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FINAL REPORT

New York State
Department of Environmental Conservation

STANLEY F. RADON, CHMM, CPG
Senior Engineering Geologist
Division of Solid and Hazardous Materials
Region 9

270 Michigan Avenue
Buffalo, NY 14203-2999

(716) 851-7220
FAX (716) 851-7226

CORRECTIVE MEASURES STUDY

BELL AEROSPACE TEXTRON WHEATFIELD PLANT

Bell Aerospace TEXTRON
Division of Textron Inc.

Prepared by:
Golder Associates Inc.
Mt. Laurel, New Jersey

913-6384

JUNE, 1991

Golder Associates Inc.
CONSULTING ENGINEERS

Start

DRAFT FINAL REPORT

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REGION 9

CORRECTIVE MEASURES STUDY
BELL AEROSPACE TEXTRON
WHEATFIELD PLANT,
NIAGARA FALLS, NEW YORK

Submitted to:

Bell Aerospace Textron
2221 Niagara Falls Boulevard
Niagara Falls, New York

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April 1991

Project No.: 913-6384

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Golder Associates Inc.
CONSULTING ENGINEERS

April 17, 1991 Project No.: 913-6384

Bell Aerospace Textron
2221 Niagara Falls Blvd.
Niagara Falls, NY 14304

Attn: Mr. Brian Smith

RE: DRAFT FINAL CORRECTIVE MEASURES STUDY, BELL AEROSPACE TEXTRON WHEATFIELD PLANT, NIAGARA FALLS, NEW YORK

Gentlemen:

Please find enclosed 13 copies of the Draft Final Corrective Measures Study, Bell Aerospace Textron Wheatfield Plant, Niagara Falls, New York. Golder appreciates the opportunity to be of service on this project.

If you have any questions, please call.

Very truly yours,

GOLDER ASSOCIATES, INC.

Richard King

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

RCFK/drs
C:CMSCL

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS
(continued)

LIST OF FIGURES (continued)

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 General

A Resource Conservation And Recovery Act (RCRA) Facility Investigation (RFI) of the Neutralization Pond Solid Waste Management Unit (SWMU) has been conducted at the Bell Aerospace Textron (BAT) Wheatfield Plant in the town of Wheatfield, New York (Figure 1). The purpose of the investigation was to determine the nature and extent of chlorinated volatile organic compounds released from the Neutralization Pond to the groundwater beneath the site and assess potential risks from this release to public health.

The RFI report was submitted to New York State Department of Environmental Conservation (NYSDEC) in February 1991 (Reference 1) with the Baseline Risk Assessment (Reference 2) submitted as an addendum in March 1991. The RFI concluded that the organic compounds released from the Pond are predominantly chlorinated organic compounds in the groundwater within the soil overburden adjacent to the Neutralization Pond, and in a Dense Non-Aqueous Phase Liquid (DNAPL) plume and an associated dissolved groundwater phase plume within the upper bedrock. Since the Rocket Test Building (SWMU No. 13) and the Helicopter Blade Bonding Building (SWMU No. 9) are adjacent to the location of the organic compound plume in the groundwater, any remediation of the plume will also include any releases which may have occurred from these two SWMUs. The locations of these SWMUs are shown on Figure 2.

In September 1990 a preliminary review and assessment of potentially applicable corrective action technologies (Reference 3) for the groundwater plumes was submitted to NYSDEC and USEPA. This review provided a preliminary screening of identified potentially applicable technologies and corrective action measures.

This Corrective Measures Study (CMS) has been prepared to evaluate in more detail the technologies which could be applied to remediate the Site. This CMS includes the results of the preliminary review and analysis (Reference 3) and the results of groundwater modeling, solute transport studies and treatability studies.

The potentially applicable corrective measures are considered appropriate for mitigation of the organic compounds within the overburden, the DNAPL, and dissolved-phase plumes within the Zone 1 aquifer. This report provides analyses of the identified corrective actions based upon engineering feasibility and potential effectiveness. Conceptual design for these actions and the outlines of the monitoring programs which would be implemented to determine their effectiveness are presented.

The identified technologies were evaluated in general accordance with USEPA's Guidance for Conducting Remedial Investigations and Feasibility Studies under the Comprehensive Environmental Response Compensation and Liabilities Act (CERCLA), Interim Final, October 1988 (Reference 4) and the criteria specified in the RCRA guidance document prepared by the USEPA (Reference 5).

1.2 Regulatory Setting, Permits, and Consent Order

As required by RCRA, BAT filed a timely Part A Permit Application for all hazardous waste storage and management units at the Plant, including the Neutralization Pond. In 1984, USEPA called for the submission of the detailed Part B Permit Application. Because the groundwater investigations completed at that time indicated that there appeared to be a groundwater release associated with the Pond, BAT elected to close the Pond and other RCRA units and so advised USEPA.

Since the Pond had been used after July 1982, clean closure or a post-closure permit was required. BAT, NYSDEC, and USEPA determined that a clean closure could not be accomplished and that the release needed to be fully investigated before a post-closure permit could define the appropriate corrective action measures.

BAT, with the concurrence of USEPA, entered into two Consent Agreements with NYSDEC (Case No. RCRA 85-020-9, Index No. 051485), one to provide for the prompt physical closure of the Pond and the other to provide for a phased investigation of the nature and extent of the contaminant plume released from the Pond.

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, backfilling and capping with clay-type material and a vegetative cover. A report titled "Summary of Closure Activities and Closure Certification of Former Rocket Neutralization Pond" (Frontier Technical 1988, Reference 7) was submitted to NYSDEC in June 1988 and was subsequently approved by NYSDEC.

2.0 GENERAL SITE CONDITIONS

2.1 Site Location and Description

Detailed descriptions of the site location, geology and hydrogeology have been provided in the RFI report (Reference 1).

A brief review of site conditions is included herein. The Neutralization Pond is located at BAT's Wheatfield Plant in the town of Wheatfield, Niagara County, New York (see Figure 1). Figure 2 shows the location of the Pond and other SWMUs within the plume in relation to the structures at the Plant and Figure 3 provides the locations and status of all other SWMUs at the Plant.

The Plant is located at the southeast corner of the Niagara Falls International Airport on a broad gently sloping clay plain which extends 2.5 miles southwards to the Niagara River. Much of the area in the vicinity of the Pond is occupied by buildings, paved roads or paved parking areas. The area north and west of the Pond consists largely of open grassed surfaces and the paved runway and taxiway system of the Niagara Falls International Airport. To the east and south of the BAT Wheatfield Plant, the area is becoming increasingly residential from its original agricultural usage.

Three creeks cross this clay plain from east to west; Cayuga Creek, north of the Plant, and Bergholtz Creek and Sawyer Creek south of the Plant (see Figure 1).

The Neutralization Pond, which was operated at the site between 1948 and 1984, was excavated within the overburden soil materials which are composed of clayey silts, silty clays, and glacial tills. The Pond received liquid wastes from the Rocket Test Cells and other areas of the Plant.

Those liquid wastes probably included 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

A detailed description of the compounds detected in the groundwater and overburden soil immediately adjacent to the Pond is provided in the RFI report (Reference 1).

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 of the completed closure was prepared by Frontier Technology Inc. in 1988 (Reference 7).

2.2 Summary of Geology and Hydrology

The geology and hydrostratigraphy of the site have been defined by analysis of regional geological information and detailed stratigraphic analysis of overburden and core samples recovered by site investigation borings. Brief reviews of the geology and hydrogeology are presented herein. Detailed descriptions and discussions are presented in the various site investigation reports submitted to NYSDEC and USEPA (see References 1, 8, 9, 10 and 11).

The overburden at the site is composed of low permeability glaciolacustrine silty clays overlying lacustrine till and basal till. These strata are about 16 feet thick at the Pond and thicken to about 30 feet at Jagow Road which is about one mile south of the Pond. In the vicinity of the Pond, a thin discontinuous lens of coarser grained sandy material was noted between the lacustrine till and the underlying basal till. The overburden soils are underlain by Zone 1 dolomite.

The Zone 1 dolomite is thinly bedded, relatively permeable and increases in thickness from about 10 feet near the Pond to about 15 feet at Jagow Road. Gypsiferous bedding planes within Zone 1, particularly at the contact with the underlying Zone 2 dolomite, have been weathered out by partial dissolution of the gypsum. This stratum at the base of Zone 1 is referred to as the A Marker Bed.

An 8-foot thick confining layer of massive dolomite, Zone 2, exists beneath the Zone 1 dolomite. This unit is considered to be an aquitard.

Beneath these two strata, a 20 feet to 25 feet thick dolomite stratum, the Zone 3 dolomite unit, also forms an aquifer. Additional dolomite layers exist beneath these strata to a depth of about 200 feet. The Rochester shale lies beneath these dolomites. All these strata dip southwards very gently, as does the bedrock surface and ground surface. Figure 4 provides a north - south geologic section through the study area.

Groundwater flow in the area between the BAT Plant and Jagow Road is generally southwards in the overburden and Zone 1 dolomite 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 pumping test at the site in December

1989, it was considered that the sanitary sewer systems located in the overburden adjacent to the east side of the BAT facility caused upward gradients within the Zone 1 dolomite. This condition is now believed to depend on the presence of storm runoff and/or the discharge of non-contact cooling water from the Rocket Test Facility (see Figure 2), to the ditch along Walmore Road. Water in this ditch is believed to seep into the granular backfill of the Walmore Road Sanitary Sewer trench, located parallel and adjacent to the surface drainage ditch and hydraulically connect with the Zone 1 bedrock aquifer. This results in an increased hydraulic head within Zone 1 and the development of variable downward hydraulic gradients between Zone 1 and Zone 3.

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 the Zone 1 bedrock.

2.3 Groundwater Chemistry

Analysis of groundwater and overburden soil samples obtained during the various phases of site investigation have provided information regarding the nature and extent of organic compounds in groundwater and in the overburden soil associated with the Neutralization Pond SWMU. Although one continuous plume, the groundwater plume is discussed herein as four plumes for convenience. These plumes which are attributed to the now closed Neutralization Pond are:

1. A plume containing organic compounds 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 in the Zone 1 bedrock containing dissolved organic compounds extending about 4,700 feet to the southeast of the Pond, roughly pear shaped, about 3,600 feet wide; and,

4. A dissolved phase plume of limited extent in the Zone 3 bedrock stratum, beneath the DNAPL plume.

The areal extent of the overburden plume is shown on Figure 5. The areal extent of the Zone 1 DNAPL plume and the Zone 1 dissolved phase plume are shown on Figure 6. The areal extent of the Zone 3 plume is shown on Figure 7.

The DNAPL is predominantly composed of trichloroethylene (67 percent) with varying amounts of methylene chloride (16 percent), 1,1,1-trichloroethane (10 percent), and acetone (4 percent). Polycyclic aromatic hydrocarbon (PAH) compounds and polychlorinated biphenol (PCB) compounds have also been detected in the DNAPL plume (Reference 1). Table 1 provides a listing of compounds detected in the DNAPL and the maximum concentrations of those compounds. Table 2 provides a list of the compounds detected in the dissolved phase plumes and the maximum concentration of those compounds.

The DNAPL plume extends southeastwards from the Neutralization Pond about 750 feet. It is about 150 feet wide and predominantly located at the base of Zone 1. In the vicinity of the Pond 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. Further restriction of DNAPL movement is provided by the presence of a natural shallow Y-shaped trough in the top of the Zone 2 aquitard. All known occurrences of DNAPL have been located within this trough.

Available groundwater quality data indicate that the Zone 2 dolomite stratum has restricted downward migration of DNAPL and dissolved-phase compounds. A dissolved phase plume of relatively low concentration is present in the Zone 3 dolomite strata directly beneath the Zone 1 DNAPL plume.

The dissolved phase Zone 1 plume extends 4700 feet south-southeast from the Neutralization Pond. 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 (DCE) and vinyl chloride (VC) tend to increase. This is considered to be due to elevated detection limits for some of the analytes near the DNAPL plume, and anaerobic biodegradation of TCE, etc., to daughter products such as DCE and VC. Based on the results of the 1990 CLP analysis of samples from all of the wells installed in the study area (Reference 1), a series of compound concentration contours have been developed. These contour maps are provided in Figures 8 through 11 for the following constituents:

Figure 8 - Methylene Chloride;
Figure 9 - Trichloroethylene;
Figure 10 - 1,2-Dichloroethylene (Total); and,
Figure 11 - Vinyl Chloride.

Figure 12 shows the distribution of the ratios of TCE:DCE:VC.

Prediction of the effectiveness of a groundwater extraction program requires assessment of the overall retardation rate of the volatile organic compounds in the plume. This retardation has been assessed by comparing groundwater velocities with plume length and plume age. The probable ranges of values of hydraulic conductivity and porosity were used with measured hydraulic gradients to calculate plume lengths for different retardation rates. Figure 13 presents the results of this comparison and indicates:

1. An overall hydraulic conductivity value of 4.1×10^{-3} cm/s is satisfactory;
2. Porosity can range from 1 percent to 3 percent; and,
3. A retardation factor of 2 is a reasonable assumption.

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 relatively limited extent as shown on Figure 7. Reported concentrations vary from 3,000 ug/l to 11,000 ug/l total volatile organic compounds 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. Studies are presently being completed to determine whether groundwater containing dissolved phase compounds in Zone 3 will migrate upward into Zone 1 if corrective action by groundwater extraction from Zone 1 is implemented. Should direct extraction from Zone 3 be required, it is essential that downward gradients not be induced between Zone 1 and Zone 3 in the plume areas.

3.0 REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

3.1 General Approach

The criteria for identifying and reviewing technologies and alternatives are discussed in this Section. The potentially applicable corrective measures have been qualitatively evaluated on the basis of:

1. Engineering feasibility;
2. Demonstrated or expected effectiveness;
3. Protection of human health and the environment; and,
4. Technical reliability.

Alternatives which do not meet these criteria either singularly or in combination have been rejected.

3.2 Corrective Measures Objectives

General corrective measures objectives are to abate and remediate any significant threat to public health and the environment due to the release from the Pond.

According to the baseline risk assessment (Reference 2), the greatest risk of exposure is due to the DNAPL plume and then to a lesser extent the dissolved phase plume within the overburden and the Zone 1 bedrock. Consequently, corrective measures for the DNAPL plume were given significant consideration.

To provide an overview of current knowledge regarding remediation of DNAPL, Mr. Stanley Feenstra, of Applied Groundwater Research, Mississauga, Ontario, Canada, was requested to complete a review of known technologies for DNAPL remediation. This review is presented in Appendix A of this report.

Mr. Feenstra's review concluded that it is currently not possible to completely remove DNAPL from the subsurface bedrock fractures in much the same way that it is not possible to remove 100 percent of the oil from an oil field. The small amounts of DNAPL remaining after "remediation" by DNAPL "removal" would have the potential to allow the development of a very large dissolved phase plume. Remediation of the DNAPL plume by pumping or other extraction methods is not a technically feasible nor effective corrective measures alternative. The technically feasible and effective alternative is to control the dissolution of the DNAPL by hydraulically or physically containing the DNAPL.

Based upon the lack of any feasible and effective DNAPL removal technologies, BAT has identified the following corrective measures goals:

1. Control off-property migration of organic compounds from the overburden plume;
2. Reduce the concentration of volatile organic compounds within the overburden;
3. Control migration of the DNAPL plume;
4. Reduce the amount of the DNAPL and the DNAPL head in the Zone 1 DNAPL plume;
5. Control continued development and migration of the Zone 1 dissolved-phase plume;
6. Reduce the concentration of organic compounds within the Zone 1 dissolved-phase plume both on and off BAT property; and,
7. Provide for reduction of organic compound concentration in the Zone 3 bedrock plume.

3.3 Corrective Measures Alternatives

3.3.1 Corrective Measures Alternatives Categories

Corrective measures which reduce the potential for migration of and/or exposure to the overburden and groundwater plumes may be placed in several categories which either singularly, or in combination, have the potential for meeting the previously identified goals:

1. Institutional measures for reducing exposure to onsite and offsite constituents;
2. Removal - excavate contaminated materials for treatment and/or disposal;
3. Containment - physically isolate groundwater or DNAPL plumes to control migration;
4. Collection - withdraw groundwater or DNAPL plumes from the aquifer for treatment and disposal;
5. Treatment - destroy, degrade, transform, or immobilize organic compounds either in situ or after extraction; and,
6. Disposal/discharge - transport or manage removed or extracted materials at an appropriate facility.

Table 3 has been developed to summarize potentially feasible and effective corrective measures and to screen out infeasible or ineffective measures. This table provides a description of the available options and/or technologies considered for corrective action and indicates the rationale for selection or rejection. Table 3 also identifies the presently preferred corrective action alternatives. Descriptions of the potential corrective measures which have been considered are provided below.

3.3.2 Institutional Measures

For a baseline comparison, an institutional measures alternative was evaluated. For this alternative, no activity would be implemented that would extract or control the organic compounds in either the overburden or the Zone 1 aquifer and no institutional controls would be implemented to mitigate potential public access to groundwater containing organic compounds. This would result in continued migration of the dissolved phase organic compounds and possible further migration of the DNAPL plume. The no action alternative recognizes the fact that the Base Line Risk Assessment (Reference 2) has indicated that both onsite and offsite risk levels are acceptable.

Minimal measures are those that neither treat nor remove the organic compounds, but limit the potential for contact or exposure to the groundwater plumes. Potential measures include limiting site access, limiting land and groundwater use through deed restrictions, local laws or construction moratoriums, and closure of privately owned groundwater wells in the vicinity of the BAT facility. These measures have been retained as potentially applicable because:

1. It is not possible to remove the overburden plume without demolition of part of the facility;
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 to reduce the potential for exposure:

1. Provided a security barrier around the closed Neutralization Pond;

2. Attempted to identify and locate every well on every property within the area of the Zone 1 dissolved phase plume;

3. Decommissioned 21 private offsite wells for which permission has been obtained, and is attempting to obtain permission to close all other known wells in the area; and,

4. 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.

Deed restrictions have been filed for that part of the land that is currently owned by BAT which includes or is in the vicinity of the contaminant plumes.

3.3.3 Removal

Since the overburden plume and Zone 1 DNAPL plume are relatively shallow (less than 30 feet below surface), the excavation of these plumes was considered as a potential corrective action alternative.

Excavation of the overburden is considered to be technically feasible by using backhoe equipment after demolition and removal of structures (Rocket Test Cells, etc.) and roads above the overburden plume area. During excavation a significant health risk could develop due to organic compounds volatilizing from the overburden and the exposed Zone 1 DNAPL. 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 determination of the requirements for treatment to meet the land disposal restriction rules prior to disposal. Given the concentrations of organic constituents in the lower zone of the overburden, it is probable that some of the overburden would not meet land disposal restrictions for direct landfilling in a RCRA hazardous waste landfill and would require incineration or other treatment prior to land disposal.

Though it is feasible to excavate the overburden, it has been rejected as a viable corrective action 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 probable treatment before land disposal;

3. Excavation would require demolition of the Rocket Test Cell facilities (now leased to Atlantic Research Corporation); and,

4. The movement of organic compounds and dissolved organic compounds 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 to the environment is considered to be minimal.

Moreover, as discussed in Appendix A and below, it is not considered feasible to fully remove or completely "treat in situ" the DNAPL. Therefore, it will be necessary to contain the DNAPL plume in perpetuity or at least until some feasible treatment technology is developed, since the overburden plume is predominantly located above the DNAPL plume, and extraction of groundwater for hydraulic control of the DNAPL plume will to some degree effect control and mitigation of the overburden plume.

Excavation of the DNAPL plume would be possible after excavation of the overburden. Although excavation of Zone 1 bedrock could be accomplished by the use of blasting, this activity would generate airborne releases and could influence the fracture apertures in the Zone 2 aquitard beneath Zone 1 resulting in the potential for migration of DNAPL through Zone 2 and into 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, during excavation this hydraulic gradient would not necessarily prevent downward migration of the DNAPL through fractures opened by blasting.

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 generally in situations where no vibration is permissible. The procedure consists of drilling a series of holes in the rock into which the expansive compounds are added. Subsequent expansion of the product splits the rock. The chemical compounds contained in the expansive rock fracturing products 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) containing DNAPL and dissolved phase organic compounds. Because of the anticipated concentration of the organic compounds and their hazardous waste classification, it is believed that much of the excavated rock would not meet land disposal restrictions and would, therefore, require pre-treatment, probably by incineration, or some washing process prior to land disposal.

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

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

1. The reasons listed for the overburden plume;
2. Groundwater control in the bedrock would be more technically complex than for the overburden (for example, it may require a grout curtain, but 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 very expensive; and,

6. Disposal of the treated bedrock would be extremely expensive.

3.3.4 Containment

Containment technologies include methods for physically isolating the organic compounds from the surrounding environment. Such methods include caps, cutoff walls, and hydraulic control.

3.3.4.1 Capping

A cap is a low-permeability cover placed over an area to restrict infiltration of precipitation and control surface water runon and runoff. This action would somewhat reduce the potential for development of a dissolved phase plume by altering the subsurface flow regime. Such caps are typically constructed of low permeability materials such as synthetic membranes, asphalt, and/or clay materials. The Neutralization Pond was closed with a low permeability cap.

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. However, 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;

4. Capping would not reduce the potential for exposure of workers servicing shallow sewer systems or telephone lines, etc.;
5. Less percolation of rainwater and snowmelt may result in an increase in organic compound concentrations in the overburden vadose zone; and,
6. Extraction of groundwater from the Zone 1 bedrock would enhance vertical migration of groundwater from the overburden to the Zone 1 bedrock and thus form a corrective action for the overburden without a low permeability cap.

Additional capping of the overburden plume is not recommended since it would not markedly enhance the present condition.

3.3.4.2 Cutoff Walls

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 corrective action response for these plumes. These containment systems fall into three categories:

1. Construction of a low permeability cutoff wall;
2. Construction of a permeable trench to act as a hydraulic barrier; and,
3. Reducing the hydraulic conductivity of in situ materials by grout injection.

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. Interlocking sheet piles;
2. Intersecting soldier pile walls;
3. Freeze walls;
4. Slurry walls;
5. Permeable slurry walls; and
6. Grout curtains.

Interlocking sheet piling systems have been developed that enable the joint between the individual piles to be sealed by grout. This method could be used for the overburden, however the presence of sewer lines, water lines etc., would involve substantial technical difficulties during construction. Additionally, it is technically difficult to guarantee a seal at the contact of the sheet pile wall with the bedrock surface. This option is rejected on engineering feasibility grounds.

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 Zone 1 bedrock DNAPL plume. It should be noted that considerable technical difficulties would be presented by the infrastructure both above and below ground surface. These subsurface difficulties would include reconnections of storm and sanitary sewers, electrical conduits, and steam pipes. Above ground problems would be posed by the presence of the complex of Rocket Test Cell buildings, roads and services.

A freeze wall consists of closely spaced, low temperature brine recirculation pipes that freeze the ground to form a vertical barrier of frozen groundwater and subsurface materials. Freeze walls are usually emergency response barriers or short-term construction systems for shafts or similar excavated structures. Though 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 are not recommended.

A slurry wall consists of a low permeability slurry, usually of bentonite clay and soil, placed in an excavated trench. Slurry walls are routinely constructed 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 while 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 soil is already known to have low hydraulic conductivity. Further reduction of horizontal movement of groundwater through the overburden may be unwarranted and, if groundwater extraction is accepted as a corrective measure, counter productive. Although slurry walls are commonly constructed in soils with much higher permeabilities than the overburden soil at the BAT site, this option has been retained as a potential corrective measure should groundwater extraction fail to provide sufficient hydraulic control of the DNAPL plume.

Slurry walls can be constructed in bedrock by using a "hydrofraz" (rock milling machine). 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 dolomites at BAT have compressive strengths in the range of 15,000 psi to 25,000 psi. Moreover, dolomitic rock is relatively abrasive. With currently available "hydrofraz" equipment it is not considered feasible to construct a slurry wall in the Zone 1 bedrock, hence 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 or infiltration 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 because it requires the support of the excavated trench during construction by a degradable starch slurry. The 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. Given the low permeability of the overburden soils and the potential to underdrain the overburden, this corrective action alternative has been rejected.

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 a dissolved phase plume. A grout curtain would also allow the hydraulic head within the grout containment area 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 viable candidate for controlling the DNAPL plume should the use of a hydraulic control system prove to be insufficiently effective. It should be noted, however, that cementitious grout with bentonite additives can result in reductions of hydraulic conductivity only to about 10^{-5} cm/sec. Further reductions usually rely on the use of non-cementitious grouts which contain organic viscosity reducing agents such as triethanolamine and ammonium persulfate, 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.

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. Should a grout curtain be required around the DNAPL plume these issues must be addressed in the design of the treatment plant for pumped groundwater. The use of a grout curtain for control of the DNAPL Plume has been deferred pending the results of hydraulic containment studies.

Though it is technically feasible to construct a grout curtain around the offsite dissolved phase plume such a control measure would not prevent private parties from extracting the groundwater contained within the grout curtain. Additionally, the movement of the offsite plume is very slow (Reference 1) so that a grout curtain would serve little purpose. This corrective measure is rejected for control of the offsite dissolved phase plume.

3.3.4.3 Hydraulic Control

Hydraulic control of a groundwater system involves manipulation of groundwater flow directions by the extraction and/or injection of groundwater. Such a manipulation can be used to prevent migration of a plume from occurring in a given direction or to cause migration of a plume in a required direction.

Prevention of offsite migration of the dissolved phase plume, generated by groundwater flowing through the DNAPL plume area, is considered to be one of the most important corrective action goals. Consequently a groundwater flow model of the study area was developed using the FLOWPATH computer code to allow assessment of the groundwater flow regime. The details of this modeling effort are provided in Appendix B. Various configurations of extraction wells were simulated by the model to determine their impact on the flow regime in the DNAPL plume area. This study indicates that the dissolved phase plume, generated by the interaction of groundwater with the DNAPL, can be captured by four extraction wells located adjacent to the DNAPL plume within the BAT Plant boundaries . No reinjection wells are required for this hydraulic containment scenario.

This corrective measure is considered to be the primary candidate for DNAPL control. Hydraulic control and extraction of the dissolved phase plume is discussed in Section 4.

3.3.5 Collection

Collection of the organic compounds from the subsurface involves the use of some form of extraction system which could include hydraulic recovery, vapor extraction, steam injection/vapour extraction, and/or in situ air stripping.

Extracted materials are then treated or disposed in an approved manner.

Several technologies have been considered for enhancement of hydraulic removal of DNAPL. At this time, none of these technologies are considered to be acceptable for use at BAT. These technologies are briefly discussed in the following subsection and presented in more detail in Appendix A.

3.3.5.1 Hydraulic Recovery

Hydraulic recovery involves the extraction of contaminated groundwater from pumping wells or infiltration trenches for treatment or disposal. As discussed in Section 3.3.4.3 hydraulic control of the groundwater flow in the DNAPL plume by four extraction wells is considered feasible. The groundwater modeling performed for the site indicated that two additional extraction wells could control the onsite Zone 1 dissolved phase plume and that six extraction wells placed along the Niagara Mohawk right-of-way could control the offsite section of the Zone 1 dissolved phase plume. Section 4.2 and Section 4.3 discuss these corrective measures in more detail.

Extraction of groundwater from Zone 1 will reduce the potentiometric head, thereby causing an upward hydraulic gradient from Zone 3 to Zone 1 and downward hydraulic gradients from the overburden to Zone 1. Studies are presently being undertaken to determine the effect of this gradient on control of the vertical movement of DNAPL through Zone 2, the impact on the Zone 3 dissolved phase plume, and the impact on the overburden plume.

3.3.5.2 Vapor Extraction

This process involves the installation of vapor extraction wells in the vadose zone. For the most part, the overburden soils in the overburden plume area are of low permeability (less than 10^{-6} cms/sec). As such, vapor extraction techniques would be ineffective since this method is usually restricted to soils with permeabilities above 10^{-5} cms/sec. It is noted, however, that a coarser grained unit (a sand lens) with higher permeability (10^{-5} cms/sec to 10^{-4} cms/sec) located above the basal till has been identified in the vicinity of the Neutralization Pond. As discussed in the RFI (Reference 1) the sand lens may well be an isolated offshore sand bar developed adjacent to the north shore of the glacial lake which inundated this area during the late stages of the Pleistocene. Since the sand lens and the basal till is located below the water table vapor extraction in the overburden, and the sand lens in particular, is rejected as a corrective action. It is considered that the downward hydraulic gradients caused by extracting groundwater from the Zone 1 bedrock onsite will effect improvement of groundwater quality in the overburden.

3.3.5.3 In Situ Steam Injection/Vapour Extraction

This process uses steam flooding to increase the temperature of a contaminated zone to vaporize the volatile organic 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-organic phases. This option is rejected for remediation of the overburden due to its low permeability 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 volatile organics compounds vapors into the overlying overburden where they may condense and be even more difficult to remove.

3.3.5.4 In Situ Air Stripping

In situ airstripping of the overburden, sometimes referred to as sparging, involves blowing air through the overburden and causing volatilization of organic compounds. 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 or additional organic compound vapor into the overburden or Zone 3, or both.

3.3.6 In Situ Treatment

Treatment technologies which have been considered include in situ vitrification of the overburden or biologic treatment. 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.

3.3.6.1 In Situ Vitrification

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 still contains organic compounds; and,
3. The process is not efficient or effective with high moisture content soils or high groundwater levels such as those at the BAT site.

3.3.6.2 In Situ Biologic Degradation

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

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

3.3.7 Treatment

The review of the potential corrective action alternatives, as discussed above, strongly indicates that the main components of the selected 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 (RTG) of Denver, Colorado. This company has completed 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 preliminary Plant Process Flow Sheets for a potential onsite system and offsite system.

The treatability study report is provided in Appendix C. These studies indicate that the treatment methods for extracted groundwater should be split into two components consisting of:

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

These treatment plants are described in Sections 4.2.2 and 4.3.2.

3.3.8 Disposal/Discharge

Hazardous and non-hazardous materials generated during corrective action implementation, such as drill cuttings and excavated overburden soils may be disposed at an appropriately licensed waste disposal facility.

The concentrations of chlorinated volatile organic compounds in the groundwater extracted from the Zone 1 groundwater extraction systems would preclude discharge to a surface discharge point or POTW without prior treatment to reduce these concentrations to acceptable limits. Though potentially feasible to discharge treated groundwater to a surface discharge point, the presently envisioned discharge option would be via a revision to BATs current discharge permit for release of water to the Niagara County No.1 District POTW sewer system.

3.4 Summary

This review has resulted in the rejection of several of the identified potential corrective action alternatives on the basis of engineering infeasibility and ineffectiveness. The available feasible and effective technologies for remediation of the overburden and the dissolved phase chlorinated organic compound plumes in the Zone 1 and Zone 3 bedrock are groundwater extraction and treatment. It must be noted, however, that the rate of remediation and the attainment of any cleanup levels for the groundwater will be difficult to predict with certainty. Consequently, groundwater extraction and treatment require monitoring for drawdowns, pumping rates, contaminant load removed, and changes in groundwater chemistry, in order to evaluate overall system effectiveness. The monitoring program for the preferred system is discussed in Section 5.

Figure 14 presents the currently preferred corrective measures program. The components of this system are listed below:

- Control of rocket test cooling water;
- Control of precipitation runoff in the drainage ditch on Walmore Road;
- Clay stops and capping of Walmore Road Sanitary Sewer trench;
- Onsite groundwater extraction wells in DNAPL plume area;
- Onsite dissolved phase groundwater extraction wells;
- Offsite dissolved phase groundwater extraction wells (subject to site access and compliance with applicable zoning rules);

- Onsite treatment plant; and,
- Offsite treatment plant (subject to site access and compliance with applicable zoning rules).

In addition, should groundwater extraction wells prove to be insufficiently effective in preventing the migration of the onsite dissolved phase plume and control of the onsite overburden plume, the following physical containment systems have been deferred for future consideration:

1. Overburden slurry wall;
2. Zone 1 bedrock grout curtain around DNAPL; and,
3. Zone 1 bedrock soldier pile wall around DNAPL.

The proposed corrective measures are described in further detail in Section 4.

4.0 CORRECTIVE MEASURES PROGRAM

4.1 Ancillary Measures

4.1.1 Control Rocket Test Cooling Water and Precipitation Runoff

During the pumping test, completed in well 87-14(1) adjacent to the DNAPL plume and within the Zone 1 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 (References 1 and 12). It is believed that water in the ditch infiltrates into the granular backfill in the adjacent sewer trench which has an invert 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 sanitary 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 this sewer. It is believed that no clay stops were installed in this trench when the sanitary sewer line was constructed.

These flows of water in the sanitary 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 trench for some period of time. This condition results in the potential for seepage from the overburden and bedrock to the backfill of the trench.

To restrict these flows of water within the sanitary sewer trench backfill, clay stops will be installed in the trench at the upstream and downstream locations of the Zone 1 DNAPL and overburden containment systems. Additionally, the discharge of water from the Rocket Testing Cells and storm water runoff will be hydraulically isolated from the Zone 1 bedrock and overburden by constructing a new drop culvert and pipeline within a clay backfilled trench. Construction of these ancillary actions will be subject to approval by the municipality and sewer authorities.

4.1.2 Control Seepage Along Walmore Road Sewer Trench

It has been observed that a considerable quantity of water flows in the backfill of the sanitary sewer which runs along the west side of Walmore Road. To prevent this and to reduce the potential for movement of groundwater in the Walmore Road Sanitary Sewer trench backfill, the preferred ancillary action is the construction of clay stops in the trench.

The clay stops would be located to the north of the Wheatfield Plant Northern boundary and at the south end of the overburden plume (see Figure 14). This ancillary action would be completed after the onsite treatment plant is constructed so that any seepage water encountered during excavation of the trench could be treated, if required, prior to discharge to the POTW. To further reduce the potential for inflow of seepage water prior to excavation sodium silicate or similar grouts could be injected into the granular trench backfill on either side of the two excavations thus forming a reduced permeability zone within the backfill.

4.2 Offsite Groundwater Control System

The most viable approach to corrective action for the Zone 1 dissolved phase plume is considered to be groundwater extraction and treatment prior to release to the POTW. These remedial measures are discussed below.

4.2.1 Offsite Groundwater Extraction System

To determine whether a groundwater extraction system could be designed for the offsite area, a finite difference computer model, FLOWPATH, developed by the University of Waterloo, Ontario, Canada, was used to simulate groundwater conditions in the area. Details regarding this model and the model analyses are provided in Appendix B. A summary of the results are provided herein.

The model was calibrated with known regional and local area groundwater and stream level data (Reference 1). Hydraulic conductivity values from the extensive testing program completed for the RFI (Reference 1) was used as input data along with porosity values of 1 percent and 3 percent for the Zone 1 aquifer. These two values were considered to represent the likely range of porosity values for Zone 1 (see Figure 13). Several extraction well configurations were simulated with varying groundwater extraction rates to determine optimum well locations given the access constraints. The configuration considered most appropriate for remediation of the offsite plume involves a system of six wells located along the Niagara Mohawk Right of Way as shown on Figure 14. These wells would be cased through the overburden to the bedrock and open across the Zone 1 dolomite. The groundwater pumped from this system, about 42 gallons per minute (gpm), would be conveyed by an underground double walled pipeline to a treatment plant. A potential location for the treatment plant is shown on Figure 14. The actual location of the wells and treatment plant will be dependent on approval by Niagara Mohawk Power Corporation and access and zoning restrictions.

The potential treatment plant design for the offsite system is discussed in Appendix C and Section 4.2.2. Detailed design of the groundwater extraction system will be presented in the Corrective Measures Implementation (CMI) Plan.

Solute transport modeling of the effectiveness of the system is presently being completed using the finite difference FTWORKS solute transport code. This model is based on the USEPA validated finite difference MODFLOW computer code. Initial simulations of the change of groundwater chemistry caused by pumping groundwater from the offsite Zone 1 plume indicates considerable improvement will occur quite quickly. The results of this solute transport modeling, which will incorporate an assessment of the impact of matrix diffusion, will be reported in the CMI Plan.

4.2.2 Offsite Groundwater Treatment System

To provide for the treatment of the extracted groundwater, two treatment plants appear to be the most viable approach. The ability to construct an offsite plant will depend on the ability of BAT to obtain the necessary permits, easements and meet the required zoning regulations.

The offsite plant would treat water from the offsite extraction system to remove and treat the volatile organic compounds, primarily trichloroethylene, 1, 2 trans-dichloroelthylene, and vinyl chloride. Preliminary results from solute transport modeling indicate initial total volatile organic compound concentration in the first year of pumping to be about 300 ppb to 600 ppb. Appendix C provides the results of the treatability tests for the onsite and offsite groundwater. These tests indicate that airstripping, UV oxidation and carbon absorption are potentially applicable for the treatment of offsite groundwater.

Based on the desire to reduce volatile organic compound emissions in a residential neighborhood and the poor loading of vinyl chloride on carbon, the currently preferred treatment system for the extracted groundwater prior to discharge to the POTW is the Ultra Violet Oxidation (UVOX) method. This methods oxidizes the chlorinated organic compound molecules to hydrochloric acid (very low levels), carbon dioxide, and water.

Testing completed by UV Peroxidation Systems Inc. of Tucson, Arizona, indicates that the concentration of volatile organic compounds in the discharge water can be reduced to very low levels. Analysis of groundwater samples for natural inorganic parameters including iron, BOD, carbonates, etc., is presently being completed to determine their potential deleterious effects on the operation of such a plant.

The detailed design of this system will be provided in the CMI Plan. A schematic of the proposed treatment plant is provided in Appendix C Figure 8.3.

4.3 Onsite Groundwater Control System

The groundwater computer model indicates that an arrangement of four extraction wells positioned around the DNAPL plume can control the generation and migration of groundwater containing organic compounds from the DNAPL plume and two additional wells in the onsite Zone 1 dissolved phase plume can capture the northern portion (north of Niagara Falls Boulevard) of the Zone 1 dissolved phase plume.

4.3.1 DNAPL Control and Onsite Groundwater Extraction System

The four DNAPL control wells and two Zone 1 dissolved phase extraction wells would be arranged approximately as shown in Figure 14. The wells would be cased through the overburden and screened across the Zone 1 dolomite. Each DNAPL well would be equipped with a system for purging DNAPL from the base of the well should it migrate to the well. The pumping rate for each well would be set, via level control switches and flow values, such that a minimum drawdown of 4 feet is achieved in the DNAPL plume area. This drawdown would develop an upward hydraulic gradient of 0.5 ft/ft between the Zone 3 and Zone 1 aquifer. This upward hydraulic gradient would have the tendency to prevent downward migration of any remobilized DNAPL through Zone 2. Horizontal movement of the DNAPL would be influenced by the horizontal gradients to some extent, but predominantly by the bedding partings, particularly in the A Marker Bed (Reference 1). The average predicted pumping rate for each DNAPL well is 3 gpm and for each dissolved phase well is 6 gpm.

Level switches will also be set to ensure that drawdown of the water level below the base of the overburden does not occur. This precaution is necessary since dewatering of DNAPL can result in remobilization due to the increased effective DNAPL head.

Water from the DNAPL wells would be conveyed by double-walled pipeline to the treatment plant (tentatively considered to be located in the Helicopter Blade Bonding Building) and co-mingled with water pumped from the two onsite dissolved phase wells.

4.3.2 Onsite Groundwater Treatment System

The groundwater extracted from the onsite dissolved phase plume will 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.

Based on the results of the treatability testing (Appendix C), the most effective components for onsite treatment are considered 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 with a thermal oxidation system followed by a quench and adsorption chamber; and,
5. Polishing the water discharged from the air strip towers by two carbon adsorption units, in series, prior to discharge to the POTW.

Figures 8-1 and 8-2 in Appendix C present the preliminary flow diagram for the onsite treatment system. It is presently anticipated that this treatment plant would be located in the containment area of the Helicopter Blade Bonding building.

4.4 Overburden Groundwater Remediation

Since the overburden has a low hydraulic conductivity, removal of contaminated groundwater directly from the overburden plume may be slow or virtually impossible. However, the preferred option for the Zone 1 DNAPL area is hydraulic control by pumping. This process would induce a downward flow of groundwater from the overburden plume, thus effecting corrective action. It should be noted that the reduction of the water level in the overburden by "dewatering" has the potential to cause differential settlement in the clays due to consolidation. The CMI Plan for onsite corrective actions will address this issue.

5.0 GROUNDWATER MONITORING PROGRAM

5.1 Monitoring Plan

The monitoring plan for the groundwater remediation program will include monitoring of groundwater quality and monitoring of the extraction and treatment systems. Because the design of the on-site and off site systems are based on the results of groundwater and solute transport modeling, the monitoring program will include data acquisition, analysis and evaluation for comparison of actual performance to the predicted performance and cleanup standards. The general approach to the monitoring program is provided herein and the details of the monitoring program will be included in the CMI.

The groundwater remediation monitoring program is anticipated to include two phases as follows:

1. Effectiveness Monitoring - A program followed during operation of the corrective action system for monitoring of its effectiveness in achieving the predicted performance and cleanup standards; and

2. Termination Monitoring - A program initiated when the cleanup standards have reached to monitor for their continued levels for a period of three years.

The Groundwater Monitoring Plan (GWMP) will describe the monitoring of the groundwater quality and groundwater levels throughout the Effectiveness and Termination Phases. The GWMP will include, but not necessarily be limited to, the following elements for each phase:

- Monitoring well locations;
- Compliance point monitoring wells;
- Groundwater level monitoring;
- Groundwater cleanup standards;

- Sampling and Analysis Plan;
- Monitoring frequency and monitoring period;
- Statistical data evaluation procedures; and
- Reporting requirements.

The Treatment System Monitoring Plan (TSMP) will describe the monitoring of the influent and effluent water quality and the effluent air quality for the operation period. The TSMP will include, but not be limited to the following:

- Influent and effluent monitoring analytes;
- Effluent standards;
- Influent and effluent monitoring frequency;
- Air discharge standards;
- Air monitoring frequency;
- Sampling and Analysis Plan; and
- Reporting requirements.

5.2 Groundwater Cleanup Standards and Point of Compliance

The groundwater monitoring program will be designed to demonstrate compliance with the groundwater cleanup standards at specified points of compliance or alternate points of compliance. It is envisioned that potentially different cleanup standards and points of compliance may be established for the on-site and off-site groundwater corrective action programs.

The cleanup standards and the points of compliance will be established with the NYSDEC and USEPA. They will consider such factors as proximity of the Neutralization Pond, proximity of the DNAPL plume, the facility boundary, access to off-site properties, practical use of the groundwater, exposure and likelihood of exposure, and the technical feasibility and effectiveness of the corrective action system. It is envisioned that these points of compliance and cleanup standards will take into consideration the groundwater modeling results which will be included in the CMI Plan.

It is presently anticipated that the groundwater cleanup standards will be based on volatile organic compounds which have been detected in the groundwater at the BAT facility. Thus, it would be proposed that laboratory analyses be based on EPA Method 624 and 524.2 procedures. Field indicator analytes would likely include trichloroethylene, dichloroethylene and vinyl chloride.

5.3 Groundwater Monitoring Locations and Well Construction

The Effectiveness and Termination monitoring phases will include groundwater monitoring from the extraction wells and specified monitoring wells. The monitoring wells to be employed in each phase will be specified in the CMI, including specific indication of point of compliance wells. It is anticipated that the monitoring wells will be located at the boundaries of the present plumes and within the present plumes. The monitoring wells will provide groundwater elevation data and allow for groundwater quality samples to be obtained. The extraction wells will be constructed with a sampling port at the well head to allow for groundwater quality samples to be collected and will include a port for water levels to be measured. Each well will also have a totalizing flow meter to monitor the volume of water being extracted.

It is presently envisioned that the monitoring wells to be incorporated into the Effectiveness and Termination phases are the monitoring wells which have been previously installed for groundwater investigation and monitoring for the BAT facility. This would include wells in the overburden, the Zone 1 bedrock and the Zone 3 bedrock. In the event that additional monitoring wells are required, they will be constructed in a similar fashion to those previously installed. These details will be incorporated into the CMI.

5.4 Groundwater Level Monitoring

Groundwater level monitoring is expected to be incorporated into the Effectiveness Phase to provide data for evaluation of the extraction system's ability to effect hydraulic control and in the Termination Phase to monitor the response of recharge. Groundwater level monitoring would include water level measurements in the extraction and monitoring well and measurement of the system pumping rates. Groundwater pressure monitoring is expected to include continuous methods, using transducers and dataloggers, along with manual measurements.

Measured water levels would be contoured and compared to seasonal fluctuations. Three transducer systems are scheduled to be installed to provide baseline data on seasonal fluctuations of groundwater pressure.

Hydraulic gradients would be calculated between specified points based on the contoured data and between the overburden, the Zone 1 bedrock and the Zone 3 bedrock. These data would be compared to the model predicted results and evaluated to determine if plume capture and hydraulic control is effective.

5.5 Influent and Effluent Monitoring

The Treatment System Monitoring Plan (TSMP) will include frequencies, parameters and methodology for sampling and analyses of the quality if the influent to the plant and the effluent from the plant. Influent and effluent data will be compared to evaluate the effectiveness of the treatment system. Effluent analyses will also be used to determine that the effluent meets the POTW discharge criteria.

Both field and laboratory analyses are anticipated to be incorporated. The field analyses will be used on a real time basis to measure the effectiveness of the system and permit operational control of the system. The frequency of the analyses is anticipated to be greater at system start-up and less frequent after the system is in normal operational mode.

5.6 Air Quality Monitoring

The TSMP is anticipated to include air quality monitoring for collection and analysis of air samples from the air discharge of the treatment system. The analytical results will be used to demonstrate compliance with air quality discharge criteria.

5.7 Sampling and Analysis Plan

The Groundwater Monitoring Plan (GWMP) for the Effectiveness Phase and Termination Phase monitoring programs is anticipated to include both field and laboratory analyses. The Termination Phase is envisioned to include laboratory analyses for parameters for which groundwater cleanup standards have been established. The Effectiveness Phase is expected to include more frequent sampling and analyses than the Termination Phase and incorporate use of field gas chromatography (GC) procedures for a list of indicator compounds. The Effectiveness Phase is also expected to incorporate periodic laboratory analyses for both quality assurance (QA) of the field analyses and for monitoring of the same compounds as included in the Termination Phase program.

The Treatment System Monitoring Plan (TSMP) is also anticipated to include both field and laboratory analyses. Field analyses are anticipated for rapid evaluation of system performance and to verify treatment standards are being met. Laboratory analyses are envisaged for QA of the field analyses and to document adherence to the effluent treatment standards.

A Sampling and Analysis Plan (SAP) will be included in the GWMP and the TSMP. The SAP will include, but not necessarily limited to, the following:

- Analytical procedures for laboratory and field analyses;
- Frequency of monitoring;
- Sample collection procedures;
- Sample preservation and shipment procedures; and
- Chain-of-Custody control procedures.

5.8 Reporting

It is presently envisioned that monitoring reports will be required on a semi-annual basis throughout the corrective action period. Semi-annual reports will be provided to the NYSDEC which will provide results of the monitoring of the groundwater quality, groundwater levels, influent volumes and treatment system effluent quality. Groundwater level data will be presented as a groundwater contour map for one round of measurements during the period. The groundwater quality data and effluent quality data will be included summaries of analytical results along with the analytical laboratory data sheets.

However, six months may not be a sufficient amount of time to determine if the system is operating effectively. It is envisioned that after about a year of operation a separate report would be prepared regarding the effectiveness of the hydraulic control of the extraction system. This report would address potential modifications to the system, the potential for additional physical containment controls which could be incorporated and potential modifications to the monitoring system to better determine system effectiveness.

5.9 Health and Safety Plan

The current site specific Health and Safety Plan will be adapted to reflect the requirements of construction, operation and monitoring of the groundwater corrective action system. This plan, coupled with the BAT Contingency Plan, will be provided in the CMI.

GOLDER ASSOCIATES INC.

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

Gary Collison, P.E.
Principal

C:CMSF

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4. USEPA "Guidance for Conducting Remedial Investigations and Feasibility Studies under the Comprehensive Environmental Response Compensation and Liabilities Act (CERCLA), Interim Final", October 1988.

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9. Golder Associates, "Results of Phase I and II Investigations Plume Definition Plan, Bell Aerospace Textron, Wheatfield, New York", May 1987.

10. Golder Associates, "Phase III Plume Definition and Proposed Additional Work Plan, Bell Aerospace Textron, Wheatfield Plant, Niagara Falls, New York", July 1988.

11. Golder Associates, "Phase IV Plume Definition and Proposed Additional Work, Bell Aerospace Textron, Wheatfield, New York, Interim Report", August 1989.

