etc.) and roads above the overburden plume area. During excavation a high health risk may develop due to solvents volatilizing from the overburden and contaminated groundwater seepage. This volatilization could be controlled by the use of suppressants such as foam. Excavation of the materials would result in the generation of a large volume of material requiring determination of its classification as hazardous waste and determining the requirement for treatment prior to disposal. Given the presence of relatively high levels of organic constituents in the lower zones of the overburden and the potential for PCB's to be associated with any residual DNAPL in the lower overburden, it is probable that some of the overburden would not be acceptable for direct landfilling in a RCRA hazardous waste landfill and would require incineration or treatment onsite prior to land disposal.

Though it is feasible to excavate the overburden, it has been rejected as a remedial technology for the following reasons:

1. Excavation would result in a higher though temporary risk of exposure for workers and the local population;

2. A considerable amount of waste would be generated with incineration being the only probable option for treatment before land disposal;

3. Excavation would require demolition of the Rocket Test Cell facilities; and,

4. The movement of solvents and dissolved solvents through the overburden has either ceased (due to the original source being removed) or is very

slow (the overburden has a very low permeability), and the resultant exposure of the environment to the solvents in the overburden is considered to be low.

Moreover, as discussed in Appendix A and below, it is not considered possible to fully remove or completely "treat in-situ" the DNAPL. It will be necessary, therefore, to contain the DNAPL plume in perpetuity (or at least until some technically feasible option is developed). Since the overburden plume is predominantly located above the DNAPL plume, it is considered feasible to control the DNAPL plume and if necessary the overburden plume with a containment system such as a slurry wall (or sheet pile wall) in the overburden and a grout curtain or intersecting soldier pile wall in the Zone 1 bedrock.

4.3.2.2 DNAPL Plume Excavation

Excavation of the DNAPL plume would be possible after excavation of the overburden (both contaminated and non-contaminated sections). Though excavation of Zone 1 bedrock could be accomplished by the use of blasting, this activity could fracture the Zone 2 aquitard beneath Zone 1 resulting in the potential for migration of DNAPL into Zone 2 and Zone 3. As discussed in Appendix A even though a strong upward gradient would be present, from Zone 3 to Zone 1, due to dewatering Zone 1, this hydraulic gradient would not necessarily prevent downward migration of the DNAPL.

Alternative rock breaking methods which would not disrupt Zone 2 include:

1. Expansive rock fracturing products; (e.g., Bristar);
2. Pneumatic rock breaking; and,
3. Hydraulic rock breakers; (i.e., Hoe Rams).

Expansive rock fracturing products are generally used for very small scale excavations in rock and are used in situations where no vibration is permissible. They are used by drilling a series of holes in the rock into which the compounds are added. Subsequent expansion of the product splits the rock. These compounds may be intrinsically hazardous and are also extremely expensive.

The use of pneumatic or hydraulic rock breaking equipment is considered possible since the dominant fracturing system, the horizontal bedding planes, are spaced less than about one foot apart in the Zone 1 bedrock and the uniaxial compressive strength of the rock is about 15,000 psi to 25,000 psi. Hydraulic Hoe Ram hammers, rather than compressed air hammers, would be the more effective rock breaking equipment due to higher impact values and greater energy efficiency of such equipment.

Excavation of bedrock in the DNAPL plume area would generate a large volume of rock waste (over 1,000,000 cubic feet) contaminated with DNAPL and dissolved phase chlorinated solvents. Since the DNAPL is composed of chlorinated solvents and also contains PCB's, it may not be acceptable for landfilling under RCRA and/or TSCA and would, therefore, require pre-treatment, probably by incineration, prior to land disposal of the treatment residual.

During excavation considerable quantities of contaminated groundwater would require pumping and treating to maintain a relatively dry excavated area, and/or a grout curtain seepage barrier. To mitigate potential exposure of the workers and surrounding population, a suppressant foam would be required to minimize volatilization of the solvents.

Though technically feasible, the excavation of the Zone 1 DNAPL phase is rejected for the following reasons:

1. The reasons listed for the overburden plume;
2. Groundwater control in the bedrock would be more technically challenging than for the overburden requiring a grout curtain (this could be used as a primary remedial technology in itself without excavating the bedrock);
3. Excavation of Walmore Road would be required and would entail relocation of two major sewer lines and service utilities, etc.;
4. Excavation would be slow with a resultant increase in potential exposure to the public;
5. Treatment of the excavated bedrock would be very slow; and,
6. Disposal of the treated bedrock would be extremely expensive.

4.3.3 Containment

Containment technologies include methods for physically isolating the hazardous substances from environmentally sensitive media. Methods include caps, cutoff walls, and hydraulic control.

4.3.3.1 Capping

A cap is a low-permeability cover used over a contaminated area to restrict infiltration of precipitation and control surface water runon and runoff. This action reduces the potential for development of a dissolved phase plume by altering the subsurface flow regime. Caps are typically constructed of synthetic e.g., high density polyethylene, asphalt, etc. and/or clay materials.

Capping is potentially feasible for the overburden plume area. It should, however, be noted that the low permeability overburden already acts as a natural cap to the DNAPL and dissolved phase plumes.

Capping could possibly result in a slight reduction of infiltration and a resultant decrease in the generation of dissolved phase plume within the overburden. The following points are noted:

1. Some of the overburden plume area is already covered by asphalt in the parking lot south of the access road from Walmore Road to the ARC rocket test facility;
2. The overburden already has low permeability;
3. Capping would not prevent horizontal flow of groundwater through the overburden from the surrounding area; and,
4. Capping would not reduce the potential for exposure of workers servicing shallow sewer systems or telephone lines etc... and may even increase the potential for this effect.

Additional capping of the overburden plume are a is rejected ← since it would not markedly enhance the present condition the as noted above. Capping of the Zone 1 DNAPL and dissolved phase plumes is rejected since the overburden effectively achieves this already.

4.3.3.2 Cutoff Walls/Hydraulic Containment

Since both the overburden and DNAPL plumes would not be effectively or completely remediated by removal or in-situ treatment, and since both plumes have the potential to generate considerable quantities of dissolved phase plume by predominantly horizontal groundwater flow, containment technologies offer an appropriate remedial response for these plumes. These containment systems fall into three categories: ✓

1. Modification of in-situ materials;
2. In-situ construction of a low permeability barrier wall; and,
3. Development of a hydraulic barrier.

Cutoff walls are vertical barriers with a low hydraulic conductivity (10^{-5} cm/sec or less). Cutoff walls can be constructed to enclose a plume or can be constructed up or downgradient of a plume to change the hydraulic regime around a source or plume. Cutoff wall options include:

1. ✓Intersecting soldier pile walls;
2. N? Freeze walls;
3. ✓Slurry walls;
4. ✓Permeable slurry walls; and
5. ✓Grout curtains.

An intersecting soldier pile wall consists of parallel vertical, bored or drilled, intersecting holes that are subsequently backfilled with tremmied grout or concrete. The resultant wall acts as a low permeability barrier to horizontal migration of groundwater or DNAPL. ✓ An intersecting soldier pile wall would be potentially applicable to the overburden plume or DNAPL plume. This technology will ~~be~~ considered in the Corrective Measures Study.

A freeze wall consists of closely spaced low temperature brine recirculation pipes that freeze the groundwater to form a vertical barrier of frozen groundwater. Freeze walls are usually emergency response barriers or short-term construction systems for shafts or similar excavated structures. Though extremely effective, any frozen barrier would have to be maintained year round. Since freeze walls are designed to be used on a short term, temporary basis, they have been rejected. ✓

A slurry wall consists of a low permeability slurry usually of bentonite clay and soil in a trench. Slurry walls are routinely completed in soil for groundwater control for civil engineering projects. Slurry walls are constructed by excavating a trench in the overburden to a low permeability geologic layer and maintaining the stability of the trench by keeping it filled with a dense thixotropic soil/bentonite clay slurry mixture. It should be noted, however, that the overburden is already known to have a very low hydraulic conductivity. Further reduction of horizontal movement of groundwater through the overburden may be unwarranted. Although slurry walls are commonly constructed in soils with much higher permeabilities than the soil at the BAT site, this option will be retained for further review in the Corrective Measures Study. ✓

Slurry walls can be constructed in bedrock by using a hydrofraz. This equipment consists of a heavy narrow steel box that encloses hydraulic motors which drive rotating cutting drums. The hydrofraz is lowered into the bedrock by a crane until it has cut a trench to the required depth. Cuttings are removed by circulating drilling mud in the trench. Presently available (world-wide) hydrofraz equipment is limited to excavation of rock material with a uniaxial strength of less than about 15,000 psi. The dolostones at BAT have compressive strengths in the range of 15,000 psi to 25,000 psi. Moreover, the dolostone includes the mineral dolomite which is relatively abrasive.

With currently available hydrofraz equipment, it is not considered possible to construct a slurry wall in the Zone 1 bedrock and this option is presently rejected.

A permeable slurry wall consists of a trench filled with graded permeable (granular) material with a drainage system at the base of the trench. The wall effectively forms a groundwater collection trench. By pumping collected water from the trench, lateral migration of groundwater past the trench is controlled. Construction of such a trench is technically more complex than for bentonite slurry walls in that it requires the support of the excavated trench by a degradable starch slurry. This slurry is then backfilled by a drain system and granular backfill. The remaining starch slurry in the backfill pore space subsequently degrades leaving a permeable trench backfill. These systems, while effective, require maintenance to ensure that the drain system at the base of the trench does not clog. This remedial technology will be retained for evaluation in the Corrective Measures Study.

A grout curtain consists of cementitious grout with minor amounts of bentonite, which is injected into the bedrock to infill the fractures within the rock mass and hence reduce the flow of groundwater through the bedrock. A grout curtain acts as a barrier to groundwater flow and would serve to control the migration of the DNAPL and the generation and migration of contaminated groundwater. A grout curtain also allows the hydraulic head within a grout containment box to be controlled more easily.

Since the construction of a grout curtain is an accepted method for reducing groundwater flow through bedrock it is viewed as a prime candidate for controlling the DNAPL plume. It should be noted, however, that cementitious grout with bentonite additives can result in reductions of hydraulic conductivity to about 10^{-5} cm/sec. Further reductions usually rely on the use of non-cementitious grouts which may be classed as intrinsically hazardous and would likely be rejected for use in a grout curtain by the NYSDEC or USEPA. Consequently, some leakage through a grout curtain must be anticipated. Grout curtains will be evaluated in the Corrective Measures Study.

A grout curtain for the control of the offsite dissolved phase plume is rejected. Though it is feasible to construct such a control measure, it would not prevent extraction of the contaminated groundwater contained within the grout curtain and is, therefore, not protective of human health. This technology is therefore rejected for control of the offsite dissolved phase plume. ?

As a general rule, the addition of cement to the subsurface regime can elevate the pH of the groundwater. Similarly, colloidal bentonite clay may increase the amount of solids suspended in groundwater pumped from the vicinity of the grout curtain or other cutoff walls. These issues must be addressed in the design of the treatment plant for pumped groundwater. ✓

Containment systems could also take the form of a groundwater pumping system used within the plume area to locally reverse the hydraulic gradient within Zone 1 and to ensure strong upward hydraulic gradients across the Zone 2 bedrock strata, thus controlling the movement of the plume. ✓ The pumped groundwater would require treatment prior to release to a POTW or surface water body. This option will be retained for further study in the Corrective Measures Study.

During the pump test completed adjacent to the DNAPL plume and dissolved phase plume, it became apparent that discharge of non contact cooling water from the Rocket Test Cells to the drainage ditch along Walmore Road results in significant pressure changes in the Zone 1 aquifer. The water in the ditch infiltrates into the granular backfill in the adjacent sewer trench. It is believed that the invert of the sanitary sewer trench is close to the bedrock surface. Observations of water flowing in the drainage ditch indicate the potential for at least several gallons of water per minute, of either storm water and/or non contact-cooling water from rocket testing, to seep into the sewer trench backfill and increase the hydraulic pressure in the Zone 1 bedrock. It is also known that a considerable quantity of water flows in the backfill of the sanitary sewer along Walmore Road. It is believed that no clay stops were installed in this trench when the sewer line was constructed.

These flows of water in the sewer trench backfill probably influence the movement and the development of the dissolved phase groundwater plume in Zone 1. Additionally, when the flows of water from runoff and rocket testing cease, the water levels in the overburden and water pressure in the Zone 1 bedrock are higher than in the sanitary sewer and storm drain trenches for some periods of time. This condition results in the potential for seepage from the overburden and bedrock to the backfill of the trench. No contamination has been detected to date within the sewer trench backfill, possibly as a result of dilution.

To restrict these flows of water within the trench backfill, clay stops could be installed in the trenches at the upstream and downstream locations of the Zone 1 DNAPL and overburden containment systems. Additionally, piping of the discharge from the rocket testing facility to the sewer pipe and lining of the drainage ditches to prevent storm water infiltration would assist in hydraulically isolating the Zone 1 bedrock and overburden. These measures will be evaluated in the Corrective Measures Study.

4.3.3.3 Extraction

Extraction technologies involve pumping from interceptor trenches or extraction wells to capture groundwater and control groundwater flow. Trenches or wells can be placed within or downgradient from a dissolved phase plume to form a capture zone surrounding the wells.

Since the overburden has a low hydraulic conductivity, removal of contaminated groundwater from the overburden plume may be slow or virtually impossible. Enhancement of the hydraulic conductivity could be achieved by the use of wick drains or sand drains. These would be installed vertically, to bedrock, and the upper section plugged to reduce vapor loss. Since the preferred option for control of the Zone 1 DNAPL area is containment and/or hydraulic control by pumping this process would also induce a downward flow of groundwater from the overburden plume, via the vertical drains. It should be noted that the reduction of the water level in the overburden by "dewatering" could cause differential settlement in the clays due to consolidation. Enhancement of the vertical permeability of the overburden will be considered in the Corrective Measures Study.

Extraction of the Zone 1 dissolved phase plume, both on and offsite, by the use of extraction wells constitutes the most likely remedial option. This option will be considered in the Corrective Measures Study.

As discussed in Appendix A, total extraction of the DNAPL by hydraulic or other means is not considered feasible. However, control of the DNAPL plume by pumping from wells, or the use of wells and a grout curtain containment system, may induce some of the DNAPL to flow to the wells. This DNAPL could be removed from the wells by the use of bottom purging pumps or removed from the pumped liquid by phase separation prior to treatment of the groundwater. The treated groundwater would be discharged to a POTW.

4.3.3.4 Treatment

Treatment technologies can be applied to either in-place materials or to removed materials. In-situ treatment could consist of steam-injection/extraction, hydraulic recovery with air stripping or carbon adsorption, biologic treatment or in-situ vitrification of the overburden. Other combinations of these technologies may also be applicable. Appendix A discusses currently available methodologies for in-situ treatment of DNAPL prior to extraction. This review indicates that the DNAPL within the bedrock cannot be effectively treated in-situ.

4.3.3.5 In-Situ Steam Injection/Vapor Extraction/Biological Degradation

This process uses steam flooding to increase the temperature of a contaminated zone to vaporize the volatile compounds. The steam and volatiles are recovered with a vacuum-enhanced vapor recovery system. The recovered vapors are treated using either carbon adsorption, condensation or other techniques to separate the steam-solvent phases. This option is rejected for remediation of the overburden due to permeability consideration and the presence of structures which limit equipment access. This option has also been rejected for use in the Zone 1 DNAPL plume because it has the potential to drive the solvent vapors into the overlying overburden where they would condense and be even more difficult to remove.

In-situ airstripping of the overburden, sometimes referred to as sparging, involves blowing air through the overburden and causing volatilization of the solvents. This process is rejected for the remediation of the overburden because of the low permeability of the overburden soils. This process is also rejected for use in the bedrock due to permeability considerations and the potential to cause mobilization of DNAPL into the overburden or Zone 3, or both.

In-situ vitrification utilizes intense electric currents to heat, melt, and solidify the overburden materials. The resultant glassy slag would be inert. This option is rejected because:

1. The infrastructure (large massive concrete Rocket Test Cells) would be in the way of the equipment;
2. It is considered to be somewhat pointless to remediate only part of the overburden where the underlying bedrock is still contaminated; and,
3. The process is not cost effective with high moisture content soils or high groundwater levels such as those at the BAT site.

In-situ biologic degradation utilizes either naturally occurring micro-organisms or the introduction of specialized species. In either case, the organisms (bacteria) are encouraged to utilize the organic contaminants directly or indirectly for food. Typically, an in-situ system requires injection and extraction wells to allow introduction of the bacteria and food, and for extraction of groundwater to stimulate migration.

No known bacteria degrade DNAPL. Bacteria can impact dissolved phase chlorinated solvents. Circumstantial evidence suggests the presence of organisms in Zone 1 that can degrade trichloroethylene to 1,2-trans-dichoroethylene. However, the size of the Zone 1 dissolved phase plume, the lack of access (much of the land is privately owned) and the general reducing environment within the aquifer preclude the use of in-situ biodegradation. The use of this process has been rejected for further consideration.

4.3.3.6 Treatment

The review of the potential remedial options, as discussed above, strongly indicates that the main components of the selected remedial system at BAT will involve extraction and treatment of groundwater. To determine the appropriate treatment technologies for the extracted groundwater, BAT retained the services of Resource Technology Group of Denver, Colorado. This company has completed preliminary studies of the treatability of groundwater from the dissolved phase plume. The work completed to date includes:

1. A pilot test of air stripping and carbon adsorption on a 12,000 gallon sample of groundwater obtained during the pumping test completed adjacent to the DNAPL zone;
2. Equilibrium Carbon Adsorption Testing;
3. Dynamic Multiple Carbon Column Testing;
4. Ultra violet/oxidation testing (completed by Perioxidation Systems Inc.); and,
5. Development of a preliminary Plant Process Flow Sheet

These studies indicate that the treatment methods for pumped groundwater should be split into two components consisting of:

1. Onsite treatment of groundwater extracted from the DNAPL plume and co-mingled with the groundwater extracted from the onsite dissolved phase plume; and,
2. Treatment of dissolved phase groundwater extracted from the offsite plume.

The most effective components for onsite treatment were determined to be:

1. A phase separator to remove DNAPL;
2. Particulate filters to remove solids such as clay etc and prevent fouling of carbon adsorption units;
3. Two air strip towers in series, with the discharge from the primary airstrip column routed to an off-gas treatment system and discharge from the secondary air strip tower to the atmosphere;
4. Treatment of off-gas from the primary airstrip tower includes a thermal oxidation system followed by a quench and absorption chamber; and,
5. Polishing the water, discharged from the air strip towers, by two, in series, carbon adsorption units prior to discharge to the POTW.

Figure 7 presents the preliminary flow system for the onsite treatment system. This treatment plant could be located above the containment sump in the Helicopter Blade Bonding building.

The offsite treatment system is based on the destruction of the chlorinated compounds in the extracted groundwater using a UV oxidation plant prior to discharge to the POTW. UV oxidation treatment plants have the advantage of destroying either all, or a considerable portion, of the organic compounds within the extracted groundwater. The plant selected would be either an LC30 or LC60 Peroxidation Systems Plant. This equipment could be housed in a building located south of Bergholtz Creek.

Figure 8 shows the layout of the components of the most likely remediation system and treatment plants.

4.3.3.7 Ancillary Actions

An ancillary activity to any remediation alternative will include groundwater monitoring. Groundwater monitoring will be used to evaluate the effectiveness of the remedial alternative selected for cleanup.

5.0 APPLICABLE REMEDIAL TECHNOLOGIES

Remedial technologies reviewed have been used to identify those that are most appropriate for the given site conditions. More detailed evaluations of the preferred remedial options will be performed during the Corrective Measures Study.

Table 2 provides descriptions of the potential remedial alternatives and technologies reviewed for this study. The following sections describe the remedial alternatives considered most appropriate and effective. These alternatives will be considered in detail by the Corrective Measures Study. Figure 8 provides the location of the remedial alternatives proposed by this review.

5.1 Minimal/No Action

For baseline comparisons, a no action alternative must be considered. For this no action option, no activity would be implemented that would mitigate public or environmental exposures to the organic compounds in either the overburden or the Zone 1 aquifer. This lack of action would result in continued migration of the dissolved phase organic compounds and possible further migration of the DNAPL plume.

Minimal actions would consist of actions such as site security (already in place), decommissioning of private wells within the vicinity of and adjacent to the dissolved phase plume (recently completed where permission has been obtained), and institutional measures, such as restrictions on groundwater usage and building moratoriums to limit site development. Deed restrictions may be required for any parcel of land that is currently owned by BAT which may be sold or leased in the future.

5.2 Applicable Remedial Alternatives

5.2.1 Overburden Plume

Remedial actions remaining after preliminary screening include:

1. Institutional actions;
2. Interceptor/containment systems; and
3. Infiltration reductions.

5.2.1.1 Institutional Actions

Since removal of the overburden phase is not considered feasible due to the presence of complex structures, other infrastructure, increased risk, and preferable alternatives, institutional actions to prevent risk to future land users will be developed. These actions include:

1. Restriction of invasive actions and the installation of wells; and,
2. Access restrictions.

5.2.1.2 Interceptor/Containment Systems

To control lateral migration of contaminants the use of interceptor trenches around the area of overburden contamination will be evaluated and compared with control by a slurry wall or sheet pile wall. In addition, vertical permeability enhancement by the use of sand or wick drains in the overburden will be considered.

5.2.1.3 Infiltration Reduction

Several sections of the area overlying the overburden plume are already effectively capped by the asphalt used for the parking lots and access roads. Additional capping requirements will be reviewed. Additional capping of more of the area above the overburden plume to potentially reduce infiltration further is presently not viewed favorably since downward percolation of precipitation, through the uncapped overburden will tend to flush the vadose zone of solvent vapors and reduce the risk for workers involved in construction activities for shallow sewers etc. Similarly, as discussed in Section 4.3.3.3, it may be possible to use wick or sand drains to enhance downward migration of contaminants from the overburden to the underlying partially depressurized Zone 1 DNAPL area.

It is known that a considerable quantity of water flows in the backfill of the sanitary sewer which runs along the west side of Walmore Road. Seepage from the overburden to the sanitary sewer trench may also be occurring. To date, no contamination in the sanitary sewer trench backfill has been detected. Additionally, it is now known that surface water, from rainfall runoff and non-contact cooling water from the rocket testing facility, enters the sanitary sewer trench backfill and influences the groundwater pressure in Zone 1. This process may well be causing movement of the plume. To prevent this process and reduce the potential for movement of groundwater in the sanitary sewer trench backfill and the adjacent storm drain trench, the preferred remedial option should include clay stops in the trenches and capping of the trench backfill. The clay stops would be located at the upstream and downstream locations of the Zone 1 DNAPL plume control system. Reduction of the flow of groundwater in the overburden, by the use of a cutoff wall will also be considered in the Corrective Measures Study.

5.2.2 Zone 1 DNAPL Plume

The remedial options considered to be applicable for the DNAPL plume do not include any options which attempt to "remove" all the DNAPL (see Appendix A). As a consequence, the only remedial actions considered to be applicable involve control "in perpetuity". Control can be affected by a variety of means as discussed in Section 4.0. It should be noted that during groundwater extraction some of the DNAPL may slowly migrate to the hydraulic pressure control wells. This DNAPL would be removed.

The potentially applicable remedial alternatives for the DNAPL plume for further study include:

1. Physical control; (i.e., grout curtain, intersecting soldier pile wall, etc.); and,
2. Hydraulic control.

Treatability studies, presently in progress have, thus far, indicated that water extracted from within the DNAPL control area to induce inward gradients can be treated prior to discharge (see Section 4.3.3.6 and Section 5.2.4).

5.2.3 Zone 1 Dissolved Phase

To reduce the potential for public exposure to the offsite Zone 1 dissolved phase plume, BAT has requested that the Town of Wheatfield pass a local law restricting the drilling of water supply wells which could impact the dissolved phase plume or extract groundwater from the plume. Additionally, BAT has completed the decommissioning of 21 private wells in the vicinity of the plume and is actively attempting to close all other known wells in this area.

Of the available technologies for remediation of dissolved phase chlorinated solvent plumes, only groundwater extraction and treatment is considered to be viable, based on the size of the Zone 1 dissolved phase plume and the known effectiveness of this technology. However, it must be noted that attainable cleanup levels for the groundwater will be difficult to predict with certainty. Consequently, groundwater extraction and treatment will need to be monitored for drawdowns, pumping rates, contaminant load removed, and changes in groundwater chemistry, in order to evaluate overall system effectiveness.

5.2.4 Treatment of Pumped Groundwater

To provide for the treatment of the extracted groundwater, two treatment plants appear to be the most viable approach. These plants would perform separate functions:

1. The groundwater from the onsite dissolved phase plume would be extracted by a series of wells. This water would be co-mingled with water extracted from the DNAPL containment area. This water stream would then be treated to remove organic constituents prior to discharge to the POTW. The treatment plant would be located in the Helicopter Blade Bonding building. The sump of this building would act as a secondary containment system.

what treatment

2. A series of wells would extract groundwater from the offsite area of the dissolved phase plume south of Bergholtz Creek. This water would be treated by a separate treatment plant to remove organic constituents. Preliminary design indicates that a UV Oxidation system would be appropriate for treatment of the water from this system prior to discharge to the POTW.

6.0 SUMMARY

This review has resulted in the rejection of several of the identified remedial technologies and alternatives on the basis of technical feasibility and applicability. The remedial options which remain will be studied in greater detail to allow the most appropriate remedy to be selected. Table 2 indicates the options remaining after review. Figure 8 presents the currently preferred remedial system.

The preferred remedial system which appears to be best suited, at this poin~~n~~t in the study, would include some of the following components:

- Control of rocket test cooling water. ✓
- Control of precipitation runoff in the drainage ditch on Walmore Road. ✓
- Clay stops and capping in storm drain and sewer trenches. ✓
- Onsite overburden groundwater control system. ✓
- Onsite overburden groundwater drainage system. ✓
- DNAPL control groundwater system. ✓
- Onsite groundwater extraction wells in DNAPL plume area. ✓
- Onsite dissolved phase groundwater extraction wells. ✓
- Offsite dissolved phase groundwater extraction wells. ✓
- Onsite treatment plant. ✓
- Offsite treatment plant. ✓

The Corrective Measures Study will complete studies of these remedial technologies and alternatives to determine their potential effectiveness and allow for remedy selection prior to detailed design and implementation. In addition, the health and safety risks associated with the final proposed remedial scheme will be assessed.

GOLDER ASSOCIATES INC.