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TABLE 1
COMPOUNDS DETECTED IN DNAPL
SEPTEMBER 1989 SAMPLING EVENT

WELL: 87-13(1) DNAPL
SAMPLED: SEPTEMBER 21, 1989

PARAMETER	UNITS	CONCENTRATION	DETECTION LIMIT
VOLATILE ORGANICS			
Trichloroethylene	ug/l	668000000.00	5000.00
Methylene chloride	ug/l	162000000.00	5000.00
1,1,1-Trichloroethane	ug/l	106000000.00	5000.00
Acetone	ug/l	45100000.00	50000.00
1,1-Dichloroethylene	ug/l	3260000.00	5000.00
Toluene	ug/l	2080000.00	5000.00
Trichlorofluoromethane	ug/l	1900000.00	5000.00
Xylene (total)	ug/l	686000.00	5000.00
Ethylbenzene	ug/l	640000.00	5000.00
1,2-Trans-dichloroethylene	ug/l	580000.00	5000.00
Tetrachloroethylene	ug/l	315000.00	5000.00
Vinyl chloride	ug/l	80000.00	2000.00
Chloroform	ug/l	74100.00	5000.00
Benzene	ug/l	<DL	2000.00
SEMIVOLATILE ORGANICS-ACID EXTRACTABLE			
2,3,4,6-Tetrachlorophenol	ug/l	52.10	100.00
2,4-Dimethylphenol	ug/l	23.70	100.00
2-Chlorophenol	ug/l	17.20	100.00
2,4-Dichlorophenol	ug/l	<DL	100.00
o-Nitrophenol	ug/l	<DL	100.00
SEMIVOLATILE ORGANICS-BASE NEUTRAL EXTRACTABLE			
1,2,4,5-Tetrachlorobenzene	ug/l	7410.00	100.00
Naphthalene	ug/l	2180.00	100.00
Di-n-octyl phthalate	ug/l	652.00	100.00
o-Dichlorobenzene	ug/l	406.00	100.00
p-Dichlorobenzene	ug/l	212.00	100.00
Anthracene	ug/l	120.00	100.00
Phenanthrene	ug/l	<DL	100.00
Benzo(a)anthracene	ug/l	<DL	100.00
Di-n-butyl phthalate	ug/l	<DL	100.00
2-Methyl napthalene	ug/l	<DL	100.00
Acenaphthylene	ug/l	<DL	100.00
Fluorene	ug/l	<DL	100.00
2-Chloronaphthalene	ug/l	<DL	100.00
Butyl benzyl phthalate	ug/l	<DL	100.00
m-Dichlorobenzene	ug/l	<DL	100.00

NOTES:
<DL : LESS THEN DETECTION LIMIT

TABLE 1
COMPOUNDS DETECTED IN DNAPL
SEPTEMBER 1989 SAMPLING EVENT

WELL: 87-13(1) DNAPL
SAMPLED: SEPTEMBER 21, 1989

PARAMETER	UNITS	CONCENTRATION	DETECTION LIMIT
<u>PESTICIDES AND PCBs</u>			
PCB-1254	ug/l	352000.00	9900.00
PCB-1260	ug/l	102000.00	2400.00
PCB-1242	ug/l	<DL	2400.00
<u>INORGANICS</u>			
Lead	ug/l	13000.00	400.00
Zinc	ug/l	4000.00	200.00
Barium	ug/l	2670.00	200.00
Selenium	ug/l	768.00	200.00
Copper	ug/l	<DL	200.00
Thallium	ug/l	<DL	4000.00
Antimony	ug/l	<DL	3000.00
Sulfide as S	ug/l	<DL	100000.00
Tin	ug/l	<DL	80000.00

NOTES:
<DL : LESS THEN DETECTION LIMIT

TABLE 2
COMPOUNDS DETECTED IN DISSOLVED PHASE PLUMES
CLP SAMPLING EVENT 1990

ZONE 1 WELLS

Stop

SAMPLING POINT	PARAMETER	CONC. (ug/l)	QUAL CODE
VOLATILE ORGANIC COMPOUNDS			
87-13(1)	1,1,1-Trichloroethane	51,000.00	
B-15(1)	1,1-Dichloroethane	17.00	
87-22(1)	1,1-Dichloroethene	47.00	J
87-18(1)	1,2-Dichloroethene (total)	12,000.00	
87-10(1)	Acetone	17,000.00	J
89-5(1A)	Benzene	1.00	J
B-14(1)	Carbon Disulfide	110.00	
87-2(1)	Chloroform	3.00	J
89-10(1)	Chloromethane	4,800.00	J
89-5(1B)	Ethylbenzene	1.00	J
87-13(1)	Methylene Chloride	1,400,000.00	
89-5(1A)	Toluene	2.00	J
87-13(1)	Trichloroethene	1,100,000.00	
87-22(1)	Vinyl Chloride	420.00	
89-5(1B)	Xylene (total)	9.00	
SEMIVOLATILE ORGANIC COMPOUNDS			
87-13(1)	2,4-Dimethylphenol	4.00	J
87-06(1)	2-Methylnaphthalene	25.00	J
87-14(1)	4-Methylphenol	16.00	
87-13(1)	Benzoic acid	31.00	J
B-15(1)	bis(2-Ethylhexyl)phthalate	56.00	B
89-14(1)	Di-n-butylphthalate	2.00	J
87-15(1)	Di-n-octylphthalate	17.00	
87-13(1)	Fluoranthene	5.00	J
87-06(1)	Naphthalene	29.00	J
87-06(1)	Phenanthrene	27.00	J
87-13(1)	Phenol	8.00	J
87-06(1)	Pyrene	25.00	J
PESTICIDES/PCBs			
B-10A(1)	Aroclor-1254	38.00	
B-10A(1)	gamma-BHC (Lindane)	3.50	

NOTES:

J: Indicates an estimated value. This flag is used when the mass spectral data indicates the presence of a compound that meets the identification criteria but the result is less than the sample quantitation limit but greater than zero.

B: This flag is used when the analyte is found in the associated blank as well as in the sample.

TABLE 3

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

Overburden Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Institutional Measures	Access restrictions	Deed restrictions/Bylaws	Deeds for property in the area of influence would include restrictions on wells.	Applicable for wells at base of overburden.	Potentially applicable.
	Alternate water supply	Wheatfield water supply	Extension of existing municipal well system to serve residents in the area of influence.	Not required.	
		New community well	New uncontaminated wells to serve residents in the area of influence.	Not required.	
	Monitoring	Groundwater monitoring	Ongoing monitoring of wells.	Will be required in Corrective Measures Implementation Plan.	Potentially applicable.
Removal	Excavation	Demolition and bulk excavation	Use of conventional earth moving equipment after demolition of infrastructure.	Though feasible not recommended for potential health hazards and reasons discussed in Section 3.3.3.	
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination.	Site already overlain by clay (lacustrine clay) Prefer to allow infiltration to flush upper soil layers.	
		Asphalt	Application of a layer of asphalt over areas of contamination.	Some of area covered with asphalt Prefer to allow infiltration to flush upper soil layers.	
		Concrete	Installation of a concrete slab over areas of contamination.	Not recommended.	
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination.	Not recommended.	
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with a soil (or cement) bentonite slurry.	This option has been retained for consideration.	Potentially applicable. This option has been retained for consideration if groundwater extraction is insufficiently effective.
		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 trench with clay to prevent infiltration.	Considered to be an ancillary action.	Potentially applicable.
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes.	Not effective in overburden. 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. Not recommended.	
	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.	

TABLE 3

(CONTINUED)

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

Overburden Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater.	Not feasible for intercepting contaminants in low permeability overburden.	Remediation of Zone 1 by groundwater extraction will tend to control groundwater flow in 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 but extraction of groundwater from Zone 1 should serve to control migration of contaminated water in overburden.	
	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. Not recommended.	
	Biological treatment	Aerobic	Degradation of organics using microorganisms in an aerobic environment.	Not applicable. Permeability of overburden too low.	
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment.	Not applicable. Permeability of overburden too low.	
	Physical/chemical treatment	Chemical alteration	Alteration of chemical equilibria to reduce solubility of the contaminants.	Potentially applicable, however, permeability of overburden too low. Not recommended.	
		Air stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air.	Potentially applicable. to groundwater extracted from Zone 1.	Potentially applicable. Water extracted with DNAPL and dissolved phase treatment system.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	Potentially applicable. to groundwater extracted from Zone 1.	Potentially applicable. Water extracted with DNAPL and dissolved phase treatment system.
		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. to groundwater extracted from Zone 1.	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.	
		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.	
	Offsite discharge	Local stream	Extracted water discharged to stream or storm water sewer.	Not applicable.	
		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.
		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. Discharge to POTW preferred.	

TABLE 3

(CONTINUED)

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

Zone 1 DNAPL Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Institutional Measures	Access restrictions	Deed restrictions	Deeds for property in the area of influence would include restrictions on wells.	Deed restrictions will be completed to prevent drilling in DNAPL area.	Potentially applicable.
	Alternate water supply	City water supply	Municipal water supply system to serve residents in the area of influence.	Not required.	
	Monitoring	Groundwater monitoring	Ongoing monitoring of wells.	This will have to be done as part of the Corrective Measures Implementation Plan.	Potentially applicable.
Removal	Excavation	Rock breaking	Use of rock breaking equipment to allow excavation of Zone 1 bedrock in DNAPL plume area.	Though feasible not recommended for potential health hazards and reasons discussed in Section 3.3.3.	
		Blasting	Use of blasting to allow excavation of Zone 1 bedrock in DNAPL plume area.	Though feasible not recommended for potential health hazards and reasons discussed in Section 3.3.3.	
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination	Flushing of shallow overburden preferable. Not recommended.	
		Asphalt	Spray application of a layer of asphalt over areas of contamination	Flushing of shallow overburden preferable. Not recommended.	
		Concrete	Installation of a concrete slab over areas of contamination	Flushing of shallow overburden preferable. Not recommended.	
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination	Flushing of shallow overburden preferable. Not recommended.	
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with a soil (or cement) bentonite slurry.	Not feasible because of bedrock. Hydrofraz equipment cannot cut greater than 15,000 psi compressive strength rock.	
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Could be used to reduce amount of pumping required to control water flow in DNAPL plume area.	Potentially applicable. Retained for consideration if hydraulic containment does not provide sufficient control on DNAPL plume.
		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	Could be used to reduce amount of pumping required to control water flow in DNAPL plume area.	Potentially applicable. Retained for consideration if hydraulic containment does not provide sufficient control on DNAPL plume.
	Horizontal barriers	Grout injection	Pressure injection of grout at a depth through closely spaced drillholes	Not required because of Zone 2 aquitard.	
		Block displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Not required because of Zone 2 aquitard.	

TABLE 3

(CONTINUED)

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

Zone 1 DNAPL Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater and control groundwater flow.	Can provide hydraulic control, however, removal of all DNAPL currently not possible. Groundwater will require treatment.	Potentially feasible.
		Extraction/injection wells	Injection wells inject uncontaminated water to increase flow to extraction wells.	Modeling studies indicate injection wells not required.	
	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 recommended.	
		Air stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air.	Applicable to discharged groundwater from the DNAPL area.	Potentially applicable.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	Applicable to dissolved organic contaminants found in groundwater at the site.	Potentially applicable.
		Phase separater	DNAPL Seperated from dissolved phase by phase seperator.	Potentially applicable prior to air stripping to reduce concentration of VOCs in offgass from air strippers.	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	Oxidation of contaminants by combustion with air and natural gass.	Applicable to dissolved organic contaminants found at the site. Collected DNAPL would be sent for incineration/distruction off-site.	Potentially applicable.
		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.	Not applicable.	
	In situ treatment	Bioreclanation	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 3 aquifer. Not recommended.	
		Permeable treatment beds	Downgradient trenches backfilled with activated carbon to remove contaminants from water.	Feasible but very difficult to construct trench and change carbon. Not recommended.	
		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 or solvents to remobilize DNAPL	System of injection wells to inject allowable surfactants or solvents to mobilize DNAPL's.	Feasible but dangerous - may loose control of DNAPL. Potential for DNAPL to migrate in Zone 3 aquifer. Not recommended with current surfactants.	
	Discharge	Local stream	After treatment extracted water discharged to stream.	Not applicable; would require NPDES permit. Acetone discharge may be a problem.	
		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/storm sewer to Niagara river	Extracted water would be treated and discharged to the river via a pipeline.	Feasibile but discharge to POTW preffered, hence separate pipeline not recommended.	

TABLE 3

(CONTINUED)

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

Zone 1 Dissolved Phase Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Institutional Measures	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.	Will be required for Corrective Measures Implementation Plan.	Potentially applicable.
Containment	Cap	Clay and soil	Compacted clay covered with soil over areas of contamination.	Not applicable. Clay cap in overburden, already exists.	
		Asphalt	Spray application of a layer of asphalt over areas of contamination.	Not feasible.	
		Concrete	Installation of a concrete slab over areas of contamination.	Not feasible.	
		Multimedia cap	Clay and synthetic membrane covered by soil over areas of contamination.	Not feasible.	
	Vertical barriers	Slurry wall	Trench around areas of contamination is filled with a soil (or cement) bentonite slurry to prevent further migration.	Not feasible. The plume is in fractured bedrock.	
		Grout curtain	Pressure injection of grout in a regular pattern of drilled holes.	Not feasible. A grout curtain would 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 feasible 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.	

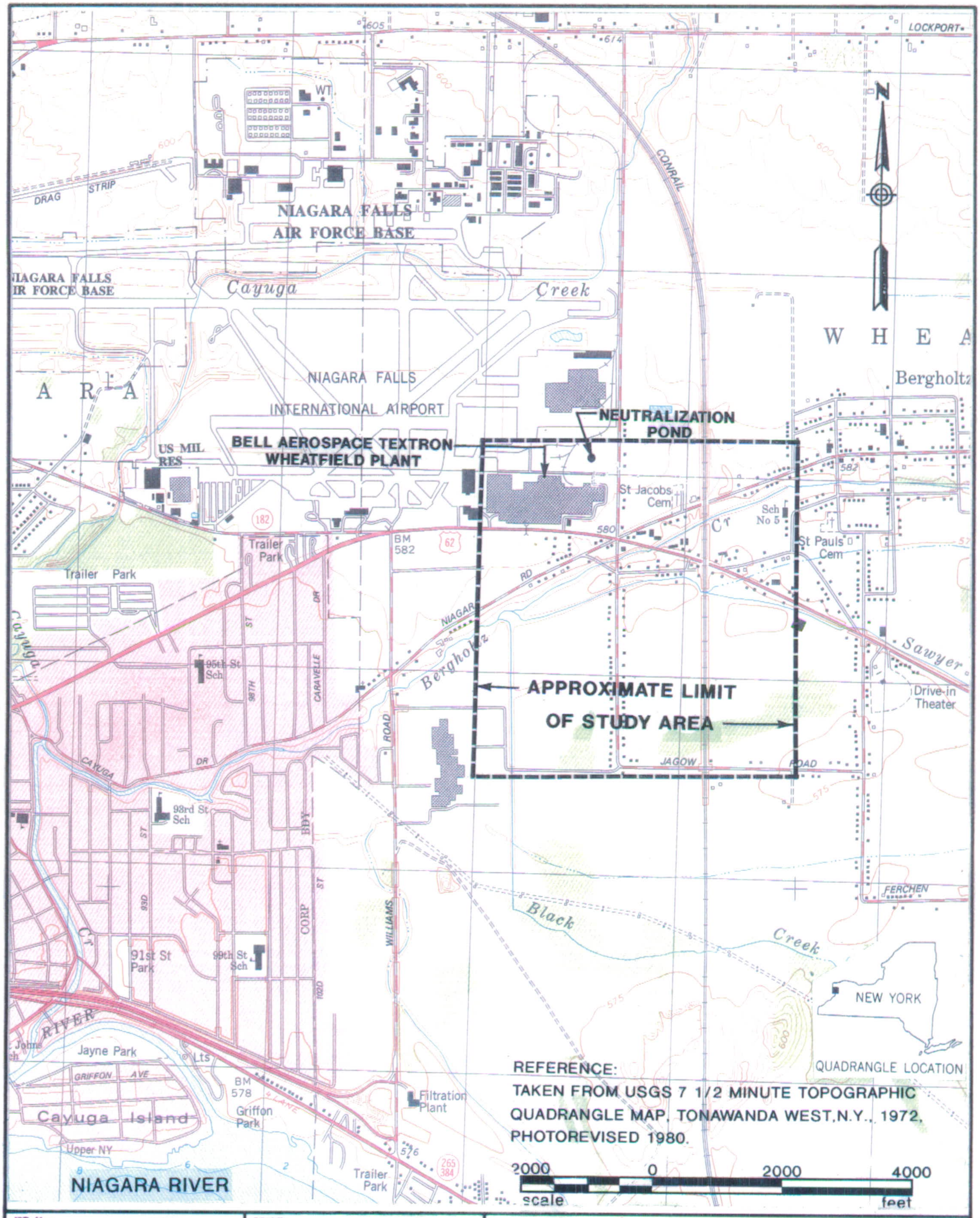
TABLE 3

(CONTINUED)

REVIEW OF ALTERNATIVE CORRECTIVE MEASURES

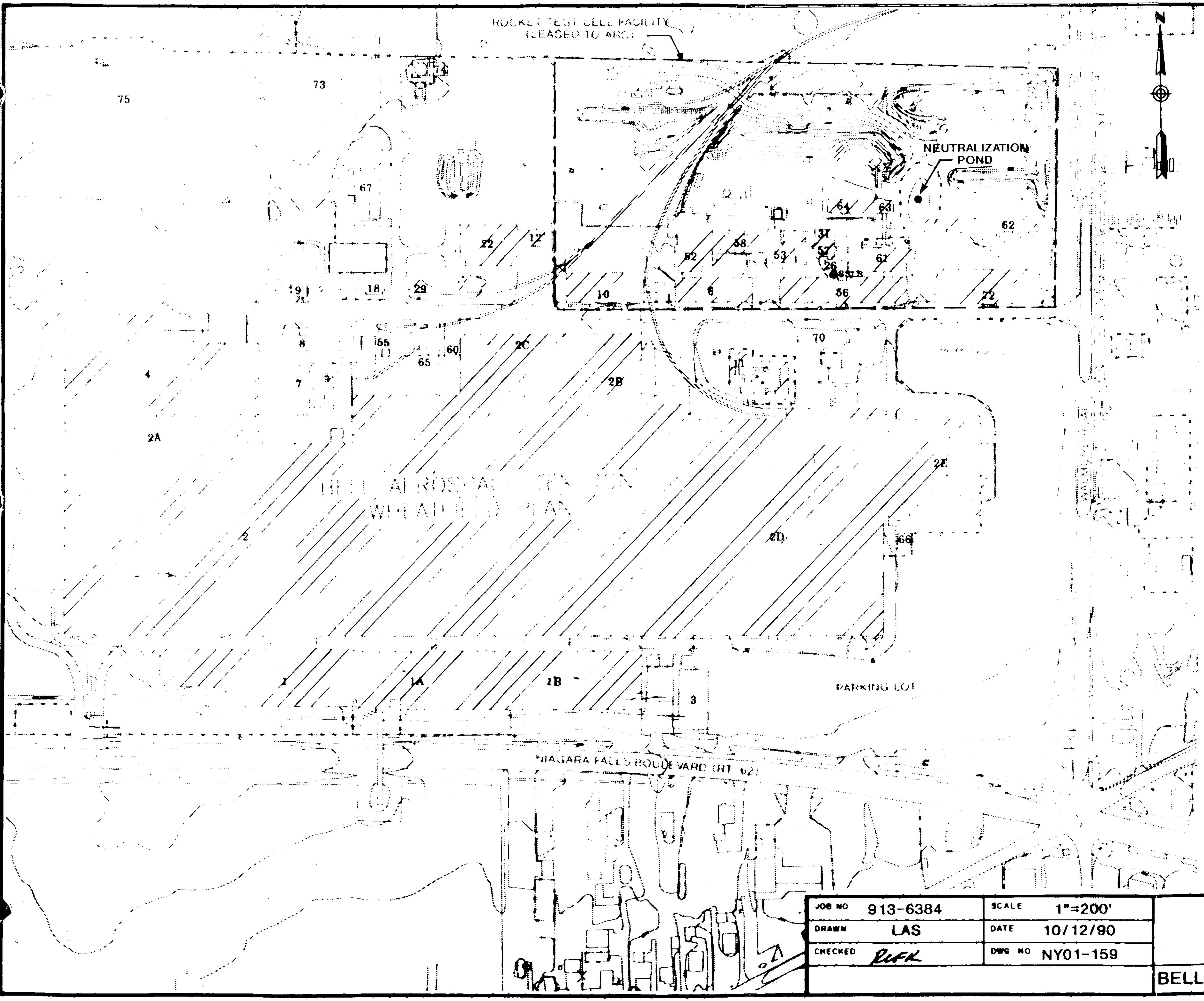
Zone 1 Dissolved Phase Plume

General Response Measure	Corrective Measures Technology	Process Options	Description	Screening Comments	Preferred Corrective Measures
Collection Treatment Discharge	Extraction	Extraction wells	Series of wells to extract contaminated groundwater	Potentially applicable. Groundwater modeling indicates capture of plume is possible.	Potentially applicable.
		Extraction/injection wells	Injection wells inject uncontaminated water to increase flow to extraction wells	Potentially applicable but groundwater modeling indicates injection wells not required. Not recommended.	
	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 but not recommended since other technologies considered more appropriate.	
		Anaerobic	Degradation of organics using microorganisms in an anaerobic environment	Not applicable to groundwater extracted from subsurface.	
	Physical/chemical treatment	Precipitation	Alteration of chemical equilibria to reduce solubility of the contaminants	Not applicable to chlorinated solvents.	
		Air stripping	Mixing large volumes of air with water in a packed column to promote transfer of VOCs to air	Recommended from treatment of organic contaminants found in groundwater at the site.	Potentially applicable.
		Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column	Recommended from treatment of organic contaminants found in groundwater at the site.	Potentially applicable.
		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. Require evaluation of inorganic constituents in groundwater for interference effects.	Potentially applicable.
	Thermal destruction	Thermal oxidation	Combustion in a thermal oxidation unit	Potentially applicable to organic contaminants after airstripping from groundwater.	Potentially applicable.
		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	Potentially applicable after site specific treatment. Could be used to treat acetone.	Potentially applicable.
		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 oxidizer into groundwater to allow aerobic bacteria to degrade contaminants.	Not feasible. 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 of size of plume and 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.	
	Offsite discharge	Local stream	After treatment extracted water discharged to stream	Potentially applicable. Would require NPDES permit. Discharge to POTW preferred.	
		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. Not recommended since discharge to POTW would achieve same results.	



REFERENCE:
TAKEN FROM USGS 7 1/2 MINUTE TOPOGRAPHIC QUADRANGLE MAP, TONAWANDA WEST, N.Y., 1972, PHOTOREVISED 1980.

JOB No.:	913-6384	SCALE:	1"=2000'	SITE LOCATION MAP	
DRAWN:	TLF	DATE:	10/05/90		
CHECKED:	Refk	DWG. No.:	NY01-149		
Golder Associates				BELL AEROSPACE TEXTRON	FIGURE 1



LEGEND

Building No.	
1	Admin. and Engineering Offices
1A	Engineering (2 floors)
1B	Engineering (3 floors)
2	Main Manufacturing
2A	Machine Shop and Cribs
2B	Foundry
2C	Maint. and Plaster Shop
2D	Manufacturing Addition
2E	Manufacturing Addition
3	Employment
4	Flight Research and Tool Room Bldg
5	Production Hangar
6	Storage and Reclamation
7	Air Compressor House
8	Oil Storage
9	Pump House
10	Automotive Garage
11	Power Station
12	Incinerator
15	Electronic Data Center
15A	A.C. Pump House
16	Fire Truck Garage
18	Lab Packs.Small Quantity Accumulation (NE Corner Only)
19	Drum Accumulation
22	Boiler House
26	Sewage Ejector
29	Gasoline Pump House (Sta. "A")
31	Rocket Maintenance Building
52	Rocket Flow Test
53	Rocket Machine Shop
54	Drum Accumulation
55	Aerodynamics Bldg.
56	Rocket Engineering Bldg.
57	Rocket Welding Bldg.
58	Rocket Test Cells A,B,C,D,S
59	Rocket Research
60	Vibration Tower & Control Room
61	Rocket Instrumentation Bldg
62	Test Cells W,X,Y,Z
63	Rocket Tank Test Bldg.
64	Test Cells H & K
65	Explosion Test Bldg.
66	Mechanical Equipment Bldg.
67	Propulsion Test Bldg
70	Rocket Area Storage Guard Houses
72	Rocket Components Test
73	ACV Test Facility
74	Rain Erosion Test Facility
75	Chemistry Laboratory

● SSLS SANITARY SEWER LIFT STATION

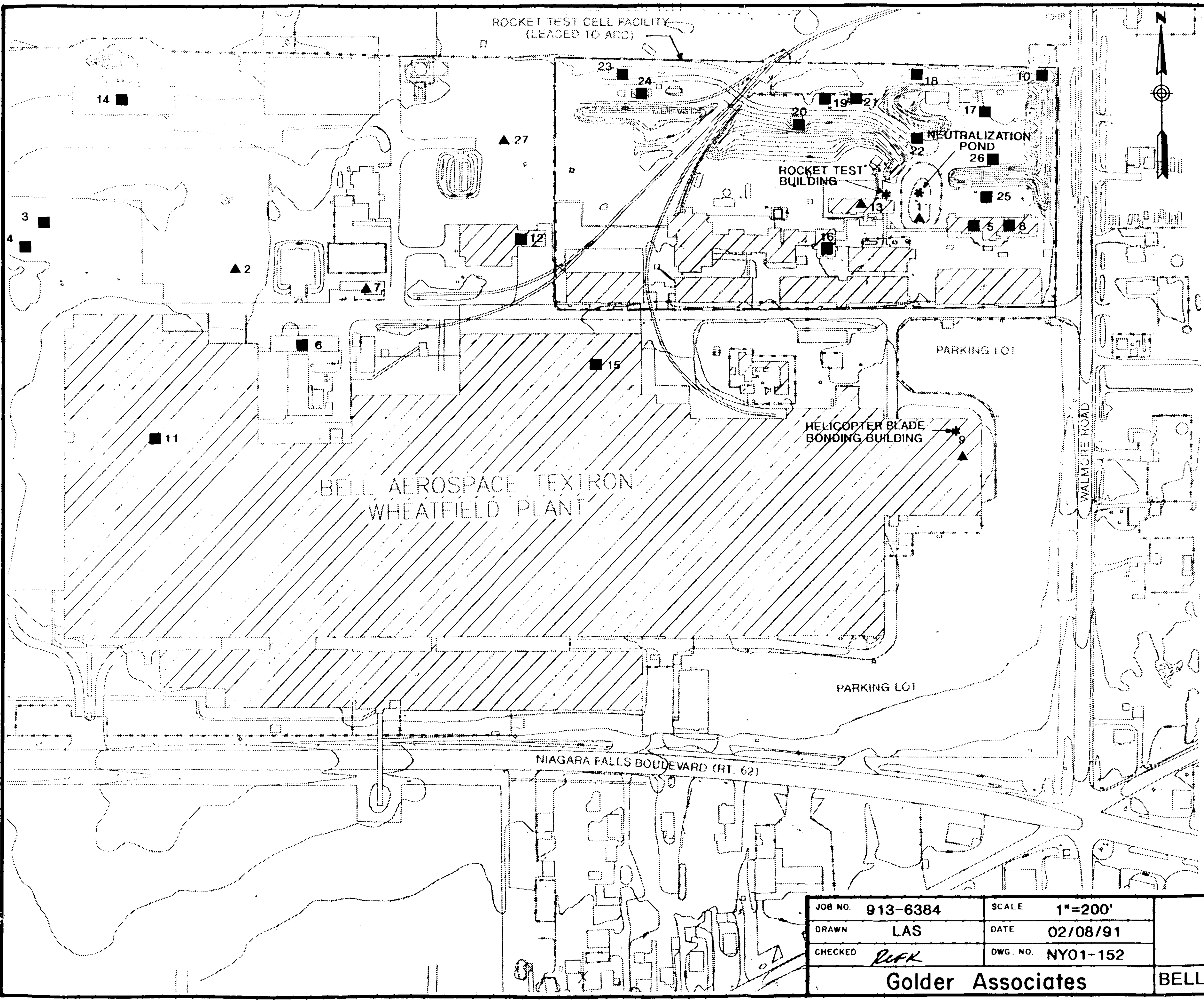
JOB NO	913-6384	SCALE	1"=200'
DRAWN	LAS	DATE	10/12/90
CHECKED	RLFK	DWG NO	NY01-159

FACILITY LAYOUT

BELL AEROSPACE TEXTRON

FIGURE 2

188110



LEGEND

Unit No.	Description	Status
1.	Neutralization Pond	RR
2.	Former Drum Storage Yard	RR
3.	Drum Accumulation	NFAR
4.	Drum Accumulation	NFAR
5.	Drum Accumulation	NFAR
6.	Drum Accumulation	NFAR
7.	Lab Pack Accumulation	RR
8.	Rock Engine Test Cells W,X,Y,Z	NFAR
9.	Helicopter Blade Bonding Building	RR
10.	Underground Transfer Lines	NFAR
11.	Underground Tanks for Aviation Gas	NFAR
12.	Incinerator	NFAR
13.	Rocket Tank Test Building	RR
14.	Chemistry Laboratory	NFAR
15.	Foundry	NFAR
16.	H Test Cells	NFAR
17.	Drum Storage Shed	NFAR
18.	Fuel Area Shed	NFAR
19.	Peroxide Catalyst Bed	NFAR
20.	Peroxide Drum Storage Area	NFAR
21.	Caustic Storage	NFAR
22.	Liquid Caustic Storage Tank	NFAR
23.	Acid Drum Storage Area	NFAR
24.	Acid Storage Tanks	NFAR
25.	Slag	NFAR
26.	Drum Storage	NFAR
27.	Drum Accumulation Boiler Houses	RR

NOTE: RR – Remediation Required
NFAR – No Further Action Required

✱	SOLID WASTE MANAGEMENT UNITS INVESTIGATED BY NEUTRALIZATION POND STUDIES
▲	SOLID WASTE MANAGEMENT UNITS REQUIRING REMEDIATION
■	SOLID WASTE MANAGEMENT UNITS REQUIRING NO FURTHER ACTION

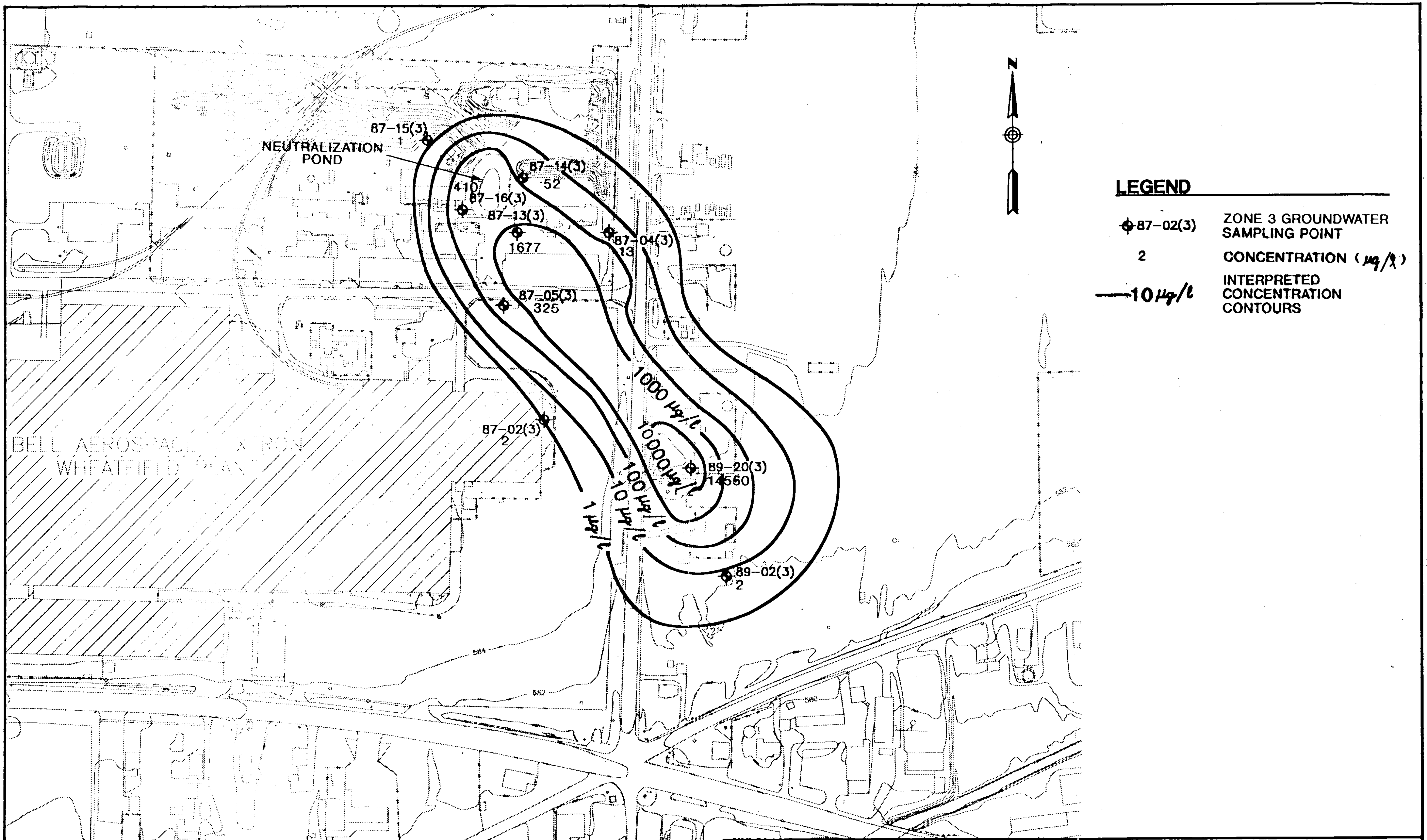
JOB NO.	913-6384	SCALE	1"=200'
DRAWN	LAS	DATE	02/08/91
CHECKED	RCFK	DWG. NO.	NY01-152

Golder Associates

SOLID WASTE MANAGEMENT UNITS

BELL AEROSPACE TEXTRON

FIGURE 3



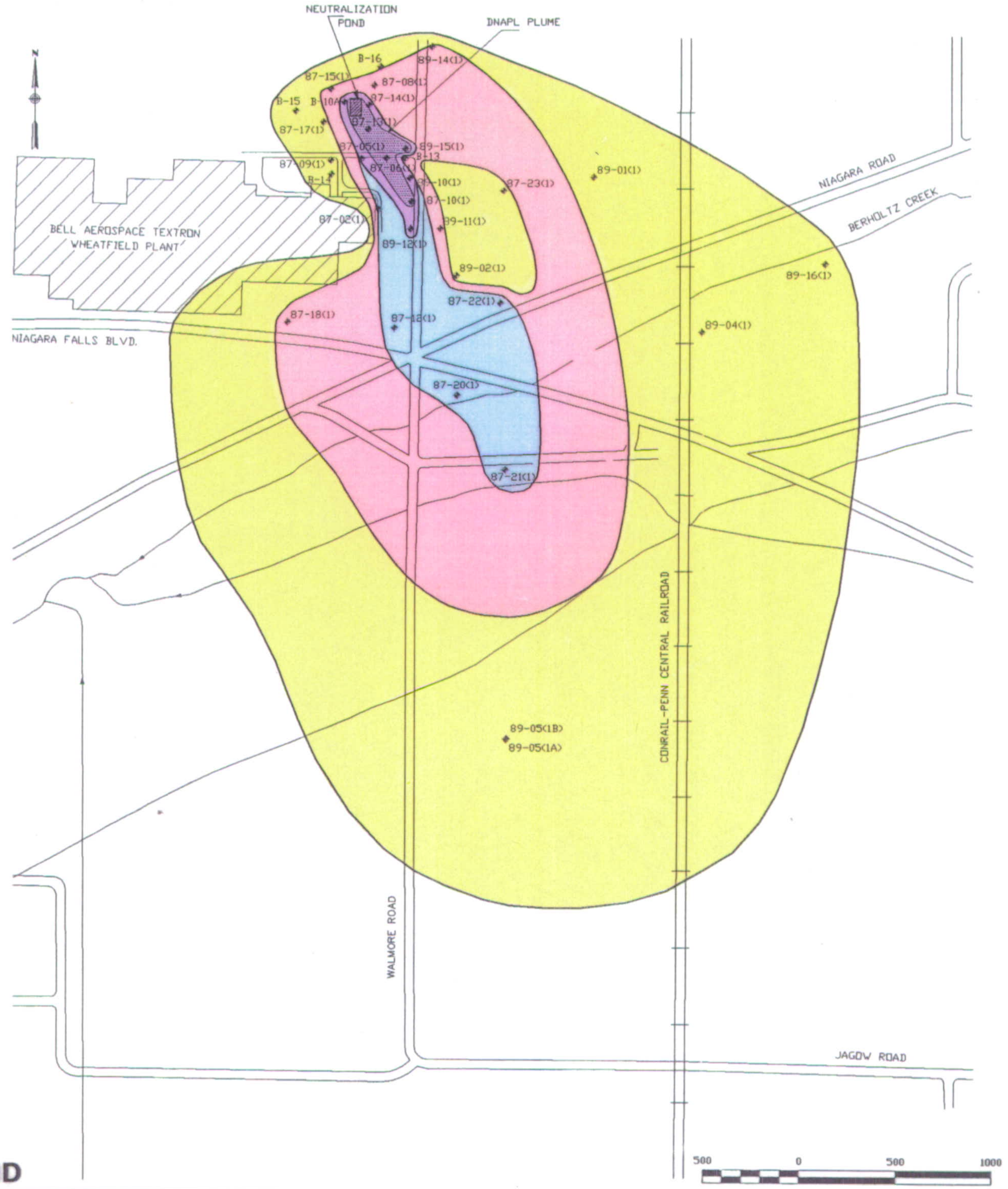
JOB No.: 913-6384	SCALE: 1"=200'		
DRAWN: CDH	DATE: 10/12/90		
CHECKED: RCFIL	DWG. No.: NY01-155		

Golder Associates

ISOCONCENTRATION CONTOURS
TOTAL VOLATILE ORGANIC COMPOUNDS
ZONE 3 AQUIFER
1990 CLP SAMPLING EVENT

BELL AEROSPACE TEXTRON

FIGURE 7



LEGEND

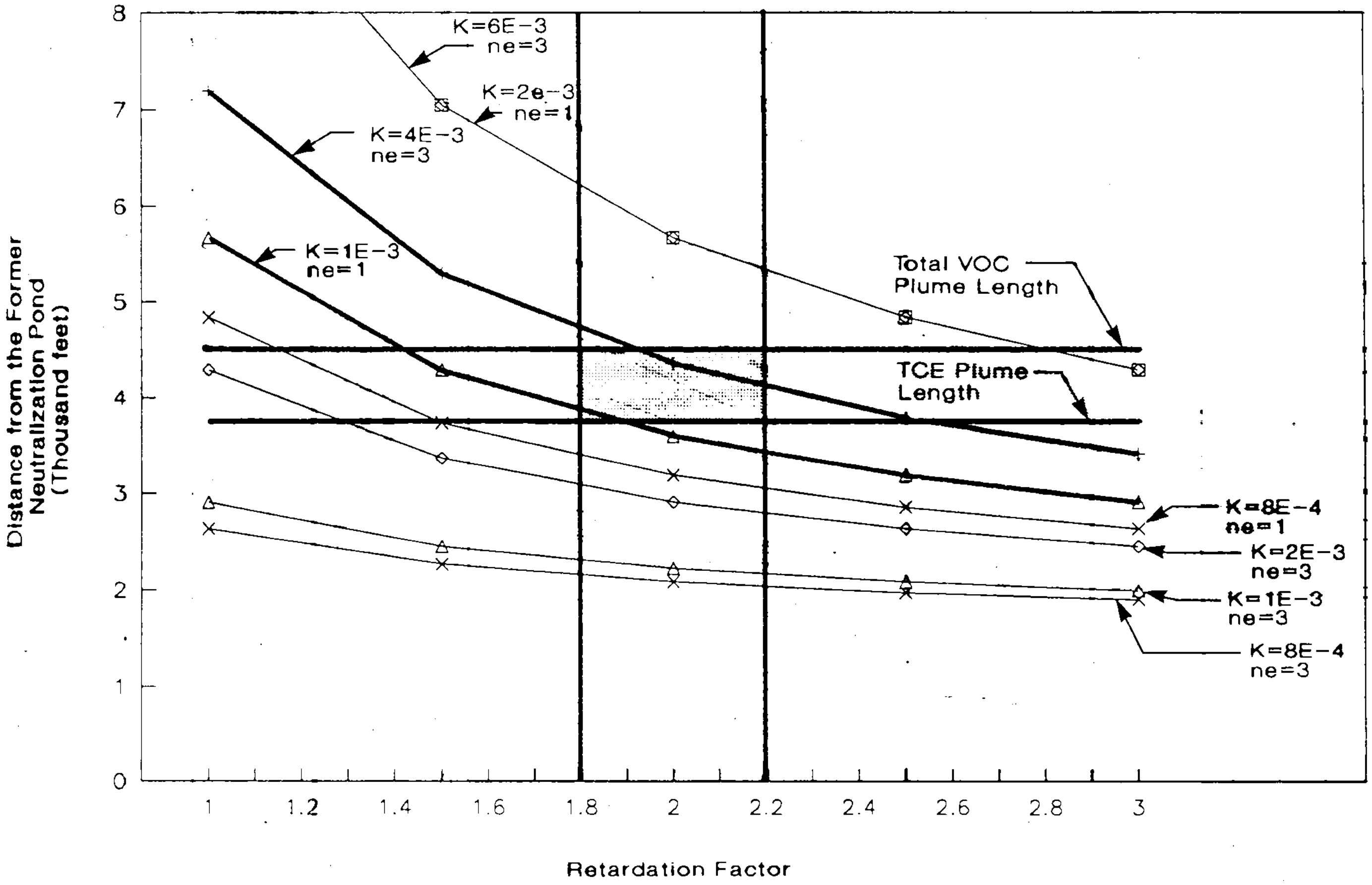
🟪	TRICHLOROETHYLENE 1,2-DICHLOROETHYLENE (TOTAL) VINYL CHLORIDE	>80% <20% <10%
🟦	TRICHLOROETHYLENE 1,2-DICHLOROETHYLENE (TOTAL) VINYL CHLORIDE	80% TO 50% 20% TO 50% <10%
🟥	TRICHLOROETHYLENE 1,2-DICHLOROETHYLENE (TOTAL) VINYL CHLORIDE	<20% 50% TO 100% <10%
🟨	TRICHLOROETHYLENE 1,2-DICHLOROETHYLENE (TOTAL) VINYL CHLORIDE	<10% 100% TO 0% 0% TO 100%

JOB NO.	913-6384	SCALE	AS SHOWN
DRAWN	MJ	DATE	03/25/91
CHECKED	RefK	DWG. NO.	NY01-140

DISPOSITION OF PLUME COMPONENTS

BELL AEROSPACE TEXTRON

FIGURE 12

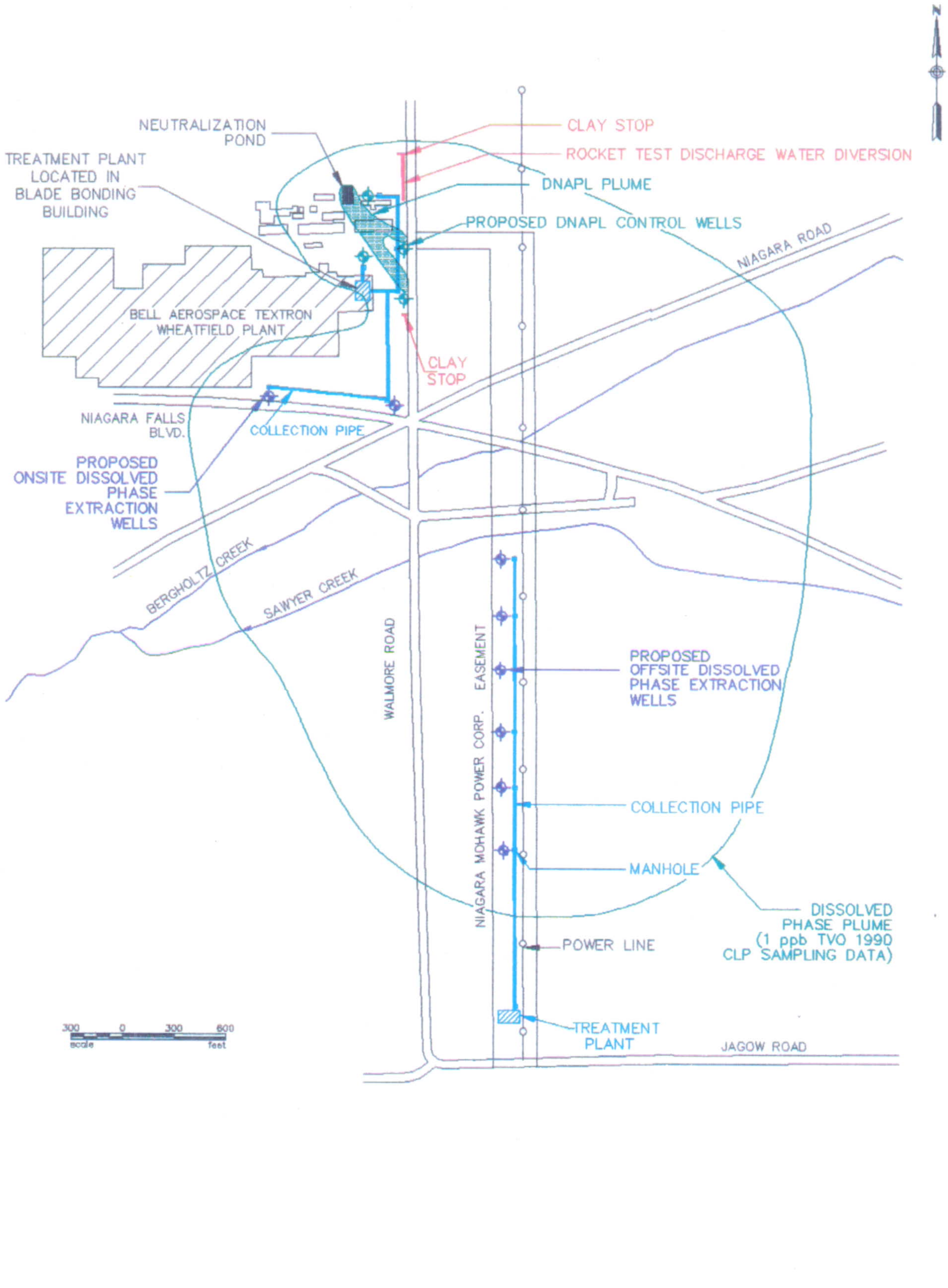


K = Hydraulic Conductivity (cm/s)

ne = Effective Porosity (%)

Note :
Site Specific Gradients
were used for Calculations

JOB No.: 913-6384	SCALE: AS SHOWN	**COMPARISON OF RETARDATION RATES**
DRAWN: FG	DATE: 04/04/91	
CHECKED:	DWG. No.: NY01-169	
Golder Associates		**BELL AEROSPACE TEXTRON** FIGURE **13**



JOB No.:	913-6384	SCALE:	AS SHOWN	**PROPOSED CORRECTIVE MEASURES**
DRAWN:	FG	DATE:	04/04/91	
CHECKED:	RCFK	DWG. No.:	NY01-168	
Golder Associates				BELL AEROSPACE TEXTRON FIGURE **14**

Appendix A

APPENDIX A

REVIEW OF DNAPL CORRECTIVE MEASURES

REVIEW OF DNAPL CORRECTIVE MEASURES

Prepared by:

Stan Feenstra
Applied Groundwater Research

TABLE OF CONTENTS

SECTION PAGE

LIST OF FIGURES

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. 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 (TCE) 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. As previously noted, DNAPL chemicals are immiscible in water and have densities greater than water. The combination of low solubility and high density enables DNAPL chemicals from waste disposal facilities or chemical spill sites 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 and can result in groundwater contamination.

A general illustration of the behavior of DNAPL chemicals in the subsurface is shown in Figure A-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 forms 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 to 30 L/m^3, with higher residual concentrations for finer-grained soils.

For the cases where the input volume of DNAPL is large, DNAPL will move into the saturated zone. 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 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, Schwille (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 any 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, the elimination of the dissolved chemical plumes can only be achieved through control or removal of the DNAPL as discussed below with currently available technology removal of all the DNAPL at the Bell Aerospace site is not considered to be feasible.

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

- Groundwater Recovery and Treatment
- 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 or groundwater extraction wells.

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 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 reducing potentially 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. The clay overburden soils at the site probably provide this cover. 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 developing a 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 would allow for the development of a dissolved phase plume.

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. 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 the 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:

$$N_C = \frac{kpgJ}{\sigma}$$

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 σ 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 A-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. For the Zone 1 dolomite beneath the Bell site, hydraulic gradients of 10 to 100 would be required to initiate 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 chemicals 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 propagated 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 of 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 zone 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 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 at the Bell site, if uncontrolled, 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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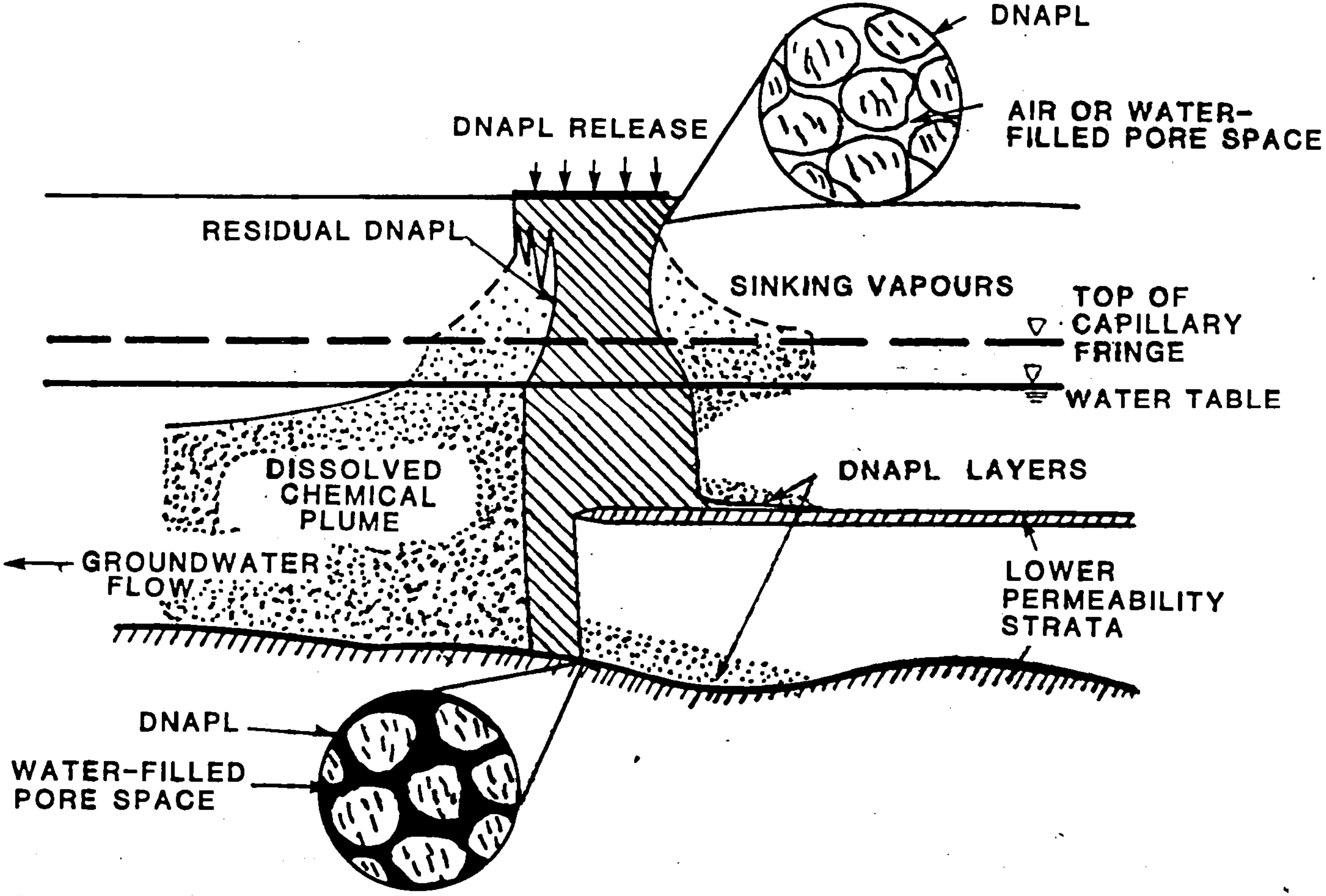

BASED ON DRAWING FROM APPLIED GROUNDWATER RESEARCH.

JOB NO. 883-6167	SCALE NTS	**BEHAVIOR OF DNAPL IN SUBSURFACE**
DRAWN LAS	DATE 07/07/89	
CHECKED	DWG. NO. NY01-029	
Golder Associates		**BELL AEROSPACE TEXTRON** FIGURE A-1

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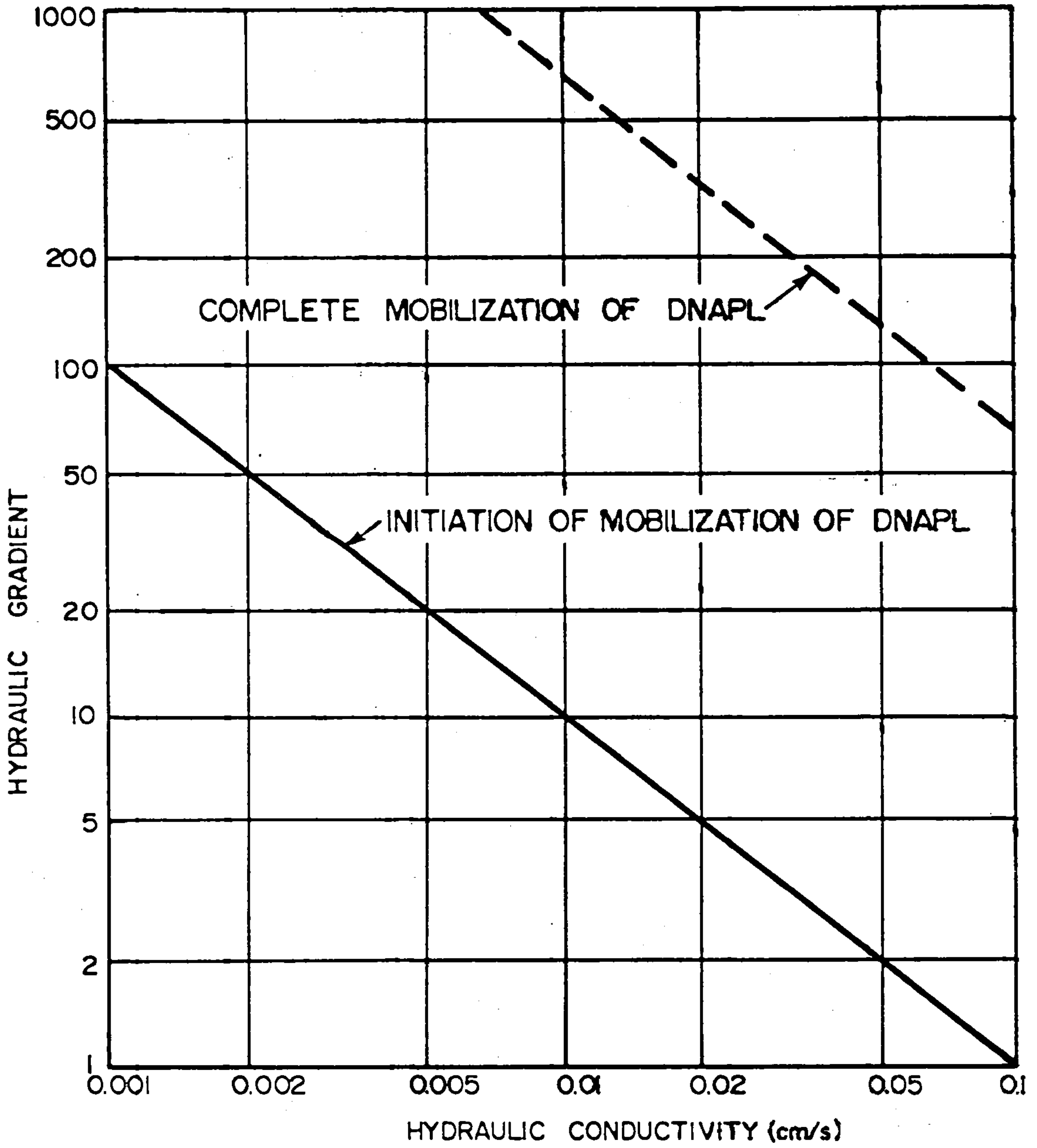

PROVIDED BY APPLIED GROUNDWATER RESEARCH.

JOB NO. 883-6167	SCALE NTS	**MOBILIZATION OF DNAPL BY GROUNDWATER FLOW**	
DRAWN LAS	DATE 07/07/89		
CHECKED	DWG. NO. NY01-030		
Golder Associates		**BELL AEROSPACE TEXTRON**	FIGURE **A-2**

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APPENDIX B

GROUNDWATER MODELING STUDY

GROUNDWATER MODELING AT
BELL AEROSPACE TEXTRON
WHEATFIELD PLANT
NIAGARA FALLS, NEW YORK

April 1991

Project No.: 913-6384

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

B1.0 INTRODUCTION

B1.1 General

The Corrective Measures Study (CMS) (see main text) screening process has identified groundwater extraction and treatment as the preferred corrective actions for control and mitigation of the DNAPL and associated dissolved phase groundwater plumes at the Neutralization Pond Corrective Action Management Unit (CAMU). This appendix provides a description and the results of the groundwater modeling study performed by Golder Associates in support of the CMS. This modeling effort indicates that two extraction systems, one located on site (within the confines of the BAT Facility) and a separate system located to the south of the plant have the potential to gain the required control over the impacted groundwater system.

Solute transport modeling is presently being undertaken to provide additional information on the effectiveness of the extraction system in achieving corrective action goals (clean up standards). This information coupled with the extraction rates and well configurations will be used to develop detailed designs for the extraction systems if New York State Department of Environmental Conservation (NYSDEC) and the United Stated Environmental Protection Agency (USEPA) approves the Post-Closure Permit Application (submitted in April 1991) and this CMS.

B1.2 Modeling Objectives

The primary objective of the modeling study was to evaluate the potential for hydraulic control of groundwater flow in the study area (see Figure B-1) in order to restrict and mitigate volatile organic compound migration. Because of the size of the Zone 1 dissolved phase plume and access restrictions, the modeling study has evaluated two groundwater extraction systems which would be operated simultaneously and independently. One system would be established to extract the "off-site" portion of the dissolved phase plume, and the other to extract the "on-site" portion of the dissolved phase plume and to contain the DNAPL phase. The modeling study focused on:

1. Establishing an optimum configuration of groundwater extraction wells for the dissolved phase plume in the study area,
2. Evaluating several configurations of extraction wells to hydraulically control the generation and migration of dissolved organic compounds from the DNAPL plume, such that DNAPL plume will not further contribute to the dissolved phase plume, to prevent the downward vertical migration of the DNAPL into lower aquifers; and,
3. To encourage flow of groundwater from the Zone 3 plume and overburden plumes such that the water quality of these components of the overall groundwater plume will be improved.

The results of the modeling study will be used as a tool to develop the design of the corrective action systems for BAT in a manner which is both technically and economically feasible and which meets regulatory requirements of the NYSDEC and the USEPA.

B2.0 SITE GEOLOGY AND HYDROGEOLOGY

B2.1 Data Sources

Initial hydrogeologic investigations of the BAT site were performed by Goldberg-Zoino Associates Inc. (GZA) between 1982 and 1985. Interim monitoring of the wells installed by GZA was continued by Frontier Technical Associates, Inc. between 1986 and 1987. The RCRA Facility Investigation (RFI) of the Neutralization Pond CAMU (Reference B-1) was completed in five phases of investigation which were performed by Golder Associates between 1987 and 1990. During these investigations, various aquifer testing programs were performed by Golder Associates. These programs included pump-in tests, a large scale pump-out test, step-drawdown testing, and rising/falling head tests and packer testing. A final draft report, "Results of the Pump-In and Pump-Out Testing, Bell Aerospace Textron, Wheatfield Plant, New York", was completed in February, 1990 (Reference B-3). A draft final RCRA Facility Investigation report (RFI) was completed by Golder in February, 1991 (Reference B-1). The RFI report summarizes the results of the geologic, hydrogeologic and plume definition investigations. The above referenced documents were used as data sources for this groundwater modeling effort and for the solute transport modeling to be reported in the Corrective Measure Implementation (CMI) Plan.

B2.2 Site Geology

The subsurface materials at the site are overburden soils composed of glacio-lacustrine silts and clays with occasional sand lenses, and glacial till underlain by Middle Silurian dolomitic bedrock. Based on geologic and hydrogeologic characteristics, the bedrock strata have been subdivided into four hydrostratigraphic zones, as follows (see Figure 4 of the CMS report and Reference B-1).

Zone 1 (10 feet to 70 feet thick) consists of fine grained, thinly bedded, light brownish gray dolomite with numerous open bedding partings (bedding fractures) that have formed by the weathering of gypsum from the bedding planes due to the dissolving action of moving groundwater. The influence of weathering is most pronounced in the upper 1 foot to 5 feet of rock beneath the bedrock surface and in the lower 1 foot to 2 feet of the zone. This lower zone stratum has been termed the A Marker Bed and is recognized as a bed of dolomite with abundant intergranular gypsum. The A Marker Bed frequently contains open bedding planes and is usually the most permeable section of the bedrock encountered at site.

Zone 2 (6 feet to 7 feet thick) consists of fresh (unweathered) medium to thickly bedded, massive dolomite with a light brown to medium gray coloration and fine to medium granularity. Well developed, serrated stylolites form subhorizontal features between rare bedding planes. Some beds within Zone 2 have a distinct white speckled appearance due to intergranular gypsum. The rock has a generally non-porous appearance; however, some beds do have the appearance of a faint porosity associated with fine pitting.

Zone 3 (18 feet to 29 feet thick) consists of a medium brownish grey, medium grained with saccharoidal textured sections, moderately porous, and medium to thickly bedded dolomite. Occasional stylolites and argillaceous laminations form subhorizontal features and bedding partings. The upper 1 foot to 1.5 feet of Zone 3 is a distinct light to medium brownish grey thinly bedded laminar textured dolomite with soft sediment slump structures. This bed is referred to as the B Marker Bed.

Zone 4 is the lowest unit explored by the deeper boreholes completed in the study area. It is a fresh, light to medium brownish grey, fine to medium grained dolomite with medium to very thick bedding. The beds exhibit massive texture.

B2.3 Site Hydrogeology

The overburden glacial till exhibits a low hydraulic conductivity (10^{-5} to 10^{-6} cm/s) and yields very little water. The overburden groundwater is unconfined. The interpreted phreatic surface is presented in Figure B-2. Bergholtz Creek is a discharge zone for the overburden groundwater. The sewers in the area also act as discharge zones for overburden groundwater.

The Zone 1 aquifer is under confined conditions and has a hydraulic conductivity ranging between 1×10^{-4} cm/s to 2×10^{-2} cm/s. Well yields during development ranged from 2 gpm to 20 gpm. The confining units of Zone 1 are the overburden glacial tills above and the Zone 2 aquitard below. These confining units allow leakage from the overburden soils to Zone 1 and between Zone 1 and Zone 3. The vertical gradients between the overburden and Zone 1 are generally downward (0.01 ft/ft to 0.02 ft/ft) with some exception where upward gradients were recorded (0.02 ft/ft to 0.2 ft/ft). The vertical gradients between Zone 1 and Zone 3 are also generally downward (0.0008 ft/ft to 0.09 ft/ft), although some upward gradients have been measured in for limited areas (0.01 to 0.05 ft/ft.). The interpreted potentiometric contours for the Zone 1 aquifer are presented on Figure B-3. As noted in the RFI report and the main text of this document, the potentiometric pressure in Zone 1 in the vicinity of the Neutralization Pond is influenced by discharge of cooling water from the Rocket Test Facility.

The effective porosity of the Zone 1 aquifer is estimated to range between 1 percent and 3 percent. The 1 percent effective porosity has been considered to be characteristic of the upper part of the aquifer and the 3 percent characteristic of the lower part of the aquifer, corresponding to the A Marker Bed. The A Marker Bed, located at the base of Zone 1 is considered to be the dominant flowpath of this unit.

The average horizontal gradient in the Zone 1 unit between Rocket Test Cell area at the BAT Facility and at the Bergholtz Creek is about 0.01 ft/ft. The groundwater seepage velocity across this area is estimated to be approximately 1.9 ft/day to 2.8 ft/day for the lower part of the aquifer (3 percent effective porosity for A Marker Bed) and 5.7 ft/day to 8.4 ft/day for the upper part of the aquifer (1 percent effective porosity). The horizontal hydraulic gradient from area around Bergholtz Creek to Jagow Road has been estimated to be between 0.002 ft/ft to 0.0008 ft/ft. This corresponds to a seepage velocity in the area south of the creek of about 0.3 ft/day to 0.4 ft/day for the lower part of the aquifer (3 percent effective porosity for A Marker Bed) and 0.9 ft/day to 1.2 ft/day for the upper part of the aquifer (1 percent effective porosity). Groundwater discharge from the Zone 1 aquifer to Bergholtz Creek is considered to be limited due to the presence of fine grained overburden and stream sediments in the bed of the creek and potentially only from the upper part of the aquifer due to the dominance of bedding planes on the flow of groundwater through Zone 1 which tends to restrict vertical movement of water.

The Zone 2 aquitard separates the Zone 1 aquifer and the Zone 3 aquifer. The hydraulic conductivity measurements in this unit range from 1×10^{-5} cm/s to 1×10^{-6} cm/s.

The Zone 3 aquifer is under confined conditions and hydraulic conductivity has been measured in the range of 9×10^{-6} cm/s to 2×10^{-4} cm/s. Well yields, determined during well development, range from 1 gpm to 10 gpm. The interpreted potentiometric contours for Zone 3 are presented in Figure B-4.

The Zone 4 aquifer has a low hydraulic conductivity (measured between $3x10^{-6}$ cm/s to $5x10^{-4}$ cm/s) and low yield.

Groundwater flow directions in the various units is predominantly southwards and reflects the regional flow direction towards the Niagara River. However, local groundwater flow directions in the overburden soils and Zone 1 may vary as a result of the influence of manmade structures, the variability of hydraulic conductivity and/or surficial streams. Downward hydraulic gradients generally exist between the overburden soils and the Zone 1 aquifer. This may also vary locally due to the influence of sewer lines and as discused above.

Within Zone 1 gradients are generally downwards towards the A Marker Bed.

Both downward and upward gradients have been measured between the Zone 1 and Zone 3 aquifers which are separated by the Zone 2 aquitard. Water measurements on August 28, 1990, in all the monitoring wells in the study area, indicated downward gradients over most of the area. Variation in the magnitude and direction of the vertical gradients may occur due to the pressure pulse phenomenon caused by the infiltration of rocket test discharge water and/or surface water runoff to the Walmore Road Sanitary Sewer trench. During such events, downward vertical gradients between Zone 1 and Zone 3 probably increase.

The dominant flow path in the Zone 1 aquifer is within the A Marker Bed at the base of this unit. It is considered that flow of water in this stratum beneath Bergholtz Creek has been the prime factor in the development of the dissolved phase plume south of the creek. Discharge of groundwater to Bergholtz Creek is considered to be limited, and potentially only from the upper part of the aquifer.

B3.0 MODELING APPROACH

B3.1 Overview of Modeling Study

Release of predominantly chlorinated organic compounds occurred during operation of the now closed Neutralization Pond. The release resulted in the development of a DNAPL plume and associated dissolved groundwater plumes within the overburden and bedrock.

Although interconnected, the groundwater plume is discussed as four plumes for convenience:

1. A plume containing organic compounds within an area of overburden around the Neutralization Pond and Blade Bonding Building (see Figure 5 in CMS Report);
2. A Dense Non-Aqueous Phase Liquid (DNAPL) plume in Zone 1 (uppermost bedrock strata) stretching about 750 feet to the southeast of the Neutralization Pond (see Figure 6 in CMS Report);
3. A plume in Zone 1 containing dissolved organic compounds extending about 4,700 feet to the southeast of the Pond, roughly pear shaped, spreading to about 3,000 feet to 4,000 feet wide (see Figures 6, 8, 9, 10 and 11 in CMS Report); and,
4. A dissolved phase plume of limited extent in the Zone 3 bedrock stratum beneath the DNAPL plume (see Figure 7 in CMS Report).

Details regarding the nature, extent and rate of migration of the organic compounds in the groundwater are presented in the draft final RFI report (Reference B-1).

The modeling approach includes evaluating groundwater extraction alternatives for corrective action of the dissolved phase plume and the on-site DNAPL plume in Zone 1. Analytical approaches to evaluate the potential effect on the overburden plume and Zone 3 plume by pumping from Zone 1 are currently being developed. The results of this work will be reported in the CMI Plan. It is possible that the dissolved phase plume can be reduced to a size and concentration acceptable to the NYSDEC depending on the extraction rate and extraction period. Because technology does not currently exist which will allow the DNAPL to be effectively and efficiently extracted, the intent of the DNAPL control wells is not to remove the DNAPL, but to hydraulically contain the DNAPL plume. This would be accomplished by a system of groundwater extraction wells which will intercept dissolved constituents emanating from the plume and prevent its vertical migration. Consequently, the DNAPL control wells would be operated indefinitely.

The computer generated simulations presented in this modeling study are governed by existing knowledge of the required model input parameters. Because the flow system developed by the model is merely a mathematical conceptualization of the actual flow system, the results of this study should be used as a guideline for the placement of the extraction system wells.

B3.2 Zone 1 Dissolved Phase Modeling Approach

The dissolved phase plume in Zone 1, as illustrated in Figure 6 in the CMS Report, extends for a distance of approximately 4,700 feet south from the former Neutralization Pond. Several well configurations were simulated to determine optimum well locations and pumping rates for extraction of the dissolved phase plume.

Because of access limitations, the simulated placement of the extraction wells was limited to the BAT Facility and along a public utility easement owned by the Niagara Mohawk Corporation. This utility easement is an ideal location for an extraction well network since the easement is about 100 feet wide, orientated in a north-south direction, and centrally located in the plume area. An extraction well network within the easement would be reasonably accessible and private land owners in the immediate area would generally not be directly impacted by installation and operation of the system.

B3.3 DNAPL Modeling Approach

The DNAPL plume in the study area behaves as a constant supply of volatile organic compounds to the groundwater. As groundwater flows past the DNAPL plume, dissolved phase migration results. The modeled corrective action includes pumping groundwater from Zone 1 in the immediate vicinity of the DNAPL plume to hydraulically contain the DNAPL and capture dissolved phase plume associated with the DNAPL.

Containment wells located around the DNAPL plume (i.e.,DNAPL and associated dissolved phase) would act as a hydraulic divide, effectively isolating the DNAPL plume from the dissolved phase plume in Zone 1. The effort to contain DNAPL in Zone 1 also includes establishing an upward hydraulic gradient between the Zone 1 and Zone 3 aquifers, which are separated by the Zone 2 aquitard. An upward hydraulic gradient would minimize the potential of downward migration of DNAPL/dissolved phase organic compounds and locally establish groundwater flow from Zone 3 to Zone 1 and mitigation of the Zone 3 dissolved phase plume. It is estimated, based on the current understanding of DNAPL behavior in a groundwater system, that a 0.5 ft/ft upward hydraulic gradient between Zone 1 and Zone 3 would be effective in restraining downward migration of DNAPL and dissolved phase toward Zone 3 (see Appendix A).

This modeling effort included simulating several pumping scenarios in the vicinity of the DNAPL plume, as well as pumping immediately downgradient of the DNAPL plume. Additionally, the modeling effort included simulating pumping inside a grout curtain which encompassed the DNAPL plume.

B3.4 Numerical Groundwater Flow Model

Modeling of the groundwater flow was performed using the computer code FLOWPATH, developed by Waterloo Hydrogeologic Software (Reference B-2). FLOWPATH is a two-dimensional numerical, finite-difference, groundwater flow model based on the algorithm developed by Prickett and Lonnquist, that can be used to simulate steady-state hydraulic head distributions, groundwater flow velocities, particle tracking with retardation, travel times, hydraulic capture zones, and wellhead protection areas. Unconfined, confined and leaky confined aquifer conditions can be simulated and flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, and surface water bodies, can also be simulated. The results of FLOWPATH have been compared to results obtained from the MODFLOW computer code (which has been validated by USEPA) and have been found to be in good agreement.

B3.5 Modeling Assumptions

The modeling study involved simulating two-dimensional groundwater flow conditions for the Zone 1 aquifer. The groundwater model is based on the following assumptions:

- Zone 1 is a leaky confined aquifer;
- Within each hydraulic conductivity zone the aquifer is homogeneous and isotropic;
- Zone 1 receives recharge from the overburden and Bergholtz Creek;
- The hydraulic head values defined for the overburden are constant; and,
- Groundwater flow is steady.

B4.0 MODEL INPUT DATA

B4.1 Regional Potentiometric Heads

Regional potentiometric head values for the Zone 1 aquifer, was obtained from the United States Geological Survey (USGS) preliminary groundwater level database (Personal Communication, 1990). These head values coupled with site specific data were used for the definition of the regional hydraulic model.

B4.2 Hydraulic Conductivity and Porosity

Results of the pumping tests indicate that Zone 1 generally has the equivalent behavior to that of a porous medium. The principal components of the hydraulic conductivity in the two-dimensional flow field are generally within one order of magnitude. An overall geometric mean horizontal hydraulic conductivity value of 4.1×10^{-3} cm/s, as determined from the hydraulic testing performed in Zone 1 at the site (Reference B-3), was used in the model for Zone 1.

Based on qualitative observations of rock core samples obtained from Zone 1 within the study area during past investigations, Golder Associates estimates that Zone 1 porosity values range from about 1 percent to 3 percent (A Marker Bed). The bulk of Zone 1 generally tends to be less porous than the lower portion of Zone 1 (A Marker Bed). Simulations were carried out using porosity values of 1 percent and 3 percent.

B4.3 Recharge

The FLOWPATH model can simulate leaky aquifer conditions by inducing a hydraulic flux exchange with the overlying and/or underlying aquifer. This flux exchange is based on the vertical hydraulic conductivity, the saturated thickness, and the hydraulic head of the material overlying or underlying the modeled zone.

Areal recharge to Zone 1 through the overburden was simulated using the following parameters in the model: vertical hydraulic conductivity for the lower portion of the overburden was assigned a value of $1x10^{-6}$ cm/s, typical of silty glacial till material (Reference B-4); the average saturated thickness of the lower overburden was input at 10 feet; and, the hydraulic head values of the overburden were based on the interpolated water table surface presented in Figure B-2. The hydraulic head values of the overburden were modified in the model during the calibration process (see Section B-6.0).

Leakage conditions were simulated for Bergholtz Creek by using estimated stage elevations observed during the summer of 1990, and estimates of bottom sediment thickness and character to determine potential leakages from the stream to Zone 1. Previous investigations in the model area suggest that Bergholtz Creek interacts, or influences Zone 1 hydraulically (Reference B-1). The portion of Bergholtz Creek included in the model area was further investigated to better evaluate its relationship with the Zone 1 aquifer. This investigation indicated that the sediment/soils along the creek bottom generally ranged in thickness from about 1 foot to 3 feet and ranged in composition from discontinuous sands and gravels to organic rich silts and clays. Input parameters for creek leakage included a hydraulic conductivity value of $1x10^{-4}$ cm/s for the creek bottom material with an average thickness of 1.5 feet. The hydraulic head values for the creek were interpreted from a USGS quadrangle map of the area and the field survey of the creek in the summer of 1990 (Reference B-1). Zones of various leakage factors and corresponding hydraulic heads are presented in Figure B-5 and Table B-1.

Recharge to Zone 1 from Zone 3, which is separated by the Zone 2 aquitard, was also evaluated. This upward component of flow is relatively small, and therefore, for the purpose of modeling, was considered negligible.

B4.4 Thickness of Zone 1

The thickness of Zone 1 ranges from 12 feet to 20 feet, as determined from corehole data from past investigations (Reference B-1). The Zone 1 thickness values used in the model are based on the corehole data and are shown in Figure B-6.

B5.0 MODEL SETUP

B5.1 Grid Dimensions and Boundaries

The finite-difference grid system developed for the model consists of one layer with 100 rows and 100 columns, totaling 10,000 nodal coordinates (Figure B-7). The model represents an area that is 10,000 feet east-west by 11,000 feet north-south. Each finite-difference block represents an area of 100 feet by 110 feet.

In order to minimize the boundary effects in the site area, the grid extends beyond the vicinity of the study area. The study area is located in the north central portion of the grid; the closest model boundary to this area is about 2500 feet. The location of the closed Neutralization Pond at the BAT Facility represents the origin of the grid coordinate system.

The regional groundwater flow of Zone 1 in the study model is generally southward, toward the Niagara River (Figure B-3). The grid system is positioned in a north-south direction to coincide with the regional groundwater flow.

B5.2 Grid Boundary Conditions

Initially, the following boundary conditions were chosen for the modeling area:

- The constant-head (or Dirichlet) boundary condition, for which the heads are specified, at the northern and southern grid boundaries (Figure B-7); and,
- The no-flow boundary condition, for which the fluxes are zero (a special form of the Neuman boundary condition), at the eastern and western grid boundaries.

During the calibration process, the northeastern portion of the northern boundary was set to no-flow boundary conditions to obtain a better calibrated match (see Section B-6.0). Potentiometric contours will intersect the no-flow boundary at right angles, thus allowing flow parallel to, but not through, the boundary. The final calibrated model boundary conditions are presented in Figure B-7.

The potentiometric data used to define the constant head boundary conditions were based on the regional preliminary potentiometric data for Zone 1 provided by the USGS. (Personal Communication, 1990).

B6.0 CALIBRATION OF THE MODEL

B6.1 Steady-State Calibration

The primary objective of model calibration was to establish a site-specific model incorporating the steady state, natural and undisturbed groundwater flow in Zone 1, the interaction between the groundwater flow in Zone 1 and the overlying and underlying aquifers (overburden and Zone 2) and the surface water bodies in the creeks that allow the model to most closely represent field conditions. The model was calibrated against the regional potentiometric Zone 1 data, but site specific groundwater features were also incorporated in the calibration process.

As discussed in Section B-4.3, previous investigations indicate that the upper portion of groundwater flow in the Zone 1 aquifer is likely influenced by Bergholtz Creek. The inflection of the potentiometric surface in the vicinity of Bergholtz Creek suggests a slight interaction between the creek and Zone 1 immediately south of the site (Figure B-3). The regional potentiometric head data of Zone 1 does not show this localized effect, probably because of the scale and availability of of data. The model was initially calibrated against the regional data as an overall generalized conceptualization of the groundwater flow system. The calibration was then focused on the more localized influence of Bergholtz Creek.

The site specific potentiometric data of Zone 1 (Figure B-3) indicate a slight mounding effect within the BAT Facility. This mounding effect, as evaluated in previous investigations (Reference B-1), is probably due to the discharge of cooling water from the Rocket Test Facility during testing operations. As discussed in the RFI and CMS, these discharges likely caused localized recharge to the Zone 1 aquifer. This recharge is anticipated to be eliminated in the future by changes in the rocket test cooling water discharge system. Therefore, the calibration process does not account for the localized mounding of the potentiometric surface within Zone 1 at the site. In addition, site specific data suggest that the Zone 1 potentiometric surface is also affected by a sewer lift station located in the central portion of the site (see Figure B-3). Because the lift station effects will eventually be impacted by changes at the Facility this feature was also ignored during calibration.

The following parameters were initially assigned to the model and were not varied during calibration:

- the finite-difference grid system configuration;
- the thickness of Zone 1; and,
- the hydraulic conductivity of Zone 1.

The following parameters were varied to achieve simulated potentiometric head levels which best match the regional and site specific potentiometric head data:

- recharge from the overlying and underlying aquifers and Bergholtz Creek; and,
- boundary conditions.

The calibration process primarily consisted of adjusting rates of recharge to Zone 1 from the overburden and Bergholtz Creek in order to obtain a reasonable match between the simulated and observed potentiometric hydraulic heads in Zone 1. Refinements in the Zone 1 head distribution were accomplished by varying areal recharge rates and by adjusting the hydraulic head values of the overburden. The creek recharge was calibrated to observed effects by varying hydraulic conductivity values for the creek bottom material. In addition, the initial boundary conditions were slightly modified to obtain improved model calibration. Model nodes which were assigned a constant-head boundary condition along the northeastern portion of the grid boundary were replaced by a no-flow boundary condition. The recharge values produced from the calibrated steady-state simulation are presented in Table B-1 and Figure B-5 while the hydraulic head values of the model boundaries are presented in Table B-2 and Figure B-7.

An iterative procedure was used to calibrate the potentiometric hydraulic heads of the Zone 1 aquifer by matching simulated and observed head values. The model head values from each computer simulation were compared to observed head values and differences were observed. Each succeeding computer simulation included revised input data. Results from the successive simulations were examined and the pertinent data were adjusted. This process was repeated until the model results approximated the observed potentiometric hydraulic heads, gradients and flow directions of Zone 1.

The calibrated steady-state potentiometric contours of the Zone 1 aquifer are presented in Figure B-8 (Run 5002). Lateral hydraulic gradients were calculated at the same locations using simulated and measured hydraulic heads. The locations of these gradient estimates are shown on Figure B-9. A comparison of the simulated and observed gradients indicates that they are in close agreement. In addition, the localized influence of Bergholtz Creek on the groundwater flow system of Zone 1 is reflected in the calibrated model.

The overall representation of the potentiometric hydraulic head values, hydraulic gradients, and groundwater flow direction of the calibrated model is considered to be a reasonable approximation of the hydrogeologic system in the study area. The calibrated model is the basis for the pumping scenarios used to evaluate groundwater correction action alternatives for the study area.

As indicated in Section B-2.3, it is considered that the influence of Bergholtz Creek is limited to the upper part of the aquifer. In order to estimate the potentiometric head reduction for the lower part of the aquifer, the leakage factor defining the creek was replaced with the adjacent values (no leakage). The result of this simulation is presented in Figure B-10. This simulation was also used as basis for pumping scenarios in order to account for the differences in porosity between the upper and lower part of the Zone 1 aquifer as well as for the differentiated influence of Bergholtz Creek against the upper and lower part of the aquifer.

B6.2 Sensitivity Analyses

To estimate the sensitivity of the calibrated model (Run 5002), the hydraulic conductivity of Zone 1 and the leakage of Bergholtz Creek were varied.

The hydraulic conductivity value of 4.1×10^{-3} cm/s was used in the calibrated model, based on an overall geometric mean hydraulic conductivity value determined from hydraulic conductivity tests in Zone 1 (Reference B-3). This hydraulic conductivity value was varied by substituting the highest and lowest hydraulic conductivity value determined from all the hydraulic conductivity tests. The low value was set at 2.2×10^{-4} cm/s and the high value at 1.1×10^{-2} cm/s. The simulations using the low and high hydraulic conductivity values are presented in Figures B-11 and B-12, respectively. The simulation using the high value resulted in Zone 1 potentiometric contours being shifted slightly from the calibrated simulation; however, the simulation using the low value resulted in unnatural positioning of potentiometric contours. These simulations indicate that the model is not very sensitive to variations of higher hydraulic conductivity values but is very sensitive to lower hydraulic conductivity values.

Sensitivity analyses were also performed by varying the hydraulic conductivity of the creek bottom material. The calibrated value of $1.0x10^{-4}$ cm/s was substituted by hydraulic conductivity values which varied by one order of magnitude. The potentiometric contours resulting from the analyses using a low value of $1.0x10^{-5}$ cm/s and a high value of $1.0x10^{-3}$ cm/s are presented in Figures B-13 and B-14, respectively. A visual comparison of these potentiometric contours to the potentiometric contours produced by the calibrated simulation indicates that the model is more sensitive to the low hydraulic conductivity value than to the high hydraulic conductivity value. This is evident by the shifting of the 570 foot contour interval, located in the immediate vicinity of Bergholtz Creek.

The high value of $1.0x10^{-3}$ cm/sec was derived from the geometric mean of the geometric means of all hydraulic conductivities from the pumping test and all recovery tests performed for each well. The low value used was about one order of magnitude lower than the lowest value obtained from a recovery test performed on open borehole 89-9(1). Therefore, because the results obtained from the low value of hydraulic conductivity yield an unrealistic distribution of hydraulic heads, this value was rejected though the high value of $1x10^{-3}$ cm/sec (taken from the means) produced a realistic calibrated flow field, the value of 4.1x10^{-3} cm/s was returned for the purpose of simulating area groundwater flow since it produced a better fit with the overall Zone 1 plume configuration (see Section B-4.2 and CMS text Section 2.2).

B7.0 MODELING OF REMEDIAL ALTERNATIVES

B7.1 General

The calibrated model was used to evaluate groundwater corrective action alternatives for the study area by simulating several extraction well configurations. The alternatives presented herein can be used as the basis for the development of extraction systems that have the potential to hydraulically control groundwater flow in the study area.

The modeling results include potentiometric contours, groundwater flow directions and particle tracking at steady-state conditions. Particle tracking is a model function that predicts the travel path of a groundwater particle over a period of time, given a particular extraction well configuration. Only those particles which would travel to a given extraction well are shown. Consequently, particle tracking defines the "capture zone", of extraction wells, for a given period of time under steady state conditions. A retardation rate of 2 was used to simulate volatile organic compound plume capture (see CMS text).

Groundwater pumping simulations were modeled using a range of porosity values for Zone 1. Porosity does not effect the hydraulic head results, but is used to calculate groundwater velocity and particle tracking. A 1 percent porosity value was used to simulate flow conditions along the upper portion of Zone 1, and a 3 percent porosity value was used to simulate flow conditions in the lower portion of Zone 1. The influence of Bergholtz Creek on the lower portion of Zone 1 is considered to be limited (Reference B-1). Therefore, the simulations for the lower portion of Zone 1 do not include impacts from Bergholtz Creek.

B7.2 Dissolved Phase Remedial Alternatives

Modeling the extraction well system for the off-site dissolved phase plume focused on utilizing a practical number of extraction wells to establish hydraulic control of the groundwater system. Placement of the extraction wells also considered minimizing the influence that the extraction system would have on Bergholtz Creek. Initial placement of the extraction wells was limited to the Niagara Mowhawk utility easement located south of the BAT Facility. Fortunately, this placed the wells in the central, downgradient portion of the plume.

Review of the simulated pumping results indicated that six extraction wells (EW-1 through EW-6), each pumping at 7 gallons per minute (gpm), spaced about 340 feet apart would provide adequate hydraulic control of the dissolved phase plume. The pumping rate is based on average reported yields for the Zone 1 aquifer (Reference B-3). The closest off-site well to Bergholtz Creek was placed about 850 feet south of the creek to minimize pumping effects on the creek. The potentiometric contours of Zone 1 at steady-state pumping conditions for the six off-site extraction wells is illustrated in Figure B-15 (Computer Run 5005).

The capture zone simulation for the six extraction wells, over a five year period, for the upper portion of Zone 1 is presented in Figure B-16. The corresponding potentiometric contours and capture zone, over a five-year period, for the lower portion of Zone 1 are presented in Figures B-17 and B-18, respectively (Computer Run 6005). The hydraulic influence of Bergholtz Creek on the upper portion of Zone 1 is apparent by the limiting extent of the pathlines in northeast portion of the plume. However, the pathlines simulated for the lower portion of Zone 1 travel beyond the limits of Bergholtz Creek, as expected.

The simulations indicate that the six extraction wells provide adequate hydraulic control to capture the dissolved phase plume over time. However, the highest reported concentration of organic compounds is present in the northwestern portion of the plume, in the vicinity of the BAT Facility (Reference B-1). Therefore, to minimize the potential for the plume to migrate beyond the capture zone of the six off-site extraction wells (EW-1 through EW-6), two additional extraction wells (EW-7 and EW-8) were placed at the southern portion of the BAT Facility (see Figure B-19).

Additional simulations were completed with these two on-site extraction wells; EW-7 pumping at 7 gpm and EW-8 pumping at 5 gpm. The potentiometric surface contours and the results of particle tracking simulations for the upper and lower portion of Zone 1 are presented in Figures B-19, B-20, B-21, and B-22 (Computer Runs 5050 and 6050). The hydraulic cone-of-depression resulting from the pumping simulation is evident in Figures B-19 and B-21. The maximum drawdown values recorded are about 8 feet at the extraction well alignment along the utility easement (Wells EW-1 through EW-6).

The six extraction wells located off-site and the two extraction wells located on-site provide a factor of redundancy in the remedial system. In the event that an extraction well becomes inoperative, the other extraction wells will minimize the hydraulic effect due to the inactive well. If local heterogeneities in the Zone 1 aquifer result in a given pair of wells not having the required impact, additional wells can be installed in the intervening space.

B7.3 DNAPL Phase Control

B7.3.1 General

Several groundwater extraction well configurations were evaluated as potential DNAPL phase control alternatives. The extraction well scenarios that were simulated using the groundwater flow model include:

1. Extraction wells placed adjacent to the DNAPL plume (Computer Runs 5041 and 6041);
2. Extraction wells placed within the DNAPL plume (Computer Runs 5015 and 6015);
3. Extraction wells placed inside a grout curtain assumed to surround the DNAPL plume (Computer Runs 5042 and 6042); and,
4. Extraction wells placed hydraulically downgradient of the DNAPL plume (Computer Runs 5027 and 6027).

Simultaneous pumping of the off-site dissolved phase extraction system was simulated during evaluation of DNAPL extraction well pumping. This was necessary because the off-site system may have a slight hydraulic influence on the groundwater system in the vicinity of the DNAPL plume.

B7.3.2 DNAPL Extraction Well Model Criteria

The modeling criteria established for pumping scenarios 1, 2, and 3 as listed above, were used to obtain an optimum extraction well configuration to hydraulically contain the DNAPL plume and prevent lateral migration while lowering the hydraulic head of Zone 1 by about 4 feet in vicinity of the DNAPL plume. A drawdown of 4 feet would produce an upward hydraulic gradient of about 0.5 ft/ft between the Zone 1 and Zone 3 aquifers and not cause desaturation of the bedrock or lower overburden in the DNAPL plume area. As discussed in Section B-3.3, this upward hydraulic gradient would minimize the potential for downward migration of DNAPL and dissolved compounds and would locally establish groundwater flow from

Zone 3 to Zone 1 and encourage migration of dissolved phase compounds from Zone 3 and the lower overburden.

The fourth extraction well scenario listed above was modeled to evaluate optimum placement of wells downgradient of the DNAPL plume to hydraulically control lateral migration of the dissolved phase in Zone 1 at a minimal pumping rate. This scenario does not attempt to model potential control of the vertical gradients in order to influence vertical migration of DNAPL or dissolved phase compounds.

B7.3.3 DNAPL Extraction Well System Scenario Number 1

This DNAPL extraction well scenario simulates extraction wells placed adjacent to the plume. The modeling results indicate that four extraction wells (DW-9 through DW-12) each pumping at 3 gpm would achieve the DNAPl plume control objectives. The pumping simulation resulted in drawdown of about 4 feet over the DNAPL plume. Placement of DNAPL extraction wells was limited to an area within the BAT Facility. The potentiometric surface of the upper part of Zone 1, under steady-state pumping conditions, is presented in Figure B-23. Figure B-24 presents the particle tracking simulation over a five year period for the upper portion of Zone 1. Figures B-25 and B-26 present the corresponding potentiometric surface and particle tracking for the lower portion of the Zone 1 aquifer.

B7.3.4 DNAPL Extraction Well System Scenario Number 2

The second DNAPL extraction well scenario simulates extraction wells placed within the DNAPL plume (DW-8, DW-9 and DW-10). The results of the pumping simulations indicate that three wells placed within the DNAPL plume, each pumping at a rate of 4 gpm, would achieve the plume control objectives. The wells are spaced about 250 feet apart along the plume's longitudinal axis. This pumping scenario resulted in drawdown values of about 3.5 feet to 4 feet over the DNAPL plume. Figure B-27 presents the potentiometric contours of Zone 1 at steady-state pumping conditions for the upper portion of the aquifer. Particle tracking simulations over a five year period for the upper portion of Zone 1 are presented in Figures B-28. Figures B-29 and B-30 present the corresponding potentiometric surface and particle tracking for the lower portion of Zone 1 aquifer.

B7.3.5 DNAPL Extraction Well System Scenario Number 3

This DNAPL extraction well scenario includes the simulation of a grout curtain surrounding the DNAPL plume with extraction wells pumping from the inside of the grout curtain. The grout curtain was simulated as having a hydraulic conductivity value of 1×10^{-5} cm/s and a porosity value of 1 percent. The model results indicate that two extraction wells (DW-9 and DW-10) located within the confines of the grout curtain, each pumping at 3 gpm, would achieve the plume control objectives. Drawdown of the potentiometric surface of 4 feet to 6 feet was predicted within the confines of the grout curtain. Figure B-31 presents the potentiometric contours of Zone 1 at steady-state pumping conditions for the upper portion of the aquifer. Particle tracking simulations over a five year period for the upper portion of Zone 1 are presented in Figure B-32. Figures B-33 and B-34 present the corresponding potentiometric surface and particle tracking for the lower portion of Zone 1 aquifer.

B7.3.6 DNAPL Extraction Well System Scenario Number 4

This DNAPL extraction well scenario simulates extraction wells located hydraulically downgradient of the DNAPL plume. The model results indicate that two wells (DW-9 and DW-10), located on the BAT Facility, each pumping at 1 gpm, would achieve the plume control objectives. The potentiometric contour map, Figure B-35, shows only a slight contour inflection due to pumping at the downgradient wells. Figure B-36 presents particle tracking simulations over a five year period for the upper portion of Zone 1. Figures B-37 and B-38 present the corresponding potentiometric surface and particle tracking for the lower portion of Zone 1 aquifer.

B8.0 CONCLUSIONS AND RECOMMENDATIONS

The modeling study considered several extraction well placement alternatives for the on-site and off-site groundwater corrective action systems in the study area. The simulation results illustrate potentiometric contours and capture zone areas for the various extraction well configurations.

Evaluation of an extraction system for the dissolved phase plume resulted in an optimum well configuration consisting of eight extraction wells. Six of the wells are located along the Niagara Mowhawk utility easement located southeast of the site and two wells are located on the BAT Facility. Golder Associates recommends using this information for the development of detailed extraction well design.

Four extraction well alternatives were evaluated for the on-site DNAPL phase control system. The alternatives included placing extraction wells in the DNAPL plume, adjacent to the DNAPL plume, and downgradient of the DNAPL plume. One additional alternative included pumping inside a grout curtain that would encompass the DNAPL plume. The three alternatives which simulate pumping in or adjacent to the DNAPL plume hydraulically control lateral and vertical contaminant migration. The alternative simulating groundwater extraction downgradient of the DNAPL plume only controls lateral migration.

Of the four modeled DNAPL extraction well alternatives, the scenario with the pumping wells located adjacent to the DNAPL phase, with or without a grout curtain, is recommended. A grout curtain may reduce the volume of groundwater extracted by about one-half but the effectiveness of installing a grout curtain versus the difficulty of treating increased groundwater concentrations of volatile organic compounds will require evaluation. Preliminary figures from the solute transport modeling indicate that the presently preferred on-site treatment plant (Appendix C) is capable of treating the water from the no grout curtain scenario.

Though placing pumping wells in the DNAPL plume is a viable alternative, there is greater potential for increased difficulty of treatment due to the increased potential for the presence of DNAPL at the well head. In addition, information developed during the pump out testing (Reference B-3) indicates that the DNAPL may be occluding the fracture systems in the DNAPL plume section of the bedrock. This has the potential to reduce the ability of an extraction well system located in the DNAPL plume to contain the fringes of the DNAPL plume.

The advantage of pumping downgradient of the DNAPL plume is that the dissolved phase plume which is migrating laterally from the DNAPL plume can be controlled with lower extraction and treatment volumes (1 gpm) compared to the other options. The disadvantage of this alternative is the lack of control on the vertical gradient in the DNAPL plume area and thus, lack of a potential to control vertical migration of DNAPL. Golder Associates does not recommend this system since control of the vertical migration of DNAPL and mitigation of the impacts to Zone 3 and the overburden would not be addressed.

In summary, the most appropriate control measure for the DNAPL is considered to be the four well scenario surrounding the DNAPl plumes. The results of the solute transport modeling will allow refinement of this option.

REFERENCES

B-1 Golder Associates Inc., "RCRA Facility Investigation Neutralization Pond, Bell Aerospace Textron, Wheatfield Plant", Draft Final Report, February, 1991.

B-2 Franz, T. and Guiguer, N., "FLOWPATH Two-dimensional Horizontal Aquifer Simulation Model, Waterloo Hydrogeologic Software, Waterloo, Ontario", 1990.

B-3 Golder Associates Inc., "Results of the Pump-In and Pump-Out Testing, Bell Aerospace Textron, Wheatfield, New York", Draft Report, February, 1990.

B-4 Freeze, R.A., and Cherry, J.A., "Groundwater", 1979.