Richard King

Richard C. F. King, P.Eng.
Associate

TABLE 1

DETECTED CHEMICALS

Volatile Organic Compounds

Methylene Chloride
1,1,1, Trichloroethane
Trichloroethylene
Acetone
1,2-Trans-dichloroethylene
Vinyl Chloride

Acid/Base/Neutral/Pesticides Compounds

Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(a)pyrene
bis(2-Ethylhxyl)phthalate
Chrysene
Anthracene
Fluorene
Phenanthrene
Pyrene
Fluoranthene
Naphthalene
Phenol
1,2,4,-Trichlorobenzene
2-methylnaphthalene

Pesticides

Dieldrin
Endosulfan I

Water Soluble Vol Compounds

Acetonitrile

Aroclors (PCB's)

Aroclor 1260

Metals

Lead
Nickel
Zinc

A:6262TAB1

Table 2

PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES

Overburden Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments	Remedial Options
No Action	None	Not applicable	No action	Required for consideration by NCP. Requires study to determine migration rate. Potentially applicable.	Required for consideration by NCP. Requires study to determine migration rate. Potentially applicable.
Institutional Actions	Access restrictions	Deed restrictions/Bylaws	Deeds for property in the area of influence would include restrictions on wells	Potentially applicable for wells at base of overburden.	Potentially applicable for wells at base of overburden.
	Alternate water supply	Wheatfield water supply	Extension of existing municipal well system to serve residents in the are of influence	This has been done. No longer applicable.	
		New community well	New uncontaminated wells to serve residents in the area of influence	Not required. No longer applicable	
	Monitoring	Groundwater monitoring	Ongoing monitoring wells	Potentially applicable will be required by Post-Closure permit	Potentially applicable will be required by Post-Closure permit
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination	Potentially applicable. Site already overlain by clay (lacustrine silt). Prefer to allow infiltration to flush upper soil layers.	Potentially applicable. Site already overlain by clay (lacustrine silt). Prefer to allow infiltration to flush upper soil layers.
		Asphalt	Application of a layer of asphalt over areas of contamination	Potentially applicable. Some of area covered with asphalt. Additionally, regrading and asphalt would be required. Prefer to allow infiltration to flush upper soil layers.	Potentially applicable. Some of area covered with asphalt. Additionally, regrading and asphalt would be required. Prefer to allow infiltration to flush upper soil layers.
		Concrete	Installation of a concrete slab over areas of contamination	Potentially applicable, but would require protection against frost heave and cracking of slabs. Cost prohibits - asphalt better. Prefer to allow infiltration to flush upper soil layers.	Potentially applicable, but would require protection against frost heave and cracking of slabs. Cost prohibits - asphalt better. Prefer to allow infiltration to flush upper soil layers.
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination	Potentially applicable, however, asphalt is considered adequate and more cost effective. Prefer to allow infiltration to flush upper soil layers.	Potentially applicable, however, asphalt is considered adequate and more cost effective. Prefer to allow infiltration to flush upper soil layers.
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with asoil(or cement) bentonite slurry	Potentially applicable. This option will be evaluated.	Potentially applicable. This option will be evaluated.
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Not effective in overburden. Job grouting would be ineffective in tills; only viable in non-cohesive materials.	
		Interlocking sealed sheet piles	Install interlocking sealed sheet pile wall	Potentially feasible. Slurry wall easier to construct given services in area.	Potentially feasible. Slurry wall easier to construct given services in area.
	Horizontal barriers	Grout injection	Pressure injection of grout at a depth through closely spaced drillholes	Not required. Zone 2 bedrock and upward gradients act as horizontal barrier.	
		Block displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Not required.	
		Prevent migration along sanitary sewer	Install clay stops upgradient and downgradient of containment system to decrease flow along sewer trench backfill. Install concrete pipe along drainage ditch and seal top of sewer trench with clay to prevent infiltration.	Potentially applicable.	Potentially applicable.

Table 2
(CONTINUED)

PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES

Overburden Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments	Remedial Options
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater	Not feasible for intercepting contaminants in low permeability overburden.	
		Extraction/Injection wells	Injection wells inject uncontaminated water to increase flow to extraction wells	Not feasible for intercepting contaminants in low permeability overburden.	
		Vapor extraction	Series of vapor extraction wells using suction to extract vapor	Not feasible for extracting volatiles from low permeability overburden.	
		Vertical permeability enhancement	Install sand drains to decrease flow path length. Plug at surface with clay seal to prevent vapor migration.	Potentially applicable.	Potentially applicable.
	Subsurface drains	Interceptor trenches	Collection pipe in trenches backfilled with porous media to collect contaminated water	Potentially applicable but require maintenance. Use drainage of underlying DNAPL zone to effect containment remediation.	Potentially applicable but require maintenance. Use drainage of underlying DNAPL zone to effect containment remediation.
	Biological treatment	Aerobic	Degradation of organics using microorganisms in an aerobic environment	Not applicable. Organic chlorinated solvents in low permeability overburden at too high concentration.	
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment	Not applicable. Organic chlorinated solvents in low permeability overburden at too high concentration.	
	Physical/chemical treatment	Chemical alteration	Alteration of chemical equilibria to reduce solubility of the contaminants	Potentially applicable, however, solvents have low solubility would require additional solvents or surfactants with potential for increased mobilization and loss of control and increased contamination. Not recomended.	Potentially applicable, however, solvents have low solubility would require additional solvents or surfactants with potential for increased mobilization and loss of control and increased contamination. Not recomended.
		Stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air	Potentially applicable. Combine with DNAPL and onsite groundwater treatment.	Potentially applicable. Combine with DNAPL and onsite groundwater treatment.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	Potentially applicable. Combine with DNAPL and onsite groundwater treatment.	Potentially applicable. Combine with DNAPL and onsite groundwater treatment.
		Reverse osmosis	Use of high pressure to force water through a membrane leaving contaminants behind	Not applicable to organic solvents found in groundwater in the overburden.	
		Ion exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water	Not applicable to organic solvents found in groundwater in the overburden.	
	Thermal destruction	Thermal Oxidation Unit	Combustion in a thermal oxidation unit	Potentially applicable. Water extracted with DNAPL and dissolved phase treatment system.	Potentially applicable. Water extracted with DNAPL and dissolved phase treatment system.
		Fluidized bed	Waste injected into hot agitated bed of sand where combustion occurs	Not applicable. Thermal oxidation considered more applicable.	
	Offsite treatment	POTW	Extracted groundwater discharged to local POTW for treatment	Potentially applicable after onsite treatment. Water extracted with DNAPL and dissolved phase treatment system.	Potentially applicable after onsite treatment. Water extracted with DNAPL and dissolved phase treatment system.
		RCRA facility	Extracted groundwater discharged to licensed RCRA facility for treatment and/or disposal	Not applicable.	
	In situ treatment	Bioreclamation	System of injection and extraction wells introduce. bacteria and nutrients to degrade contamination	Not feasible because of low permeability of overburden.	
		Aeration	System of wells to inject air into groundwater to remove volatiles by air stripping	Not feasible because of low permeability of overburden.	
		Permeable treatment beds	Downgradient trenches backfilled with activated carbon to remove contaminants from water	Not feasible because of low permeability of overburden and presence of methylene chloride which does not load well on carbon, depth of overburden, difficult to remove carbon.	
		Chemical reaction	System of injection wells to inject oxidizer such as hydrogen peroxide or ozone to degrade contaminants	Not feasible because of low permeability of overburden.	
	Onsite discharge	Local stream	Extracted water discharged to stream or storm water sewer	Not applicable.	
	Offsite discharge	POTW	Extracted water discharged to local POTW after treatment	Potentially applicable after treatment of pumped groundwater from overburden, DNAPL and onsite dissolved phase.	Potentially applicable after treatment of pumped groundwater from overburden, DNAPL and onsite dissolved phase.
		Deep well injection	Extracted water discharged to deep well injection system	Deep aquifer injection not allowed.	
		Pipeline to river	Extracted water discharged to river after treatment	Potentially applicable; treatment and NPDES permit would be required.	

Table 2
(CONTINUED)

PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES

Zone 1 DNAPL Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments*	Remedial Options
No Action	None	Not applicable	No action	Required for consideration by NCP. DNAPL and groundwater flow would continue to develop dissolved phase. Considered to be not applicable.	
Institutional Actions	Access restrictions	Deed restrictions	Deeds for property in the area of influence would include restrictions on wells	Potentially applicable Deed restrictions will be completed tp prevent drilling in DNAPL area.	Potentially applicable Deed restrictions will be completed tp prevent drilling in DNAPL area.
	Alternate water supply	City water supply	Extension of existing municipal well systen to serve residents in the area of influence	Not required. This has been done.	
		New community well	New uncontaminated wells to serve residents in the area of influence	Not required. This has been done.	
	Monitoring	Groundwater monitoring	Ongoing monitoring wells	Potentially applicable. This will have to be done as part of the Post-Closure Permit.	Potentially applicable. This will have to be done as part of the Post-Closure Permit.
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination	Potentially applicable, however, flushing of shallow overburden preferable.	Potentially applicable, however, flushing of shallow overburden preferable.
		Asphalt	Spray application of a layer of asphalt over areas of contamination	Potentially applicable, however, flushing of shallow overburden preferable.	Potentially applicable, however, flushing of shallow overburden preferable.
		Concrete	Installation of a concrete slab over areas of contamination	Potentially applicable, however, flushing of shallow overburden preferable.	Potentially applicable, however, flushing of shallow overburden preferable.
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination	Potentially applicable, however, flushing of shallow overburden preferable.	Potentially applicable, however, flushing of shallow overburden preferable.
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with asoil(or cement) bentonite slurry	Not feasible because of bedrock. Hydrofraze equipment cannot cut greater then 15,000 psi compressive strength rock.	
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Potentially applicable in fractured bedrock. Would be used to reduce amount of pumping required.	Potentially applicable in fractured bedrock. Would be used to reduce amount of pumping required.
		Vibrating beam	Vibrating force to advance beams into the ground with injection of slurry as beam is withdrawn	Not feasible because of bedrock.	
		Intersecting soldier piles	Construction of intersecting concrete or slurry soldier pile using large diameter drillholes	Potentially applicable.	Potentially applicable.
	Horizontal barriers	Grout injection	Pressure injection of grout at a depth through closely spaced drillholes	Potentially applicable.	Potentially applicable.
		Block displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Not required because of Zone 2 aquitard.	

Table 2
(CONTINUED)

PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES

Zone 1 DNAPL Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments*	Remedial Options
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater	Potentially feasible for intercepting contaminants in fractured bedrock, however, removal of all DNAPL currently not possible. Groundwater will require treatment.	Potentially feasible for intercepting contaminants in fractured bedrock, however, removal of all DNAPL currently not possible. Groundwater will require treatment.
		Extraction/injection wells	Injection wells inject uncontaminated water to increase flow to extraction wells	Injection wells not required. Must not increase effective head of DNAPL or DNAPL may remobilize. Potential for DNAPL to migrate in Zone 3 aquifer.	
	Subsurface drains	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to collect contaminated water	Not applicable. Extraction feasible with wells. Bedrock too hard to excavate without blasting. Blasting may cause problems with integrity of Zone 2. Potential for DNAPL to migrate in Zone 3 aquifer.	
	Biological treatment	Aerobic	Degradation of organics using microorganisms in an aerobic environment	Not applicable to DNAPL. DNAPL poisons bacteria.	
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment	Not applicable to DNAPL. DNAPL poisons bacteria.	
	Physical/chemical treatment	Chemical alteration	Alteration of chemical equilibria to increase solubility of the contaminants	Potentially applicable to DNAPL, but dangerous. Not reconmended.	Potentially applicable to DNAPL, but dangerous. Not reconended.
		Stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air	Potentially applicable to dissolved organic contaminants found in groundwater at the site.	Potentially applicable to dissolved organic contaminants found in groundwater at the site.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	Potentially applicable to dissolved organic contaminants found in groundwater at the site.	Potentially applicable to dissolved organic contaminants found in groundwater at the site.
		Phase separater	DNAPL Seperated from dissolved phase by phase seperator	Potentially applicable.	Potentially applicable.
		Reverse osmosis	Use of high pressure to force water through a membrane leaving contaminants behind	Not applicable to DNAPL.	
		Ion exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water	Not applicable to DNAPL.	
	Thermal destruction	Thermal oxidation	Combustion in a horizontally rotating cylinder designed for uniform heat transfer	Potentially applicable to dissolved organic contaminants found at the site. Collected DNAPL would be sent for incineration/distruction off-site.	Potentially applicable to dissolved organic contaminants found at the site. Collected DNAPL would be sent for incineration/destruction off-site.
		Fluidized bed	Waste injected into hot agitated bed of sand where combustion occurs	Not applicable to organic contaminants found in groundwater at the site.	
	Offsite treatment	POTW	Extracted groundwater discharged to local POTW for treatment	Not applicable.	
		RCRA facility	Extracted groundwater discharged to licensed RCRA facility for treatment and/or disposal	Potentially applicable. See thermal oxidation.	Potentially applicable. See thermal oxidation.
	In situ treatment	Bioreclamation	System of injection and extraction wells introduce bacteria and nutrients to degrade contamination	Not feasible because of DNAPL poisoning bacteria.	
		Steam Injection	System of wells to inject steam into groundwater to remove volatiles by volatilization	Potentally feasible but potential for DNAPL to condense in overburden or to migrate in Zone aquifer.	Potentally feasible but potential for DNAPL to condense in overburden or to migrate in Zone aquifer.
		Permeable treatment beds	Downgradient trenches backfilled with activated carbon to remove contaminants from water	Not feasible because of DNAPL. Very difficult to construct trench and change carbon.	
		Chemical reaction	System of injection wells to inject oxidizer such as hydrogen peroxide to degrade contaminants	Not feasible because iron pyrite in bedrock would use up peroxide.	
		Use of surfactants solvents to remobilize DNAPL	System of injection wells to inject allowable surfactants to mobilize DNAPL's	Not feasible; dangerous - may loose control of DNAPL. Potential for DNAPL to migrate in Zone 3 aquifer.	
	Onsite discharge	Local stream	After treatment extracted water discharged to stream	Not applicable; would require NPDES permit. Acetone discharge may be a problem.	
	Offsite discharge	POTW	After treatment extracted water discharged to local POTW	Not applicable. DNAPL would not be accepted by POTW.	
		Deep well injection	Extracted water discharged to deep well injection system	Deep aquifer injection not allowed.	
		Pipeline/storm sewer to Niagara river	Extracted water would be trated and discharged to the river	Not applicable for DNAPL.	

Table 2
(CONTINUED)

PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES

Zone 1 Dissolved Phase Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments*	Remedial Options
No Action	None	Not applicable	No action	Required for consideration by NCP. Not applicable. Plume would continue to generate and/or migrate.	
Institutional Actions	Access restrictions	Deed/Bylaw restrictions	Deeds for onsite property in the area of influence would include restrictions on wells. Bylaws for offsite property would prevent future well drilling.	Potentially applicable	Potentially applicable
	Alternate water supply	City water supply	Existing municipal system serves residents in the area of influence.	Already in existence.	
		New community well	New uncontaminated wells to serve residents in the area of influence	Not applicable. Existing municipal water supply system supplies all homes.	
	Monitoring	Groundwater monitoring	Ongoing monitoring wells	Potentially applicable. Will be required for Post Closure Permit and measurement of effectivness of remedial system.	Potentially applicable. Will be required for Post Closure Permit and measurement of effectivness of remedial system.
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination	Clay cap in overburden, already exists.	
		Asphalt	Spray application of a layer of asphalt over areas of contamination	Not applicable.	
		Concrete	Installation of a concrete slab over areas of contamination	Not applicable.	
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination	Not applicable.	
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with asoil(or cement) bentonite slurry	Not applicable The Plume is in fractured bedrock.	
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Not applicable. Probably leak and not effect remediation of the plume. Length of grout curtain would result in prohibitive costs.	
		Vibrating beam	Vibrating force to advance beams into the ground with injection of slurry as beam is withdrawn	Not possible because plume in fractured bedrock.	
	Horizontal barriers	Grout injection	Pressure injection of grout at a depth through closely spaced drillholes	Not required. Plume already contained horizontally by Zone 2 bedrock.	
		Block displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Not required. Plume already contained horizontally by Zone 2 bedrock.	

Table 2
(CONTINUED)
PRELIMINARY SCREENING OF REMEDIAL ALTERNATIVES
Zone 1 Dissolved Phase Plume

General Response Actions	Remedial Technology	Process Options	Description	Screening Comments*	Remedial Options
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater	Potentially applicable.	Potentially applicable.
		Extraction/injection wells	Injection wells inject uncontaminated water to increase flow to extraction wells	Potentially applicable.	Potentially applicable.
	Subsurface drains	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to collect contaminated water	Not applicable. Trenches in bedrock difficult, no more effective than wells in horizontally bedded bedrock.	
	Biological treatment	Aerobic	Degradation of organics using microorganisms in an aerobic environment	Potentially applicable.	Potentially applicable.
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment	Potentially applicable.	Potentially applicable.
	Physical/chemical treatment	Precipitation	Alteration of chemical equilibria to reduce solubility of the contaminants	Not applicable to chlorinated solvents.	
		Stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air	Potentially applicable to organic contaminants found in groundwater at the site.	Potentially applicable to organic contaminants found in groundwater at the site.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	Potentially applicable to organic contaminants found in groundwater at the site	Potentially applicable to organic contaminants found in groundwater at the site
		Reverse osmosis	Use of high pressure to force water through a membrane leaving contaminants behind	Not applicable.	
		Ion exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water	Not applicable.	
		UV Peroxidation	Hydrogen Peroxide added to contaminated water and irradiated with UV light.	Potentially applicable.	Potentially applicable.
	Thermal destruction	Thermal oxidation	Combustion in a thermal oxidation unit	Potentially applicable to organic contaminants found in groundwater at the site.	Potentially applicable to organic contaminants found in groundwater at the site.
		Fluidized bed	Waste injected into hot agitoted bed of sand where combustion occurs	Not applicable to organic contaminants found in groundwater at the site.	
	Offsite treatment	POTW	Extracted groundwater discharged to local POTW for treatment	Potentially applicable after treatment. Can be used to treat acetone.	Potentially applicable after treatment. Can be used to treat acetone.
		RCRA facility	Extracted groundwater discharged to licensed RCRA facility for treatment and/or disposal	Not applicable.	
	In situ treatment	Anaerobic Bioreclamation	System of injection and extraction wells introduce bacteria and nutrients to degrade contamination	Anaerobic degradation probably occurring now. Transition from TCE to vinyl chloride relatively fast. Vinyl chloride to non-toxic product very slow. Not recommended for main remediation. Will influence fate of any residual contaminants after groundwater extraction has stopped.	
		Aerobic Bioreclamation	System of wells to inject air into groundwater to remove volatiles by air stripping	Potentially applicable but area very large and access restricted. Pyrite in bedrock would use up oxygen.	Potentially applicable but area very large and access restricted. Pyrite in bedrock would use up oxygen.
		Permeable treatment beds	Downgradient trenches backfilled with activated carbon to remove contaminants from water	Not feasible because plume is in bedrock.	
		Chemical reaction	System of injection wells to inject oxidizer such as hydrogen peroxide to degrade contaminants	Not feasible because fractured bedrock contains pyrite which would use up hydrogen peroxide. Solvents may not be amenable to direct oxidation by hydrogen peroxide.	
	Onsite discharge	Local stream	After treatment extracted water discharged to stream	Potentially applicable. Would require NPDES permit.	Potentially applicable. Would require NPDES permit.
	Offsite discharge	POTW	After treatment extracted water discharged to local POTW	Potentially applicable.	Potentially applicable.
		Deep well injection	Extracted water discharged to deep well injection system	Deep aquifer injection not allowed.	
		Pipeline to river	Extracted water would be treated and discharged to the river	Potentially applicable. Would require NPDES permit.	Potentially applicable. Would require NPDES permit.

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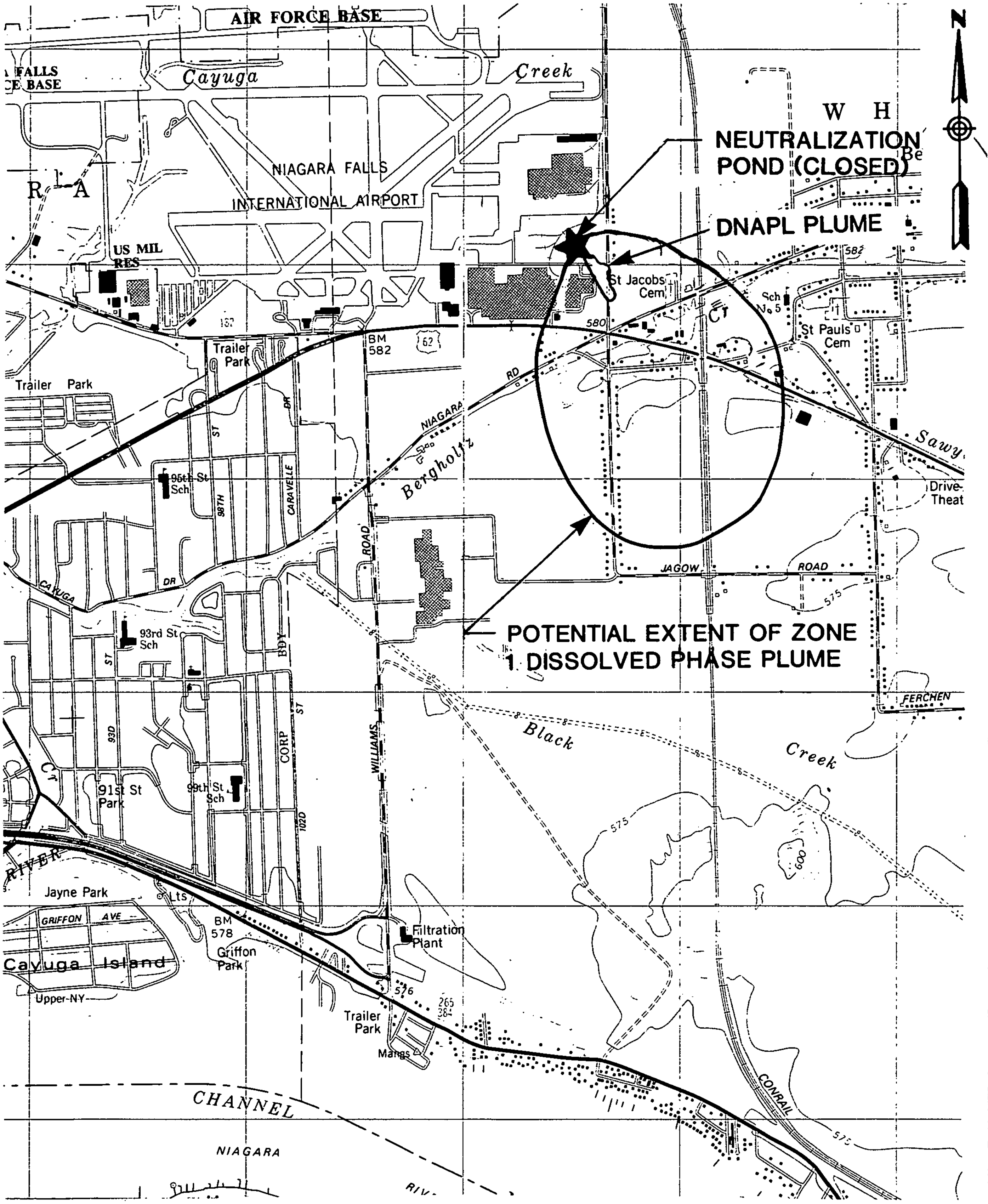

SOURCE: TONAWANDA WEST QUADRANGLE,NEW YORK, 7.5' SERIES, DATED 1980

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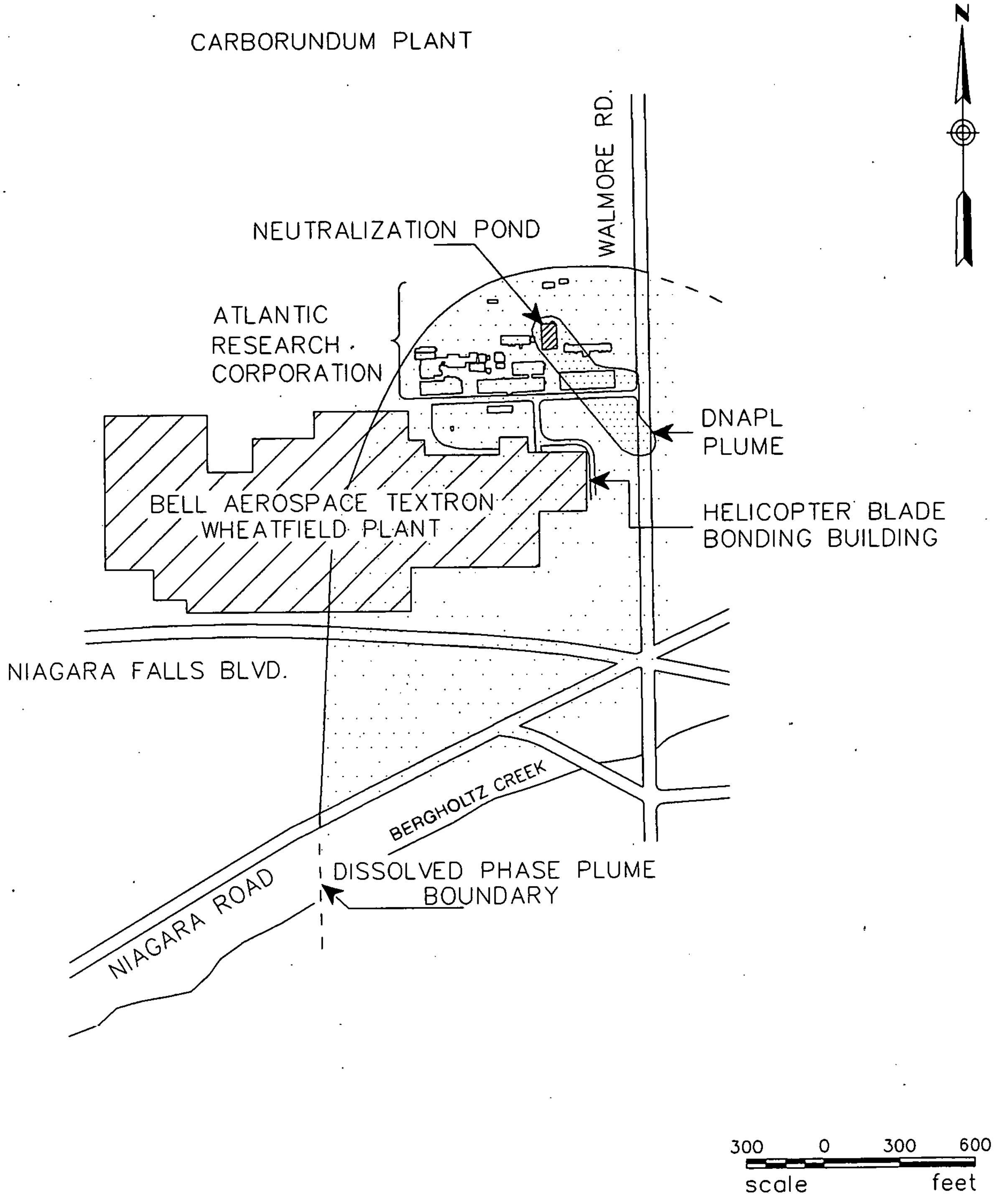
CHECKED FG	DWG. NO. NY01-050	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE 1