TABLE B -1
LEAKAGE FACTORS AND HYDRAULIC HEADS IN UPPER AQUIFER

ZONE NUMBER	LEAKANCE FACTOR (1/day)	HYDRAULIC HEAD (ft)
1	3.00E-04	570.00
2	3.00E-04	565.00
3	3.00E-04	575.00
4	3.00E-04	580.00
5	3.00E-04	585.00
6	3.00E-04	567.00
7	3.40E-02	568.00
8	1.70E-02	568.00
9	1.70E-02	568.50
10	1.70E-02	569.00
11	1.70E-02	570.00
15	1.70E-02	570.50
16	3.00E-04	568.50

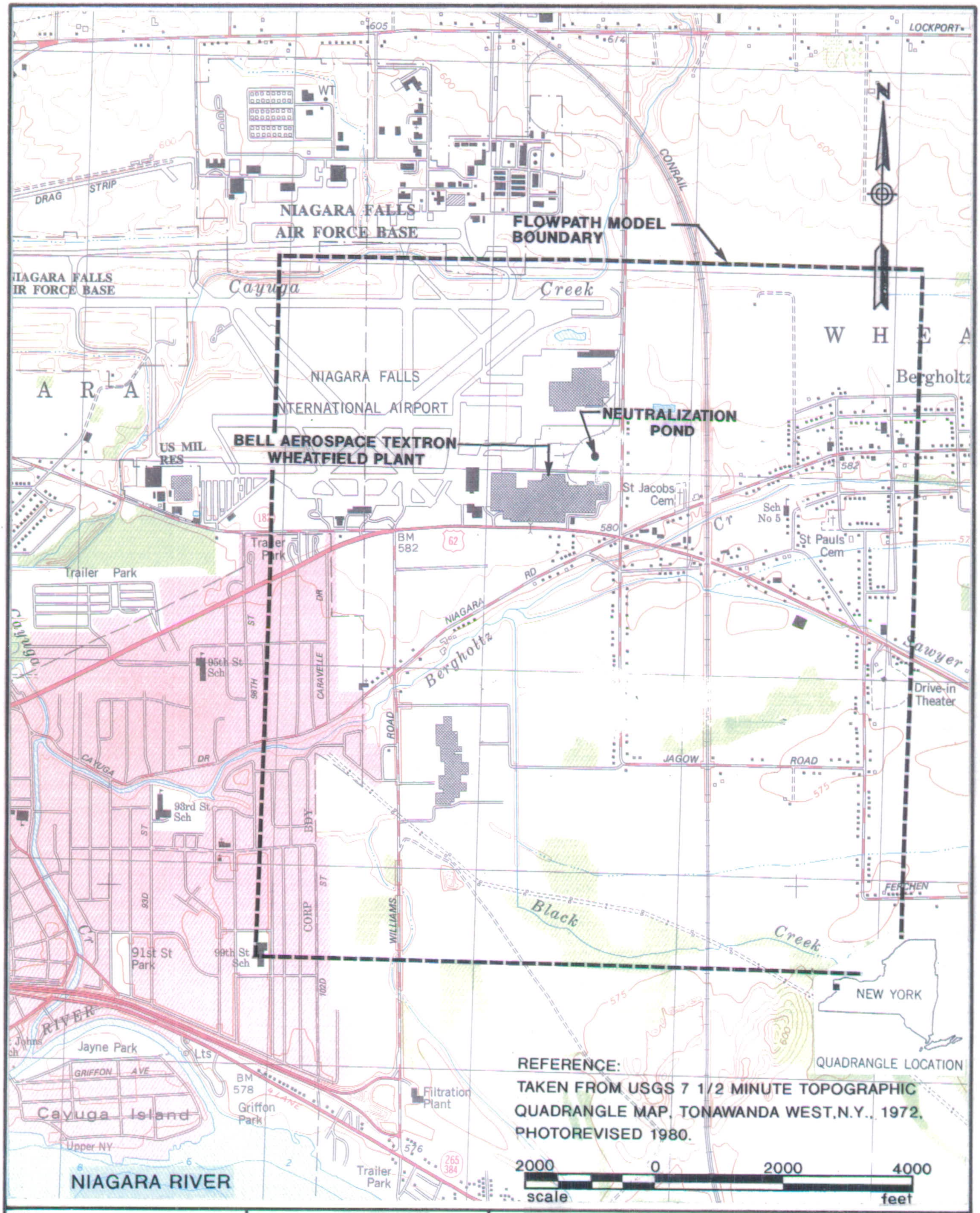
TABLE B-2
CONSTANT HEAD NODES

COLUMN	ROW	HEAD (ft)
1	1	566.50
2	1	566.51
3	1	566.52
4	1	566.53
5	1	566.54
6	1	566.55
7	1	566.56
8	1	566.57
9	1	566.58
10	1	566.59
11	1	566.60
12	1	566.61
13	1	566.62
14	1	566.63
15	1	566.64
16	1	566.65
17	1	566.66
18	1	566.67
19	1	566.68
20	1	566.69
21	1	566.70
22	1	566.71
23	1	566.72
24	1	566.73
25	1	566.74
26	1	566.75
27	1	566.76
28	1	566.77
29	1	566.78
30	1	566.79
31	1	566.80
32	1	566.81
33	1	566.82
34	1	566.83
35	1	566.84
36	1	566.85
37	1	566.86
38	1	566.87
39	1	566.90
40	1	566.92
41	1	566.95
42	1	567.00
43	1	567.01
44	1	567.02
45	1	567.03
46	1	567.04
47	1	567.05
48	1	567.06
49	1	567.07
50	1	567.08
51	1	567.09
52	1	567.10
53	1	567.11
54	1	567.12
55	1	567.13
56	1	567.14
57	1	567.15
58	1	567.16
59	1	567.17
60	1	567.18
61	1	567.19
62	1	567.20
63	1	567.21
64	1	567.22
65	1	567.23
66	1	567.24
67	1	567.25
68	1	567.27
69	1	567.28
70	1	567.29
71	1	567.30
72	1	567.31
73	1	567.32
74	1	567.33
75	1	567.34
76	1	567.35
77	1	567.36
78	1	567.40
79	1	567.45
80	1	567.50
81	1	567.55
82	1	567.60

TABLE B-2 (CONTINUED)
CONSTANT HEAD NODES

COLUMN	ROW	HEAD (ft)
83	1	567.65
84	1	567.70
85	1	567.75
86	1	567.80
87	1	567.85
88	1	567.82
89	1	567.85
90	1	567.87
91	1	567.90
92	1	567.92
93	1	567.94
94	1	567.96
95	1	567.98
96	1	567.98
97	1	567.98
98	1	567.98
99	1	567.98
100	1	568.00
1	100	584.00
2	100	584.17
3	100	584.34
4	100	584.50
5	100	584.67
6	100	584.75
7	100	584.92
8	100	585.00
9	100	585.17
10	100	585.34
11	100	585.50
12	100	585.67
13	100	585.80
14	100	585.95
15	100	586.00
16	100	586.06
17	100	586.12
18	100	586.18
19	100	586.24
20	100	586.30
21	100	586.36
22	100	586.42
23	100	586.50
24	100	586.55
25	100	586.60

COLUMN	ROW	HEAD (ft)
26	100	586.70
27	100	586.80
28	100	586.90
29	100	587.00
30	100	587.03
31	100	587.06
32	100	587.09
33	100	587.12
34	100	587.15
35	100	587.18
36	100	587.21
37	100	587.24
38	100	587.30
39	100	587.33
40	100	587.36
41	100	587.39
42	100	587.43
43	100	587.46
44	100	587.50
45	100	587.37
46	100	587.24
47	100	587.11
48	100	587.00
49	100	586.88
50	100	586.77
51	100	586.66
52	100	586.55
53	100	586.44
54	100	586.33
55	100	586.22
56	100	586.11
57	100	586.00
58	100	585.80
59	100	585.60
60	100	585.40
61	100	585.20
62	100	585.00
63	100	584.84
64	100	584.70
65	100	584.56
66	100	584.42
67	100	584.28



REFERENCE:
TAKEN FROM USGS 7 1/2 MINUTE TOPOGRAPHIC QUADRANGLE MAP, TONAWANDA WEST, N.Y., 1972, PHOTOREVISED 1980.

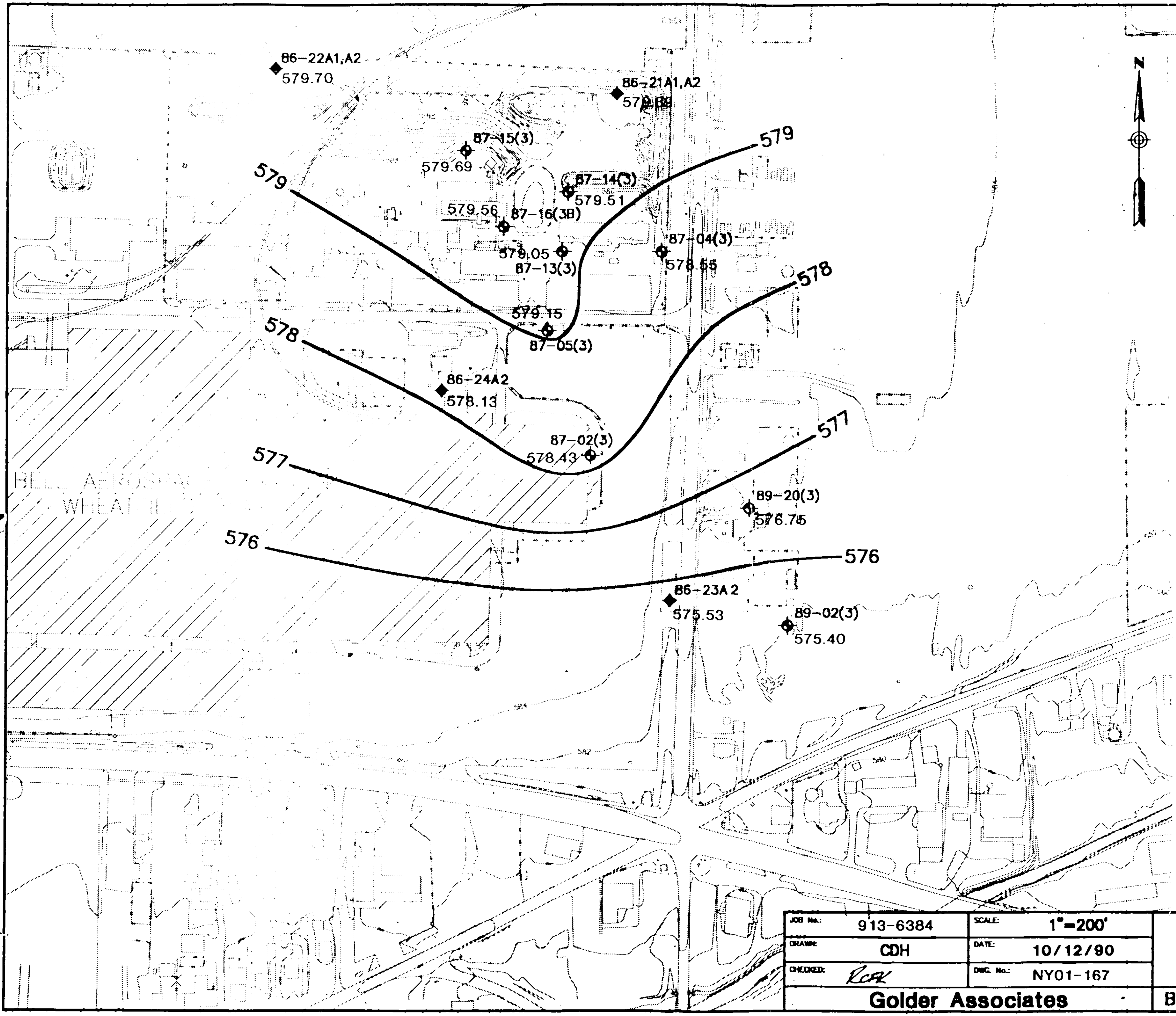
JOB No.:	913-6384	SCALE:	1"=2000'
DRAWN:	TLF	DATE:	10/05/90
CHECKED:	Reck	DWG. No.:	NY01-149

SITE LOCATION MAP AND FLOWPATH MODEL BOUNDARY

Golder Associates

BELL AEROSPACE TEXTRON

FIGURE **B-1**



LEGEND

◆ 86-21A2	ZONE 3 PIEZOMETER
⌖ 87-15(3)	ZONE 3 WELL
—— 578	ELEVATION CONTOURS
575.40	ELEVATION (M.S.L.)

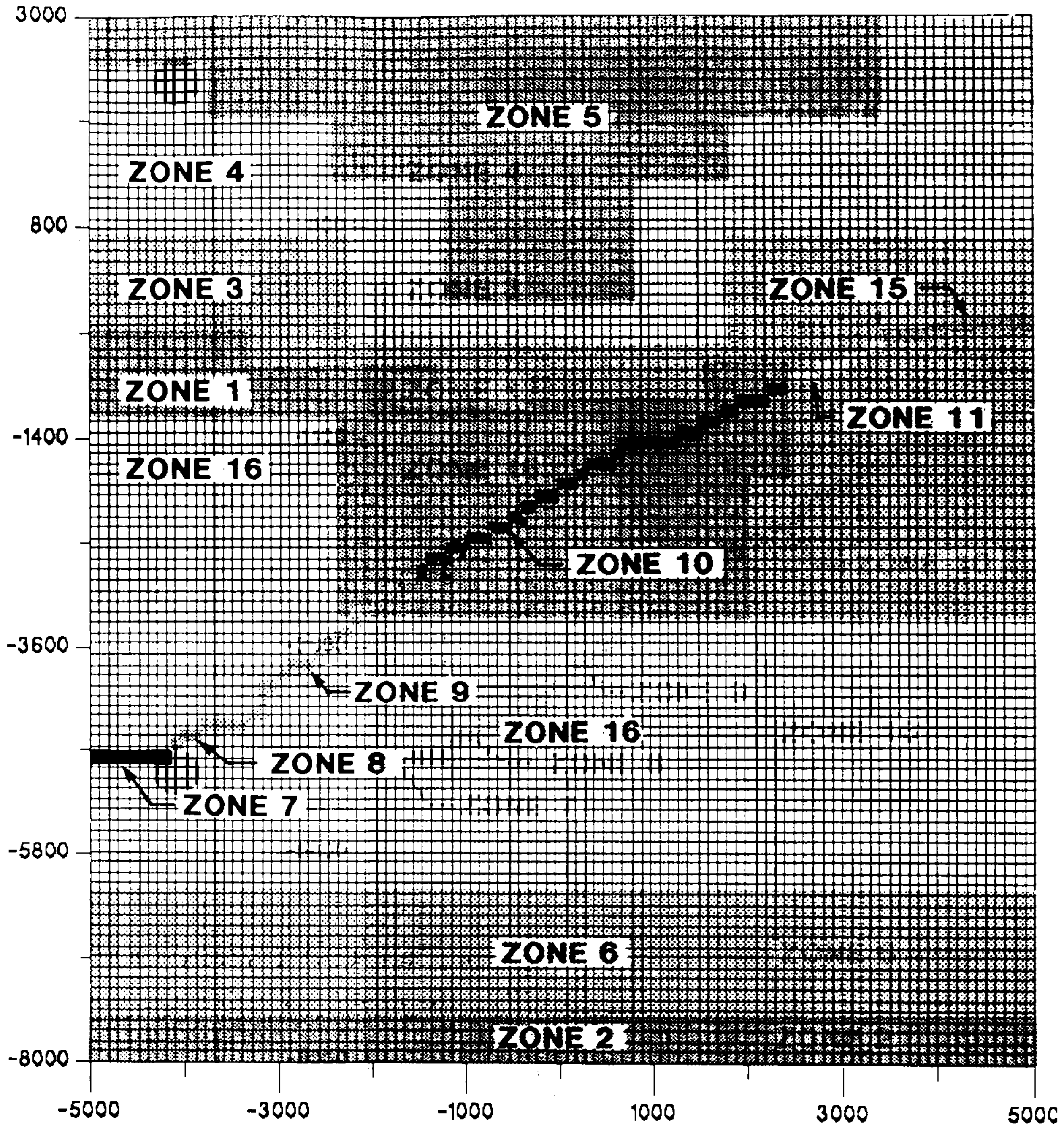
JOB No.:	913-6384	SCALE:	1"=200'
DRAWN:	CDH	DATE:	10/12/90
CHECKED:	RCK	DWG. No.:	NY01-167

Golder Associates

INTERPRETED ELEVATION CONTOURS ZONE 3 POTENTIOMETRIC SURFACE

BELL AEROSPACE TEXTRON

FIGURE B-4



NOTE

SEE TABLE B-1 FOR LEAKAGE FACTOR
AND HYDRAULIC HEAD IN UPPER AQUIFER

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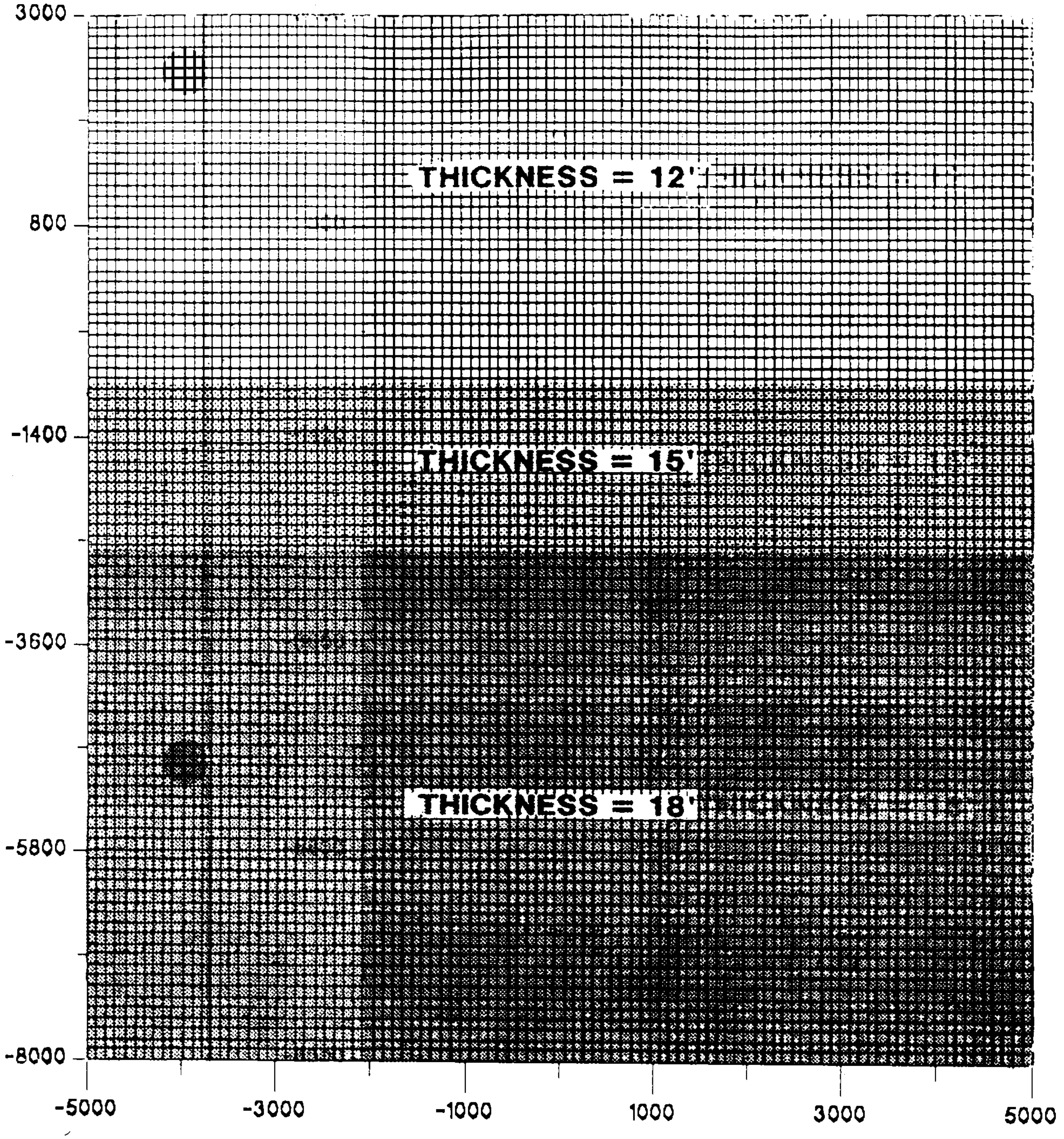
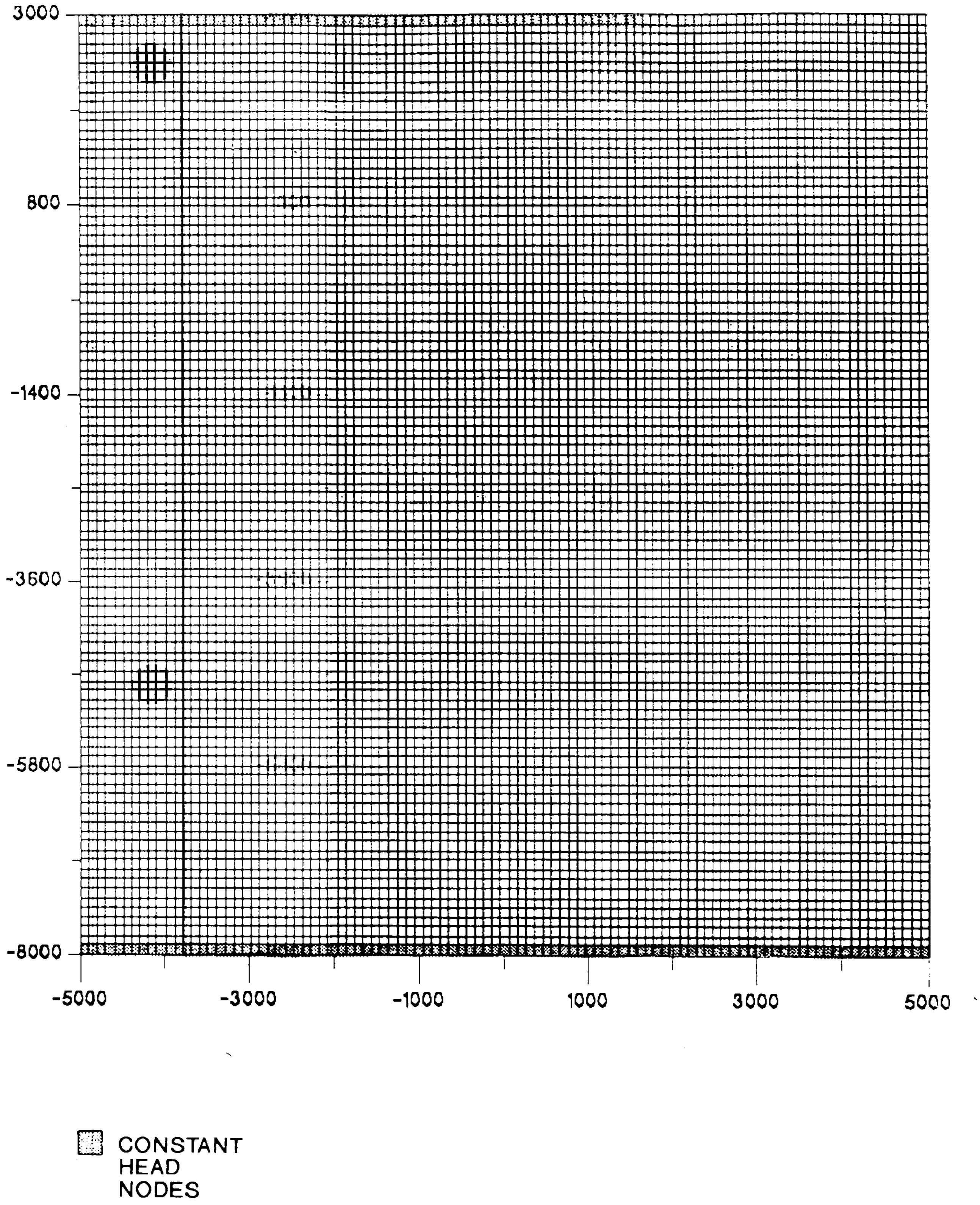
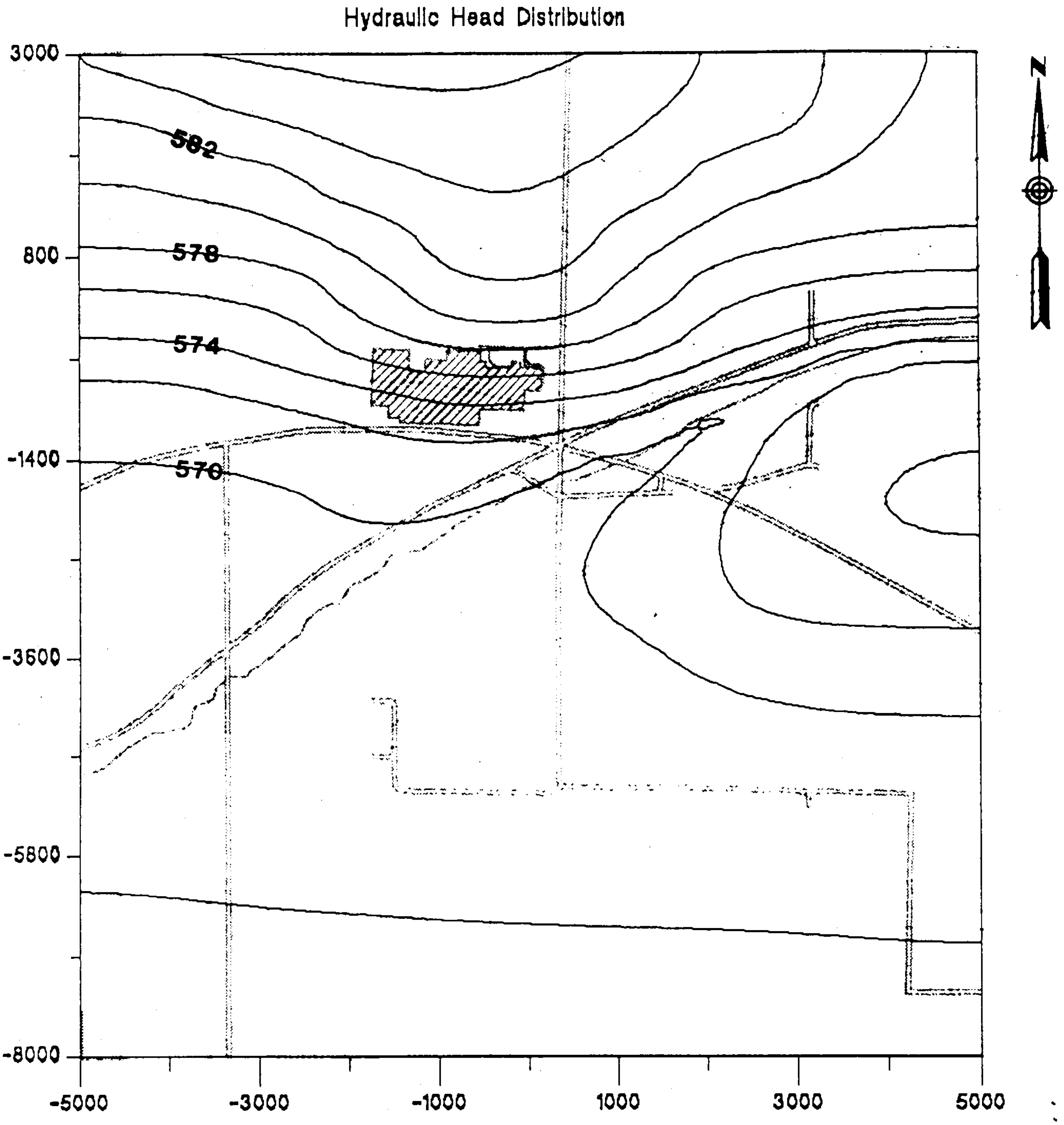
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON
		FIGURE B-5



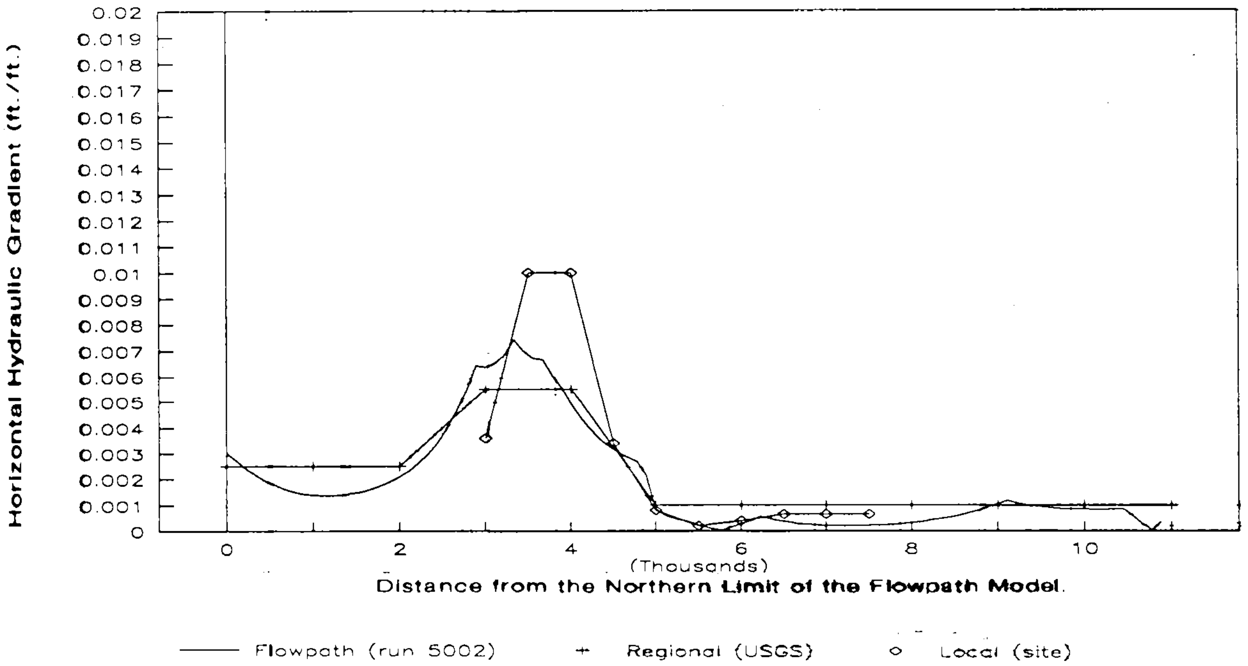
JOB No.: 913-6384	SCALE: N/A	**FINITE DIFFERENCE GRID,** **AQUIFER THICKNESS**
DRAWN: FG	DATE: 03/25/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE **B-6**



JOB No.: 913-6384	SCALE: N/A	**FINITE DIFFERENCE GRID, CONSTANT HEAD NODES**
DRAWN: FG	DATE: 03/25/91	
CHECKED:	DWG. No.:	
Golder Associates	BELL AEROSPACE TEXTRON	FIGURE **B-7**



JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, COMPUTER RUN 5002	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		**BELL AEROSPACE TEXTRON**	FIGURE **B-8**



JOB No.: 913-6384	SCALE: AS SHOWN	CROSS SECTION WITH MEASURED VERSUS SIMULATED HORIZONTAL GRADIENT
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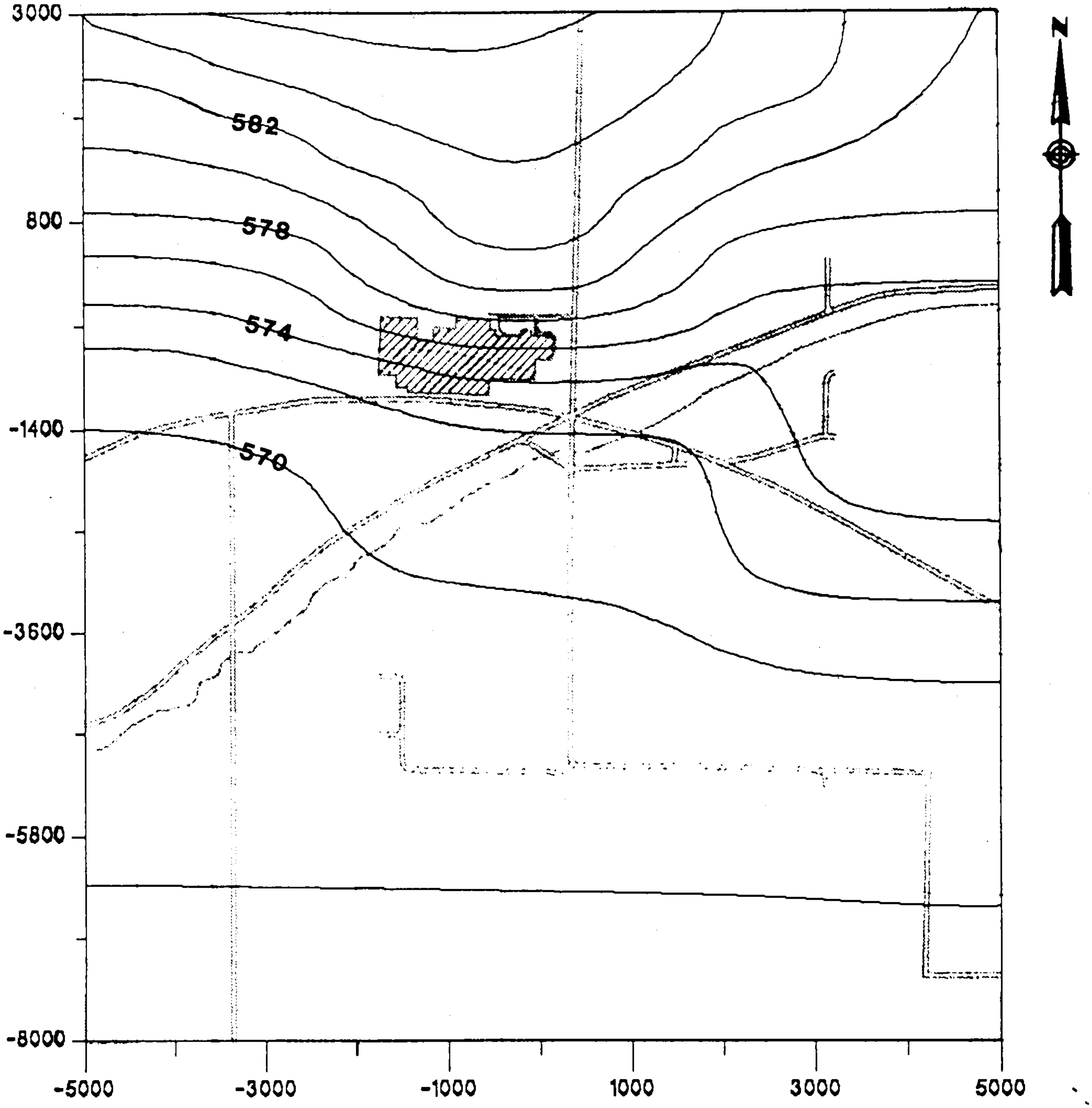
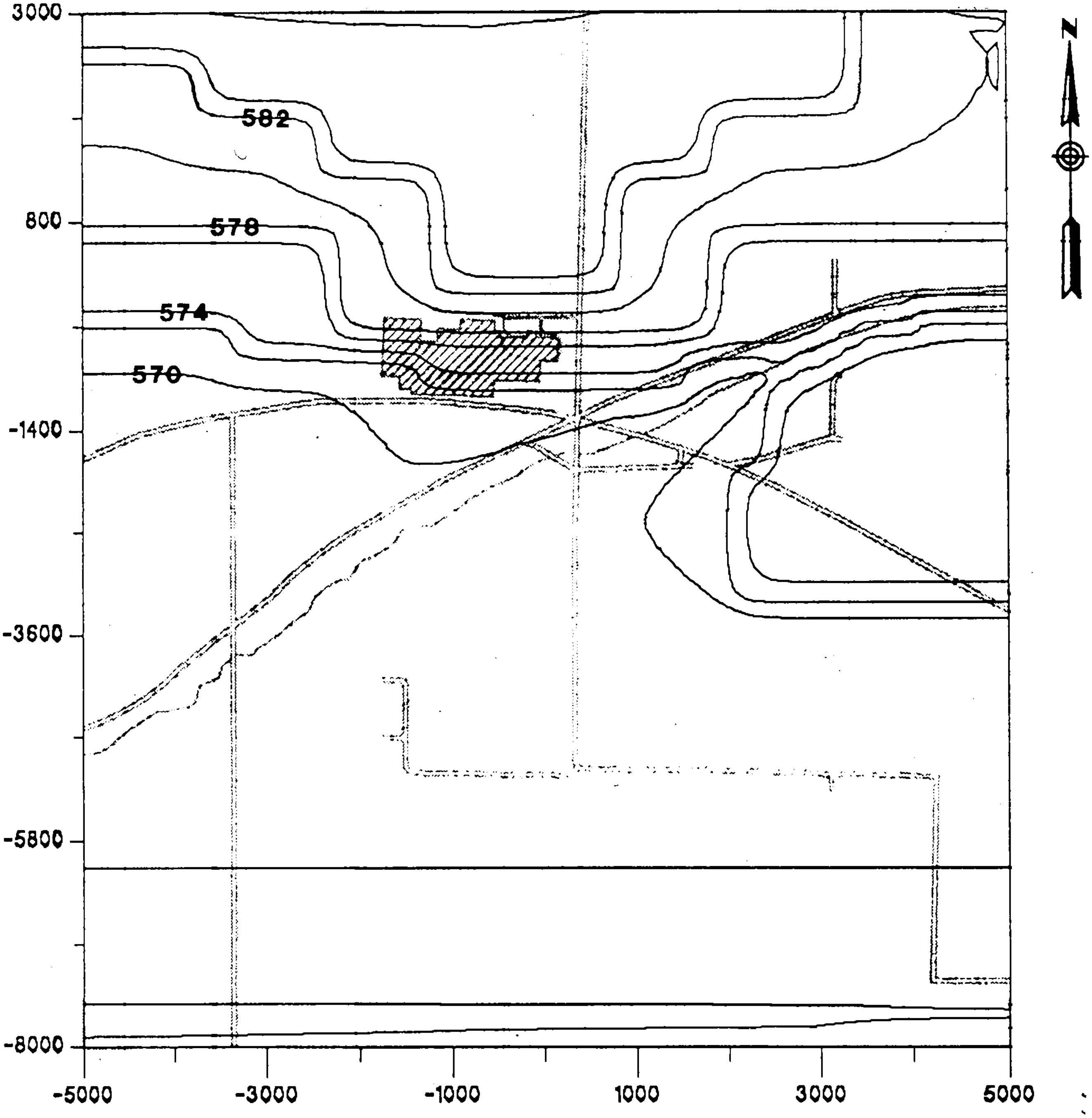
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON
		FIGURE B-9

15896



JOB No.: 913–6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, COMPUTER RUN 6002
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B-10

Hydraulic Head Distribution



JOB No.: 913-6384	SCALE: AS SHOWN	SENSITIVITY ANALYSIS, SIMULATED POTENTIOMETRIC CONTOURS FOR K= 2.2×10^{-4} cm/s COMPUTER RUN 4001	
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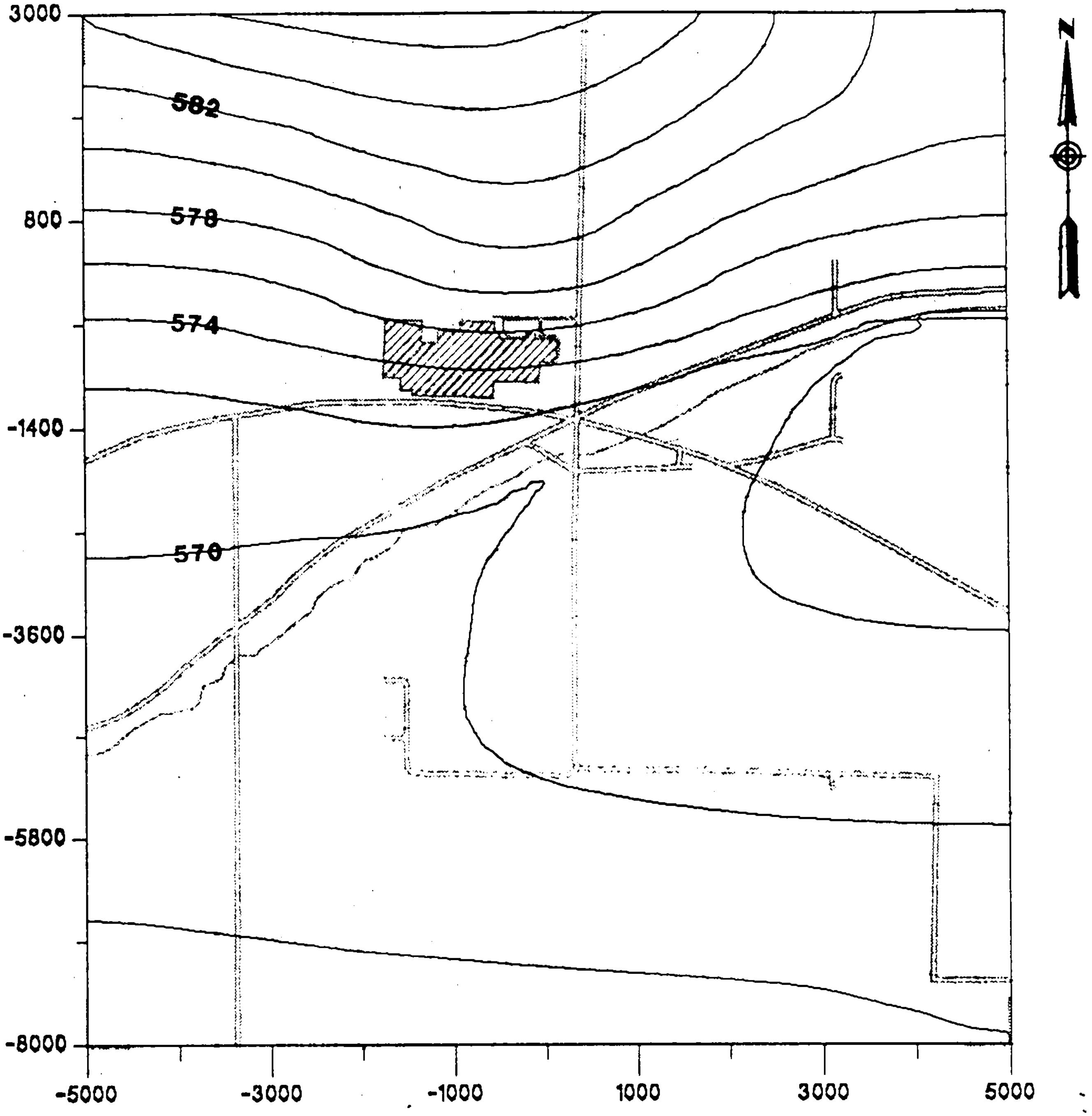
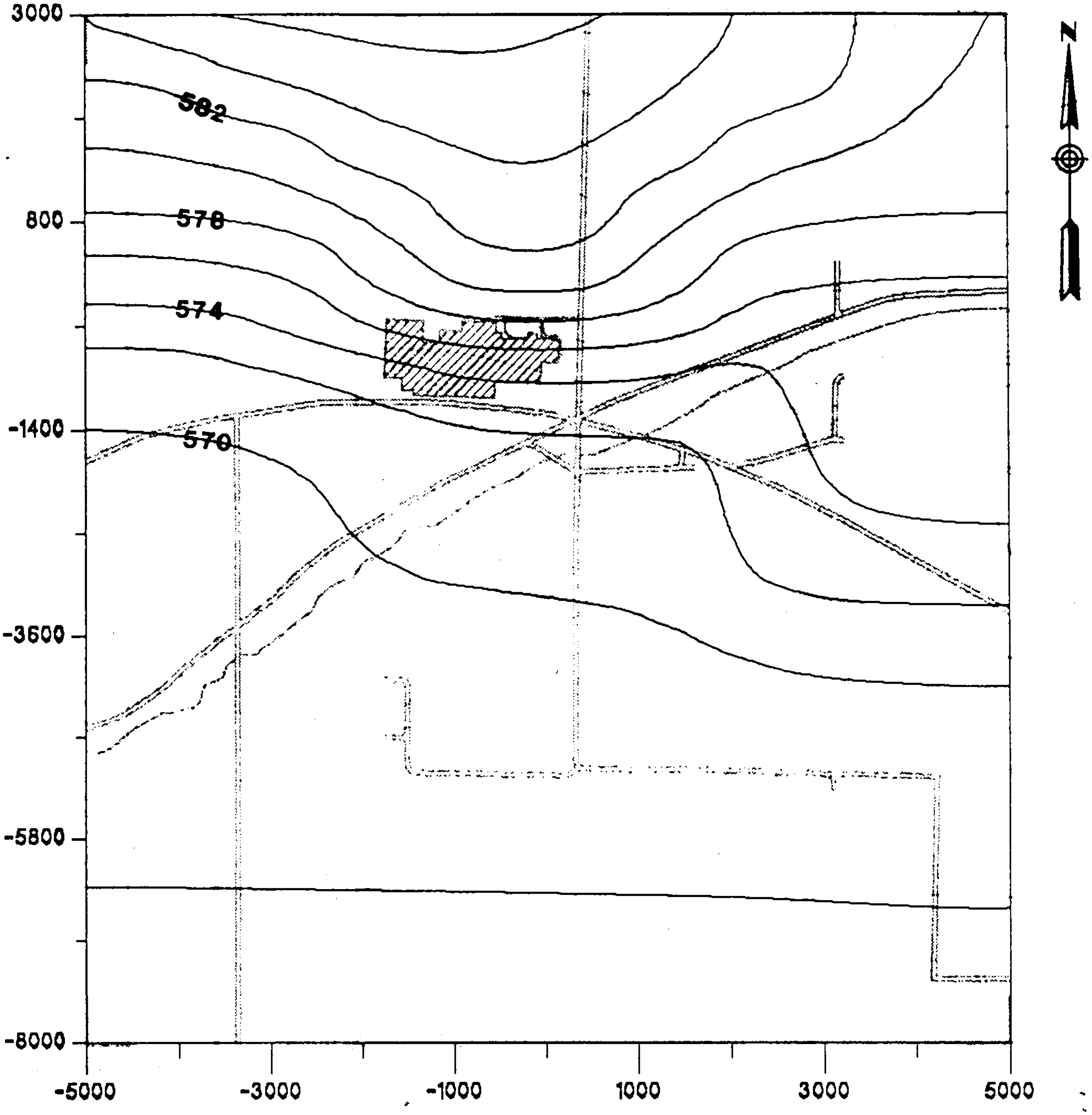
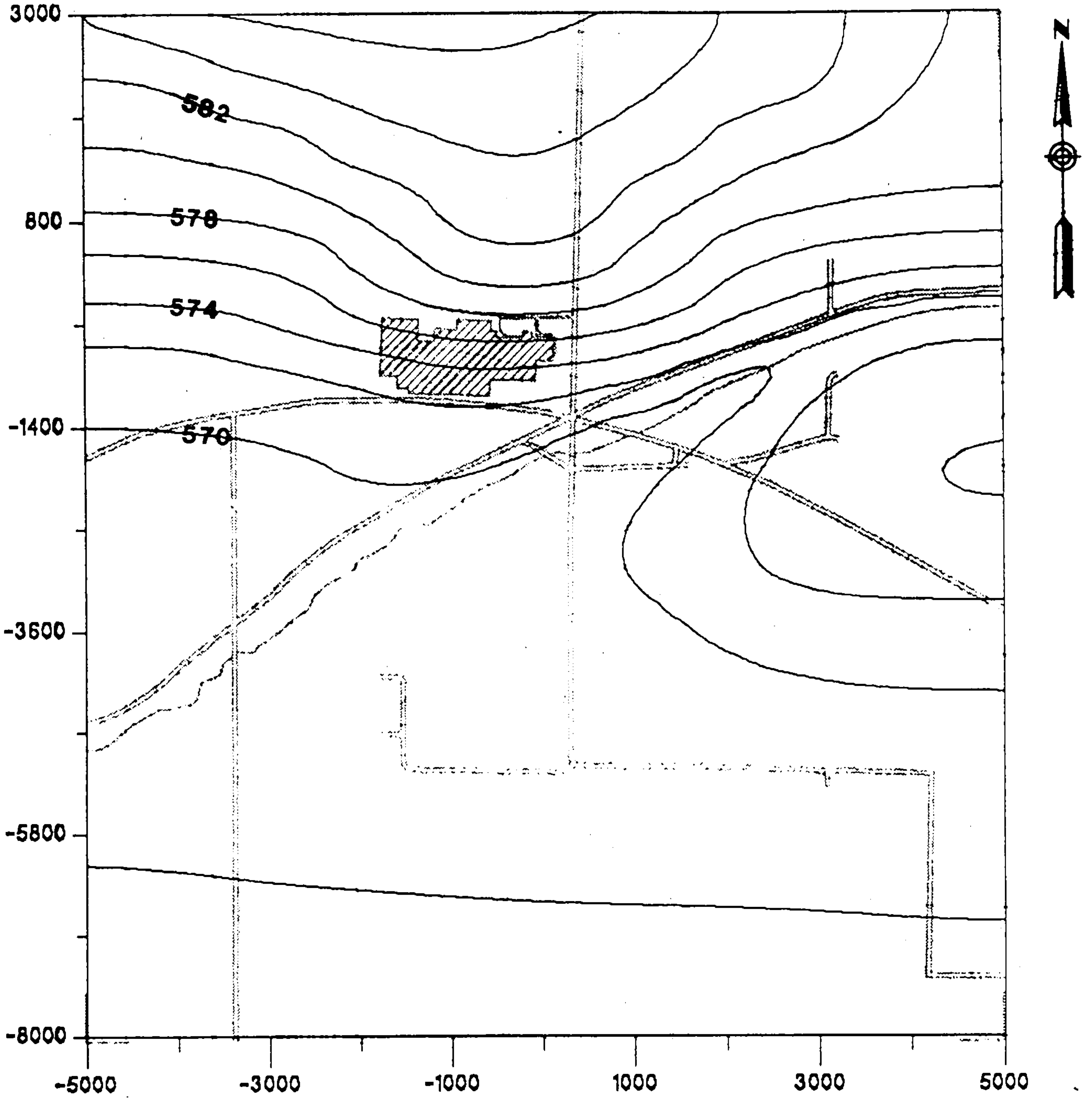
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE **B-11**



JOB No.: 913-6384	SCALE: AS SHOWN	SENSITIVITY ANALYSIS, SIMULATED POTENTIOMETRIC CONTOURS FOR K= 1.1×10^{-2} cm/s COMPUTER RUN 4002	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-12

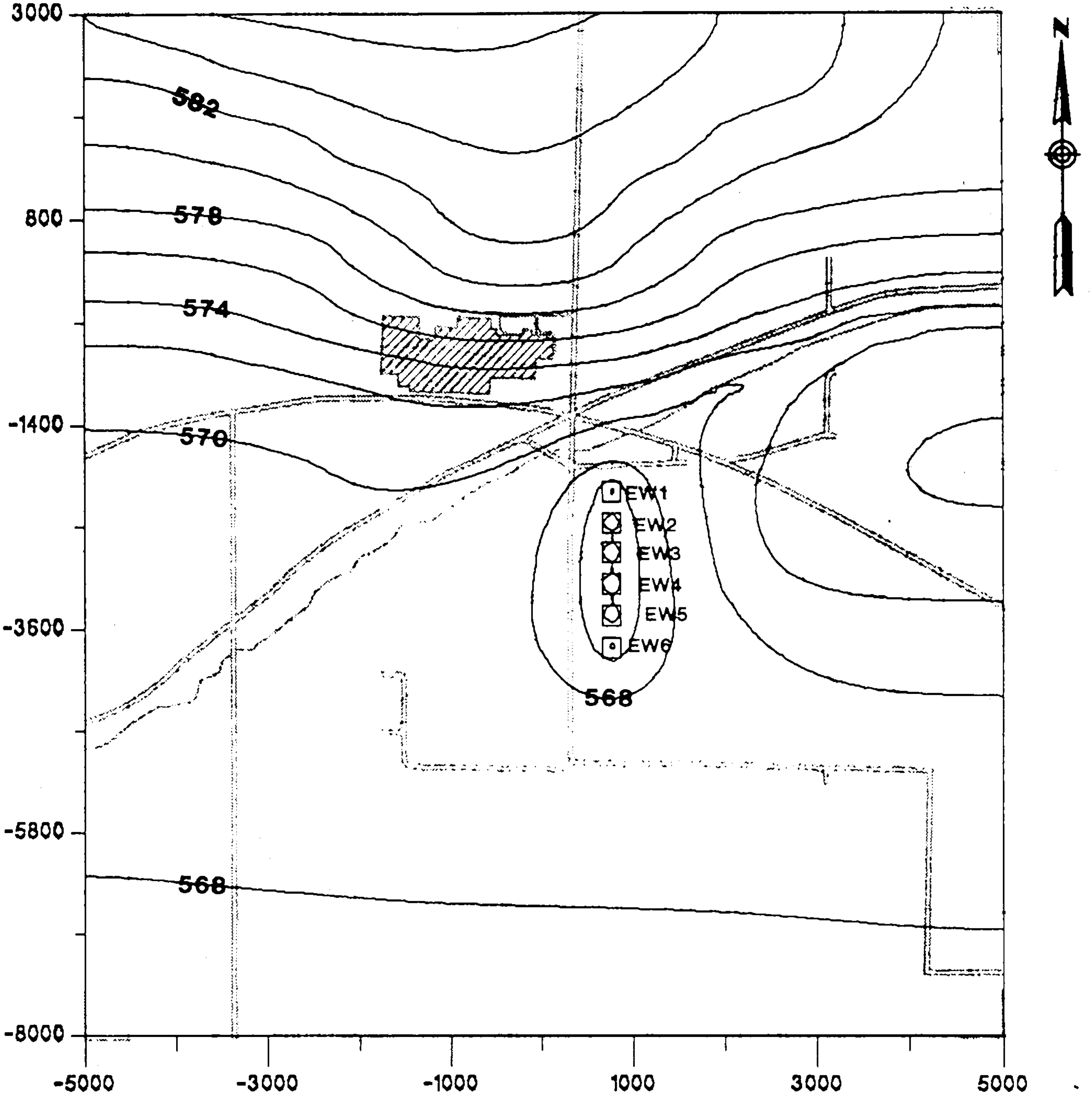


JOB No.: 913-6384	SCALE: AS SHOWN	**SENSITIVITY ANALYSIS, SIMULATED POTENTIOMETRIC CONTOURS FOR RIVER BOTTOM MATERIAL WITH K= 1.0×10^{-5} cm/s COMPUTER RUN 4004**
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE **B-13**



JOB No.: 913-6384	SCALE: AS SHOWN	SENSITIVITY ANALYSIS, SIMULATED POTENTIOMETRIC CONTOURS FOR RIVER BOTTOM MATERIAL WITH K= 1.0x10-3 cm/s COMPUTER RUN 4003
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON

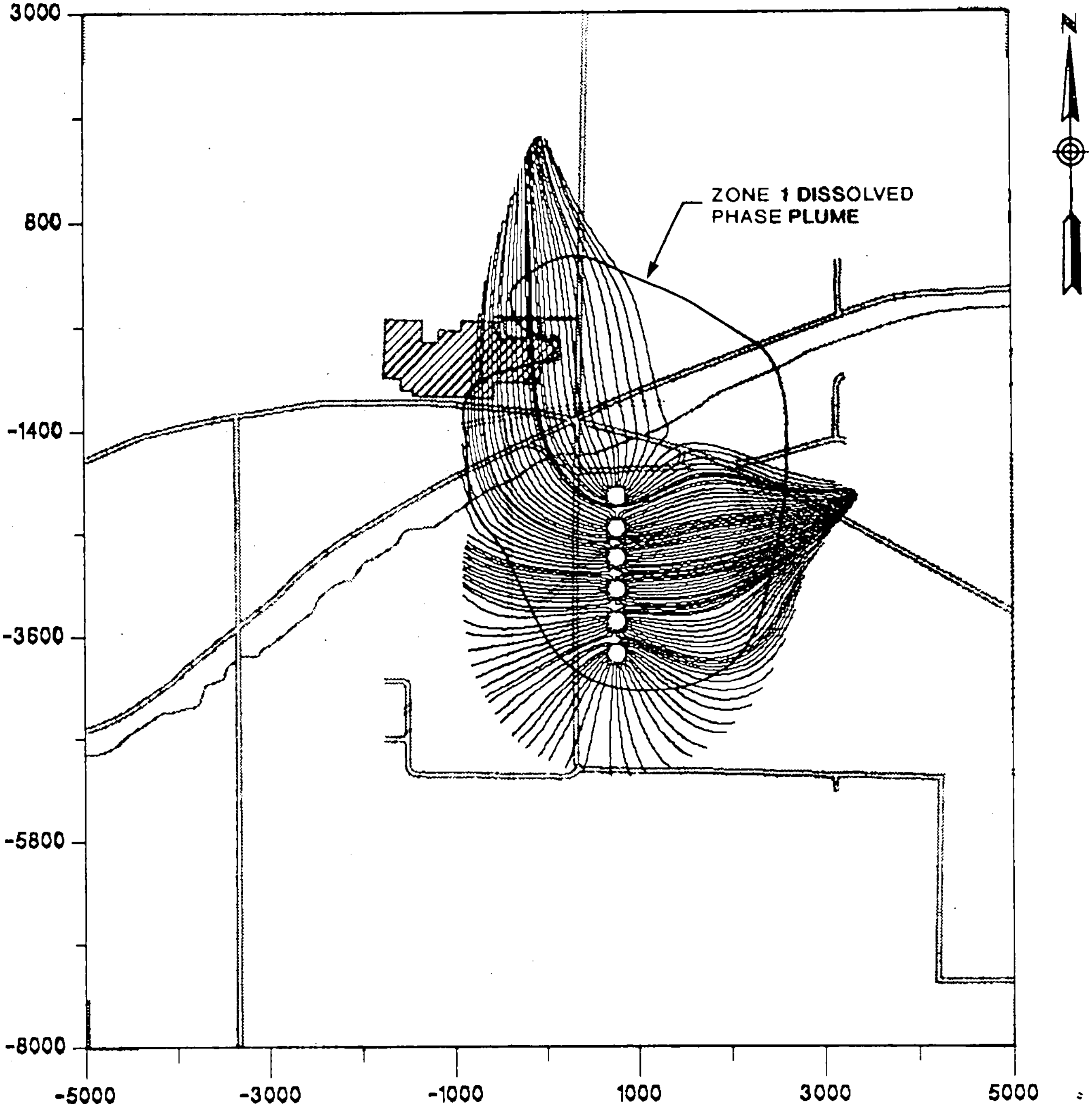
FIGURE **B-14**



NOTES

PUMPING RATE 7gpm FOR EACH WELL.
TOTAL PUMPING RATE 42 gpm.

JOB No.:	913-6384	SCALE:	AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS. COMPUTER RUN 5005
DRAWN:	FG	DATE:	03/20/91	
CHECKED:		DWG. No.:		
Golder Associates				BELL AEROSPACE TEXTRON FIGURE **B-15**

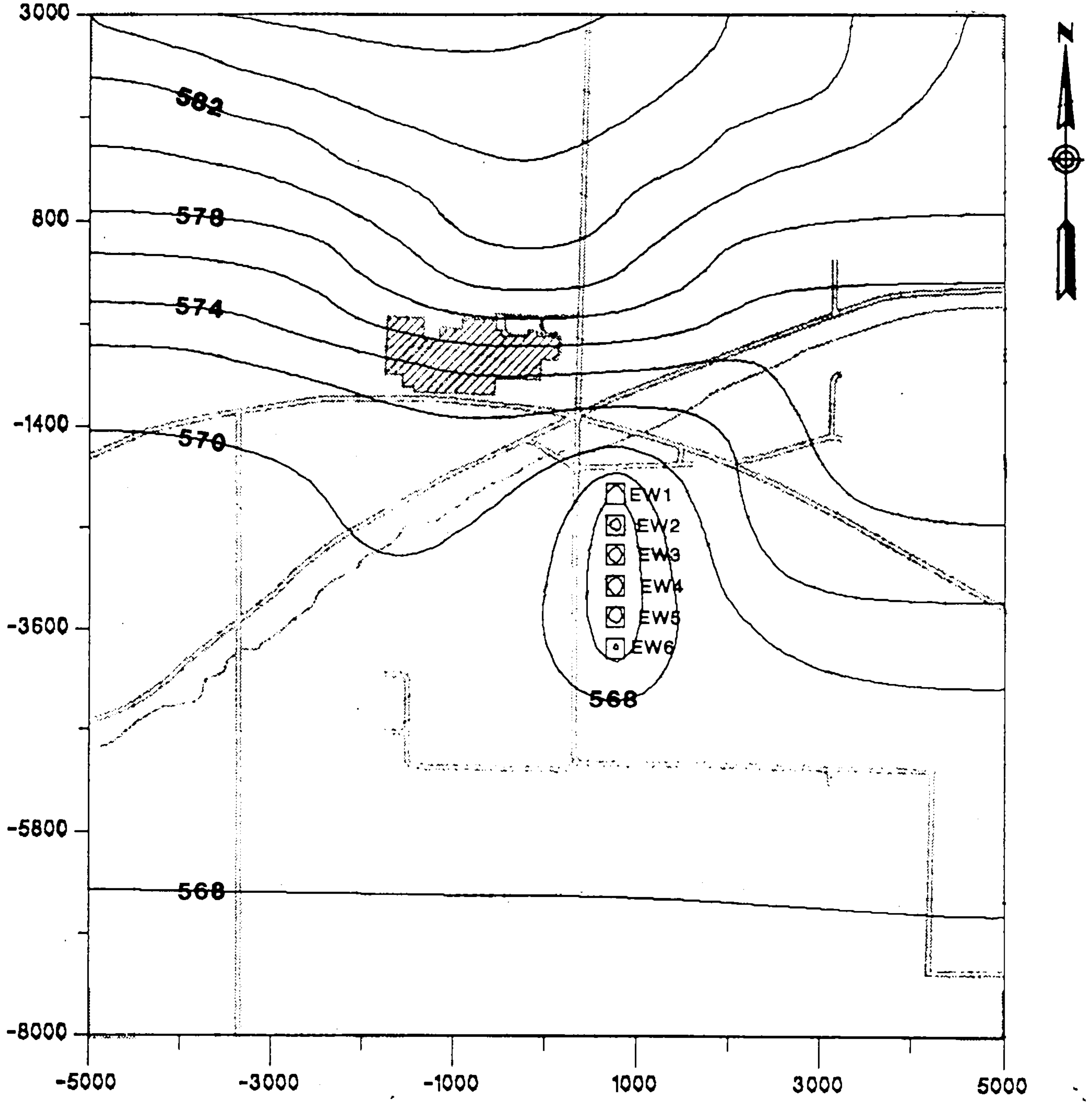


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

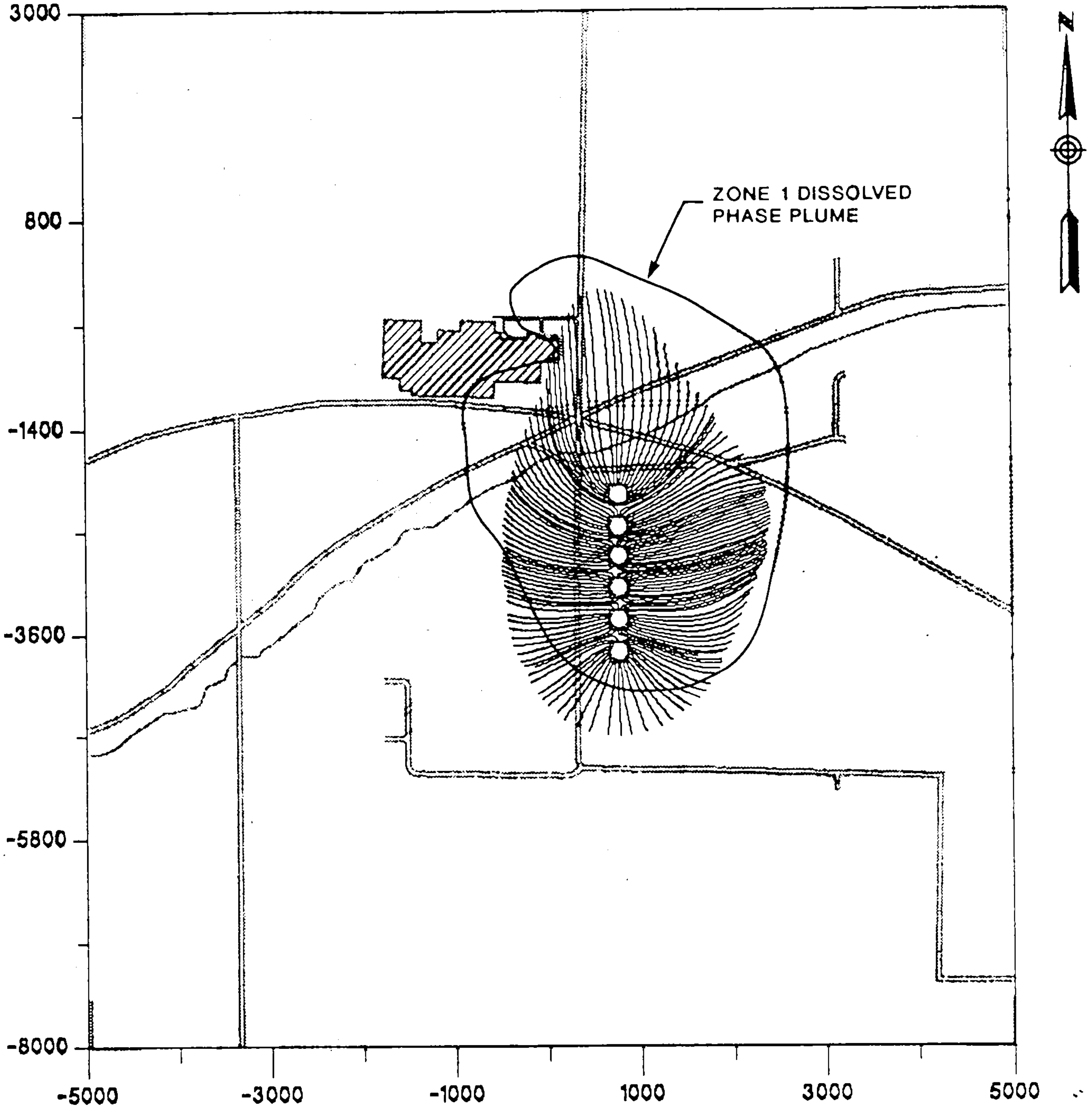
JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS. COMPUTER RUN 5005	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-16



NOTES

PUMPING RATE 7 gpm FOR EACH WELL.
TOTAL PUMPING RATE 42 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS. COMPUTER RUN 6005
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B-17

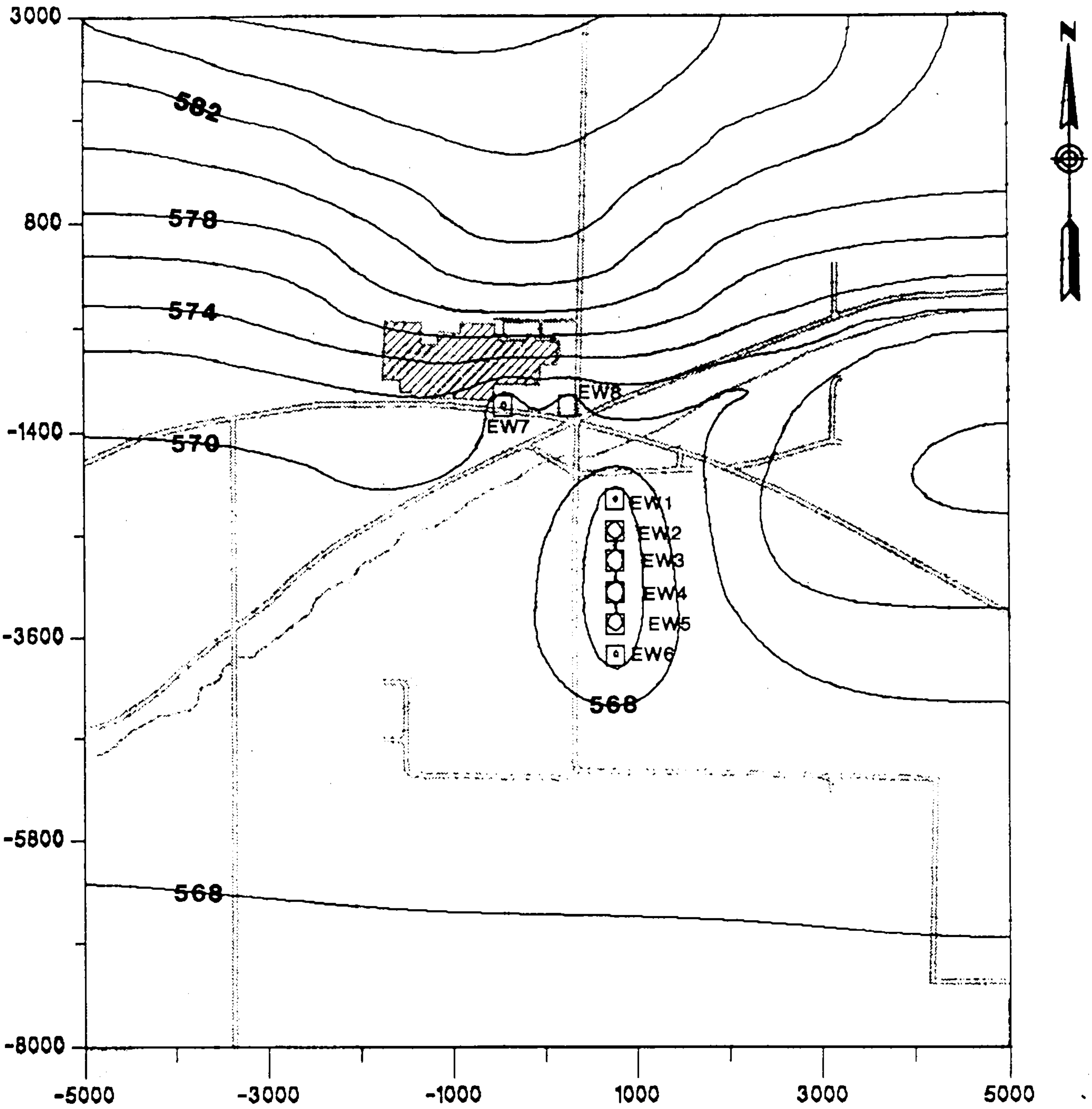


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913–6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS. COMPUTER RUN 6005	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE **B–18**



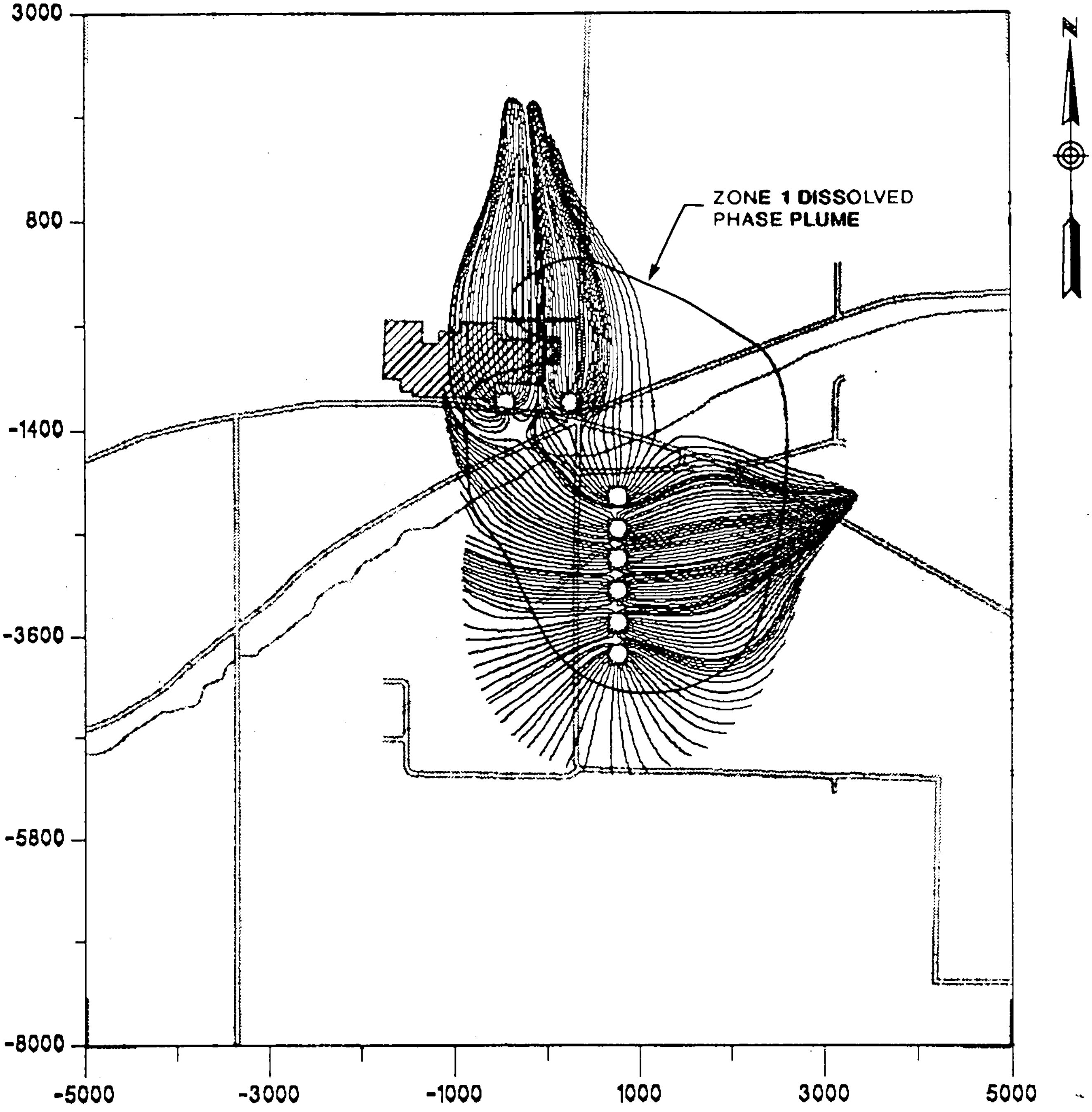
NOTES

PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

TOTAL PUMPING RATE 54 gpm.

JOB No.:	913-6384	SCALE:	AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS AND TWO ON SITE WELLS. COMPUTER RUN 5050
DRAWN:	FG	DATE:	03/20/91	
CHECKED:		DWG. No.:		
Golder Associates				BELL AEROSPACE TEXTRON — FIGURE B-19

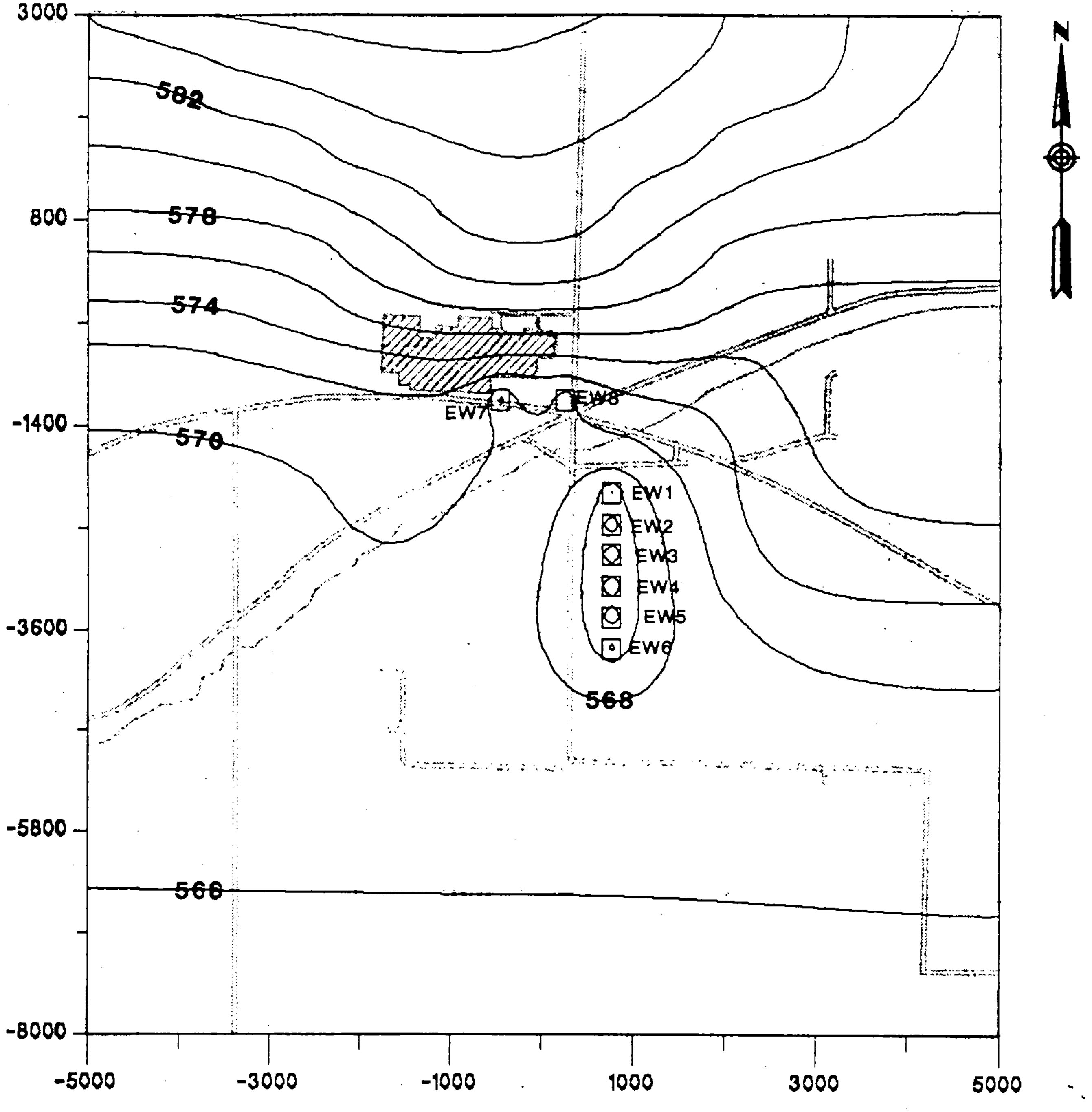


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS AND TWO ON SITE WELLS. COMPUTER RUN 5050
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B-20



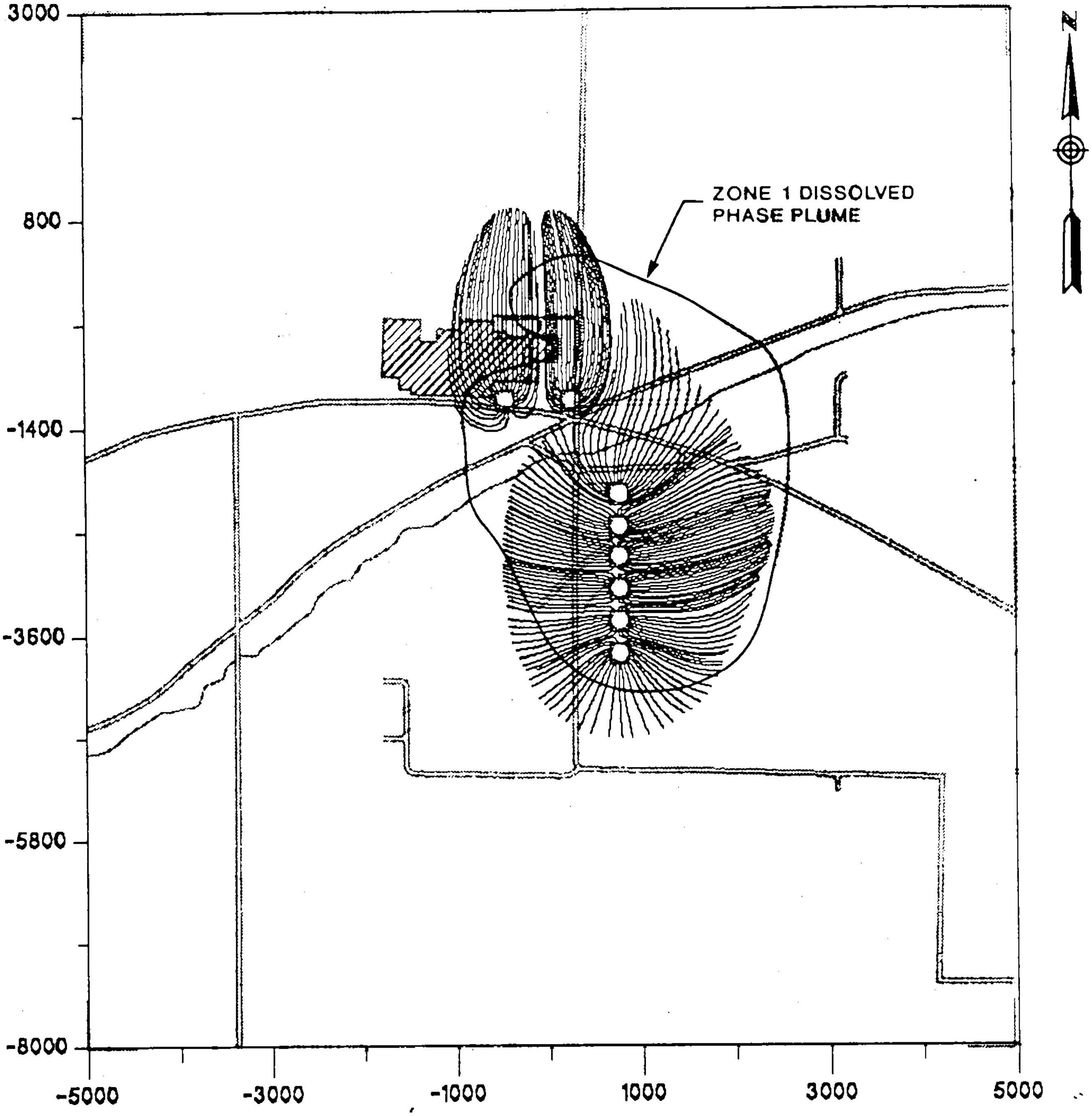
NOTES

PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

TOTAL PUMPING RATE 54 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS AND TWO ON SITE WELLS. COMPUTER RUN 6050	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-21

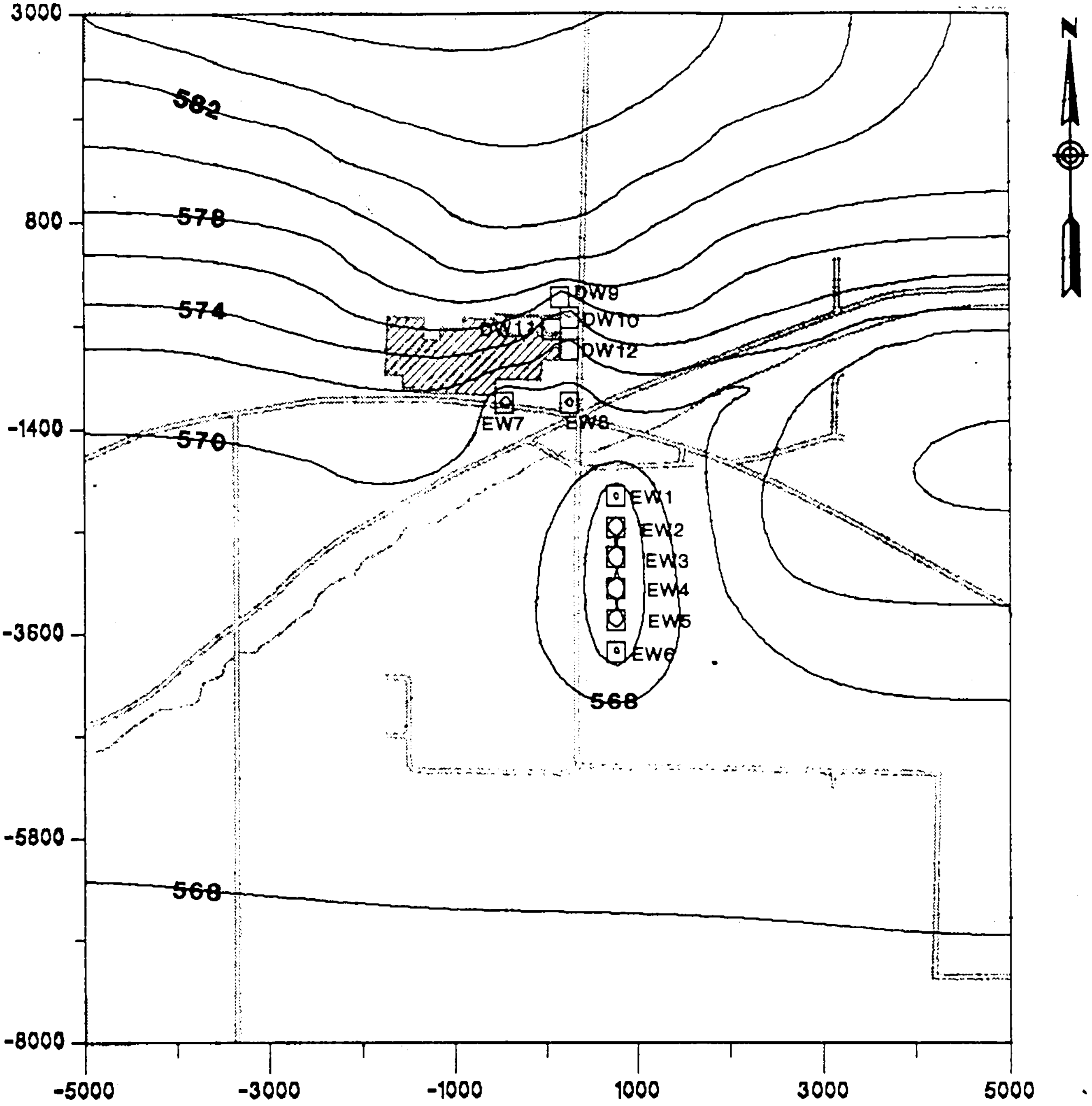


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS AND TWO ON SITE WELLS. COMPUTER RUN 6050		
DRAWN: FG	DATE: 03/20/91			
CHECKED:	DWG. No.:			
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE **B-22**	



NOTES

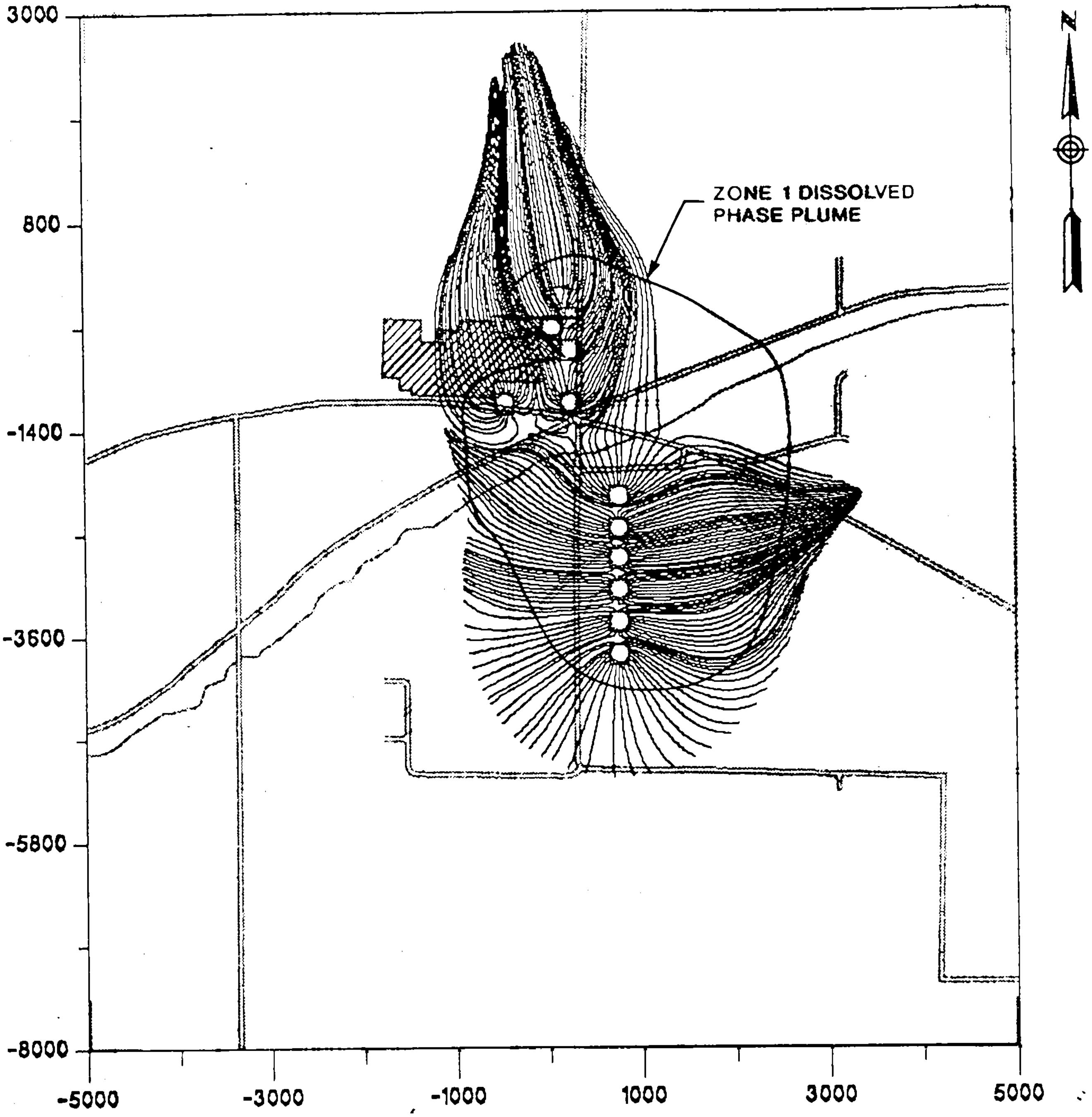
PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW9 THROUGH DW12
3 gpm FOR EACH WELL.

TOTAL PUMPING RATE 66 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	**SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND FOUR DNAPL WELLS.** **COMPUTER RUN 5041**
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON | FIGURE **B-23**

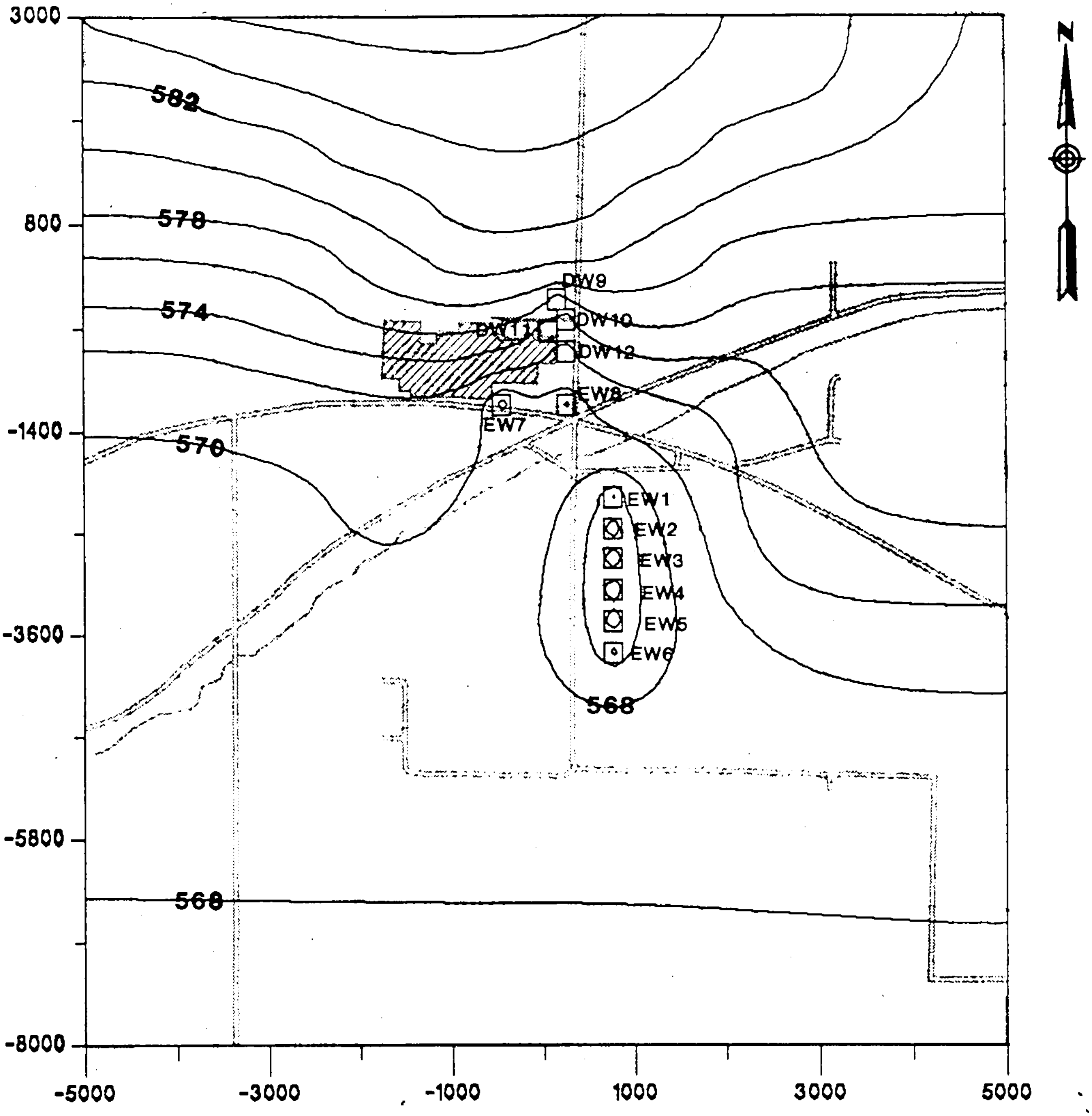


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND FOUR DNAPL WELLS. COMPUTER RUN 5041
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B-24



NOTES

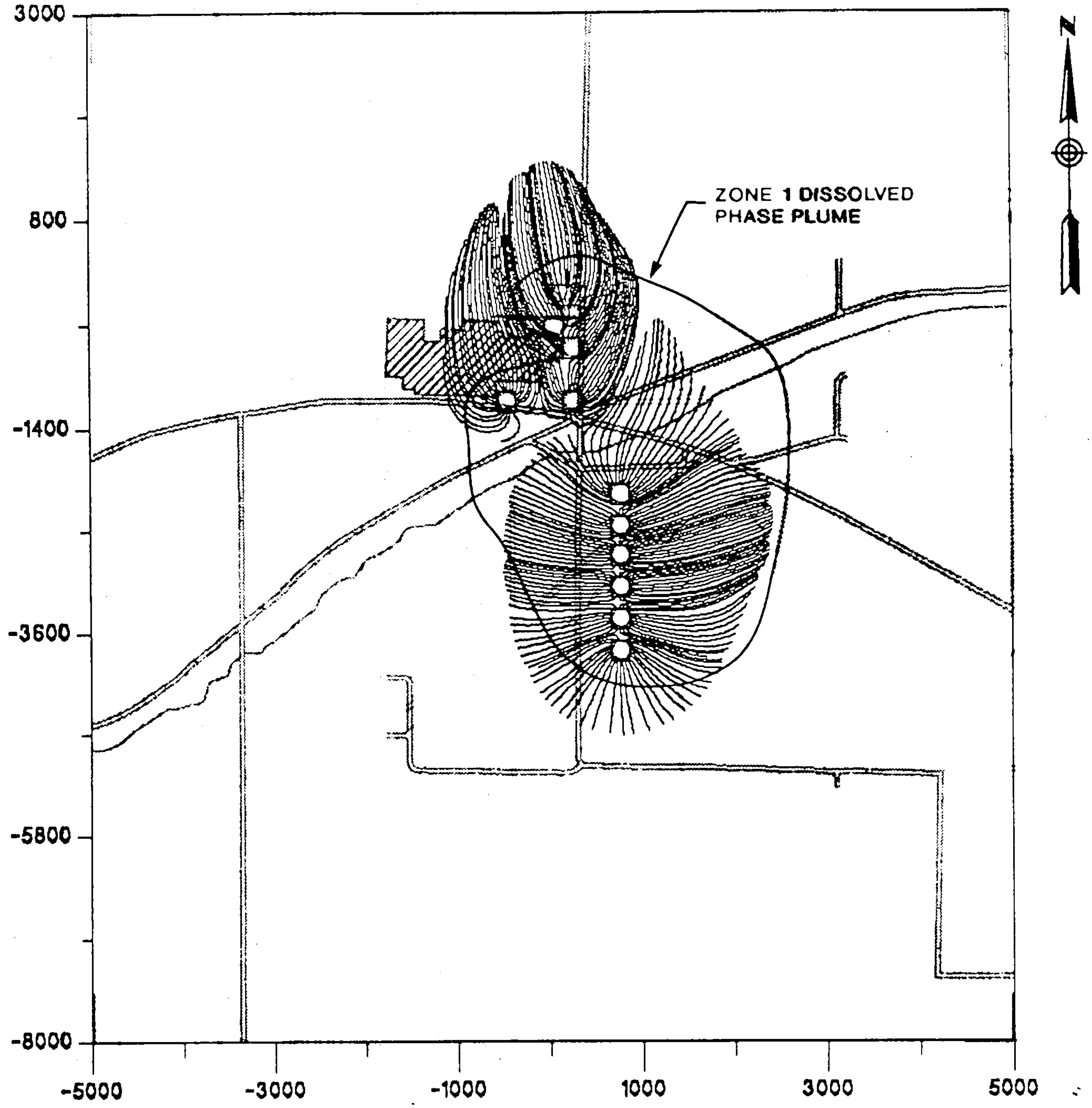
PUMPING RATE FOR EW1 THROUGH EW7 7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW9 THROUGH DW12 3 gpm FOR EACH WELL.