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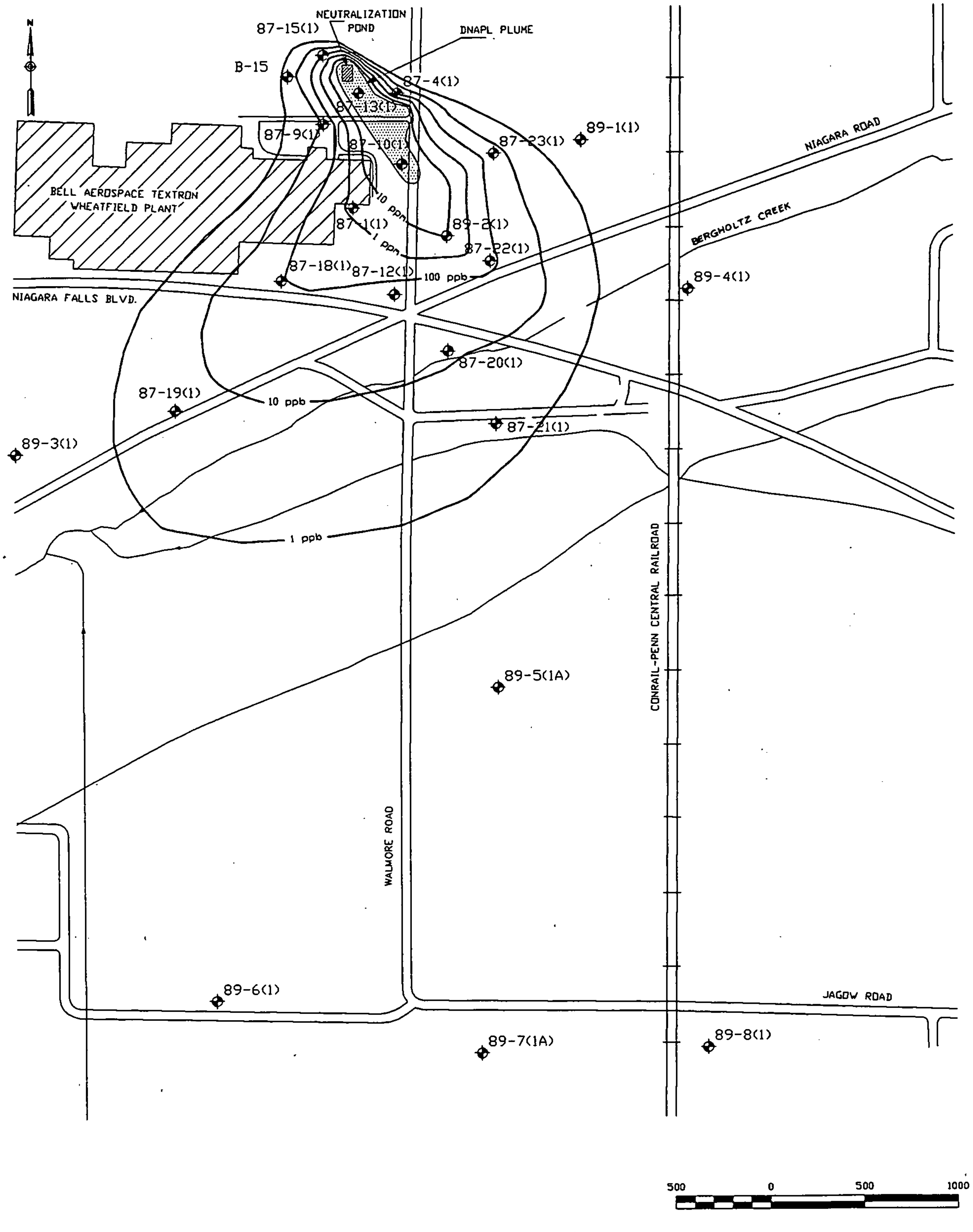
CHECKED RCFK	DWG. NO.	
Golder Associates		BELL AEROSPACE TEXTRON FIGURE 2

152978



DATA FROM 4TH QTR. '88 – 3RD QTR. '89

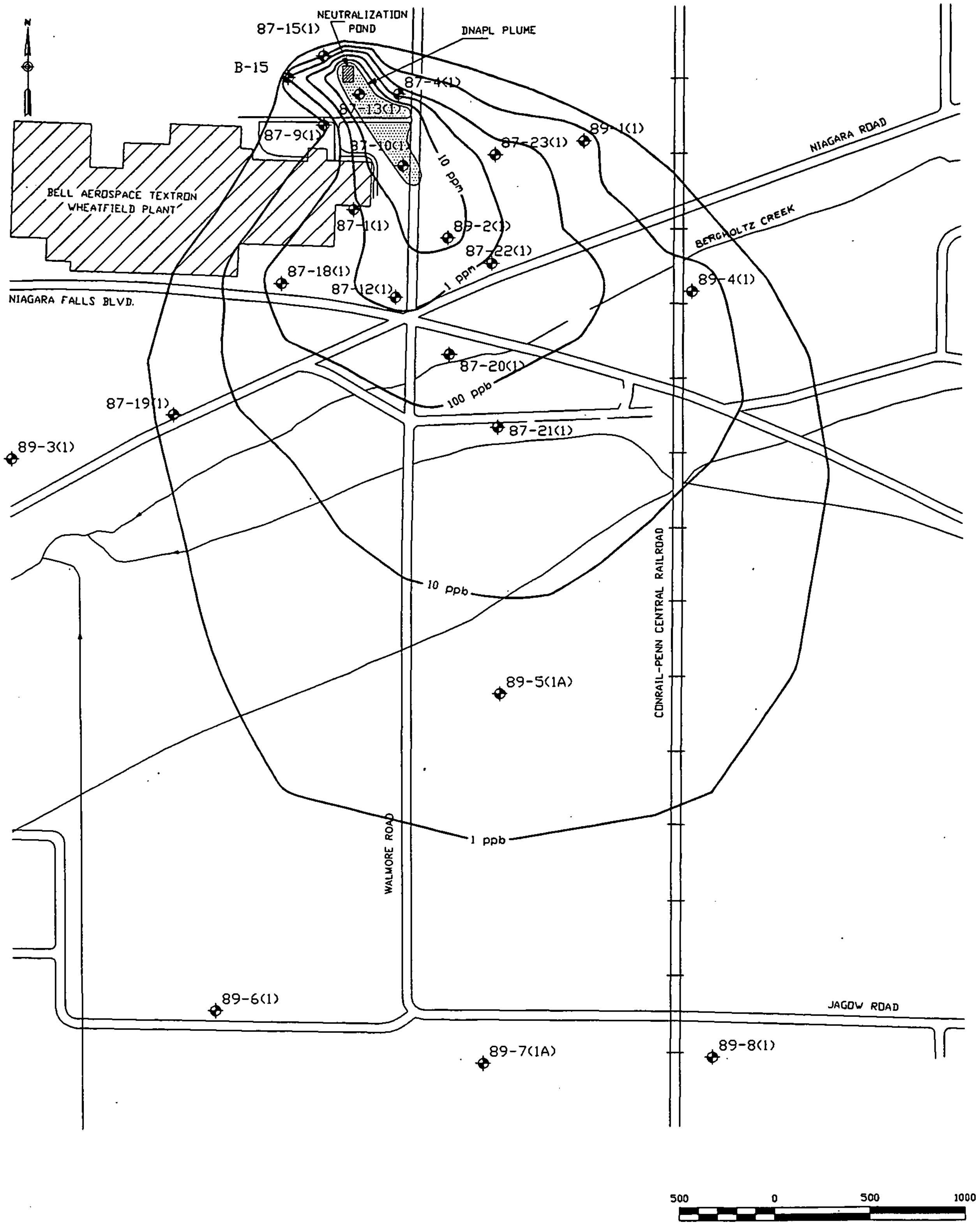
JOB NO. 893-6262
SCALE 1" = 800'
DRAWN FG
DATE 6/17/90
CHECKED RCFK
DWG. NO.

ESTIMATED AVERAGE METHYLENE CHLORIDE CONCENTRATION CONTOURS ZONE 1 AQUIFER

Golder Associates

BELL AEROSPACE TEXTRON

FIGURE 3



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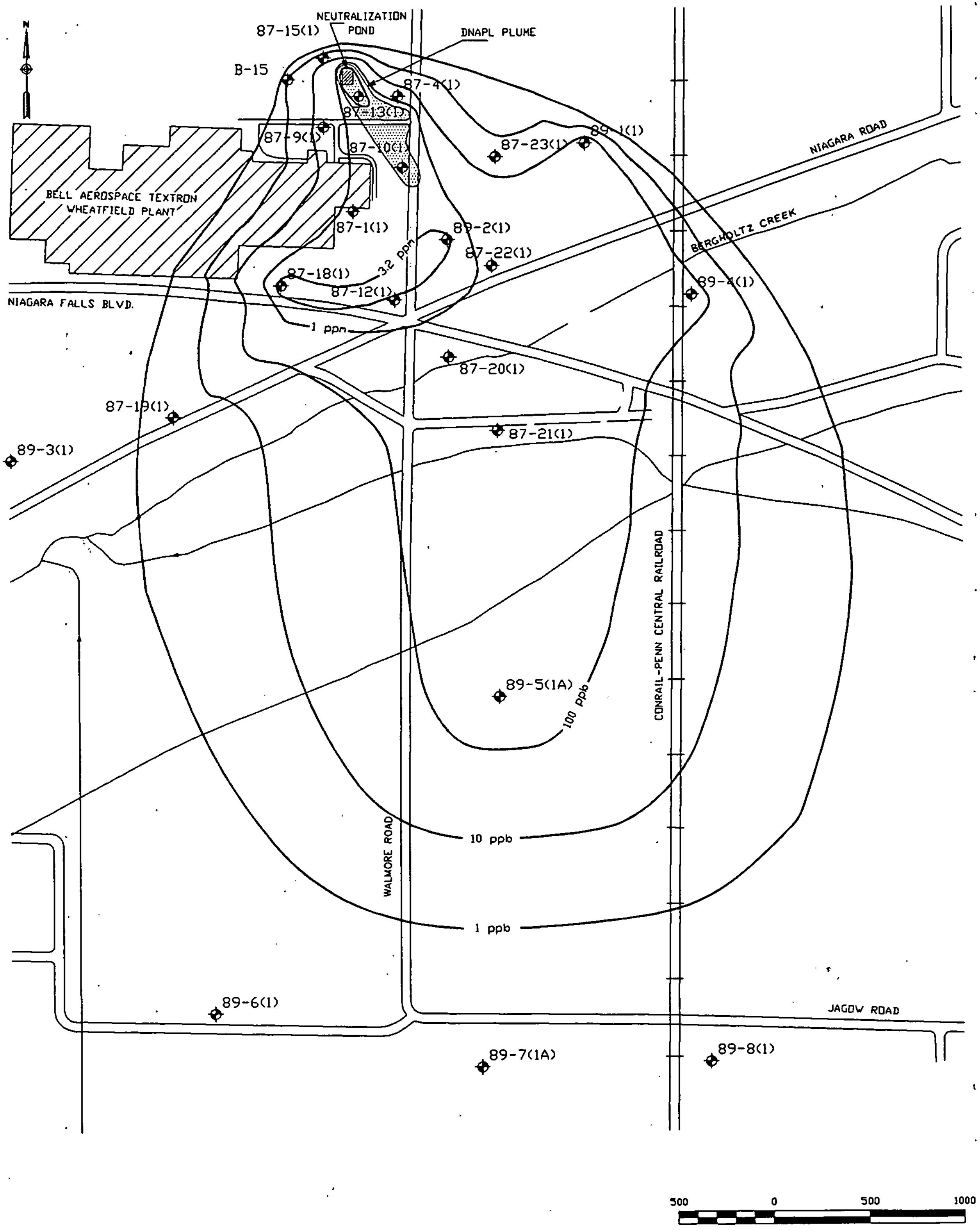
CHECKED	RCFK	DWG. NO.		

Golder Associates

BELL AEROSPACE TEXTRON

FIGURE 4



DATA FROM 4TH QTR. '88 - 3RD QTR. '89

JOB NO.	893-6262	SCALE	1" = 800'
DRAWN	FG	DATE	6/17/90
CHECKED	RCFK	DWG. NO.	