TOTAL PUMPING RATE 66 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF-SITE WELLS, TWO ON-SITE WELLS, AND FOUR DNAPL WELLS. COMPUTER RUN 6041	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-25

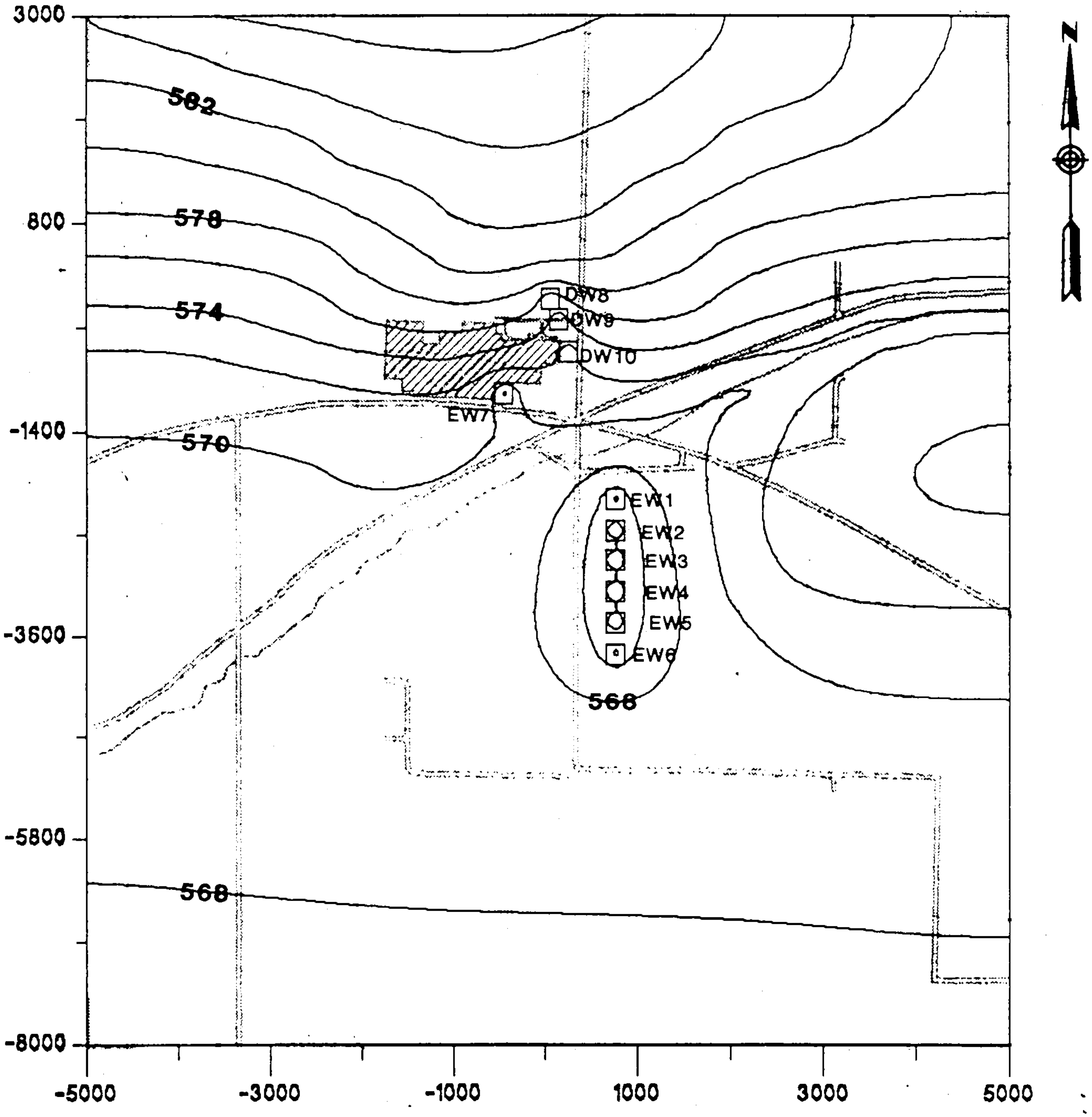


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND FOUR DNAPL WELLS. COMPUTER RUN 6041	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-26



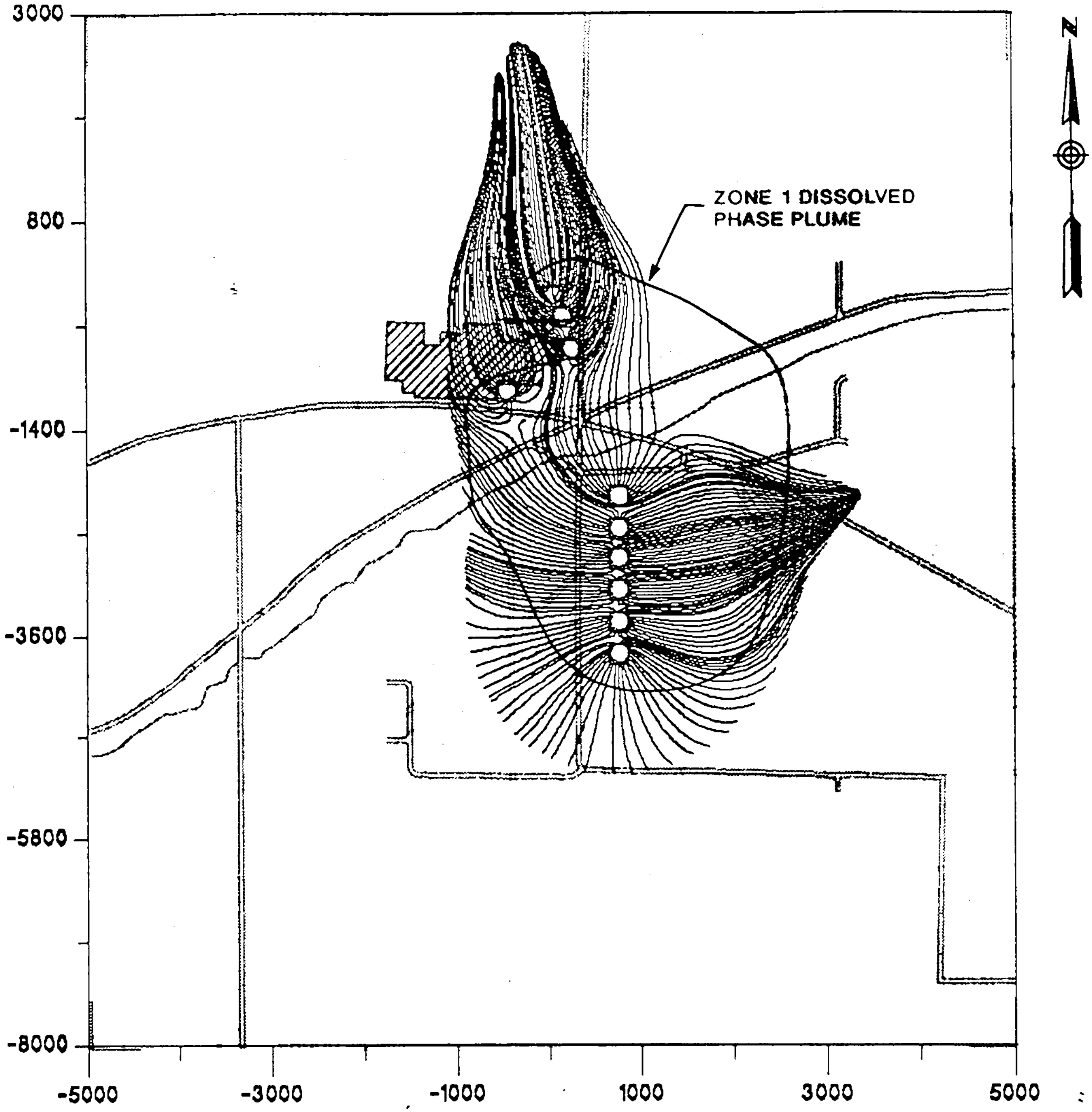
NOTES

PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR DW8 THROUGH DW10
4 gpm FOR EACH WELL.

TOTAL PUMPING RATE 61 gpm.

JOB No.: 913–6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS, ONE ON SITE WELL, AND THREE DNAPL WELLS. COMPUTER RUN 5015
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B–27

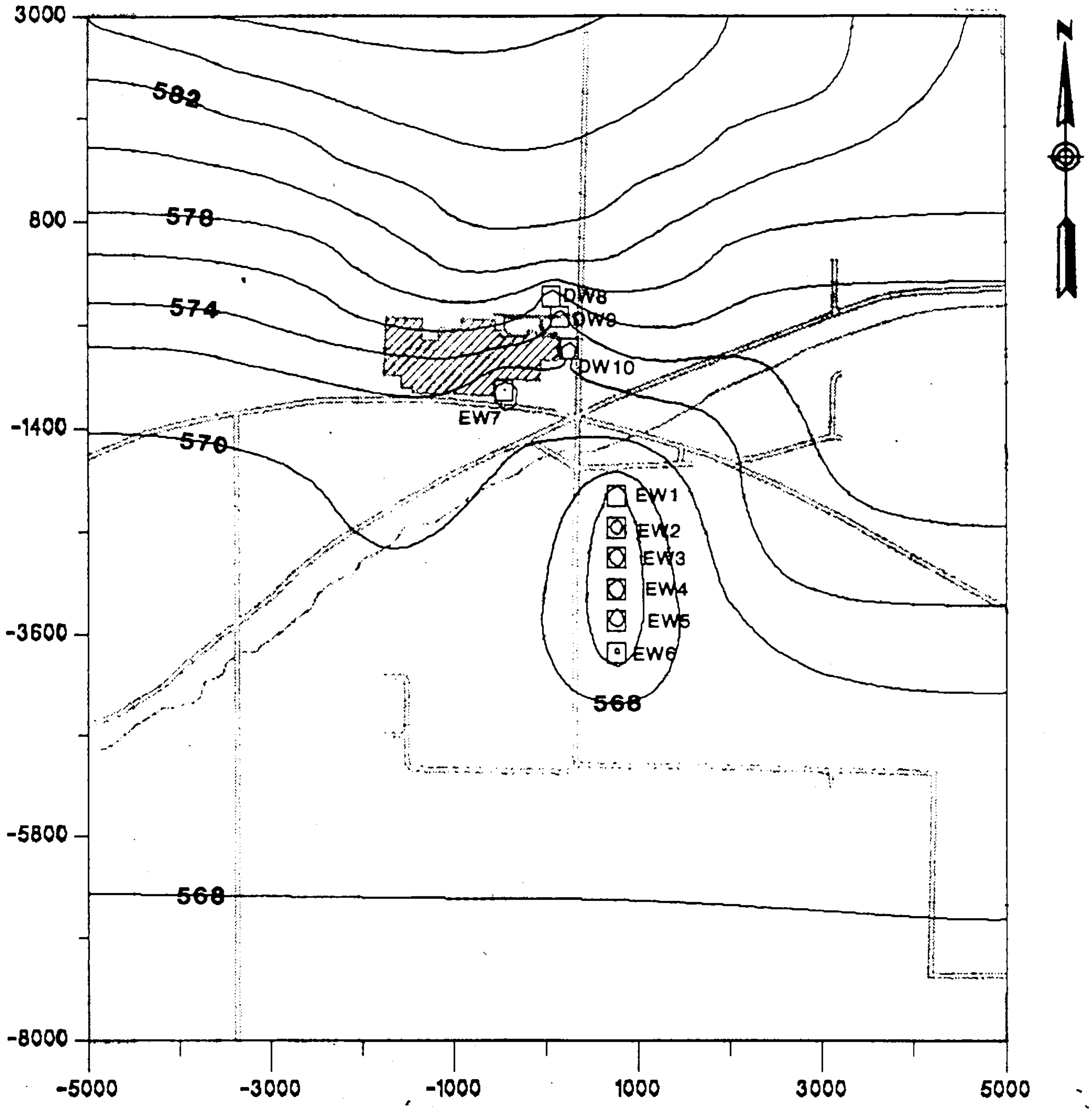


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

JOB No.:	913-6384	SCALE:	AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, ONE ON SITE WELL, AND THREE DNAPL WELLS. COMPUTER RUN 5015
DRAWN:	FG	DATE:	03/20/91	
CHECKED:		DWG. No.:		
Golder Associates				BELL AEROSPACE TEXTRON — FIGURE B-28



NOTES

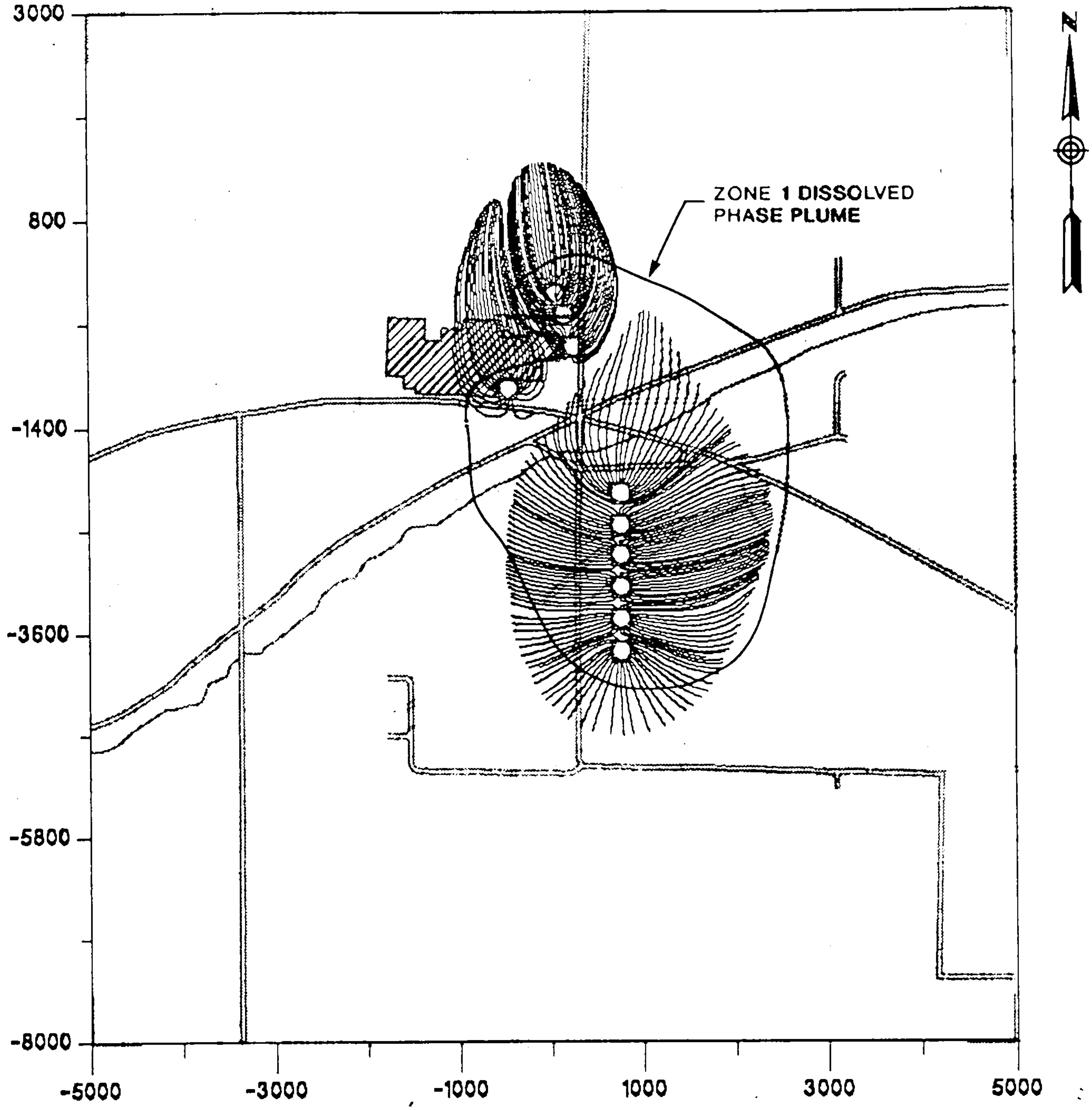
PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR DW8 THROUGH DW10 4 gpm.
FOR EACH WELL.

TOTAL PUMPING RATE 61 gpm.

JOB No.:	913-6384	SCALE:	AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS, ONE ON SITE WELL AND THREE DNAPL WELLS. COMPUTER RUN 6015
DRAWN:	FG	DATE:	03/20/91	
CHECKED:		DWG. No.:		

Golder Associates | BELL AEROSPACE TEXTRON | FIGURE **B-29**

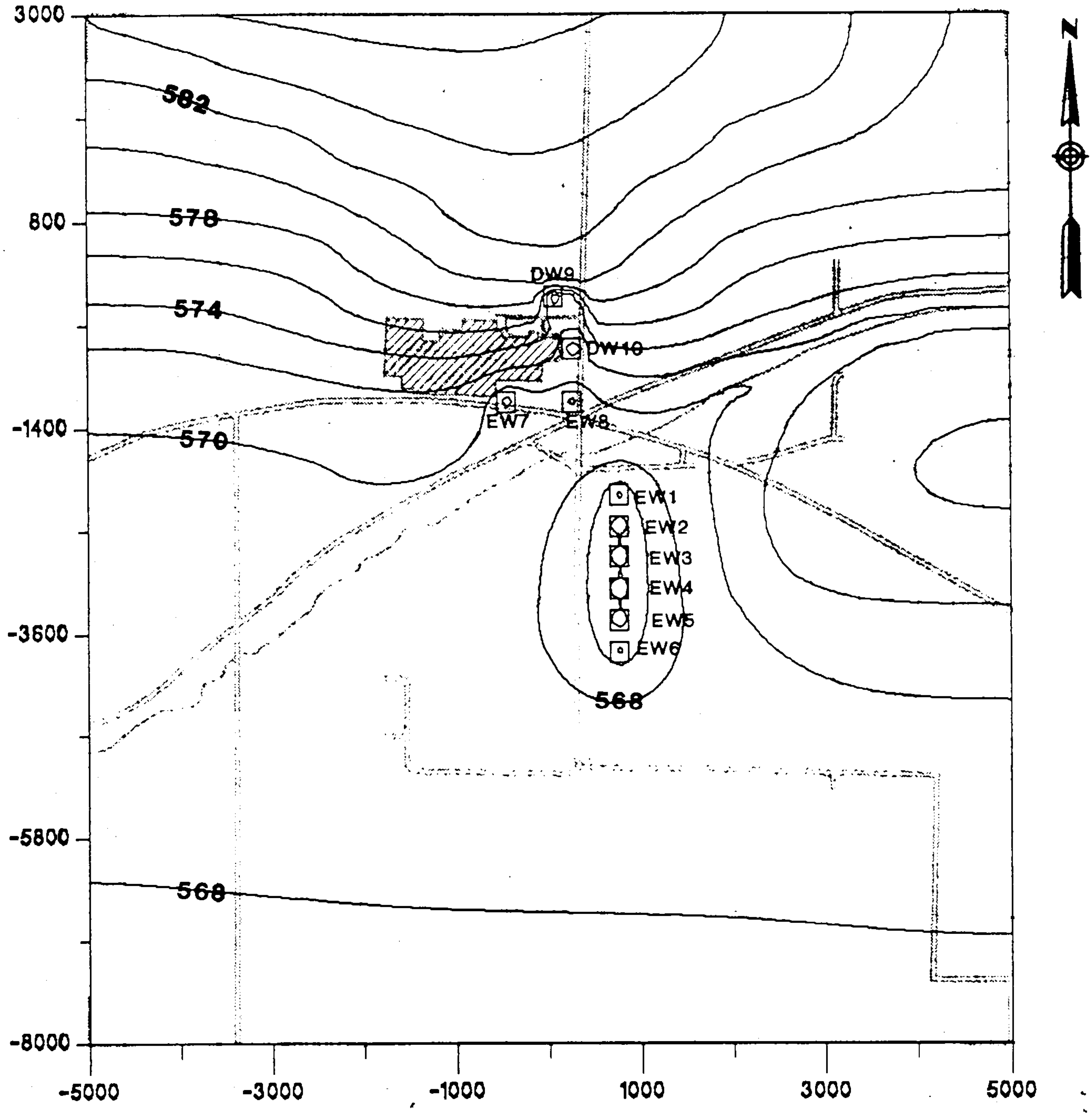


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, ONE ON SITE WELL, AND THREE DNAPL WELLS. COMPUTER RUN 6015		
DRAWN: FG	DATE: 03/20/91			
CHECKED:	DWG. No.:			
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-30	



NOTES

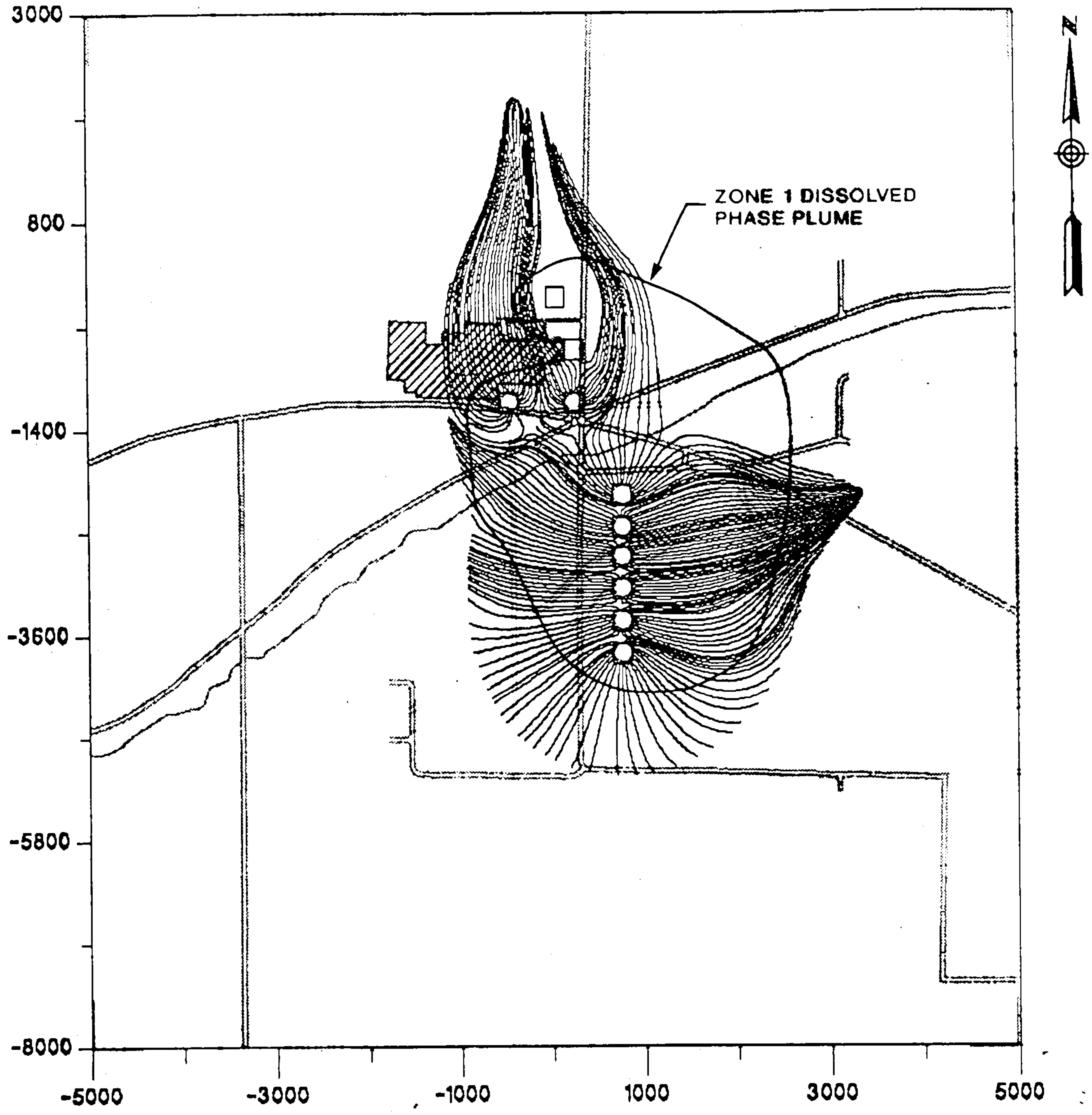
PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW9 AND DW10
3 gpm FOR EACH WELL.

TOTAL PUMPING RATE 60 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, GROUT CURTAIN AND EXTRACTION WELLS. COMPUTER RUN 5042
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON FIGURE B-31

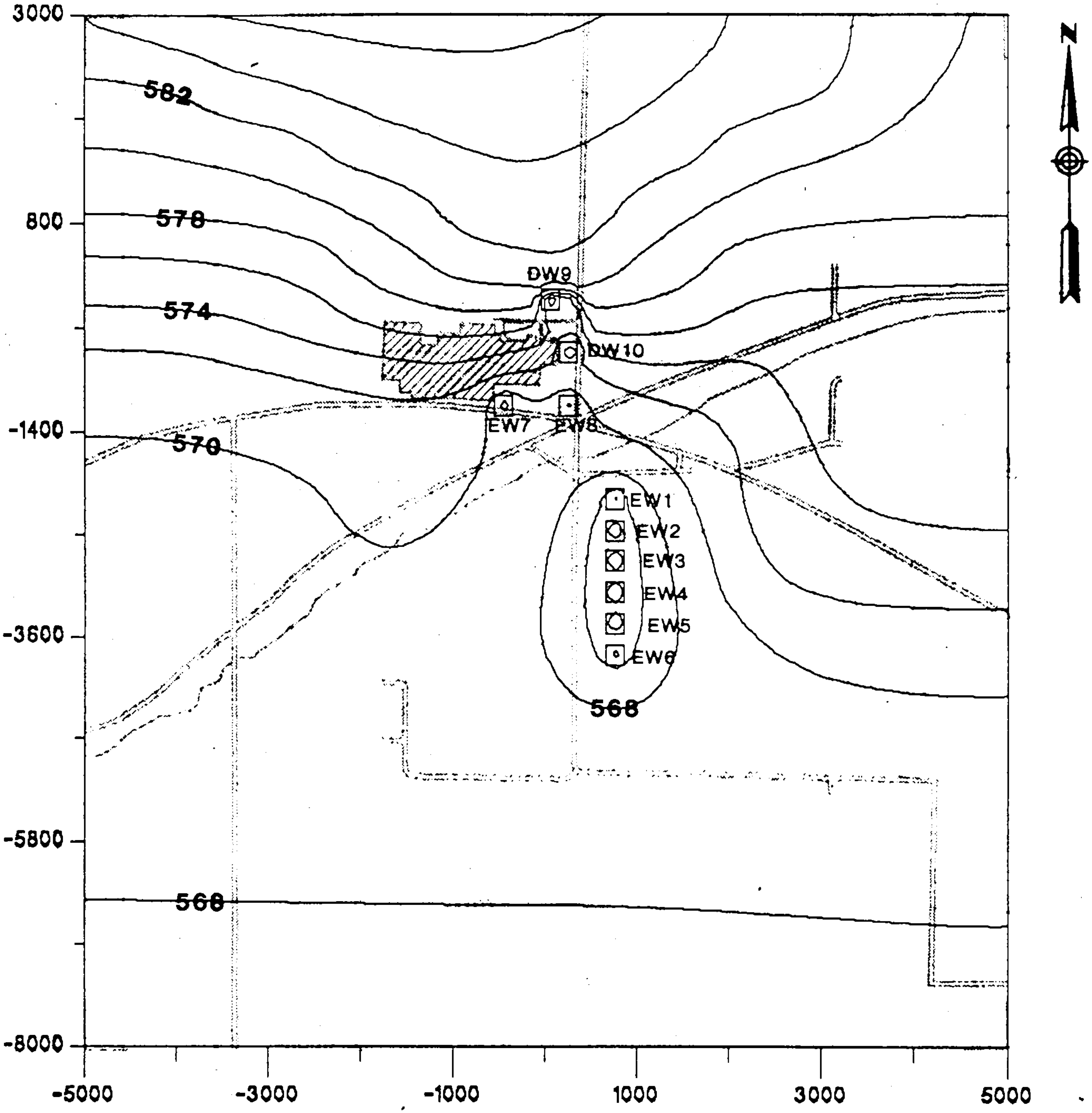


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, GROUT CURTAIN, AND EXTRACTION WELLS. COMPUTER RUN 5042	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-32



NOTES

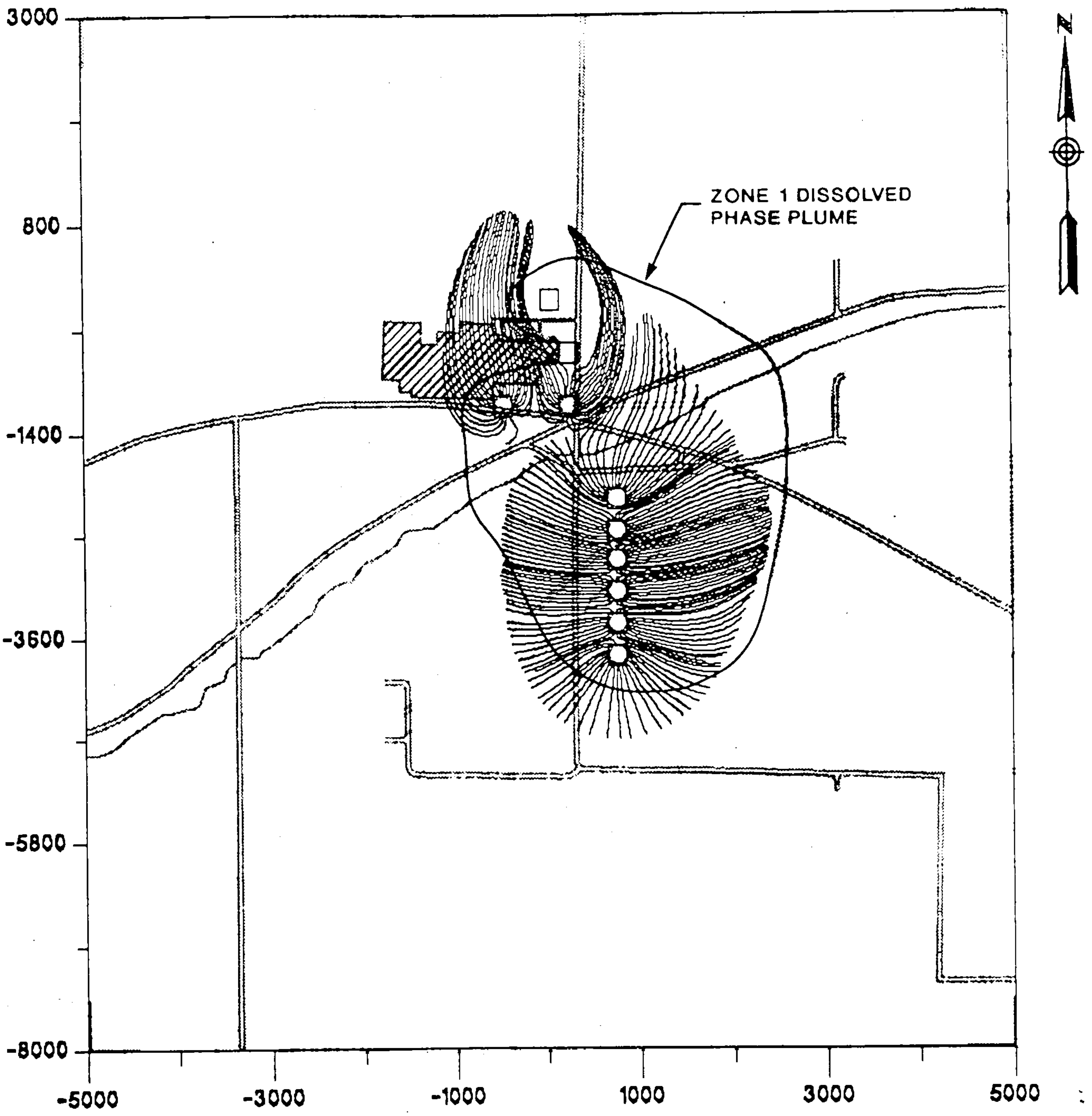
PUMPING RATE FOR EW1 THROUGH EW7 7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW9 AND DW10 3gpm FOR EACH WELL.

TOTAL PUMPING RATE 60 gpm.

JOB No.: 913–6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, GROUT CURTAIN, AND EXTRACTION WELLS. COMPUTER RUN 6042
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates		BELL AEROSPACE TEXTRON — FIGURE B–33

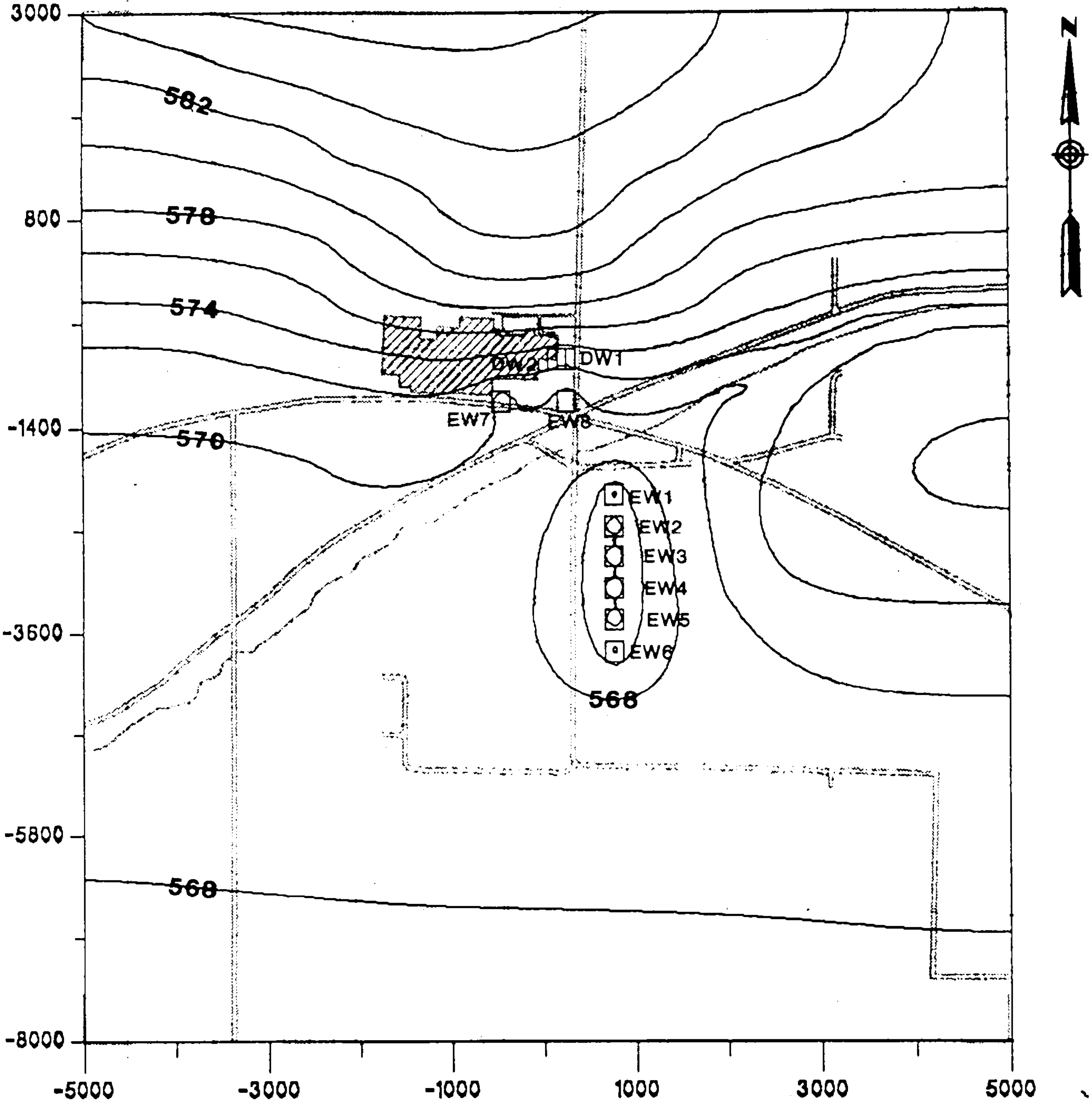


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913–6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, GROUT CURTAIN AND EXTRACTION WELLS. COMPUTER RUN 6042		
DRAWN: FG	DATE: 03/20/91			
CHECKED:	DWG. No.:			
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE **B-34**	



NOTES

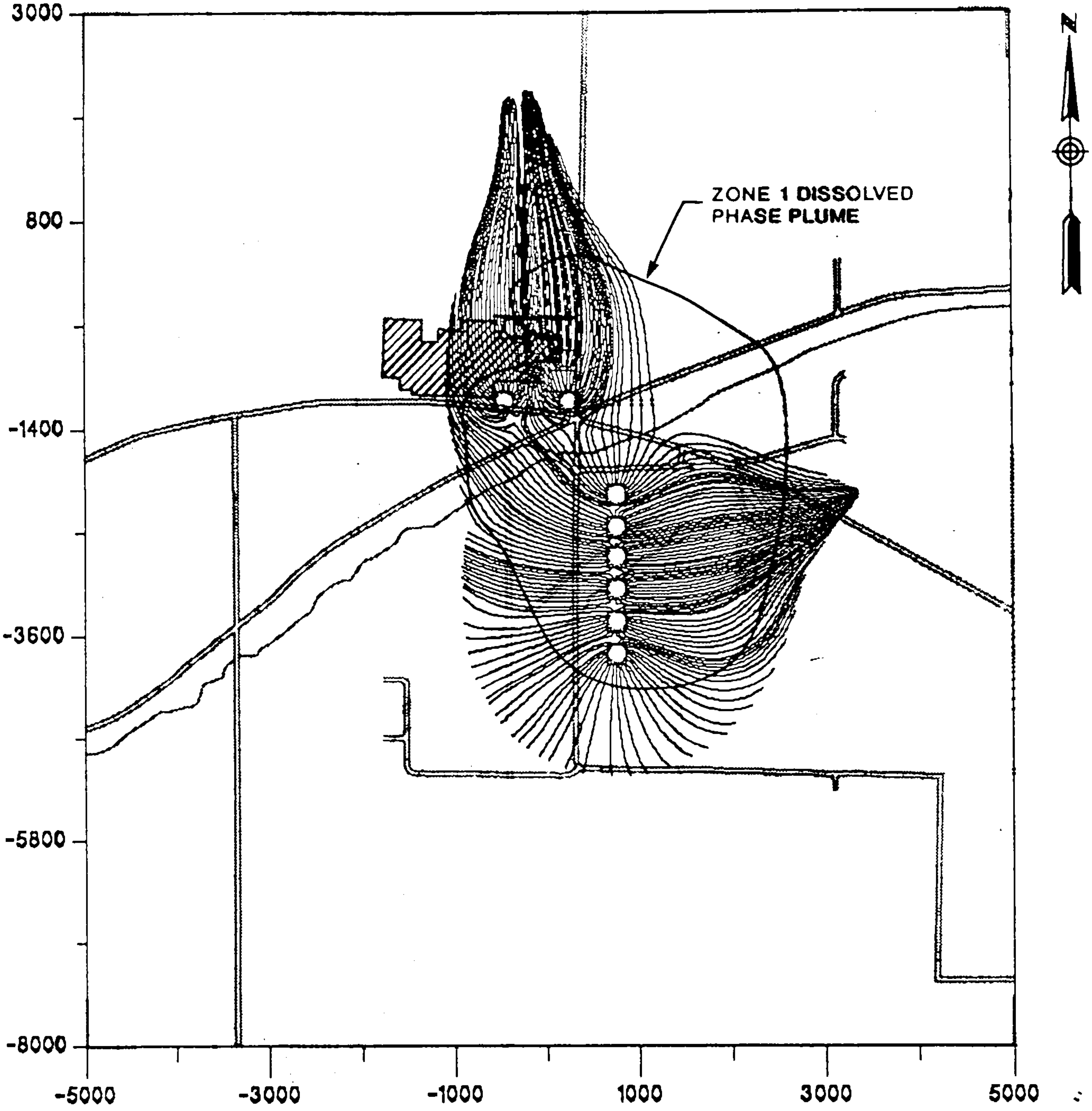
PUMPING RATE FOR EW1 THROUGH EW7
7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW1 AND DW2 1 gpm
FOR EACH WELL.

TOTAL PUMPING RATE 56 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND TWO DNAPL WELLS. COMPUTER RUN 5027
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates	BELL AEROSPACE TEXTRON	FIGURE B-35

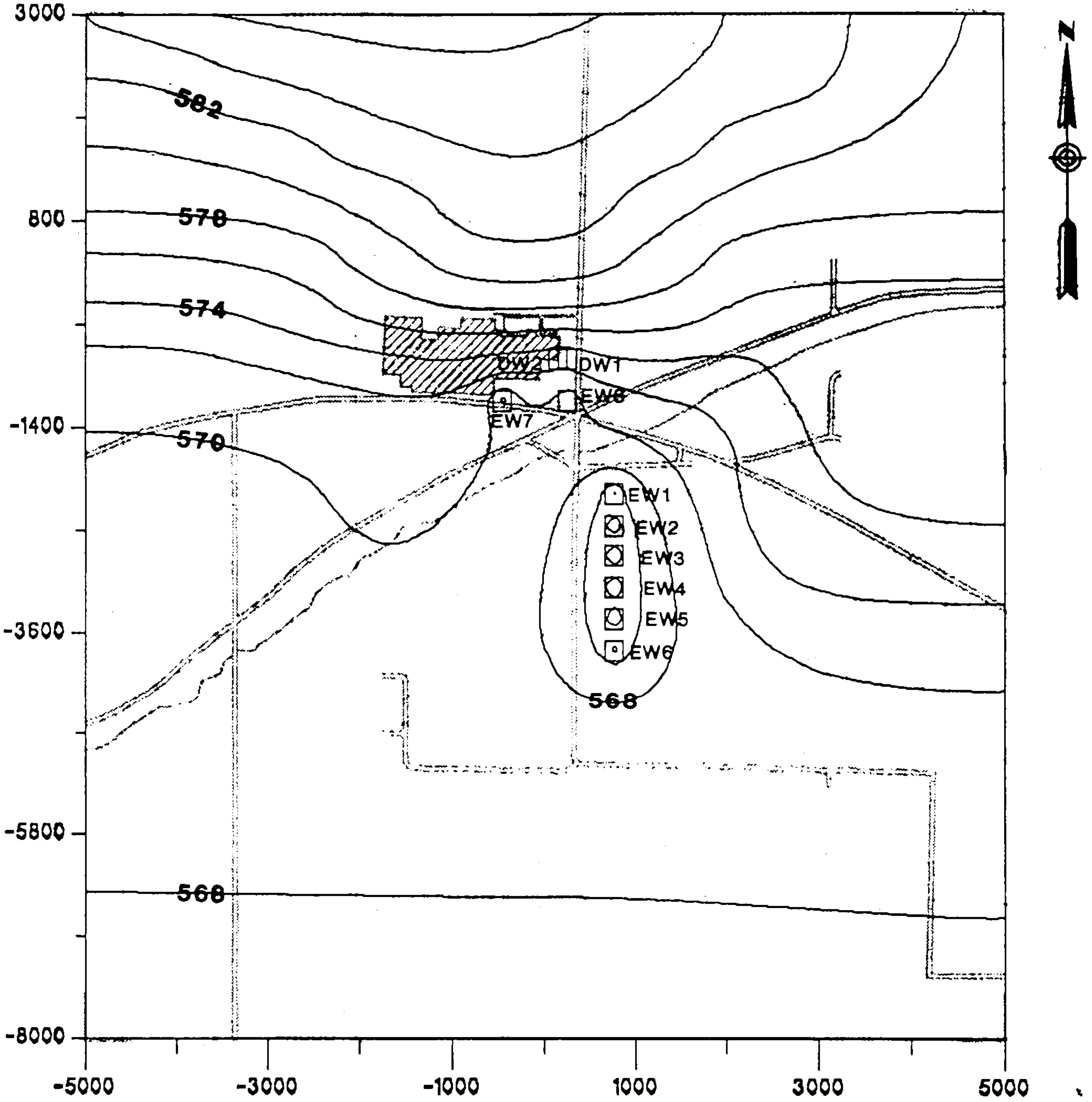


NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

1% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND TWO DNAPL WELLS. COMPUTER RUN 5027	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-36



NOTES

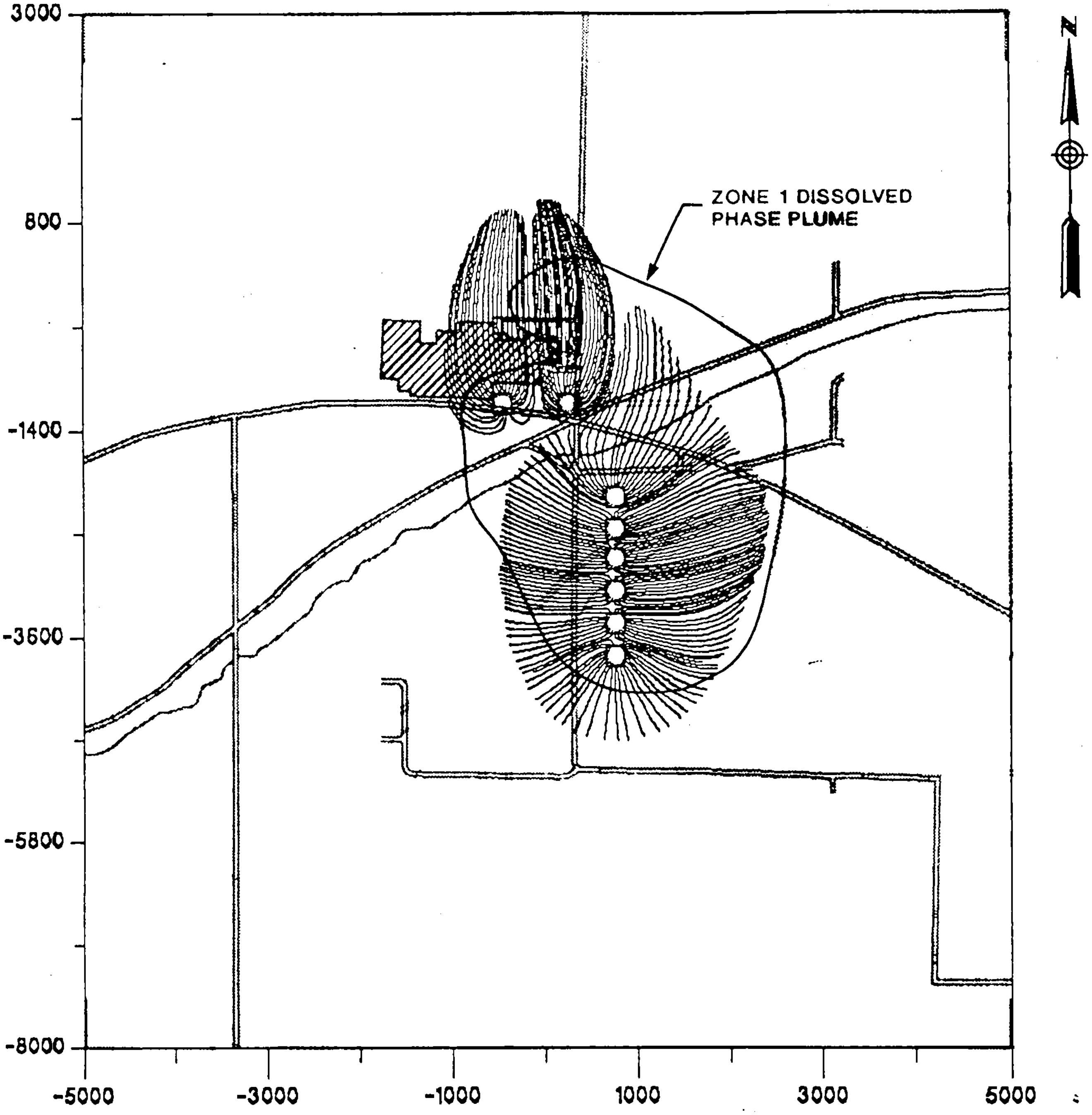
PUMPING RATE FOR EW1 THROUGH EW7 7 gpm FOR EACH WELL.

PUMPING RATE FOR EW8 5 gpm.

PUMPING RATE FOR DW1 AND DW2 1 gpm FOR EACH WELL.

TOTAL PUMPING RATE 56 gpm.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED POTENTIOMETRIC CONTOURS, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND TWO DNAPL WELLS. COMPUTER RUN 6027
DRAWN: FG	DATE: 03/20/91	
CHECKED:	DWG. No.:	
Golder Associates	BELL AEROSPACE TEXTRON	FIGURE B-37



NOTES

RETARDATION FACTOR 2.
TIME 5 YEARS.

3% EFFECTIVE POROSITY.

JOB No.: 913-6384	SCALE: AS SHOWN	SIMULATED CAPTURE ZONE, SIX OFF SITE WELLS, TWO ON SITE WELLS, AND TWO DNAPL WELLS. COMPUTER RUN 6027	
DRAWN: FG	DATE: 03/20/91		
CHECKED:	DWG. No.:		
Golder Associates		BELL AEROSPACE TEXTRON	FIGURE B-38

Appendix C

APPENDIX C

TREATABILITY STUDY ON CONTAMINATED GROUNDWATER

TREATABILITY STUDY ON CONTAMINATED GROUNDWATER

Bell Aerospace Textron
Niagara Falls, New York

March 25, 1991

Prepared for: Bell Aerospace Textron
P.O. Box 1
Buffalo, NY 14020

Prepared by: Resource Technologies Group, Inc.
3190 S. Wadsworth Blvd., Suite 250
Denver CO 80227

TABLE OF CONTENTS

BELL AEROSPACE TEXTRON
GROUNDWATER TREATABILITY STUDY

TABLE OF CONTENTS Continued)

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS Continued)

1.0 INTRODUCTION

Resource Technologies Group, Inc, (RTG) of Denver, Colorado has been retained by Bell Aerospace Textron (BAT) of Niagara Falls, New York to conduct a treatability study for removal of specific contaminants from groundwater. The treatability study consisted of two phases:

- A pilot test was conducted at the BAT site in November of 1989 to determine the optimum conditions for removal of volatile organic compounds (VOC) from groundwater extracted from a dissolved phase chlorinated solvent plume.
- Laboratory studies were conducted on water samples taken from this phase to evaluate the removal of organics by carbon adsorption or oxidation using ultra-violet light and chemical treatment (UV/OX).

The results of the air stripping pilot tests were used to design an air stripping system capable of removing 99.9% of the VOCs and the results of the laboratory studies were used to determine the potential for the use of a UV/OX system and carbon adsorption system to treat the contaminated groundwater. The data from these tests was used to estimate the capital and operating cost of the conceptual treatment systems.

The conceptual systems as designed, are potentially capable of meeting a 5 ppb discharge limit for methylene chloride (MeCl) and trichloroethylene (TCE), the two major contaminants in the groundwater contaminant plume. The 5 ppb discharge limit was assumed on the basis of present or proposed standards for organic compounds in drinking water.

2.0 EXECUTIVE SUMMARY

RTG conducted a Pilot Test Program for BAT to treat and discharge groundwater generated during an aquifer test and to develop data which would allow RTG to design conceptual groundwater treatment systems. Groundwater samples, taken during the Pilot Test along with groundwater samples taken at the BAT Plant boundary, were used by RTG and Peroxidation Systems, Inc. (PSI) to conduct treatability studies using carbon adsorption and ultra violet-oxidation techniques.

The samples taken prior to and during the Pilot Test were from the vicinity of the Zone I DNAPL plume and contained significant quantities of volatile organic compounds (VOCs) and minor amounts of semivolatiles. No organochlorine pesticides or PCBs were detected in any of the RTG samples. Since the VOC content of the samples varied significantly, the concentrations used in the treatability study were based on the maximum VOCs measured.

The samples taken from wells 87-18(1) and 87-22(1) located near the BAT Plant boundary contained from approximately 10 mg/l to 30 mg/l of total VOCs based on samples taken during pumping. The pumped samples were shipped to the treatability laboratory in drums; samples taken after shipment showed that the MeCl and TCE were gone and that only 1,2, dichloroethylene (DCE) was detected. The best data available indicates that the MeCl and TCE were lost due to bacterial activity and volatility. Due to the loss of the MeCl and TCE, it was necessary to add known quantities of MeCl to the groundwater in order to conduct treatability studies.

The air strip data developed during the Pilot Test were used in conjunction with reference data and computer modeling to design a conceptual air strip system capable of removing up to 99.5% of MeCl per stage. Since the carbon absorption studies showed that effective removal of MeCl required large amounts of carbon, a two-stage air strip system was planned.

Since air discharge limits for MeCl are relatively low, it was assumed that an off-gas treatment system for the primary air stripper would be required by the regulatory agencies. Based on current discharge limits, off-gas treatment will probably be required only for Stage 1 of the stripping system. Two off-gas treatment systems were evaluated:

- Carbon adsorption of the vapor phase followed by steam regeneration in-place.
- Thermal oxidation of the contaminants in the off-gas.

Thermal oxidation was chosen as the preferred alternative based on capital cost and operating cost which includes waste disposal and process efficiency. The major problems with the carbon/steam system were:

- The presence of 1,1,1 TCA (which forms hydrochloric acid with steam) required that the system be constructed of Hastelloy which doubled the capital cost.
- The solubility of MeCl in water (16 to 20 g/l) made it very difficult to recycle the water from the steam condensate system.
- The limited adsorption of vapor phase MeCl on carbon required frequent regeneration of the carbon.

After air stripping, the conceptual treatment system calls for UV/OX to remove residual VOCs and to remove PCBs, if present. The UV/OX treatability study showed that MeCl could be effectively treated and reference data from UV/OX vendors indicated that PCBs, should they be present, can be effectively removed. The capital and operating cost for UV/OX is relatively high, consequently RTG evaluated a second case which uses a sacrificial carbon column to absorb PCBs. Carbon adsorption was thoroughly evaluated and the treatability study showed that TCE was efficiently adsorbed by carbon and that MeCl was very poorly adsorbed by carbon. The poor loading of MeCl on carbon clearly indicated that MeCl would be most effectively removed to as low a level possible by air stripping or by UV/OX. The RTG conceptual design would use two stages of air stripping to remove the VOCs as effectively as possible. The carbon adsorption system would remove residual VOCs, semivolatiles, and PCBs (should they be present) that are not removed by upstream treatment. The carbon adsorption system would be exposed to minimal loading and probably would require carbon changes annually or less frequently.

3.0 FIELD SAMPLING

In November and December 1989, a pump-out test of well 87-14 (1) was completed at the BAT Plant. This well is located adjacent to the Neutralization Pond and Zone I DNAPL plume. During the test, 12,000 gallons of contaminated groundwater were extracted from the well and stored in a storage tank with a secondary containment system. To provide for treatment of this water prior to discharge to the Niagara River District No. 1 POTW, a Pilot Test Treatment Plant was designed and constructed on site by RTG. This treatment plant consisted of an air strip tower and carbon adsorption units (see Section 4.0) in accordance with the Pump Test Work Plan submitted to NYSDEC and the POTW in 1989.

The original design for the Pilot Test and the treatability study proposal was based on the chemical analysis of groundwater samples taken from well 87-13 (1) found in the RFP for the Pilot Test. When RTG obtained the analysis on the feed to the Pilot Test system (taken from well 87-14(1)), it was noted that the concentration of VOCs were about a factor of 10 lower than the concentrations in well 87-13 (1), which was originally intended to be the pumped well. This well was rejected due to its low yield. A comparison of the chemical conposition of groundwater samples from these wells is provided in Table 3.1

During the pump-out test, several samples of water discharged from well 87-14(1) were sent to Alpha Analytic Laboratory for analysis of VOCs using EPA 624 Methods. The results of this testing were provided in "Results of the Pump-In and Pump-Out Testing, Bell Aerospace Textron Wheatfield Plant New York Draft Report, Golder, February 1990".

During the pump-out test of well 87-14 (1), RTG took approximately 500 gallons (10 drums) of samples for treatability testing. These samples were taken after the air stripping and prior to carbon

TABLE 3.1

	Oct. 1988 Data From RFP (ppb) Well 87-13 (1)	Feed to Pilot Test 11/28/89 (ppb) Well 87-14 (1)
MeCl	1,140,000	138,000
1,2, DCE	--	4,960
1,1,1 TCA	60,500	13,600
TCE	377,000	82,000

treating since the objective of the treatability program was to determine the effectiveness of carbon adsorption and/or UV/Oxidation. The 10 drums of air stripped groundwater were distributed to the participants of the treatability program. A sample of this water was also submitted to Rocky Mountain Analytical Laboratory (RMAL) in Denver, Colorado for analysis. When the analytical data were received from RMAL, it was noted that the data on the VOCs agreed very well with the VOC data from Alpha Analytical (See Table 3.2). The analyses conducted by RMAL on the semivolatiles and organochlorine pesticides/PCBs showed no compounds with the exception of those listed in Table 3.2. Alpha Analytical was not requested to analyze the samples taken during the pumpout testing and treatability testing for the semivolatiles or organochlorine pesticides/PCBs.

At approximately the same time, RTG received the data on samples taken from wells 87-18(1) and 87-22(1) in October 1989. These data are shown in Tables 3.3 and 3.4. As can be seen from these data, the analyses on the samples taken at the BAT site showed much higher levels of VOCs than the samples shipped to Denver for the treatability studies.

It was expected that some of the VOCs would be lost in transit because it was necessary to leave a head space in the drums for freeze protection, but the losses noted were inconsistent with the Henry's constants of the compounds. The Henry's constants, which are a ratio of the partial pressure of a compound to the solubility of a compound, would predict that the TCE and 1,2 DCE would be lost and that MeCl would be retained. On the actual samples, the MeCl was lost and the 1,2, DCE retained. This indicates that the losses may probably be due to biological activity (bacterial degradation). The reduction of TCE to 1,2 DCE and the reduction of MeCl to methane by biological activity have been observed in the past. (Wood at al, 1980).

TABLE 3.2

PILOT PLANT SAMPLES

Feed to Carbon Cannisters and Treatability Study Samples (ppb) from Well 87-15

	AA	RMAL
	TS-8	RTG #2
MeCl	1,490	1,500
CFC	16	N/A
Trans 1,2, DCE	77	75
1,1,1 TCA	148	250
TCE	788	1,700
Acetone	N/A	210
MEK	N/A	360
Phenol	N/A	5.7
4-Methyl Phenol	N/A	1.5
2,4 DMP	N/A	2.5
2-EHP	N/A	6.6

AA - Alpha Analytical

RMAL - Rocky Mountain Analytical Lab

TABLE 3.3

Well 87-18 (1)
Results in ppb

	AA 10/20/89	RMAL 1/17/90
MeCl	3,000	< 500
Trans 1,2,DCE	11,600	10,000
TCE	1,010	< 500
PCE	240	< 500
Anthracene	6.8	N/A
Di-n-octylphalate	12.7	N/A
Napthalene	7.3	N/A

AA - Alpha Analytical

RMAL - Rocky Mountain Analytical Lab

TABLE 3.4

Well 87-22 (1)
Results in ppb

	AA 10/20/89	RMAL 12/15/89
Vinyl Cl	<250	340
MeCl	4,480	23
Trans 1,2, DCE	9,240	6,900
1,1,1, TCA	430	88
TCE	17,100	230
PCE	353	<25
Di-n-octylpthlate	10.8	<10
Napthalene	6.8	<10

AA - Alpha Analytical

RMAL - Rocky Mountain Analytical Lab

The original treatability study called for laboratory testing of the pilot plant solution after air stripping and the site boundary samples taken from well 87-18 (1) and 87-22 (1). After noting the difference on the air strip samples when compared to the data from 87-13 (1), RTG requested a resample from the highly contaminated zone adjacent to the pond. Golder personnel resampled well 87-13(1) in January, 1990 and samples were sent to the various labs for treatability studies. Samples from 87-13 (1), were split and analyzed for VOCs at Alpha Analytical and also analyzed at the treatability labs (Peroxidation Systems, Inc., (PSI) and RTG). Results of these analyses are shown in Table 3.5

A review of the data in Table 3.5 indicates substantial variability on samples from well 87-13 (1) and it also indicates a significant difference in detection limits between various labs. This lab difference was particularly noticeable when comparing the RMAL data of 6 February 1990 to the October, 1988 data from the RFP and the Alpha Analytical data from 18 January 1990. The different detection limits are due to different analytical methods. Discussion with RMA personnel indicated that they felt that Method 8240 was the appropriate analytical method and the Alpha Analytical personnel felt that Method 524.2 was a suitable method. Table 3.6 shows a copy of the letter from RMAL stating their position. Since RMAL is a participant in the Contract Lab Program (CLP), it was determined that all future analyses for treatability testing by RMAL would use Method 8240.

The data in Table 3.5 also indicated that the semivolatiles and the pesticides/PCBs were below the lab detection limits and that treatability testing could be conducted only on the VOCs.

TABLE 3.5

Analysis of Various Samples
from Well 87-13 (1) (ppb)

	1982/1989*	Oct. 88 Data from RFP	AA 1-18-90	PSI 1-23-90	RMAL 2-6-90
Vinyl Cl	240	-	3,390	N/A	<100,000
Acetone	N/A	112,000	502	N/A	<100,000
MeCl	500,000	1,140,000	671,000	1,040,000	2,000,000
CFC	< 10	-	2,820	8,410	N/A
1,1 DCA	950	-	2,590	1,530	< 50,000
1,1,DCE	660	-	<220	17,000	< 50,000
Cis 1,2,DCE	-	-	661	-	-
Trans 1,2,DCE	8,800	-	5,980	5,110	< 50,000
1,2,DCA	< 5	-	34,200	< 10	N/A
TCE	550,000	377,000	308,000	844,000	1,200,000
PCE	380	280	900	< 50,000	
Toluene	560	1,140	N/A	< 50,000	
Chloroform	110	<180	315	< 50,000	
1,1,1 TCA	40,000	60,500	<140	84,000	72,000
Phenol	-	26.2	-	-	17
Anthracene	-	2.4	-	-	< 20
Benzo(a)Anthracene	-	13	-	-	< 20
Benzo(a)Pyrene	-	6	-	-	< 20
Benzo(b)Fluoranthene	-	23	-	-	< 20
Benzo(ghi)Perylene	-	10	-	-	< 20
Bis (2EH)D	-	16	-	-	29
Chrysene	-	10	-	-	< 20
Fluoranthene	-	35	-	-	< 20
Fluorene	-	2.4	-	-	< 20
Napthalene	-	8.5	-	-	< 20
Phenarthrene	-	20	-	-	< 20
Pyrene	-	30	-	-	< 20
1,2,4 TCB	-	7.6	-	-	< 20
Dieldrin	-	0.38	-	-	< 0.1
Endosulfan I	-	0.12	-	-	< 0.05
Arachlor 1260	-	7.9	-	-	< 1.0
Acetonitrile	-	49	-	-	N/A

* From Phase IV Plume Definition - Aug. 1989
AA - Alpha Analytical, Buffalo, NY
PSI - Peroxidation Systems, Inc., Tucson, AZ
RMAL - Rocky Mountain Analytical Lab, Denver, CO

Table 3.6

Enseco

March 13, 1990

Mr. Bart Conroy
Resource Technologies Group Inc.
3190 South Wadsworth Blvd.
Suite 250
Lakewood, CO 80227

Dear Bart:

As mentioned in our phone conversation on March 13, 1990, Enseco RMAL prefers to analyze samples containing significantly high concentrations of target compounds by Method 8240, as opposed to Method 524.2 for the following reasons:

- Method 524.2 was designed for the analysis of "drinking waters" which typically do not contain high concentrations of contaminants.

- Sample dilution factors would be higher for 524.2.

- Protect instrument from possible "saturation".

Please call me at 421-1025 if you have any questions.

Sincerely,

Craig Huff
Program Administrator

CH/kas

Enseco Incorporated
4955 Yarrow Street
Arvada, Colorado 80002
303/421-6611 Fax: 303/431-7171

The treatability studies were thus conducted on the matrix water from wells 87-18 (1), 87-22 (1) and 87-14 (1) with the concentration of the MeCl and TCE adjusted to the desired level by the addition of reagent grade chemicals.

4.0 PILOT AIR STRIP TEST

4.1 Test Description

Air stripping tests were conducted in the field utilizing the water obtained from the Pump-out Zone I aquifer testing program. Approximately 12,000 gallons of water obtained from well 87-14 (1) was available for testing. An air strip unit constructed of fiberglass was used for the field tests. The air strip unit had a diameter of 14 inches (equivalent to 1.07 square feet of area) and had an overall height of approximately 27 feet with 17.6 feet of packing. The packing was 2.5 inch diameter LANPAC. The base of the stripper consisted of a two foot diameter clearwell surge tank with 3 level controls tied into the discharge pump.

During the treatment of the water obtained from the aquifer test the following parameters were evaluated:

- Liquid Loading (gpm/ft^2) - The liquid loading was varied from approximately 5 gpm/ft^2 to approximately 10 gpm/ft^2. This data was used to establish the optimum liquid loading and subsequently the column diameter for a full scale system.

- Air to Liquid Ratio - The air to liquid (A:L) ratio was varied from 50 to 200 for 10 gpm/ft^2 and 200 to 400 for 5 gpm/ft^2 and the efficiency of VOC removal measured. Generally, the stripping efficiency will initially increase as the A:L ratio increases. However, beyond a specific A:L ratio, no further increase in efficiency is observed. The objective of this test was to determine this optimum A:L ratio.

4.2 Test Results and Discussion

The influent to the air strip system was analyzed for VOCs and the results are found in Table 4.1. Effluent samples from the air strip unit were taken at various conditions and these samples were analyzed for VOCs. The sample points were:

- Influent to the air strip system
- A:L ratio of 50 and liquid loading of 10 gpm/ft^2
- A:L ratio of 100 and liquid loading of 10 gpm/ft^2
- A:L ratio of 150 and liquid loading of 10 gpm/ft^2
- A:L ratio of 200 and liquid loading of 10 gpm/ft^2
- A:L ratio of 200 and liquid loading of 5 gpm/ft^2
- A:L ratio of 300 and liquid loading of 5 gpm/ft^2
- A:L ratio of 400 and liquid loading of 5 gpm/ft^2

The analytical results obtained on the various samples taken after air stripping at the A:L ratios listed above can also be found in Table 4.1. As can be seen from the data, approximately 99% of the VOCs were removed in the air strip unit.

The mass transfer coefficients for methylene chloride and TCE were calculated from the pilot plant data and are found in Table 4.2. The equation used to calculate the mass transfer coefficient is found on Table 4.3. This equation (Gosset, 1985), allow prediction of stripper performance as a function of: (1) column size, (2) liquid and gas flow rates, (3) Henrys Constant, and (4) overall mass transfer coefficient, is based on the following assumptions:

- o The amount of volatile compound in either phase is small with respect to total volume of each phase.
- o Volumes of air and water do not change during flow through the column.

TABLE 4.1

		EFFLUENT CONCENTRATION mg/l						
		Soln. throughput of 5 gpm/ft^2			Soln. throughput of 10 gpm/ft^2			
VOC	Feed Concen. mg/l	A/L 200:1	A/L 300:1	A/L 400:1	A/L 50:1	A/L 100:1	A/L 150:1	A/L 200:1
Methylene chloride	138.00	0.76	0.83	1.5	1.49	1.64	1.44	1.67
Trichloro-fluoromethane	4.65	0.024	ND	ND	0.016	0.016	0.016	0.024
Trans 1,2 dichloroethane	4.96	0.031	0.03	0.04	0.077	0.06	0.06	0.08
1,1,1, Tri-chloroethane	13.6	0.09	0.09	0.15	0.15	0.17	0.12	0.21
Trichloro-ethylene	82.0	0.45	0.39	0.6	0.79	0.69	0.70	0.79

N.D. - Non Detectable

A/L - Air to Liquid Ratio

TABLE 4.2

MASS TRANSFER COEFFICIENTS

(min^{-1})

A/L	LIQUID LOADING	MeCl	TCE
200:1	5 gpm/ft^2	0.192	0.186
300:1	5 gpm/ft^2	0.186	0.192
400:1	5 gpm/ft^2	0.162	0.192
50:1	10 gpm/ft^2	0.378	0.342
100:1	10 gpm/ft^2	0.336	0.342
150:1	10 gpm/ft	0.324	0.342
200:1	10 gpm/ft^2	0.342	0.330

Table 4.3

AIR STRIPPER PERFORMANCE EQUATION

$$\frac{C_1}{C_2} = \exp\frac{\left[\frac{ZA}{L}\left(1 - \frac{LRT}{GH}\right)(K_1a)\right] - \frac{LRT}{GH}}{1 - \frac{LRT}{GH}} \qquad \text{(Gosset, 1985)}$$

Where:

C = Solute concentration in water; 1–influent, 2–effluent
Z = Packed height of tower
A = Cross-sectional area of tower
L = Liquid flow rate
G = Gas flow rate
R = Universal gas content
T = Temperature at which gas flow is referenced
H = Henry's Constant
K_1a = Overall mass transfer coefficient

- A gas phase/solution equilibrium relationship exists for individual compounds, known as Henrys law:

  $$P_1 = HC_1$$

  Where:

  P_1 = Partial pressure of the solute
  C_1 = Solute concentration
  H = Henrys Constant

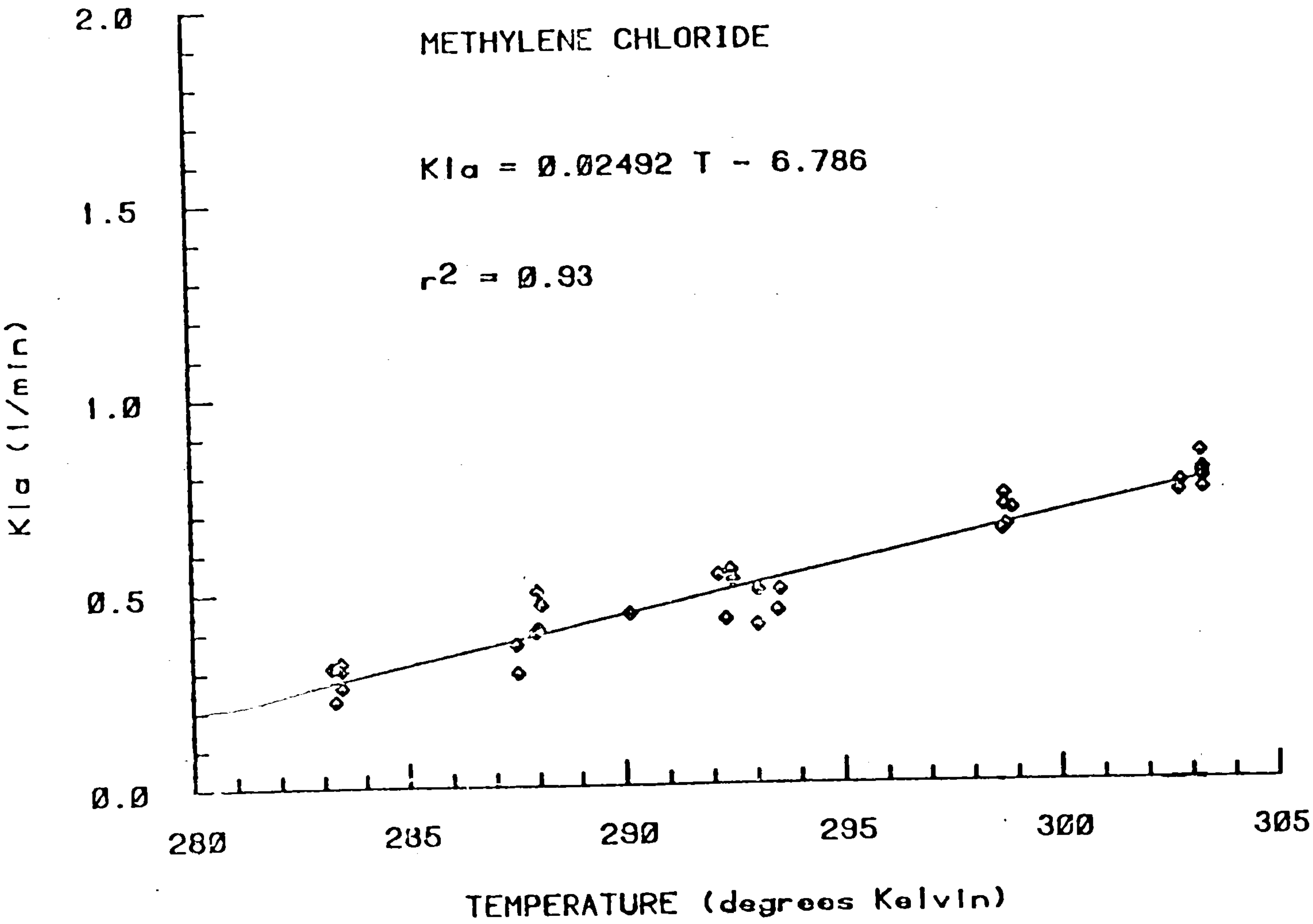
- Influent air does not contain any of the compound being stripped.

The mass transfer coefficients found in Table 4.2 are for an air stripping test conducted at 7.8°C (46°F). Mass transfer coefficients increase as temperature increases and this is shown in Figure 4.1 for methylene chloride. It is expected that a full scale air strip system located in a building would be operated at 20°C and all subsequent calculations will be made for that temperature.

The mass transfer coefficients found in Table 4.2 are almost identical for the major volatile organic constituents which are MeCl and TCE. We expected to see mass transfer coefficients for TCE in the range of 0.75 and it is not clear why they are in the 0.3 to 0.4 range. In general, the mass transfer coefficient for MeCl is consistent with literature values.

The data from the pilot program and reference data from the literature indicates that MeCl is going to be the limiting compound in the design of a full scale air strip unit.

Figure 4



$K_\ell a$ vs Temperature -- Methylene Chloride. (1-Inch Polypropylene Pall Rings, L_v = 1.36 m·min^{-1}, G_v = 10.95 m·min^{-1} [Ref: 25°C, 1 atm]).

4.3 Computer Modeling

The RTG computer simulation is based on the Gosset Equation shown earlier. The design criteria used by RTG was based on the following:

- Liquid Flow - 46 gpm average
  50 gpm maximum
- Percent Removal (MeCl) 99.5 per stage
- Stages - 2
- Hydraulic Loading - 15 gpm/ft^2

RTG has chosen a two stage air stripping unit in order to remove the MeCl as completely as possible. The results of the carbon adsorption test showed that even small amounts of MeCl consumed significant quantities of carbon and that it is advantageous to remove as much MeCl as possible by air stripping.

The design criteria for the air stripper also took into consideration the need for off-gas abatement. It is very unlikely that New York State will allow VOC emissions with no abatement. RTG designed the potential air strip system with off-gas treatment on the first stage and no off-gas treatment on the second stage.

It should be noted that RTG evaluated the air strip treatment for a conceptual groundwater extraction system with wells adjacent to the DNAPL zone and wells located along the southern boundary of the BAT Plant.

The results of the computer runs on the four major VOCs are shown in Tables 4.4 to 4.7. The feed concentrations used to determine the values used for the computer modeling are found in Table 4.8. The concentrations are based on the analyses of samples from wells 87-13 (1), 87-18 (1) and 87-22 (1) and are assumed to be representative values. Due to the wide range of analytical results obtained on samples of groundwater from these wells, a best estimate for the contaminant content of the combined flow of 46 gpm was made and follows:

MeCl - 270 ppm (6 gpm at 2000 ppm and 40 gpm at 10 ppm)
TCE - 165 ppm (6 gpm at 1200 ppm and 40 gpm at 10 ppm)
1,1,1 TCA - 9.4 ppm (6 gpm at 72 ppm and 40 gpm at 0)
1,2, DCE - 8.7 ppm (6 gpm at 0 ppm and 40 gpm at 10 ppm)

The most difficult compound to remove by air stripping is MeCl and the maximum removal efficiency that could be obtained with a packing height of 25 feet was 99.5% removal. Packing heights of greater than 25 feet were required to obtain removal efficiencies of 99.9% (~33 feet was the exact value) and the increased efficiency may not be commensurate with the increased problems (increased pressure drop, fabrication and installation problems, etc.).

The mass transfer coefficient used in the MeCl computer runs is that obtained in the pilot testing corrected to 20°C.

In summary, the two stage air strip system is designed to remove the major VOCs to less than 10 ppb. As was stated earlier, the potential high carbon consumption by MeCl suggested that MeCl be removed as completely as possible by air stripping rather than using carbon adsorption for MeCl removal

Table 4.4

```
                    RTG PACKING HEIGHT CALCULATOR

PROJECT OR CLIENT NAME......................BAT

DESIGN PARAMETERS

     STRIPPED SPECIES_______________________MECL

     HENRY'S LAW CONSTANT___________________135

     LIQUID LOADING RATE____________________45

     AIR/WATER RATIO________________________75

     INSIDE TOWER DIAMETER__________________24

     INFLUENT CONCENTRATION_________________1.35

     PERCENT REMOVAL________________________99.5

     MASS TRANSFER COEFFICIENT______________.00633


CALCULATED PACKING HEIGHT IS________________23.21 ft
```

Table 4.5

```
                     RTG PACKING HEIGHT CALCULATOR

PROJECT OR CLIENT NAME.......................BAT

DESIGN PARAMETERS

     STRIPPED SPECIES____________________________TCE

     HENRY'S LAW CONSTANT________________________509

     LIQUID LOADING RATE_________________________46

     AIR/WATER RATIO_____________________________75

     INSIDE TOWER DIAMETER_______________________24

     INFLUENT CONCENTRATION______________________165

     PERCENT REMOVAL_____________________________99.999

     MASS TRANSFER COEFFICIENT___________________.01833


CALCULATED PACKING HEIGHT IS_____________________21.13 ft
```

Table 4.6

```
                     RTG PACKING HEIGHT CALCULATOR

PROJECT OR CLIENT NAME......................BAI

DESIGN PARAMETERS

     STRIPPED SPECIES___________________________DCE

     HENRY'S LAW CONSTANT_______________________263

     LIQUID LOADING RATE________________________46

     AIR/WATER RATIO____________________________75

     INSIDE TOWER DIAMETER______________________24

     INFLUENT CONCENTRATION_____________________8.7

     PERCENT REMOVAL____________________________99.5

     MASS TRANSFER COEFFICIENT__________________.0089


CALCULATED PACKING HEIGHT IS_______________20.53 ft
```

Table 4.7

```
                    RTG PACKING HEIGHT CALCULATOR

PROJECT OR CLIENT NAME......................EAT

DESIGN PARAMETERS

     STRIPPED SPECIES________________________TCE

     HENRY'S LAW CONSTANT____________________100

     LIQUID LOADING RATE_____________________45

     AIR/WATER RATIO_________________________75

     INSIDE TOWER DIAMETER___________________24

     INFLUENT CONCENTRATION__________________9.4

     PERCENT REMOVAL_________________________99.999

     MASS TRANSFER COEFFICIENT_______________.0233


CALCULATED PACKING HEIGHT IS_________________17.52 ft
```

TABLE 4.8

Feed Concentrations to Air Strip System (ppb)

	2/6/90 Well 87-13 (1)	10/20/89 Well 87-18 (1)	10/20/89 Well 87-22 (1)
MeCl	2,000,000	3,000	4,480
TCE	1,200,000	1,010	17,100
1,1,1 TCA	72,000	< 70	430
1,2, DCE	--	11,600	9,240

4.4 Conclusions

The combination of data from the air strip pilot test, data from other references and computer modeling provided the design information necessary to design an air strip system capable of removing 99.5% per stage of the MeCl in the feed. Since MeCl is the most difficult VOC to strip, the other VOCs will be removed in excess of 99.9%. The potential air strip system designed for full-scale operation would be a two-stage system because of the need to reduce MeCl to as low as possible in order to minimize carbon consumption.

5.0 EQUILIBRIUM CARBON ADSORPTION TESTS

Application of activated carbon for removal of organics from aqueous solution is well known and is based on a property known as the adsorption capacity of carbon. The equilibrium adsorption procedure is a method used for the determination of this (adsorptive) capacity. The test can be used to compare adsorption capacities of different carbons for a given organic compound or to measure the adsorbability of different organic compounds on a given carbon. To determine the effectiveness of carbon adsorption treatment of groundwater from the BAT site, tests were carried out with only one activated carbon type (Calgon Filtrasorb 400). A brief description of the method follows:

5.1 Description of Method

- Preparation of Adsorbent

Although granular carbons can be compared or evaluated in their original form, the general procedure is to pulverize the carbon. The carbon is usually pulverized to assure more rapid attainment of equilibrium. The Calgon carbon was pulverized until approximately 90% of the sample passed the 200-mesh sieve. The pulverized carbon was then dried overnight in a drying oven at 105°C and then stored in a desiccator until it was used for experimental purposes.

- Preparation of Activated Carbon Stock Slurry

A sample of the oven-dried and cooled pulverized carbon from the desiccator was taken and weighed out to 25 grams. This carbon was transferred to a one liter volumetric flask for preparation of a stock slurry. Organic-free boiled water (prepared by passing deionized water through a bed of activated carbon and boiling it) was added to the flask until the required dilution was achieved. One ml of this stock slurry contained 25 mg of carbon. A wide range of carbon dosages could be provided with various volumes of stock slurry. For example, 5 ml of stock slurry provided 125 mg of carbon, 10 ml of 250 mg, and so on.

- Test Procedure

One liter samples of ground water containing organic contaminants were placed in five ground-glass stoppered reagent bottles. An increasing carbon dosage was added to each successive groundwater sample by withdrawing predetermined volumes of carbon slurry from the stock slurry in a volumetric flask. For control purposes, a one liter sample of organic-free water was added to the sixth bottle and no carbon was added to this water sample. This sample was labeled as "blank". After the addition of carbon slurry to the samples, the reagent bottles were immediately filled to the bottom of the ground-glass stopper with additional organic-free water so that there was no air space in the bottles. This was done to minimize the loss of volatile organics. The groundwater test solution concentrations were corrected for dilution associated with completely filling the reagent bottles. The completely filled bottles contained approximately 1060 ml of sample which is equivalent to a dilution of approximately 6%.

The carbon-dosed samples, along with the blank sample, were placed on a coordinated magnetic stirrer. The samples were stirred for a 24-hour period. At the end of the contact period, the samples were withdrawn from the reagent bottles and transferred into centrifuge tubes. The samples were centrifuged to separate the pulverized carbon from the solution. To ensure a minimum head space was maintained in the centrifuge tubes, the centrifuge tubes were completely filled. After centrifugation, the solution samples were decanted into glass sample vials and were submitted to the laboratory for analysis. A simplified sketch of the apparatus used for the tests is shown in Figure 5.1.

5.2 Test Results and Discussion

The tests were carried out with water samples from three different areas; well 87-22 (1) water, well 87-22 (1) water spiked with methylene chloride and trichloroethylene, well 87-13 (1) water and spiked 87-14 (1) well water.

The carbon dosages, assay results, etc., for each test are summarized in Tables 5.1 through 5.4. All pertinent volatile organic compound concentrations are given in the Tables. Carbon dosages are shown in the left-hand column. The next column for each set of data indicate the amount of residual contaminants remaining in solution after carbon treatment (C_f). The amount of organic constituents adsorbed (X) was calculated by subtracting each C_f value from C_0 (initial amount) and is summarized in appropriate columns. By dividing X in mg by the carbon dose in grams, the adsorption capacity (X/M) per gram of carbon was calculated in each case. X/M values were plotted as a function of C_f on logarithmic paper. The plots are shown in Figures 5.2 through 5.5. The Freundlich parameters (K & 1/n) were calculated from the plots. The K parameter refers to the intercept of the curve on the Y-axis and 1/n refers to the slope of the curve.

A brief description of each test and discussion of results is as follows:

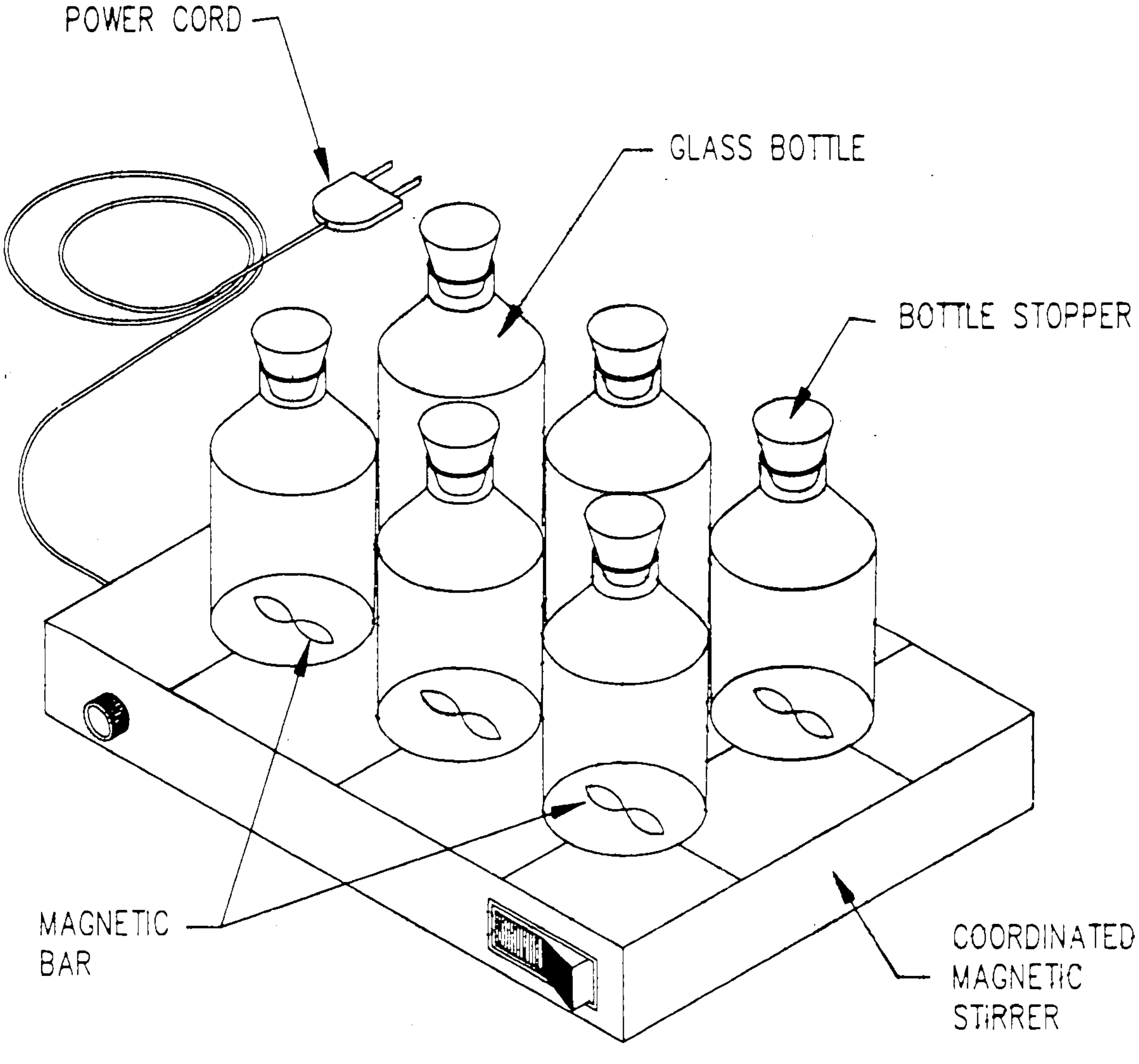
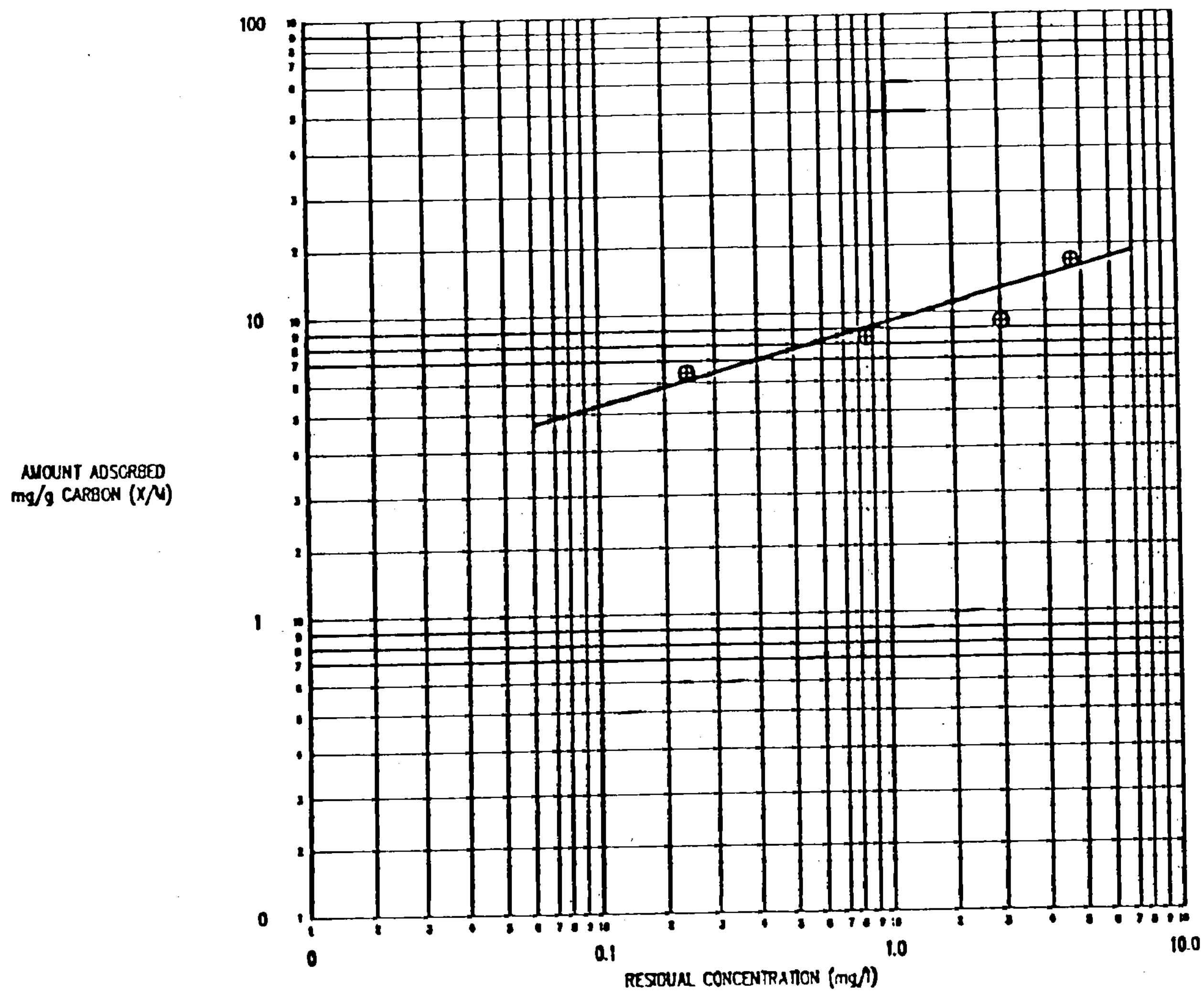


FIGURE – 5.1

SET UP FOR EQUILIBRIUM CARBON ADSORPTION TEST



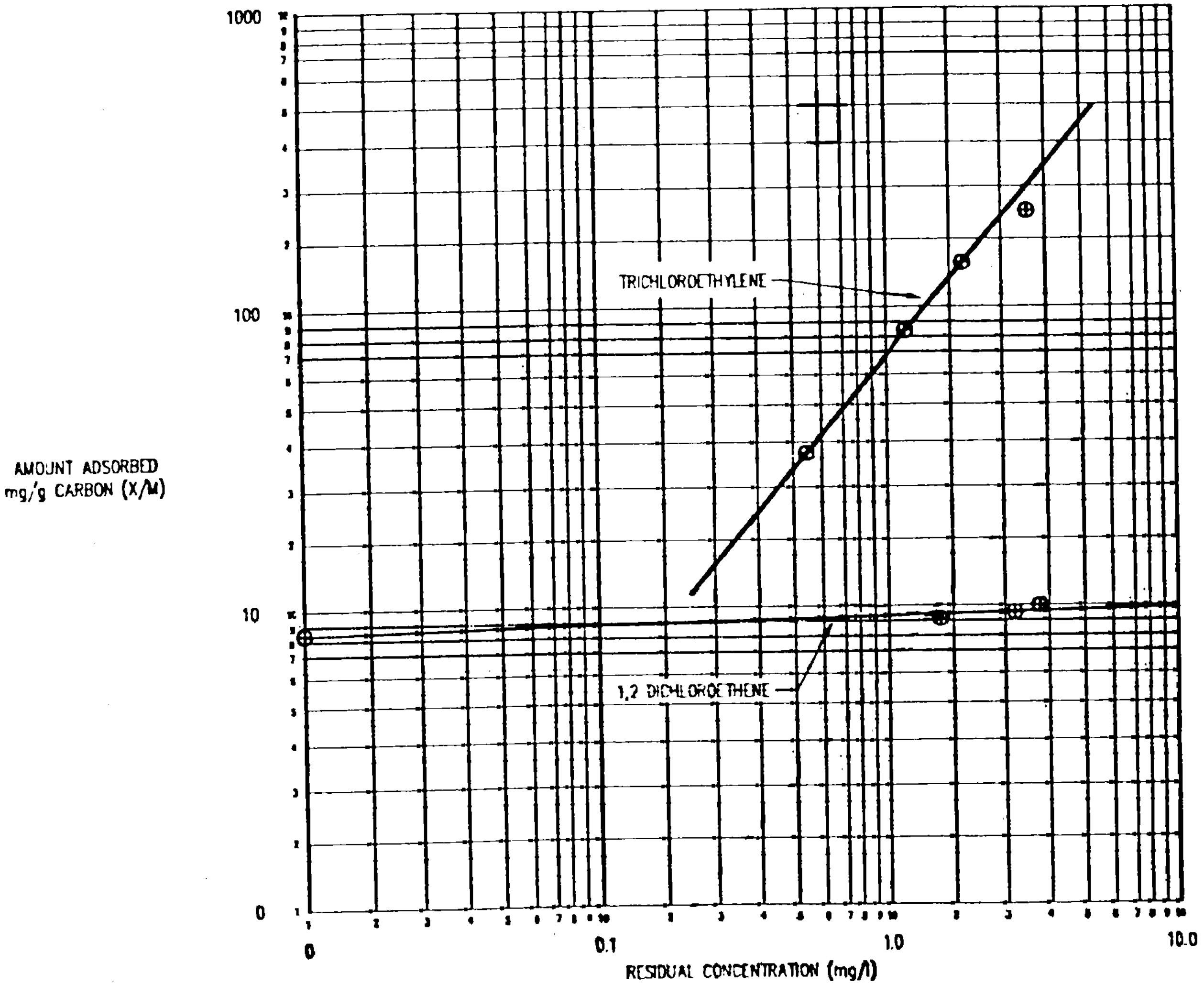
TEST #1

INITIAL CONCENTRATIONS

1,2 DICHLOROETHENE (DCE)	5.3 ppm
METHYLENE CHLORIDE (MeCL)	0 ppm
TRICHLOROETHYLENE (TCE).	0 ppm

K = 10.0
1/n = 0.33

RAWN BY: MDB ATE: 4/25/90	REV. 0	RESOURCE TECHNOLOGIES GROUP, INC. DENVER, CO	FIGURE – 5.2 EQUILIBRIUM CARBON ADSORPTION TEST WITH WELL 87-22 WATER



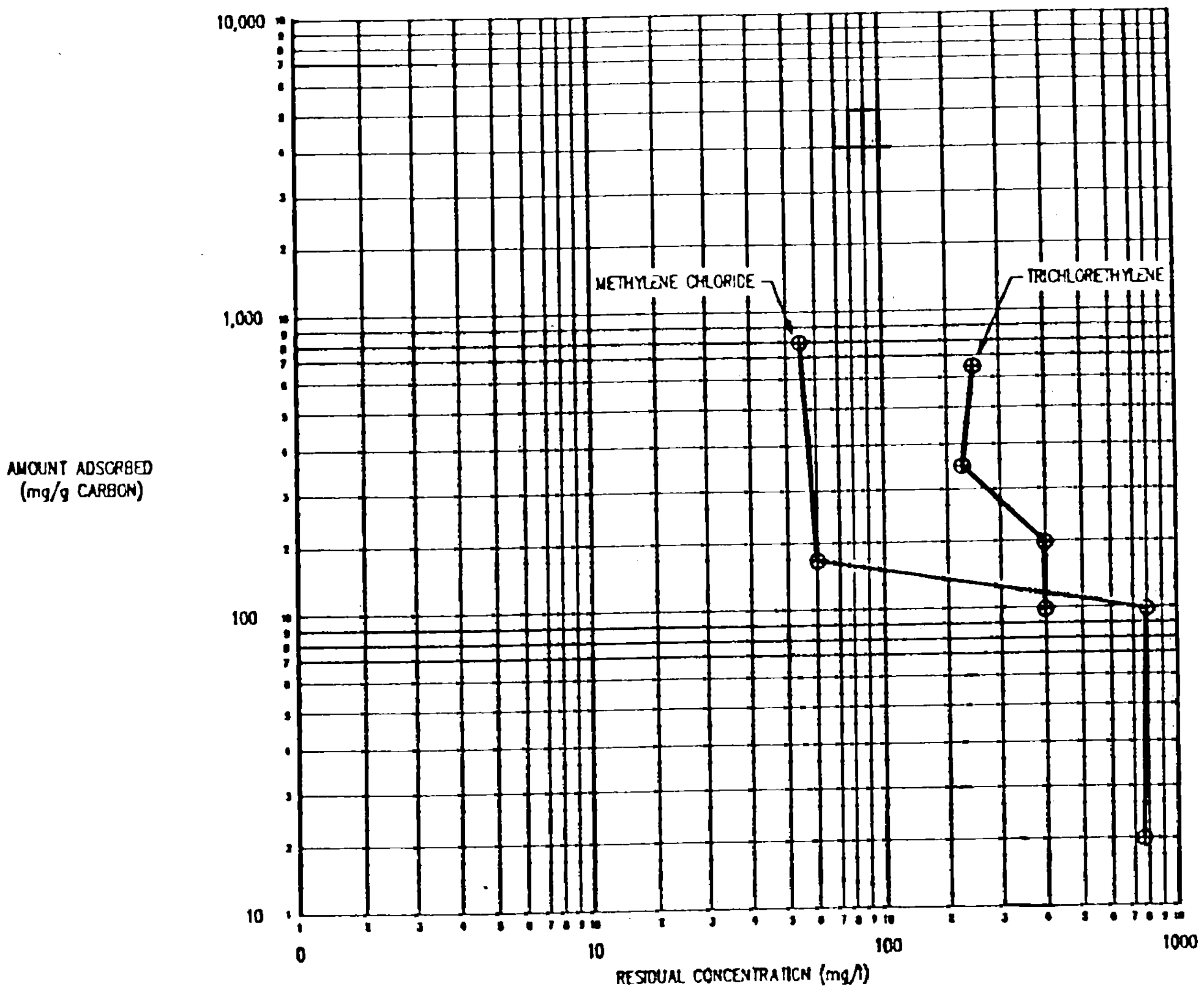
TEST #2

INITIAL CONCENTRATIONS

1,2 DICHLOROETHENE (DCE)	4.1 ppm
METHYLENE CHLORIDE (MeCL)	4.7 ppm
TRICHLOROETHYLENE (TCE)	10.0 ppm

K = 9.0
1/n = 0.08

DRAWN BY. MDB DATE: 4/25/90	REV. 0	RESOURCE TECHNOLOGIES GROUP, INC. DENVER, CO	FIGURE - 5.3 EQUILIBRIUM CARBON ADSORPTION TEST WITH SPIKED 87-22 WELL WATER

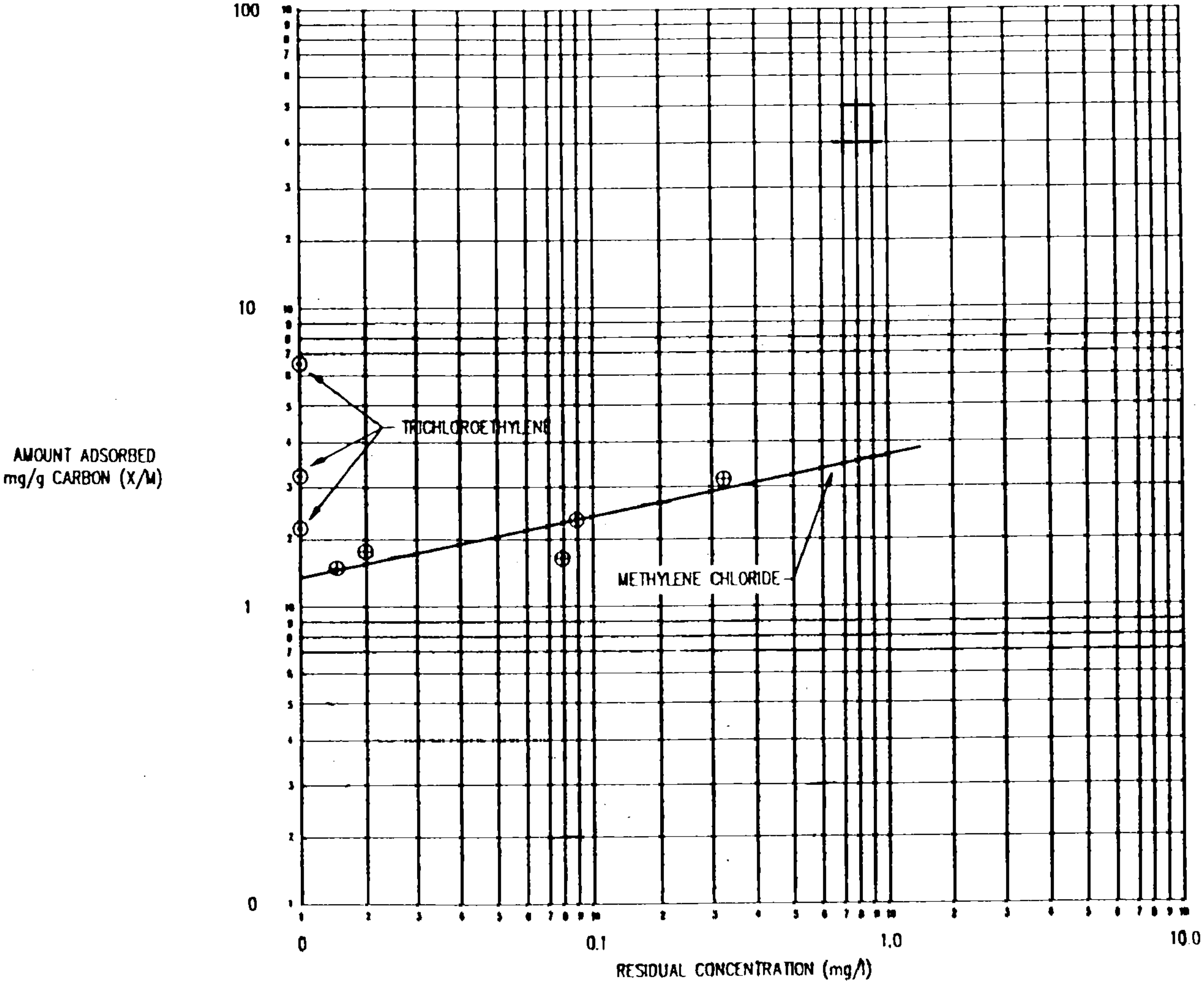


TEST #3

INITIAL CONCENTRATIONS
METHYLENE CHLORIDE (MeCL) 750 ppm
TRICHLOROETHYLENE (TCE) 410 ppm

DATA TOO ERRATIC

DRAWN BY: MDB	REV. 0	RESOURCE TECHNOLOGIES GROUP, INC. DENVER, CO	FIGURE - 5.4 EQUILIBRIUM CARBON ISOTHERM FOR TEST #3
DATE: 4/25/90			



TEST #4

INITIAL CONCENTRATIONS

METHYLENE CHLORIDE (MeCL)	3.1 ppm
TRICHLOROETHYLENE (TCE)	1.6 ppm

K = 1.3
1/n = 1.01

DRAWN BY: MDB	REV.	RESOURCE TECHNOLOGIES GROUP, INC. DENVER, CO	FIGURE - 5.5
DATE: 4/25/90	0		EQUILIBRIUM CARBON ADSORPTION TEST WITH SPIKED 87-14 WELL WATER

- Test #1 - This test was carried out with water from well 87-22 (1). This sample was supposed to have contained methylene chloride, trichloroethylene, etc., as indicated by the field samples taken from this well in the past. The analysis, however, showed that methylene chloride and trichloroethylene were not present. The only volatile organic shown by the assay report was 1,2 dichloroethene, consequently only the equilibrium isotherm for 1,2 dichloroethene could be developed. Data for this isotherm is given in Table 5.1 and the isotherm is shown in Figure 5.2.