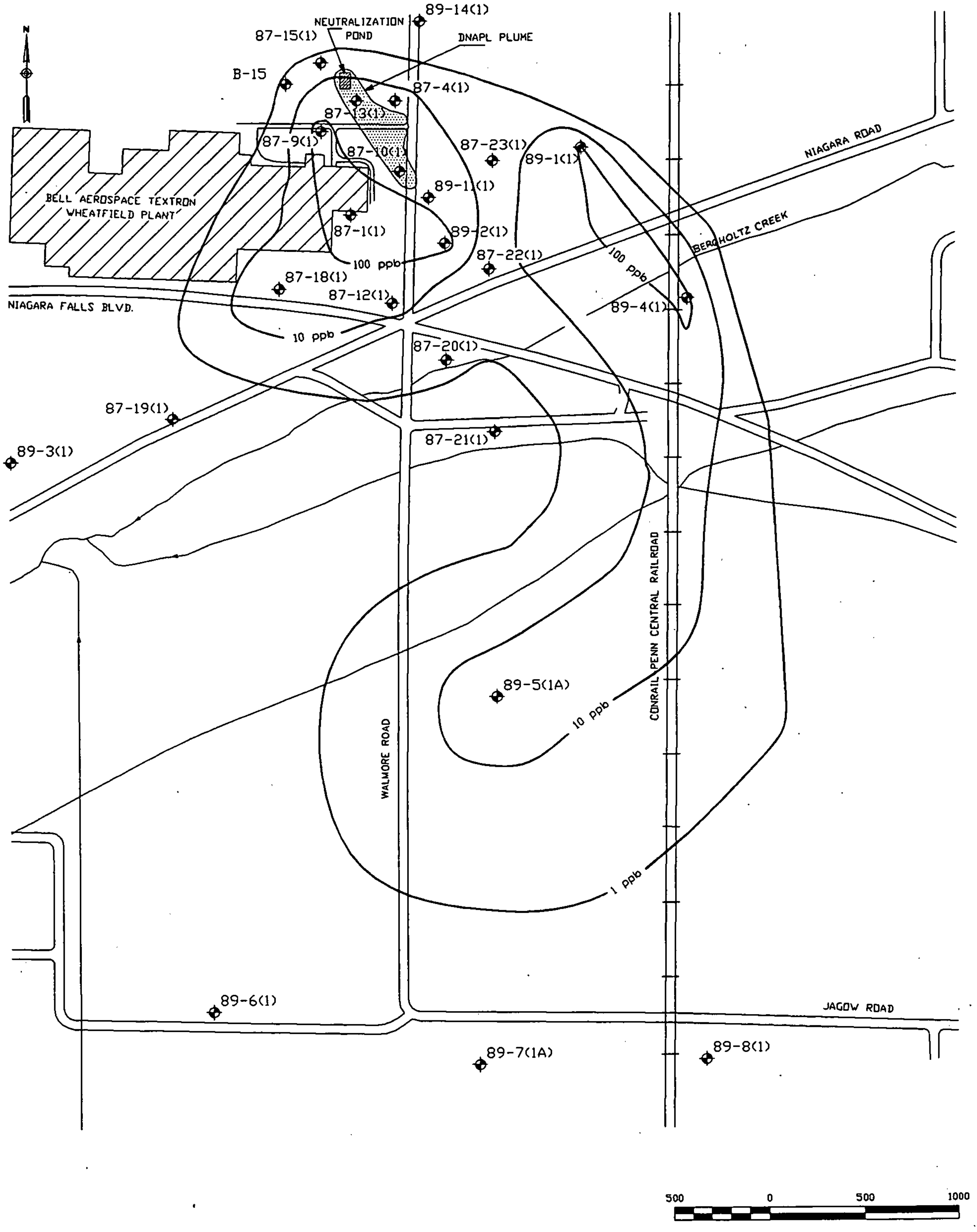
Golder Associates

ESTIMATED AVERAGE 1, 2 - TRANS - DICHLOROETHYLENE CONCENTRATION CONTOURS ZONE 1 AQUIFER

BELL AEROSPACE TEXTRON

FIGURE 5

152978



DATA FROM 4TH QTR. '88 - 3RD QTR. 89

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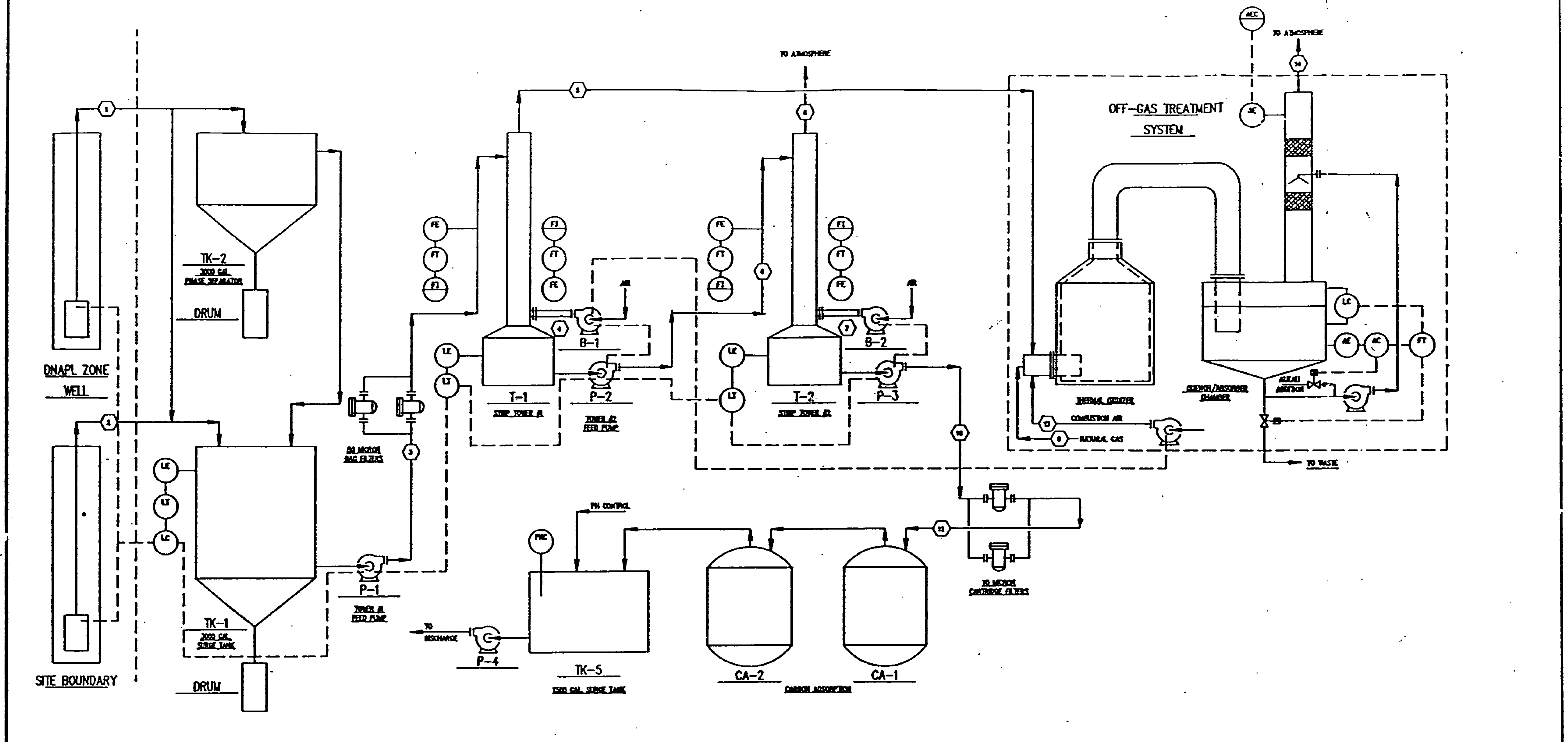
Golder Associates		BELL AEROSPACE TEXTRON FIGURE 6



STREAM # / ITEM	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
TOTAL POUNDS/HOUR	3006	20,027	23,0[illegible]	2300	2330	23,0[illegible]	2300	2300	66	23,0[illegible]	3.6	23,025	1004	2330 SCFM
FLOW RATE (GPM)	6.0	40.0	46.0	600 SCFM	600 SCFM	46	600 SCFM	600 SCFM	10.7 SCFM	46	7 gal/day	46	247	[illegible]
MeCl POUNDS/HOUR	6.0	0.2	6.2	–	6.[illegible]	0.0[illegible]	–	0.0[illegible]	–	[illegible]	–	–	–	–
TCE POUNDS/HOUR	3.6	0.1	3.0	–	3.700	0.000[illegible]	–	–	–	–	–	–	–	–
TCA POUNDS/HOUR	0.22	–	0.22	–	0.2[illegible]	0.0000[illegible]	–	–	–	–	–	–	–	–
PPM MeCl	2000	10	2[illegible]0	–	2[illegible]	1.35	–	14.0	–	0.00[illegible]	–	–	–	–
PPM TCE	1200	10	1[illegible]5	–	1000	0.0074	–	–	–	–	–	–	–	–
PPM TCA	72	–	8.6	–	100	0.00[illegible]	–	–	–	–	–	–	–	–

DWG. NO.

REFERENCE DRAWINGS

REVISIONS

PRINT DISTRIBUTION

DRAWING STATUS

BAT WASTEWATER TREATMENT FACILITY
FLOW DIAGRAM

SCALE: NONE | PROJECT LOCATION: NIAGARA FALLS, NY | PROJECT #

RTG RESOURCE TECHNOLOGIES GROUP, INC.

DRAWING IS NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED AND DATED. ALL PRINTS ARE TO BE DESTROYED HAVING AN EARLIER DATE AND/OR REVISION NUMBER.

BELL AEROSPACE TEXTRON
NIAGARA FALLS, NY

FIG – 8.1

JOB NO.	893-6262	SCALE	N/A
DRAWN	MRM	DATE	09/18/90
CHECKED	FG	DWG. NO.	

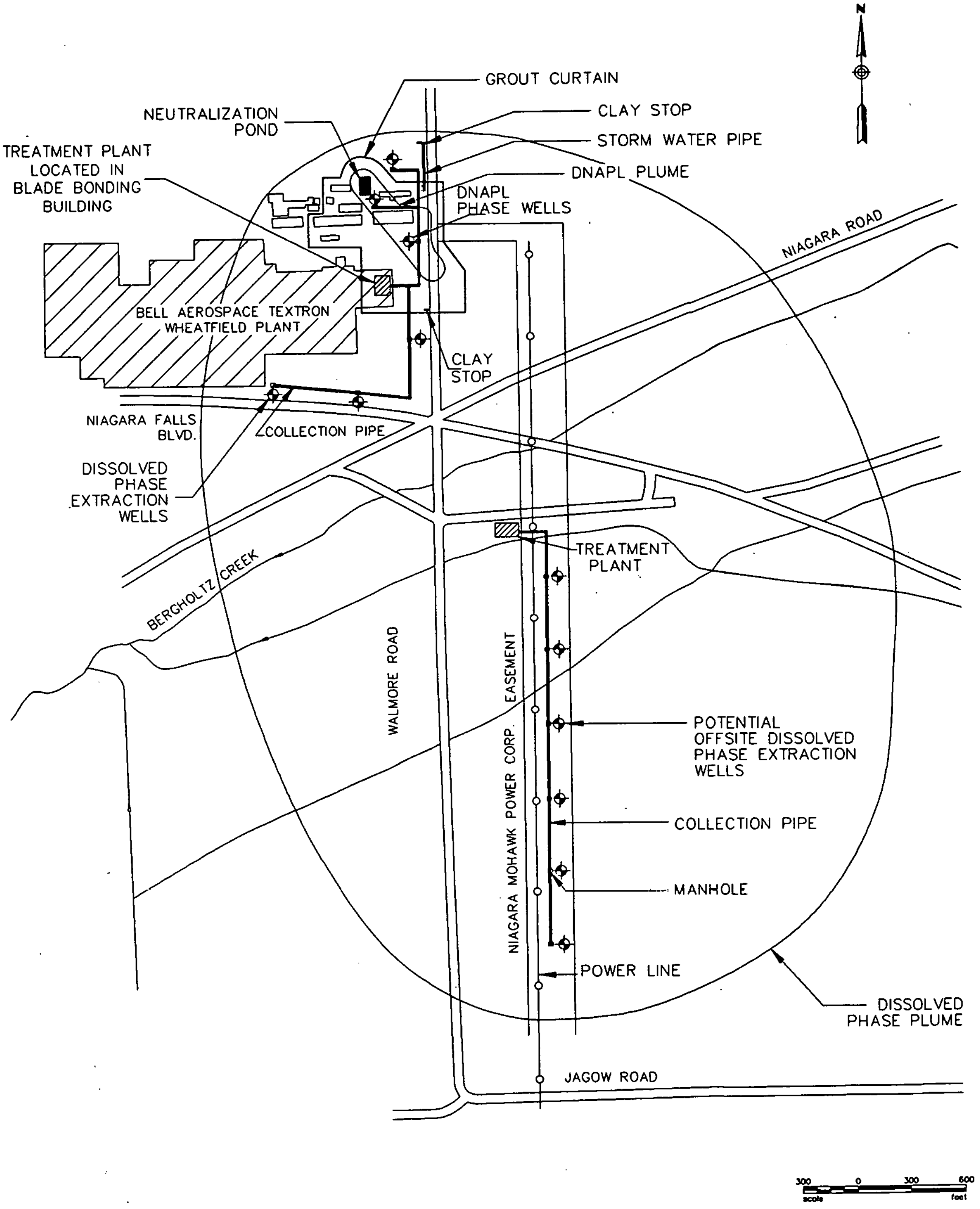
Golder Associates

BAT WASTEWATER TREATMENT FACILITY FLOW DIAGRAM

BELL AEROSPACE TEXTRON

FIGURE 7

152110



JOB NO. 893-6262	SCALE AS SHOWN	**PRELIMINARY REMEDIAL ALTERNATIVES**	
DRAWN FG	DATE 6/17/90		
CHECKED RCFK	DWG. NO.		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE 8

APPENDIX A

Review of DNAPL and Remedial Technologies

REVIEW OF DNAPL
AND REMEDIAL TECHNOLOGIES

Prepared by:

Stan Feenstra
Applied Groundwater Research

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1.0 DNAPL BEHAVIOR IN THE SUBSURFACE

Substances such as chlorinated solvents, polychlorinated biphenyls (PCB), and halogenated benzines comprise a group of chemicals which in their pure form can be categorized as DNAPL chemicals. In the past decade DNAPL chemicals have been found to be a major and increasing cause of groundwater contamination. For example, in the United States, DNAPL is present or suspected to be present at many of the abandoned hazardous waste disposal sites investigated for Superfund. Groundwater contamination resulting from DNAPL chemical sources in the subsurface is of serious concern because dissolved concentrations of several ug/L in groundwater used for water supply can result in taste and odor problems and/or potential health risks.

Because drinking water standards for many DNAPL chemicals are so low, even small quantities introduced into the subsurface can result in large-scale groundwater contamination problems. For example, 1 gallon (3.785 L) of trichloroethylene (TC) could potentially contaminate 300 million gallons (10^9 L) of groundwater to a concentration of 5 ug/L, the USEPA drinking water standard.

The potential for groundwater contamination by DNAPL chemicals is also significant because of their distinctive physical and chemical properties. DNAPL chemicals are immiscible in water and have densities greater than water. The combination of low solubility and high density enables DNAPL chemicals to penetrate downward into the subsurface through the unsaturated and saturated zones as a separate non-aqueous phase. The tendency for DNAPL chemicals to sink through the saturated zone differs from that of petroleum hydrocarbons which will float on the groundwater in the saturated zone due to their lower density. In the subsurface, small but significant quantities of chemicals can be dissolved by groundwater in contact with the DNAPL which can result in groundwater contamination over a larger area.

A general illustration of the behavior of DNAPL chemicals in the subsurface is shown in Figure B-1. DNAPL chemical can penetrate downward through the unsaturated zone and the saturated zone due to its high density. In cases where the quantity of chemical is small, all of the DNAPL may form a residual in the unsaturated zone because the input volume does not exceed the retention capacity of the vadose zone. Within this residual zone, the DNAPL is present as immobile unconnected and partially connected blobs and filaments. Residual concentrations for DNAPL chemicals in unsaturated sandy soils determined by Schwille (1988) ranged from 3 L/m^3 to 30 L/m^3, with higher residual concentrations for finer-grained soils.

For cases where the input volume of DNAPL exceeds the retention capacity of the vadose zone, DNAPL will move into the unsaturated and saturated zones. Residual concentrations of DNAPL will also be retained as DNAPL passes through the saturated zone. Residual concentrations in saturated soils determined by Schwille (1988) were slightly higher than for unsaturated soils, ranging from 5 L/m^3 to 50 L/m^3. The presence of DNAPL residual in the pore space will reduce the hydraulic conductivity of the medium by a factor of 5 to 10 times, thereby reducing the groundwater flow through these zones. The presence of lower permeability strata will have a very significant effect on downward movement of DNAPL. The combination of low permeability and capillary resistance can act to prevent downward movement, deflect DNAPL movement laterally and cause the formation of pools or puddles. Within these pools or puddles, DNAPL fills most of the pore space. In situations where the confining stratum is sloped, DNAPL can continue to move downslope and its movement need not be influenced by the direction of groundwater flow.

DNAPL chemicals can also penetrate into fractured rock and clayey strata. The pattern of DNAPL movement will be controlled primarily by the orientation and interconnection of the fractures. Based on laboratory experiments by Schwille (1988), there will be a small quantity of residual DNAPL retained on the fracture surfaces, either above or below the water table, but the bulk residual concentrations in fractured media are substantially less than residual concentrations for porous media. For planar fractures of 0.2 mm aperture, Schwill (1987) estimated that the residual retention would be less than 0.05 L/m^2. For this situation, DNAPL would occupy approximately 25% of the fracture opening and would significantly reduce the hydraulic conductivity of the fracture. For a fractured rock with a three-dimensional network of fractures and a fracture frequency of 10 per metre, this retention capacity would represent a residual concentration of less than 1.5 L/m^3, substantially less than residual concentrations for soils. Similarly, the total fracture porosity of fractured media is typically much lower than for porous media. Therefore, for a given volume of DNAPL chemical introduced into the subsurface, contamination in fractured media can spread to a much greater extent areally and to a greater depth than in porous media.

Groundwater which comes in contact with the DNAPL becomes contaminated by dissolved chemicals. The solubility of most DNAPL chemicals is not sufficiently high for dissolution by groundwater to be an effective mechanism for the removal of DNAPL from the subsurface under natural groundwater flow conditions.

Groundwater contamination develops as dissolved chemical contaminants are released from the DNAPL. The dissolved chemicals migrate away from the DNAPL in the direction of groundwater flow and at a velocity controlled by the velocity of groundwater and the influence of any attenuation processes. Sorption and biodegradation are the principal processes which will attenuate or reduce the rate of migration of dissolved organic chemical contaminants in groundwater. In fractured porous rock or fissured clay materials, matrix diffusion may also be an important attenuation process.

2.0 REMEDIAL ALTERNATIVES FOR THE DISSOLVED CHEMICAL PLUMES

2.1 Background

The objective of remedial actions directed at the subsurface contamination at the Bell Aerospace site is to minimize unacceptable environmental impact of groundwater contamination emanating from the site. Although the mass of chemical in the dissolved chemical plumes is small compared to the mass of chemical in the DNAPL zone, it is the dissolved plumes which result in the migration of chemical contaminants off-site. Therefore, a key step in any remedial action at the Bell site should be to control migration of the dissolved chemical plumes without specific consideration of the DNAPL. Elimination of the generation of dissolved chemical plumes can only be achieved through control or removal of the DNAPL source because the large mass of chemical present in the DNAPL represents a continuing source of contamination.

The remedial alternatives for control or elimination of the dissolved chemical plume can be categorized as:

- o Groundwater Recovery and Treatment
- o In Situ Treatment

The various remedial alternatives which may be potentially applicable at the Bell site are described in the following sections. Groundwater recovery and treatment methods have been used at a variety of chemical spill sites and waste disposal facilities in the remediation of dissolved chemical plumes. The degree of success of such methods is dependent on the site and the design and implementation of the methods. In contrast, the in situ treatment methods described in the following paragraphs have only been evaluated on a theoretical or experimental basis. At the present time there are no in situ treatment methods which have been demonstrated on a field scale to be effective for remediation of dissolved chlorinated solvents in groundwater.

2.2 Groundwater Recovery and Treatment

Recovery and treatment of contaminated groundwater is a method used commonly for the control of migration of dissolved chemical plumes. Groundwater recovery can be accomplished by means of purge well systems or collector trenches installed at appropriate locations and depths to intercept the contaminated groundwater. Collector trenches are trenches installed below the water table, and from which contaminated groundwater can be pumped. Purge wells can be installed to any depth in soil or rock formations, whereas collector trenches are usually used in soil at shallow depths (<10 m). The collected groundwater is treated in an appropriate on-surface treatment facility to remove the chemical contaminants to a level which is acceptable for discharge to a sewer system or surface water course, or for re-injection into the groundwater system.

Recovery and treatment of contaminated groundwater is an obvious alternative for control of the dissolved chemical plumes in Zones 1 and 3 at the Bell site. Because the dissolved plume in Zone 1 is situated at depths of approximately 10 to 15 m below ground surface, it may also be feasible to control the shallow plume using collector trenches excavated through the overburden and into the upper 5 to 10 m of the bedrock. Although a collector trench system would likely have a higher installation cost compared to a purge well system, it could also have several advantages at the Bell site. A purge well system relies on the creation of zone of influence to draw the plume toward the wells. Heterogeneities in the hydrogeologic conditions (such as areal variation in the hydraulic conductivity of the bedding plane partings) can result in variations in the pattern of groundwater flow which can in turn disrupt the development of the zone of influence from the purge wells. In contrast, a collector trench can be installed to intersect the full depth of the contaminated zone and the full width or circumference of a plume, thereby eliminating the concern about variations in groundwater flow patterns.

A purge well system installed near the periphery of the plume would collect large volumes of uncontaminated water in addition to the contaminated water. However, a collector trench system installed near the periphery of the plume could be constructed so that the bottom and side of the trench away from the contaminated area are lined or grouted with low permeability material to reduce the inflow of uncontaminated groundwater into the trench, thereby reducing the volume of water which would need to be treated.

Control of the dissolved plumes would have several benefits. Recovery of contaminated groundwater from the shallow plume would retard any further lateral migration of dissolved chemicals off-site and thus restrict the areal size of the shallow plume. It is considered that the chemicals detected in the Zone 3 plume originate principally from the leakage of dissolved chemicals from the shallow plume downward through vertical fractures. Therefore, if the area of the shallow plume is smaller there will be less leakage downward into the deeper plume, thereby reducing potential contamination in the deeper bedrock. Similarly, the pumping of the Zone 1 plume will cause the hydraulic gradients to be upward from Zone 3 into Zone 1, thereby potentially reducing the contamination in Zone 3.

2.3 In Situ Treatment

In situ treatment methods such as bioreclamation and chemical destruction are methods which have been considered at other sites for the control of dissolved organic chemical plumes. Insitu bioreclamation methods have been successfully applied to treatment of petroleum hydrocarbon contaminants in groundwater. Such methods involve the injection of oxygen and nutrients into the groundwater to stimulate the growth and activity of naturally occurring aerobic bacteria which can degrade the dissolved petroleum compounds. Laboratory studies suggest that TCE may undergo biodegradation by methane-oxidizing bacteria under aerobic conditions (Fogel et al., 1986) but TCE and other chlorinated solvents are generally considered to be resistant to aerobic degradation. In situ biodegradation of TCE in groundwater typically occurs under anaerobic conditions with production of dichlorothylene (DCE) and vinyl chloride (VC), two equally undesirable contaminants. No methods for in situ bioreclamation of chlorinated solvents have been demonstrated in field-scale tests.

In situ chemical destruction has been successfully applied to the treatment of groundwater contaminated by reactive chemicals such as formaldehyde. Such methods involve the injection of chemical agents, such as hydrogen peroxide in the case of formaldehyde, which result in the destruction of the chemical contaminants in the groundwater. TCE and other chlorinated solvents are relatively inert chemicals, and in situ treatment of groundwater contaminated by these chemicals has not been demonstrated on a field scale.

3.0 REMEDIAL ALTERNATIVES FOR THE DNAPL PLUMES

3.1 Background

Remedial alternatives for removal or containment of the DNAPL can be categorized as:

- Excavation
- Containment
- In Situ Recovery

The various remedial alternatives which may be potentially applicable at the Bell site are described in the following sections. Excavation of contaminated soil and rock and the containment of contaminated zones in the subsurface are remedial measures which have been used at a variety of chemical spill sites and waste disposal facilities. The degree of success of such methods is dependent on the site conditions, and the design and implementation of the methods. In contrast, the in situ recovery methods described in the following paragraphs have only been evaluated on a theoretical or experimental basis. At the present time there are no in situ recovery methods which have been demonstrated on a field scale to be effective for the removal of DNAPL chemicals from the subsurface.

3.2 Excavation

Excavation of the contaminated soil has been a common remedial method used for removal of subsurface sources of groundwater contamination at chemical spill sites and waste disposal facilities. It is typically accomplished using conventional excavation techniques for soils and the excavated material is treated or disposed of in on-site or off-site facilities. Excavation of bedrock is very seldom employed. Excavation is conceptually simple and potentially capable of complete removal of subsurface DNAPL sources. Successful remediation of DNAPL sources can only be achieved when the DNAPL can be located and when the DNAPL is accessible using available excavation techniques and equipment. At many sites, excavation of DNAPL sources is not feasible because the DNAPL has penetrated to a significant depth or has penetrated into otherwise inaccessible areas such as beneath buildings. At sites where the DNAPL chemicals are volatile or the method of excavation could release contaminated particulate material, the emission of contaminants into the air may be of sufficient environmental concern to prohibit excavation.

3.3 Containment

The objective of containment of the DNAPL is to prevent further potential movement of the DNAPL and to restrict the flow of groundwater through the contaminated zone. Methods for the containment of DNAPL depend on the placement of some form of low permeability barrier around the plume. Such barriers include cut-off walls and grout curtains installed vertically through either soil or rock formations, and low permeability covers to reduce vertical infiltration through DNAPL zones.

Cut-off walls or slurry walls consist of a trench excavated through soil or rock which is backfilled with a low permeability material, usually a bentonite clay and soil mixture. The hydraulic conductivity of such cut-off walls may be approximately 10^{-7} cm/s.

Grout curtains are constructed by drilling a line of closely spaced boreholes. A grout material is then injected under pressure into each borehole so that the grout fills the pore space or fractures in the formation surrounding the borehole. Grout is typically a cement-bentonite mixture but chemical grouts can also be used. The principal characteristic of the grouts is that they are initially fluid enough to enter the pores and fractures in the formation and then set or harden to plug the formation. In construction of a grout curtain, a critical consideration is that the boreholes be spaced closely enough that a low permeability barrier or curtain is created. If the boreholes are not close enough, gaps or windows will exist between the boreholes which will allow movement of fluids through the curtain. The hydraulic conductivity of a typical, properly constructed, cement-bentonite grout curtain is considered to be approximately 10^{-5} to 10^{-6} cm/s.

Low permeability covers to reduce vertical infiltration from the ground surface can consist simply of compacted clay soil, synthetic membranes such as high density polyethylene or composite covers with multiple layers. Properly constructed covers can have effective hydraulic conductivities of less than 10^{-8} cm/s.

Containment of the DNAPL at the Bell site would require some type of vertical barrier around the periphery of the DNAPL to prevent horizontal movement of the DNAPL and horizontal groundwater flow through the DNAPL plus a cover to prevent significant infiltration of precipitation and surface water from above. Vertical barriers could be established using either cut-off walls or grout curtains.

A key uncertainty in containment of the DNAPL is the fact that it is not possible to contain the bottom of the zone. Despite the fact that the DNAPL may be contained laterally and across the top, DNAPL can move downward along fractures present through Zone 2. The ability of DNAPL to move further downward will depend on factors such as the fracture apertures, DNAPL density and interfacial tension. Although there is little evidence to suggest that DNAPL has entered Zone 3, it is not possible to predict with confidence that it cannot occur, especially if the hydraulic or chemical conditions in Zone 1 are altered during remedial activities. In particular, pumping of Zone 1 with desaturation of the bedrock will result in some degree of remobilization of the residual DNAPL with the potential for further downward movement. The effect could be counteracted by sufficiently large upward hydraulic gradient which could restrict downward flow of DNAPL. The maximum upward hydraulic gradient required to prevent downward flow of DNAPL is dependent on the density of the DNAPL and can be estimated theoretically by:

$$\frac{\Delta h}{\Delta Zn} = \frac{(pn \cdot pw)}{pw}$$

where Δh is the difference in hydraulic head across the DNAPL column, ΔZn is the height of the DNAPL column, Pn is the DNAPL density and Pw is the water density. For a DNAPL with density of 1.5 g/cm^3 such as TCE, an upward hydraulic gradient of 0.5 would be required to prevent downward DNAPL migration. This relationship estimates the maximum upward gradient required because capillary forces may combine with the upward gradient to restrict downward flow of DNAPL.

3.4 In Situ Removal and Treatment

Several of the insitu removal methods described in the following paragraphs are methods used in the petroleum industry for secondary and enhanced recovery of oil from oil fields. Although the principles of such methods are well understood and the methods are frequently effective for oil recovery, the methods cannot be directly applied to the clean-up of DNAPL contamination. It should be remembered that secondary and enhanced oil recovery methods are employed in confined formations hundreds to thousands of metres in depth where much higher pressures can be applied by pumping or injection. Similar pressures cannot be exerted in near surface (<50 m) groundwater environments. Similarly, the standard by which secondary or enhanced oil recovery is judged to be effective is far different from the standard by which DNAPL recovery methods must be judged. For example, if conventional oil recovery removes 30% of the oil resident in the formation, secondary and enhanced recovery methods would be deemed highly successful if they resulted in recovery of an additional 20 to 30%, still leaving 40% or more of the oil in-place. In contrast, in order to significantly reduce or eliminate groundwater contamination emanating from a large DNAPL source, it is likely that recovery of virtually all of the in-place DNAPL would be required.

3.4.1 Hydraulic Recovery

In porous materials where it is possible to locate pools or zones of free DNAPL in the subsurface, it is possible to remove some portion of the DNAPL with recovery wells or collector trenches. Villaume et al. (1983) showed that significant quantities of coal tar could be recovered from a 3.5 m thick pool in a gravel stratum in Pennsylvania. In fractured media, experience at the Smithville, Ontario site (Golder Associates, 1987) and at other sites (Ferry et al., 1986) has shown that although it is possible to recover small quantities (<1 L) of DNAPL, recovery rates are slow and it is often not possible to sustain continued recovery. In either case, even following recovery of the free DNAPL, a significant amount of residual DNAPL will remain in the subsurface and will continue to be a source of groundwater contamination.

Remedial methods for the hydraulic removal of DNAPL chemicals from residual zones would involve increasing the rate of groundwater flow through the DNAPL zones sufficiently to mobilize the residual DNAPL and recover it at the well. This could be accomplished with a network of pumping wells and injection wells. Be definition, the DNAPL present as blobs and filaments in the residual zones is immobile under the prevailing groundwater flow conditions. Capillary forces acting on the DNAPL residual will provide resistance to further movement of the DNAPL by groundwater flow or density-induced sinking.

The key factor which will control the mobilization of residual DNAPL by groundwater flow will be magnitude of the capillary forces acting to hold the DNAPL in place compared to the hydrodynamic force of the groundwater acting to move the DNAPL blobs and filaments (see Wilson and Conrad, 1984). These counteracting forces can be compared by means of a dimensionless ratio of the forces defined as the Capillary Number, N_C:

$$N_C = \frac{k p g J}{\sigma}$$

where k is the intrinsic permeability of the formation in cm^2, p is the density of the water phase in g/cm^3, g is the gravitational acceleration in cm/s^2, J is the hydraulic gradient and o is the interfacial tension between the water and the DNAPL in dynes/cm.

For conditions where the permeability of the formation is low and the hydraulic gradient is low or the interfacial tension is high, the Capillary Number will be low. This indicates that the capillary force acting to hold the residual in place is high compared to the hydrodynamic force acting to mobilize the DNAPL. For conditions where the permeability of the formation is high and hydraulic gradient is high or the interfacial tension is low, the Capillary Number will be high. This indicates that the hydrodynamic force acting to mobilize the residual is high compared to the capillary resistant and consequently mobilization of the residual is facilitated.

Based on laboratory experiments on a large number of sandstone formations of differing character and a variety of fluids, two critical values of the Capillary Number can be defined:

N_c* is the Capillary Number at which mobilization of the residual is initiated,

N_c** is the Capillary Number at which all of the residual is mobilized.

For a large number of laboratory tests, Wilson and Conrad (1984) reported that these values were relatively constant with $N_c* = 2 \times 10^{-5}$ and $N_c** = 1.3 \times 10^{-3}$. Using the relationships described above and an estimated value for the interfacial tension between a typical chlorinated hydrocarbon and water (Horvath, 1982), it is possible to calculate the hydraulic gradients which would be required to mobilize residual DNAPL from formations of various hydraulic conductivities. Most chlorinated hydrocarbons have an interfacial tension of approximately 50 dynes/cm. The results of these calculations are summarized on Figure B-2. As shown in this figure, very large hydraulic gradients would be required to mobilize the residual DNAPL. Larger gradients are required for formations of lower hydraulic conductivity. With Zone 1 beneath the Bell site, hydraulic gradients of 10 to 100 would be required to initial mobilization of the residual DNAPL. Complete mobilization would require gradients exceeding 1000. It is clearly not possible to create and maintain hydraulic gradients of this magnitude in near surface groundwater environments.

3.4.2 Chemically Enhanced Hydraulic Recovery

Hydraulic recovery of residual DNAPL may be enhanced by the addition of surfactants or other chemical agents into the groundwater which will reduce interfacial tensions of the DNAPL and allow the chemical to be more readily displaced by flowing groundwater. Such techniques are frequently used for the enhanced recovery of crude oil in oil fields. The addition of surfactants can reduce interfacial tensions by a factor 1000 or more and increase the potential mobility of the DNAPL by the same order. There are a wide variety of water soluble surfactants available including anionic surfactants such as carboxylic acid salts and sulfonic acid salts commonly used in detergents, cationic surfactants and non-ionic surfactants. In enhanced oil recovery systems, surfactants are added to the injected water at reasonably high concentrations (several tenths of a percent to several percent by weight) to achieve the desired reduction in interfacial tension and increase in oil mobility.

In addition to the effect of reducing the interfacial tensions and enhancing mobility of the DNAPL, some surfactants will also dissolve or emulsify the DNAPL at concentrations significantly higher than its water solubility. This will be discussed further in a following section on chemically enhanced solubilization.

The chemically enhanced hydraulic recovery of DNAPL chemicals from the subsurface, although potentially feasible, has not been demonstrated on a field scale. There are several key considerations which would need to be addressed prior to implementation of a field trial of an enhanced recovery scheme. Oil (petroleum) recovery operations are conducted hundreds to thousands of metres below the ground surface where there is little concern about contamination of the subsurface by the surfactant chemicals added to the injection water. However, in a near surface groundwater environment, many of the surfactant chemicals which could be considered for use pose a significant environmental concern in their own right. Consequently, the environmental effect of surfactant chemicals selected for use in an enhanced DNAPL recovery scheme should be carefully evaluated.

Another key consideration in the design of an enhanced DNAPL recovery scheme is that the mobilized DNAPL may escape the recovery system. The enhanced DNAPL recovery system must be designed such that the hydrogeologic conditions together with the groundwater injection and recovery system will provide for complete recovery of the mobilized DNAPL. For example, if downward penetration of DNAPL along a fracture has been arrested due to capillary resistance, addition of a surfactant in this area will reduce the interfacial tensions and the capillary resistance will be reduced, thus allowing the DNAPL to penetrate further downward into zones which were previously uncontaminated. This difficulty could be overcome by creation of sufficiently large upward hydraulic gradients between Zones 1 and 3.

3.4.3 Steam Displacement

Displacement of hydrocarbons by injected steam is a method used in enhanced oil recovery operations. At the present time, the only evaluation of the removal of volatile immiscible phase chemical such as TCE by steam displacement has been conducted by means of laboratory experiments (Hunt et al., 1988) and small field pilot-scale tests (Baum, 1988; Udell et at., 1989) by researchers at the University of California at Berkeley. The laboratory experiments used TCE, a benzene-tolune mixture and gasoline at residual contents of approximately 25 L/m^3 in glass columns packed with silica sand. Low pressure steam was injected at one end of the initially water-filled column. As the steam front propogated through the column, the column effluent was monitored for immiscible-phase chemical. Immediately before breakthrough of the steam front for the TCE experiment, virtually all of the immiscible phase TCE remaining in the column was displaced. Prior to steam injection, dissolved TCE concentrations in the column effluent were at 1,100 mg/l, the pure phase solubility. Following steam displacement and the passage of one pore volume of steam through the column, dissolved TCE concentrations in the effluent were 0.1 mg/l.

A pilot-scale field test of steam displacement was conducted at a solvent recycling facility in California. At this site, sandy materials above the water table were contaminated by 1,1-dichloroethylene, dichloromethane, Freon-113, TCE, 1,1,1-trichloroethane and other solvents to concentrations up to 30,000 ppm. A system consisting of a single 6 m deep recovery well and ring of 6 steam injection wells also 6 m deep, was operated for 5 days until breakthrough of the steam front occurred in the recovery well. Approximately 500 kg of chemicals were recovered from the system. However, because the highly variable initial chemical concentrations in the soil and the effect of vapor migration into the test area from surrounding contaminated zones, it was not possible to calculate removal efficiencies. Soil analyses do suggest that recovery is more complete through higher permeability zones and less complete through low permeability zones. This suggested, as could be expected, that heterogeneities in the subsurface will likely prohibit the rapid and complete removal exhibited in the laboratory tests.

No evaluation of steam displacement has yet been made for fractured rock environments. One potential drawback in the use of steam displacement is the creation of a zone of immiscible-phase chemical ahead of the steam front. In this zone, the DNAPL will be highly mobile and has the potential to sink to deeper levels. At the Bell site, this could be overcome by pumping Zone 1 to maintain a sufficiently large hydraulic gradient upward from Zone 3.

3.4.4 Accelerated Dissolution

For relatively soluble compounds, the removal of DNAPL below the water table may be possible using methods to increase the rate of groundwater flow through the contaminated zones thus increasing proportionately the rate at which the DNAPL is dissolved and removed. As with the hydraulic removal methods, the increased groundwater flow would likely be implemented by a system of injection wells and purge wells. Available data on the dissolution of DNAPL chemicals suggest that mass transfer coefficients may increase proportionally with increasing groundwater velocity, therefore facilitating acceleration of dissolution. For reasonably soluble DNAPL chemicals such as dichloromethane (solubility 10,000 mg/L) and 1,2-dichloroethane (solubility 8700 mg/L), accelerated dissolution may be a feasible method for recovery of the DNAPL chemicals from the subsurface. However, the solubility of TCE solubilities is much lower being 1,100 mg/L. In most hydrogeologic settings it is not possible to increase the groundwater velocity over wide areas by more than a factor of several times. An increase in the mass removal rate of several times is unlikely to be of significant benefit because the DNAPL source at the Bell site may produce dissolved chemicals for decades to centuries.

3.4.5 Chemically Enhanced Solubilization

Accelerated dissolution methods for the removal of DNAPL from residual zones and pools may also be enhanced by the addition of miscible co-solvents or surfactants to the groundwater to increase the solubility of DNAPL. Chemically enhanced dissolution of PCB from soil and TCB DNAPL has been evaluated on a laboratory scale. Ellis et al. (1985) evaluated the extraction of PCB from soils using several non-ionic surfactants and found removal efficiencies of 92% using a 1.5% aqueous solution of the surfactants. Extraction of PCB from the same soils using water resulted in removal efficiencies several orders of magnitude lower. General Electric (GE) Company has also evaluated the extraction of PCB Aroclor 1260 from soils using anionic and non-ionic surfactants. GE found that 0.1% to 1.0% surfactant solutions were capable of increasing the PCB solubility by a factor of 10^5 to 10^6 times. Zenon Environmental Inc. (1986) evaluated TCB solubility in methanol, ethanol and iso-propanol solutions and found that alcohol concentrations of 30% to 50% were required to increase TCB solubility by a factor of ten times.

Research is presently underway at the State University of New York at Buffalo to evaluate the effectiveness of a wide range of non-ionic surfactants at solubilization of chlorinated solvents. These laboratory experiments are presently limited to agitated batch experiments to compare the solubilization potential and several classes of surfactants have been found to be highly effective. Further column studies are underway to assess solubilization rates under non-agitated conditions more representative of subsurface conditions.

Chemically enhanced DNAPL dissolution, although potentially feasible, has not been demonstrated on a field scale. The considerations discussed previously for chemically enhanced DNAPL recovery are also applicable to enhanced dissolution. The environmental effect of the co-solvent or surfactant chemicals used should be carefully evaluated. Also, the enhanced dissolution scheme must be designed so that the hydrogeologic conditions together with the groundwater injection and recovery system will provide for complete recovery of the dissolved chemicals. As with chemically enhanced hydraulic recovery, and steam displacement, the potential remobilization of DNAPL and downward sinking must be considered.

3.4.6 In Situ Treatment

In situ treatment methods such as bioreclamation have been considered at other sites for the control of dissolved chemical plumes and mildly contaminated soils. Although laboratory studies suggest that TCE at low concentrations may undergo biodegradation by methane oxidizing bacteria under aerobic conditions, bacterial action on TCE requires that the TCE be in dissolved form. Therefore, the rate of depletion of DNAPL would likely be limited by the rate of DNAPL dissolution even if biodegration were effective at eliminating the dissolved-phase chemical. In situ bioreclamation of DNAPL TCE contaminated soil or rock has not been demonstrated on a field scale.

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