- Test #2 - The Test #1 result showed that the water from well 87-22 (1) did not contain methylene chloride or trichloroethylene. The water was therefore spiked with these compounds so that isotherms for methylene chloride and trichloroethylene could be studied. The data for this test is presented in Table 5.2 and the isotherms are shown in Figure 5.2. This test was successful in satisfactorily defining the isotherm for trichloroethylene, but it was not successful in defining the isotherm for methylene chloride because of competition from trichloroethylene. The carbon dosages were not adequate and so only two data points could be obtained for methylene chloride.

- Test #3 - This test was carried out with water from well 87-13 (1). This water contained high concentrations of methylene chloride and trichloroethylene. A sample of this water was taken, and left uncovered to allow volatilazation. The concentrations did reduce, but not significantly (1000 ppm to 700 ppm for methylene chloride). The assay results and equilibrium isotherms

TABLE 5.1

Test #1

Equilibrium Isotherm Test With 87-22 (1) Well Water

Initial Sample Size = 1,000 ml

Sample Size After Dilution = 1,060 ml

Initial Concentration:

1,2 Dichloroethene (DCE) = 5.3 ppm (5.3 mg)
Methylene Chloride (MeCl) = 0
Trichloroethylene (TCE) = 0

Sample No.	Carbon Dosage (mg)	Residual Amt. (mg)) 1,2 DCE	Amt. Adsorbed (mg) 1,2 DCE	Adsorptive Capacity mg/gram of Carbon 1,2 DCE
CAC-1	25	4.8	0.5	20.0
CAC-2	50	5.6	0	0
CAC-3	250	3.18	2.12	8.5
CAC-4	500	0.94	4.36	8.7
CAC-5	750	0.24	5.06	6.7

TABLE 5.2

Test #2

Equilibrium Isotherm Test with Spiked 87-22 (1) Well Water

Sample Size = 1,000 ml

Sample Size After Dilution = 1,060 ml

Initial Concentrations:

1,2 Dichloroethene (DCE) = 4,100 ppb (4.1 mg)
Methylene Chloride (MeCl) = 4,700 ppb (4.7 mg)
Trichloroethylene (TCE) = 10,000 ppb (10.0 mg)

Sample No.	Carbon Dosage (mg)	Residual Amt. (mg)			Amount Adsorbed (mg)			Adsorptive Capacity mg/gram of Carbon		
		1,2 DCE	MeCl	TCE	1,2 DCE	MeCl	TCE	1,2 DCE	MeCl	TCE
87-22-C1	25	4.03	4.66	3.82	0.07	0	6.18	2.8	0	152.8
87-22-C2	50	3.60	4.87	2.12	0.50	0	7.88	10.0	0	157.6
87-22-C3	100	3.18	4.77	1.27	0.92	0	8.73	9.2	0	87.3
87-22-C4	250	1.80	4.13	0.53	2.3	0.57	9.47	9.2	2.28	37.9
87-22-C5	500	0.73	3.39	0	3.37	1.31	10.0	6.7	2.62	20.0

for this test are given in Table 5.3 and Figure 5.3, respectively. In this test, the results for methylene chloride were quite erratic and so a satisfactory isotherm for the same could not be developed. The trichloroethylene results were also somewhat scattered, perhaps due to the high level of this constituent in the water.

- Test #4 - In tests 1 through 3, the equilibrium isotherm for methylene chloride could not be developed for the reasons noted in the Section 5.2 Discussion. Test #4 was carried out to develop this isotherm. To reduce the competition from trichloroethylene for carbon, well 87-14 (1) water was spiked with methylene chloride and trichloroethylene (3.1 ppm methylene chloride and 1.6 ppm trichloroethylene) so that the methylene chloride concentration was twice that for trichloroethylene. Samples of this water were treated with varying amounts of carbon as explained in Section 5.1. The results from this test are given in Table 5.4 and the equilibrium isotherm plot is shown in Figure 5.4. Based on this isotherm, the equilibrium adsorptive capacity of carbon for methylene chloride was calculated to be approximately 3 mg/gm of carbon for water containing approximately 2 ppm of methylene chloride.

Discussion

The test results show that the carbon is more selective for trichloroethylene than it is for methylene chloride. In all the tests, trichloroethylene was observed to adsorb on carbon for any dosage of carbon, whereas, methylene chloride did not adsorb until most or all of the trichloroethylene had adsorbed. Significant adsorbtion of methylene chloride occurred only when the residual concentration of trichloro-

TABLE 5.3

Test #3

Equilibrium Isotherm Test with 87-13 (1) Well Water

Initial Sample Size = 1,000 ml.

Sample Size After Dilution = 1,060 ml

Initial Concentration:

1,2 Dichloroethene (DCE) = N/D
Methylene Chloride (MeCl) = 750 ppm (750 mg)
Trichloroethylene (TCE) = 410 ppm (410 mg)

Sample No.	Carbon Dosage (mg)	Residual Amt. (mg)		Amt. Adsorbed (mg)		Adsorptive Capacity mg/gram of Carbon	
		MeCl	TCE	MeCl	TCE	MeCl	TCE
D5-C1	50	770	400	0	10	0	200
D5-C2	100	740	400	10	10	100	100
D5-C3	250	550	240	200	170	800	680
D5-C4	500	740	230	10	180	20	360
D5-C5	1000	600	0	150	410	150	410

TABLE 5.4

Test #4

Equilibrium Isotherm Test with Spiked 87-14 (1) Well Water

Initial Sample Size = 1,000 ml.

Sample Size After Dilution = 1,060 ml

Initial Concentration:

Methylene Chloride (MeCl) = 3,100 ppb (3.1 mg)

Sample No.	Carbon Dosage (mg)	Residual Amount (mg) MeCl	Amt. Adsorbed (mg) MeCl	Adsorptive Capacity mg/gram of Carbon MeCl
CI-1	256	2.33	0.768	3.07
CI-2	500	1.91	1.19	2.38
CI-3	750	1.80	1.3	1.73
CI-4	1,000	1.27	1.83	1.82
CI-5	1,250	1.17	1.93	1.55

ethylene was low or zero. The selectivity and adsorbtion capacity of carbon for trichloroethylene are, therefore, superior to that for methylene chloride.

The K and 1/n values for trichloroethylene, methylene chloride and dichloroethane were calculated from the test results. The comparison with the values reported in the literature for the same compounds from pure solutions is given below:

	Values from Test Results			**Values Reported in the Literature**		
Parameter	**MeCl**	**TCE**	**DCE**	**MeCl**	**TCE**	**DCE**
K	1.3	70	10	1.3	28	5.3
1/n	1.01	1	0.33	1.16	0.6	0.83

The comparison shows that the values for TCE and DCE are higher than the values reported in the literature. Most likely this is due to a matrix effect. For methylene chloride, the values are close to the values reported in the literature, probably because the loading of this compound does not occur until most or all of the trichloroethylene has been adsorbed, thereby reducing the competition from trichloroethylene.

For methylene chloride to adsorb on carbon, it is important, therefore, that the concentration of trichloroethylene in the water feed to the carbon column is low to zero. Given the conceptual design discussed in Section 8.0, feed to the carbon columns in the plant would be the effluent from the air strip tower, it is very likely that this water will have a lower trichloroethylene concentration compared to methylene chloride. The reason is that trichloroethylene has a higher Henry's constant and overall mean transfer coefficient than methylene chloride. Since the efficiency of removal in the air strip tower is directly proportional to these two factors, trichloroethylene should air strip more effectively thab methylene chloride. The Computer simulation completed to determine the effectiveness of the air stripping are presented and discussed in Section 4.0 of this report. Data from these simulations also indicate that trichloroethylene will strip preferentially over methylene chloride. It is therefore, appropriate to conclude that the adsorption characteristics of methylene chloride on carbon in the conceptual plant design is likely to be the characteristics observed in the tests discussed above. With zero to low concentration of trichloroethylene expected in the feed water to the carbon columns, the loading behavior of the methylene chloride from the plant water is likely to be the same as that from the pure water.

5.3 Conclusions

Based on the results and discussions presented in Section 5.2, the following conclusions can be drawn:

- Trichloroethylene is more selectively adsorbed on carbon than is methylene chloride. Methylene chloride does not load on carbon until all or most of the trichloroethylene has been adsorbed.

- The equilibrium capacity of carbon for trichloroethylene in the sample water was higher than it's capacity for trichloroethylene from pure water solutions.

- The equilibrium adsorption capacity of carbon for methylene chloride from sample water is much closer to it's capacity for methylene chloride from pure water provided carbon dosage is large enough to adsorb all or most of the trichloroethylene. In other words, the presence of other contaminants in sample water, such as trichloroethylene, significantly influences the adsorption capacity of carbon for methylene chloride in sample water.

The loading behavior of methylene chloride on carbon from plant feed water is likely to be the same as that from the pure water since the feed to the carbon columns in the plant is not likely to have significant trichloroethylene concentrations higher than the methylene chloride concentrations.

It is expected that the methylene chloride concentration will be higher than the concentration of trichloroethylene. If this is the case, the equilibrium methylene chloride loading expected on the carbon in the plant is likely to follow the loading curve for methylene chloride from pure water solutions.

6.0 DYNAMIC MULTIPLE CARBON COLUMN TESTS

The equilibrium carbon isotherms, described in the previous section, are useful screening tools for determining preliminary carbon usage rates and evaluating the relative adsorbability of a particular compound in comparison to the other compounds. The equilibrium isotherms are batch tests, while actual full-scale granular activated carbon columns are dynamic, continuous processes. Also, isotherms do not take into account competitive adsorption where several compounds may be present in the water being treated. As a result, bench scale column tests were carried out to develop the necessary design criteria. The basic criteria required are:

- Flow rate (both average and maximum).
- Empty bed contact time (EBCT).
- Specific flow rate.
- GAC usage rate.
- GAC depth.
- Type of GAC.

Of all the parameters listed above, the two design parameters which are critical for any treatment system are the EBCT and GAC usage rate. A brief description of each is as follows:

- Empty Bed Contact Time

  The EBCT is an important design parameter in that it has a significant impact on the carbon usage rate. If a sufficient EBCT is provided, the carbon usage rate will approach the equilibrium capacity of the GAC for a given compound.

- Carbon Usage Rate

This basic design parameter indicates the rate at which carbon will be exhausted or replaced and, therefore, affects the operating cost of the treatment system. The dynamic column tests provide the necessary information to estimate the optimum carbon usage rate and, hence, the optimum carbon replacement time or treatment costs.

6.1 Description of Set-up

The set-up used for the bench scale tests is shown in Figure 6.1. It was comprised of four sets of glass columns each 1/2" in outside diameter. Stainless steel tubing of 1/4" size was used for connecting the columns in series as shown in Figure 6.1. Four columns were used so that different EBCT could be studied simultaneously. Rubber stoppers wrapped with Teflon were used to close the top and bottom openings of the columns. Stainless steel ball valves were provided on the tubings so that samples of solution exiting from each column could be withdrawn for analysis. A Masterflex constant speed pump was used to feed the columns. Feed to the columns in all the tests was approximately 15 ml/min which translates into a specific flow rate of 5 gpm/ft^2. A floating polyethylene cover was used to minimize the head space in the feed drum containing the contaminated water so that loss of the volatiles during the duration of the test was minimum. Each column was filled with Calgon Filtrasorb 400 (GAC) to a predetermined height of 24". This height provided an EBCT approximately 3 minutes in each column at a flowrate of 15 ml/min. Bed support for the GAC was prepared by placing a nominal 1" deep layer of glass wool into the column first and then placing a layer of 3 mm diameter glass beads over the glass wool as shown in Figure 6.1.

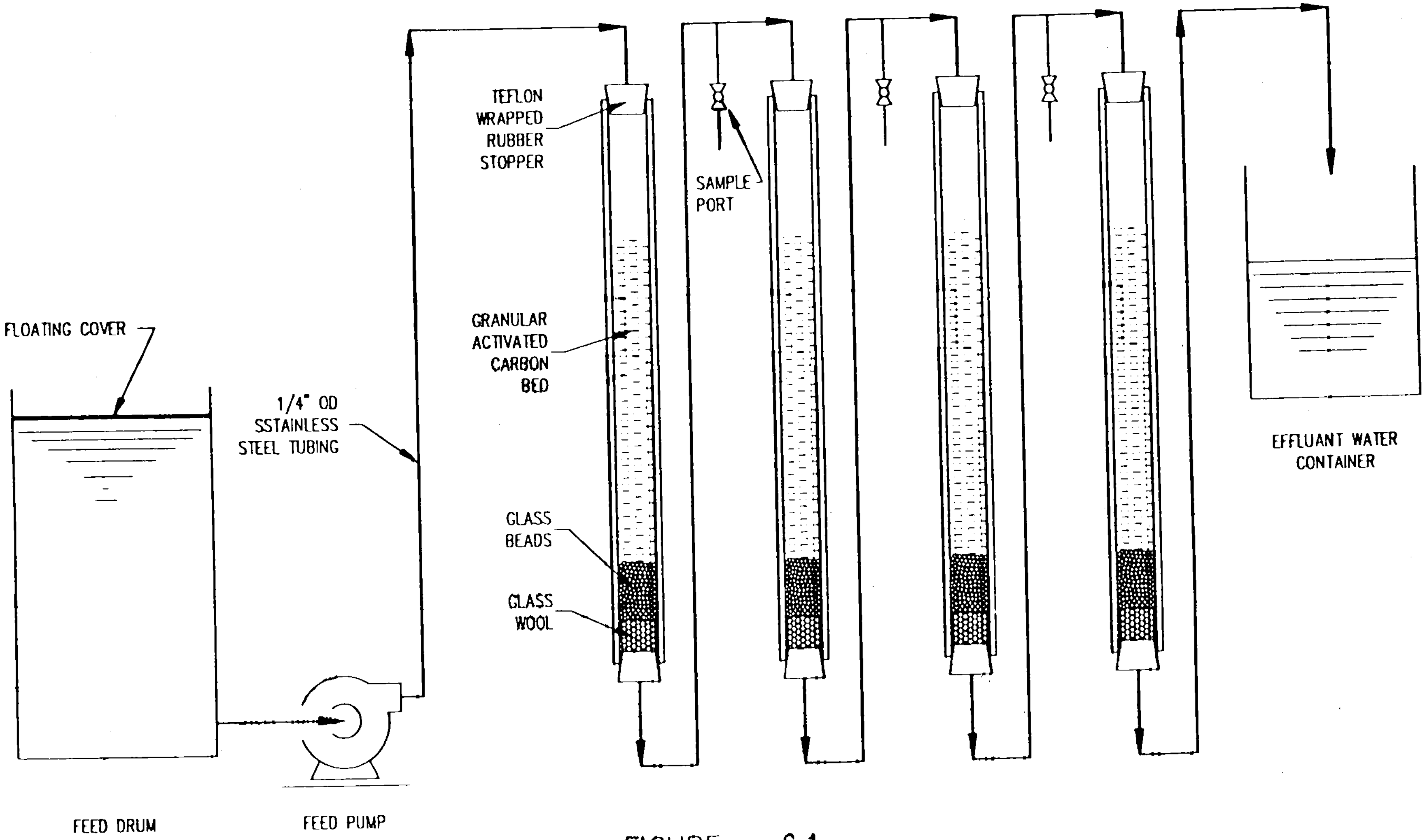


FIGURE – 6.1

SET UP FOR BENCH SCALE DYNAMIC CARBON COLUMN TESTS

Approximately 45 ml of 12 x 40 mesh GAC was poured into a beaker containing organic-free water. The columns were filled by slurrying GAC from this beaker with a stream of organic-free water from another beaker. It was ensured that the columns had several inches of organic-free water prior to filling with GAC. Each time a column had to be drained to pour more slurry of GAC into the column, several inches of water were left above the settled carbon such that the carbon bed was free of air all the time. This procedure was followed until all the carbon in the beaker was transferred into the columns.

The test was started by turning the feed pump on. The water exiting from the fourth column (effluent) was collected in a container and the volume recorded before disposal. The progress of the test was monitored by sampling the water exiting from each column and analyzing for methylene chloride and trichloroethylene, etc. by a head space gas analysis method. A brief description of this method is given in Appendix B. Based on the test results obtained by this method, samples were selected for submittal for volatiles analysis by the more accurate EPA Method 8240. This arrangement was adopted to reduce the number of samples assayed by the EPA method. The assay results and other necessary test data are presented in Section 6.2.

6.2 Description of Tests and Results

Two different tests were carried out. The only difference between the two test conditions was the difference in the concentration of the contaminants in the feed water. The test conditions along with the test results are summarized in Tables 6.1 and 6.2.

TABLE 6.1

Summary of Test Conditions and Assay Results for Test #1

Sample Water = Spiked 87-22 (1) well water
Feed Rate = 15 ml/min (5 gpm/ft^2)

Carbon Bed Depth -
Column 1 = 22"
Column 2 = 23"
Column 3 = 24"

Influent Conc. in the Beginning of Test	Influent Conc. at the End of Test
Methylene Chloride = 2600 ppb	Methylene Chloride* = 1800 ppb
Trichloroethylene = 1200 ppb	Trichloroethylene* = 1400 ppb
1,2 Dichloroethene = 860 ppb	1,2 Dichloroethene = Not Assayed

Sample Number	Accumulated Volume of Feed Water Passed (ml)	Concentration of Methylene Chloride in Effluent (ppb)		
		Column 1	Column 2	Column 3
CCC-1.1*	6,050	11	-	-
CCC-1.2*	15,390	18	-	-
CCC-1.3	18,845	380	-	-
CCC-1.4	22,015	510		
CCC-1.6	33,650	1600	-	-
CCC-1.7	37,875	1300		
CCC-1.10	54,985	1500	-	-
CCC-2.5	25,110	-	11	-
CCC-2.6	41,400	-	310	-
CCC-2.7	44,765	-	350	-
CCC-2.8	55,085	-	860	
CCC-3.8	55,185	-	-	18

* Assay results by head space gas analysis method.
All other assay results are by EPA Method 8240.
There was no detectable leakage of trichloroethylene.

TABLE 6.2

Summary of Test Conditions and Assay Results for Test #2

Sample Water = Spiked effluent for the Air Strip Demonstration Test
Feed Rate = 15 ml/min (5 gpm/ft^2)

Carbon Bed Depth -
Column 1 = 20"
Column 2 = 20"
Column 3 = 20"

Feed Conc. in the Beginning of Test	Feed Conc. at the End of Test
Methylene Chloride = 3800 ppb	Methylene Chloride* = 1800 ppb
Trichloroethylene = 2100 ppb	Trichloroethylene* = 3800 ppb

Sample Number	Accumulated Volume of Feed Water Passed (ml)	Concentration of Methylene Chloride in Effluent (ppb)		
		Column 1	Column 2	Column 3
CC-1.1*	3,820	2	-	-
CC-1.2*	5,695	5	-	-
CC-1.4	15,895	490	-	-
CC-1.6	23,505	1300	-	-
CC-1.8*	34,460	2400	-	-
CC-1.9	40,060	2600	-	-
CC-1.11*	55,720	2620	-	-
CC-1.12	61,770	2400	-	-
CC-2.5	26,660	-	78	-
CC-2.7	56,020	-	1900	-
CC-2.9	68,010	-	1500	-
CC-2.10	77,310	-	1800	-
CC-3.5	68,010	-	-	500
CC-3.6	77,310	-	-	1000

* Assay results by head space gas analysis method.
All other assay results are by EPA Method 8240.
There was no detectable leakage of trichloroethylene..

The feed water for Test #1 was the water from well 87-22 (1). This water sample was assayed and no methylene chloride and trichloroethylene were detected in this water. The water was, therefore, spiked with pure methylene chloride and trichloroethylene compounds so that the feed water had concentrations of these two constituents close to the levels that are typical from this well; 1 - 3 ppm methylene chloride. During this test, all the feed water was used up and so the test was stopped after 3 days. Nevertheless, the data from this test were useful in providing necessary design information.

The feed water for Test #2 was the effluent water from the air strip tower field demonstration test carried out at Bell Aerospace Textron's plant during the last week of November, 1989. The effluent water from this field test was collected in drums during the test and shipped to RTG in Denver for use in the carbon column tests. This water was sampled and assayed at the end of the demonstration test and was found to contain approximately 1.0 ppm of methylene chloride. The water was spiked with pure methylene chloride and trichloroethylene compounds before starting the laboratory tests. The assay results are provided in Table 6.2. The water was spiked to provide higher concentrations of methylene chloride and trichloroethylene in order to reduce the duration of the test. This water is considered to be more representative of the water that will require treatment during pump and treat corrective action than the water from well 87-22 (1) because it had been processed by the air strip tower, whereas, water from well-87-22 (1) had not. In a real situation, water from the air strip tower would be fed to the carbon columns.

6.3 Discussion

It was mentioned earlier that the progress of the tests was monitored by assaying the samples by the head space gas analysis method. This method provides approximate values of contaminants of interest viz. methylene chloride and trichloroethylene in a short time (2 to 3 hours), whereas, EPA Method 8240 takes several days to complete the assays. For this reason, head space gas analysis was used to determine progress of the tests. Some samples were assayed by both the methods and the comparison of the results is given in Table 6.3. For most samples, the test results by the said methods did not differ substantially, and all data were used to evaluate breakthrough. The breakthrough curves are shown in Figures 6.2 and 6.3. The breakthrough curve or plot is a relationship between the accumulative volume of feed water passed through the carbon bed and the concentration of contaminant(s) of interest in the effluent water from the carbon column. At the beginning of the test, carbon is fresh and adsorbs dissolved organics completely. The initial effluent will, therefore, be free of organics. As more and more water is passed through the carbon column, carbon no longer adsorbs all the organics to the same degree (depending on the affinity of carbon for a given organic), with the result that total adsorption of the organics does not occur. This point is called the breakthrough point. After this point is reached, the concentrations of organics rise in the effluent until their concentrations of organics in the effluent and influent are the same. Figures 6.2 and 6.3 show breakthrough curves for only methylene chloride because other organics (trichloroethylene and 1, 2 dichloroethene) did not breakthrough under the conditions of the tests. The compound controlling the carbon usage rate is, therefore, methylene chloride as it is expected to reach the breakthrough point first and exceed acceptable discharge limits before the other compounds.

TABLE 6.3

Comparison of Assay Results by Head Space Gas Analysis and EPA Method 8240

Sample Number	Assay by Head Space Gas Analysis Method (ppm)	Assay by EPA Method 8240 (ppm)
CCC-1.3	0.34	0.38
CCC-1.6	0.77	1.6
CCC-1.7	1.0	1.3
CCC-1.10	1.1	1.5
CCC-2.6	0.23	0.31
CCC-2.7	0.38	0.35
CCC-2.8	0.58	0.86
CC-1.4	0.49	0.49
CC-2.5	0.02	0.08
CC-2.7	2.1	1.9

TEST #1

INFLUENT CONCENTRATIONS AT START OF TEST

METHYLENE CHLORIDE (MeCL) 2600 ppb

EFFLUENT CONCENTRATIONS AT END OF TEST

METHYLENE CHLORIDE (MeCL) 1800 ppb

FLOW RATE = 15ml/MIN. (5.2 gpm/ft²)

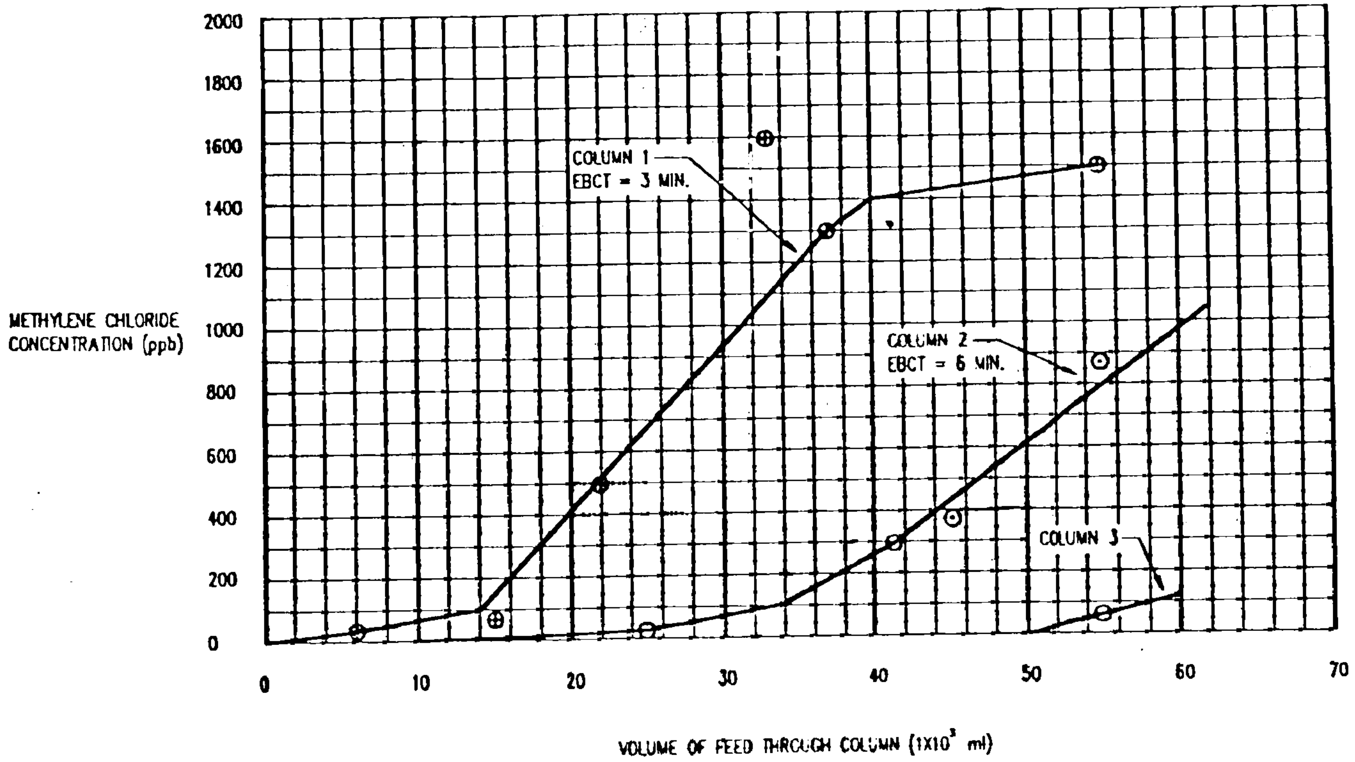


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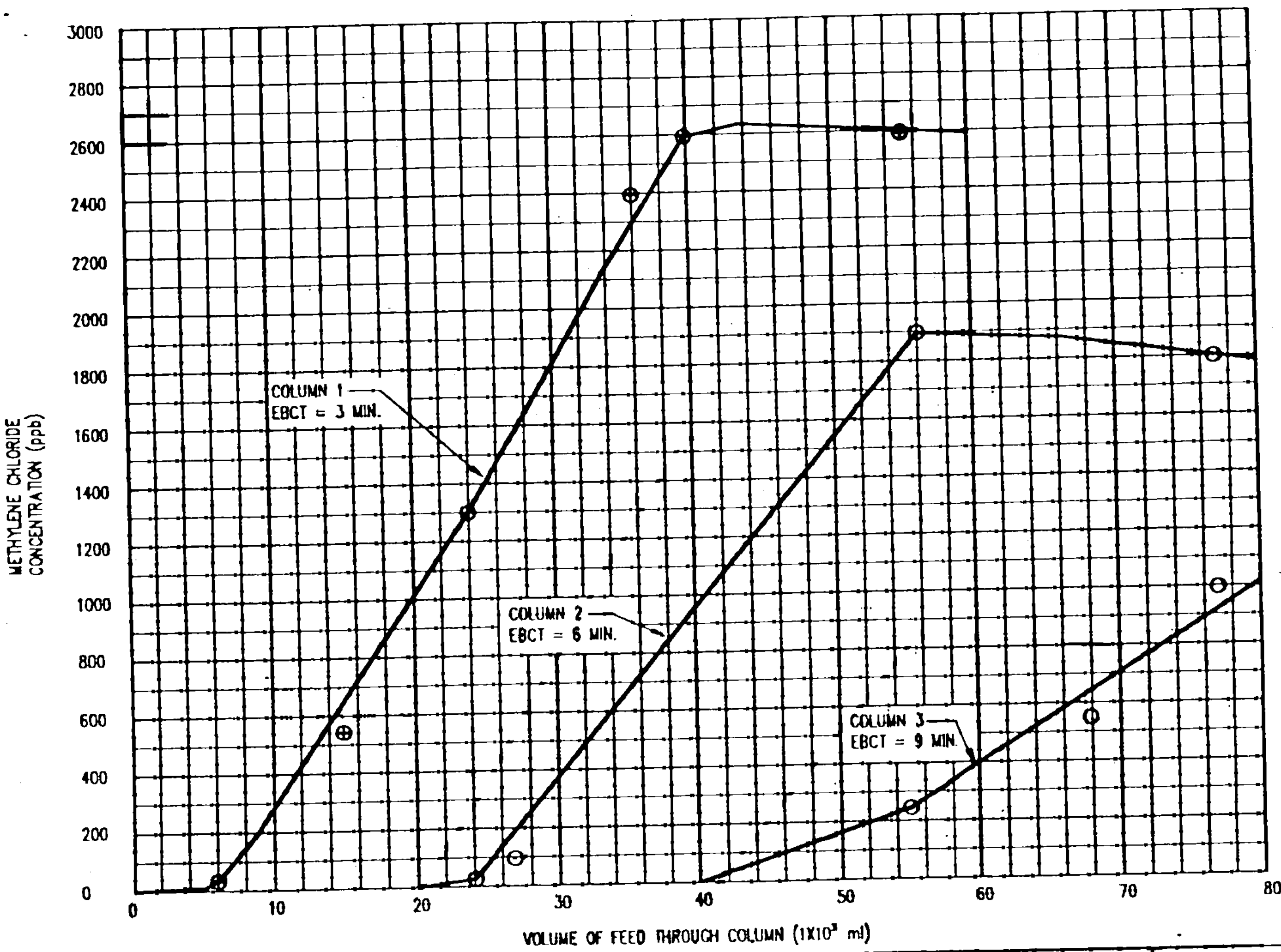
FIGURE - 6.2

BREAKTHROUGH CURVES FOR TEST #1



TEST #2

INFLUENT CONCENTRATIONS AT START OF TEST

METHYLENE CHLORIDE (MeCL) 3800 ppb

EFFLUENT CONCENTRATIONS AT END OF TEST

METHYLENE CHLORIDE (MeCL) 1800 ppb

FLOW RATE = 15ml/MIN. (5.2 gpm/ft²)

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Although four columns were used in the tests, the breakthrough curves for only three are given. The reason is that the methylene chloride did not breakthrough in the fourth column during the test period. This was not expected when the tests were designed. The runs had to be stopped because the available feed water was used up. Although no data for the fourth column could be collected because of the reason given above, data provided by the three are considered to be adequate for the design of carbon columns for a treatmant plant with a 50-60 gpm capacity.

It should be noted, that although a floating cover was used on the top of the feed water supply drum to reduce the loss of volatiles (during the course of tests) due to head space, volitization, assay of the feed samples taken at the beginning and at the end of the tests show that there was significant loss of methylene chloride in spite of the floating cover. (see Tables 6.1 and 6.2). The reason for this is not clear.

Though this loss probably influenced the results somewhat, the basic information and data provided by the tests, such as poor loading of methylene chloride on carbon, is considered to be valid.

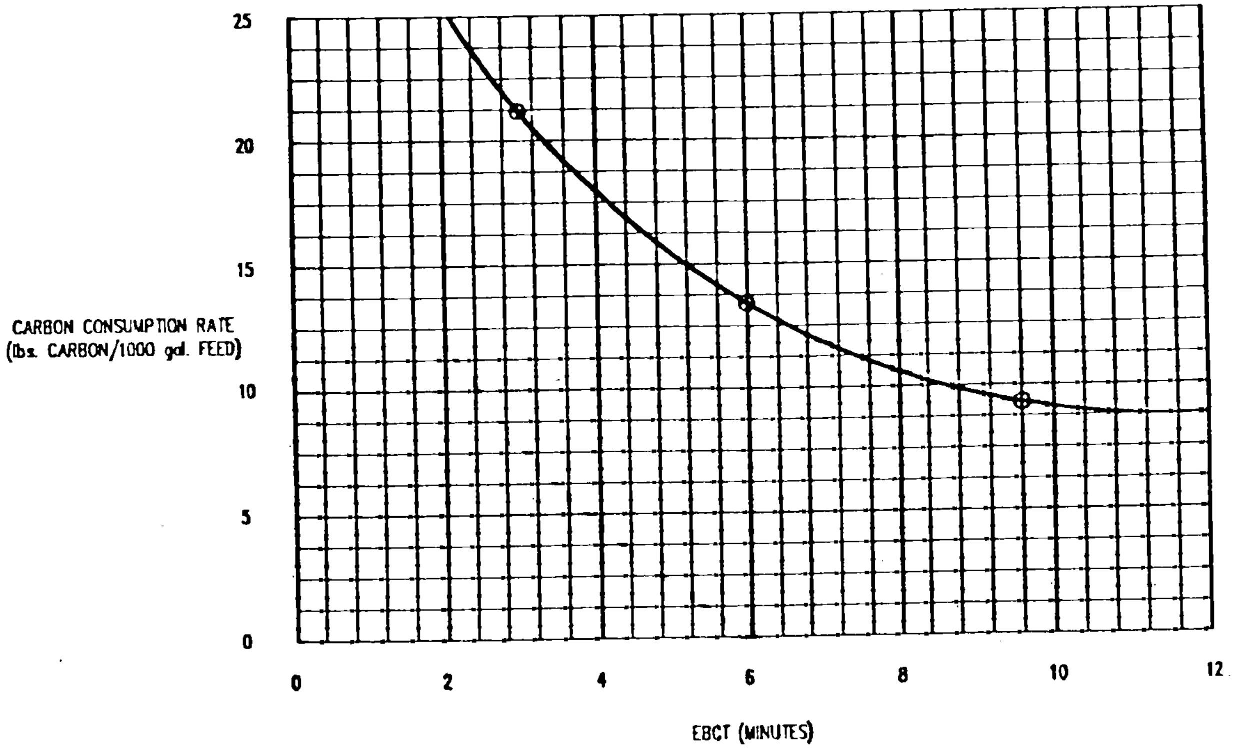
- Estimate of Optimum EBCT

The breakthrough curves for different EBCT are shown in Figures 6.2 and 6.3. The curves show that approximately 8000 ml of water can be passed through the bed for an EBCT of 3 minutes without exceeding a methylene chloride concentration of 5 ppb in the effluent. Comparatively, the volumes of water that can be treated for an EBCT of 6 and 9 minutes are estimated at 24,000 ml and 50,000 ml respectively. This means that with an increase in EBCT, the volume of water that can be processed without exceeding 5 ppb for methylene chloride also increases. Since carbon will have to be replaced or regenerated when the effluent concentration exceeds the regulatory limit (to be defined), the regeneration rate for the three EBCT's (3 min., 6 min., and 9 min.), are estimated at 21 lb. of carbon/1000 gal., 13.9 lb./1000 gal., and 9.6 lb./1000 gal. respectively. The calculations assume that the regeneration will take place as soon as methylene chloride in the effluent exceeds a regulatory limit. In other words, the carbon bed is not taken to saturation capacity for methylene chloride. This is further discussed in the subsequent section.

The plot of estimated carbon consumption rate vs. EBCT is shown in Figure 6.4. This plot shows that beyond an EBCT of 9 to 12 minutes, there is no significant drop in the carbon consumption rate. Since higher EBCT requires a larger carbon inventory and, hence, larger size column and cost, having an EBCT greater than 9 to 12 minutes is not likely to be cost-effective. For this reason, it appears that the optimum EBCT for the water treated in the tests is between 9 to 12 minutes.

- Optimum Carbon Usage Rate

It was mentioned earlier that the carbon usage rate is an important variable and it significantly affects the operating cost. The curve for Column #3 in Figure 6.2 shows that if a single column providing an EBCT of 9 minutes is used then carbon will have to be replaced after 50,000 ml of solution has passed through the bed in order to maintain the concentration of methylene chloride in the effluent below 5 ppb. This translates into a consumption rate of 9.6 lb. of carbon/1000 gal. of water treated or a loading of approximately 1.8 mg methylene chloride per gram of carbon. The saturation capacity of carbon for methylene chloride was calculated from



DRAWN BY: MDB	REV. 0	RESOURCE TECHNOLOGIES GROUP, INC. DENVER, CO	FIGURE – 6.4 ESTIMATED CARBON CONSUMPTION RATE AS A FUNCTION OF EBCT
DATE 4/25/90			

the breakthrough curve and is estimated to be approximately 2.9 mg of methylene chloride/gram of carbon. So by allowing the carbon in the column to reach it's saturation capacity, it appears that the carbon consumption can be reduced to 5.96 lb. of carbon/1000 gal. of water treated. The carbon can be made to approach it's saturation capacity by having two columns operating in series. In this arrangement, leakage from the first column is adsorbed by the carbon in the second column. Two columns operating in series rather than one column would be approximately twice as expensive as the one column, but since the project is long term, the cost savings in the operating cost through savings in the carbon replacement cost more than justify the use of two columns in series (rather than one single column) for a commercial plant. Even with two columns, the usage rate for carbon is estimated to be at least 5.96 lb./1000 gal. For a 46 gpm plant, this usage rate translates into a consumption of approximately 396 lb. of carbon per day which is quite substantial. It is, therefore, imperative that the equipment or process used ahead of the carbon columns (air stripping and UV Oxidation) is designed to work as efficiently as possible; especially the air strip tower which is a relatively low capital cost item, so that feed to the carbon columns is as close to 5 ppb for methylene chloride as possible. In other words, the role of the carbon columns in the plant should be just for polishing the effluent water before it is discharged rather than removing contaminants. With this goal in mind, the carbon usage rate can be substantially reduced from the usage rate projected by the experimental data.

6.4 Computer Modeling

A computer model developed by TIGG Corporation, referred to as Adsorption Predictive Technique (APT), was used to predict carbon usage rates for different concentrations of methylene chloride in the feed water. The usage rates predicted by this model are given in Table 6.4. For a 2 ppm methylene chloride

TABLE 6.4

Estimates of Carbon Consumption Predicted by Computer Model

Methylene chloride Conc. in Feed (ppm)	Flow rate (gpm	Est. Consumption # Carbon/day
20	46	874
2	46	454
0.2	46	241
0.02	46	121
0.005	46	73.5

concentration in the feed water, the model predicts that the carbon usage rate for the commercial plant (46 gallons/minute) would be 454 pounds per day. The usage rate calculated from the experimental data for a 46 gpm plant is 395 pounds/day which is close to the value predicted by the model. At 5 ppb methylene chloride concentration, the carbon usage rate is expected to be 73.5 lb/day. The data in Table 6.4 shows that to reduce the carbon usage rate, the methylene chloride concentration in the feed to the columns should be as low as possible. Based on the conceptual treatment plant design, the feed water to the columns would first be treated in air strip towers, the design and performance of the air strip system will control the methylene chloride level in the feed to the carbon columns. The air strip units, therefore, need to be designed for the maximum practible efficiency. For this reason, two air strip towers in series, instead of one, are recommended for the plant.

6.5 Conclusions and Recommendations

Based on the discussion presented in the previous sub-section, the following conclusions can be drawn:

- Under the test conditions, methylene chloride is the controlling compound for EBCT and carbon usage rate determinations.

- The optimum EBCT is estimated to be at 9 minutes.

- Two carbon columns in series are recommended rather than single columns or two columns in parallel. Series operation is likely to provide significant savings in the carbon usage rate and, hence, the operating cost.

- The tests were carried out at a specific flow rate of 5 gpm/ft^2, but it is recommended that the columns be designed for 2 to 3 gpm/ft^2 instead, as this would provide additional EBCT and, hence, some insurance against wide fluctuations in the feed concentration.

- Carbon bed depth of 4 ft. is recommended. This bed depth would provide an EBCT of 12 minutes at a specific flow rate of 2.5 gpm/ft^2.

- Due to poor adsorbtion of methylene chloride on carbon, carbon usage rate may be substantial. It is therefore imperative, that the unit operations ahead of the carbon columns be designed for effective removal of methylene chloride.

7.0 UV/OXIDATION TEST

A UV/Oxidation test was conducted on groundwater samples obtained from Well 87-13 (1). This test was conducted by Peroxidation Systems, Inc. (PSI) of Tucson, AZ.

The original UV/OX treatability study plan was based on the data as noted in Section 3. The samples taken during the Pilot Test and subsequent samples did not show measurable semivolatiles or PCBs. The UV/OX test conducted by PSI was based on the removal of the most difficult compound to oxidize which was Methylene Chloride. The procedures used by PSI and the results obtained by PSI are in the PSI report which has been included herein in its entirety.

CONFIDENTIAL TESTING REPORT

DESTRUCTION OF ORGANIC CONTAMINANTS IN GROUNDWATER WITH THE **perox-pure**^{tm} PROCESS

for

Resource Technologies Group, Inc.
Lakewood, Colorado
Purchase Order No. RTG-90-15

by

Peroxidation Systems, Inc.
4400 E. Broadway, Suite 602
Tucson, Arizona 85711

April 5, 1990

The information contained in this report includes descriptions and procedures which are confidential to Peroxidation Systems, Inc. The report shall not be copied nor released to third parties without prior approval from Peroxidation Systems, Inc.

TABLE OF CONTENTS

INTRODUCTION

The **perox-pure**^{tm} Process destroys dissolved organic contaminants in water by means of chemical oxidation. Ultraviolet (UV) light catalyzes the chemical oxidation of organic contaminants in water by its combined effect upon the organic contaminants and its reaction with hydrogen peroxide (H2O2). Many organic contaminants absorb UV light and may undergo a change in their chemical structure or may become more reactive with chemical oxidants. More importantly, UV light at less than 400 nm wavelength reacts with H2O2 molecules to form hydroxyl radicals. These powerful chemical oxidants then react with the organic contaminants in the water. If carried to completion the reaction products of hydrocarbon oxidation with the **perox-pure**^{tm} Process are carbon dioxide and water.

Peroxidation Systems, Inc. (PSI) was contracted by Resource Technology Group, Inc. (RTG) to perform a treatability study on contaminated groundwater using the **perox-pure**^{tm} Process. The source of the groundwater was identified as Well #87-13 at a Bell Aerospace Textron Site in Niagara Falls, New York. The groundwater reportedly contained approximately 1,500 mg/l of methylene chloride (MeCl), 1,1,1-trichloroethane (TCA) and trichloroethene (TCE) as well as low ug/l concentrations of phenol, polychlorinated biphenyls (PCBs) and pesticides. The groundwater was to be air purged by PSI to strip out 99% of the volatile organics to simulate the air stripping process that would preceed the **perox-pure**^{tm} equipment at a full-scale installation. The treatment objective specified by RTG was the destruction of the total toxic organics (TTO) in the purged groundwater to less than 2 mg/l. Given the initial concentrations of the organic contaminants, meeting the TTO objective would depend entirely on MeCl, TCA and TCE destruction.

A bench-scale **perox-pure**^{tm} treatability study was performed on the groundwater during February, 1990 at the PSI Testing Laboratory in Tucson, Arizona. These tests were designed to provide a range of data from which full-scale treatment criteria and costs would be projected.

TESTING PROCEDURES

Description of Groundwater

On January 22, 1990, nine gallons of groundwater from Well #87-13 was received from RTG at the PSI Laboratory in Tucson, Arizona. The water was contained in 1-gallon glass bottles.

The groundwater as received contained some fine, suspended solids which gave the water a cloudy characteristic. The water was gravity filtered to remove these solids. Characterization of the filtered water sample was then performed by PSI to determine parameters of importance for **perox-pure**^{tm} treatment. The results were as follows:

Visual Color:	Pale yellow
pH:	7.7
Iron (mg/l):	0.5
Chloride (mg/l):	900
Chemical Oxygen Demand (mg/l):	800
Total Organic Carbon (mg/l):	152
Total Dissolved Solids (mg/l):	4,100
Total Suspended Solids (mg/l):	<10
Alkalinity (mg/l):	1,240
Turbidity (FTU):	10

After characterization, the groundwater was analyzed by PSI via EPA Method 601 for volatile organic halogens. The results were as follows:

Methylene Chloride (mg/l):	1,040
Trichloroethene (mg/l):	844
1,1,1-Trichloroethane (mg/l):	84

Testing Protocol

The groundwater was purged with air for one hour prior to **perox-pure**^{tm} treatment to reduce the concentration of the MeCl to approximately 10 mg/l (99% removal). The MeCl was used to gauge the air purging because of its high initial concentration and its relative difficulty to oxidize compared to TCE and TCA. After air purging, the COD of the groundwater was reduced to 200 mg/l and the TOC was reduced to 75 mg/l.

The bench-scale **perox-pure**^{tm} test unit was charged by placing an aliquot of the purged water into a recycle reservoir. A pump was started which circulated the solution through the reactor and back into the reservoir providing continual mixing in the closed system. Sulfuric acid for pH adjustment, when used, was added at this time. The UV lamp was illuminated to start a test, and H2O2 was added as required to maintain a constant concentration in solution. The solution temperature was controlled through use of an in-line cooling coil. All materials in contact with the solution were glass, quartz, stainless steel, viton or teflon.

After the appropriate retention times, samples of the treated water were collected in duplicate 40-ml vials. An untreated sample was also collected in the same way. These samples were analyzed by PSI via EPA Method 601 for volatile organic halogens.
Selected samples from the best test were shipped to Enseco Rocky Mountain Analytical at RTG's request for analysis of volatile organics, phenol, PCBs and pesticides.

TESTING RESULTS

Three **perox-pure**^{tm} treatment tests were performed by PSI on the purged groundwater. These tests were designed to determine the effects of H_2O_2 dosage and groundwater pH on the rates of MECl, TCE and TCA destruction. The test conditions are shown in Table 1. The pH of the groundwater was adjusted in Test 3 with 0.04% (vol) sulfuric acid.

Table 1

Bench-Scale **perox-pure**^{tm} Treatment Conditions
for the Bell Aerospace Well #87-13 Groundwater

Test	H_2O_2 in Solution (mg/l)	Initial pH
1	150	7.7
2	50	7.7
3	50	3.8

The PSI analytical results for Tests 1 through 3 are shown in Table 2 along with the MeCl results provided by Enseco. The untreated samples contained approximately 15 mg/l of MeCl. The PSI and Enseco results agreed very well. No TCE or TCA was detected in any of the samples, probably because they were purged out of the water prior to testing. The best MeCl destruction was achieved in Test 1, made with the highest H_2O_2 dosage of 150 mg/l. The pH adjustment in Test 3 did not significantly affect the rate of MeCl destruction.

Table 2

Bench-Scale **perox-pure**^{tm} Treatment Results
for the Bell Aerospace Well #87-13 Groundwater

Test	Full-Scale Oxidation Time (min)	Methylene Chloride (mg/l) By PSI	Methylene Chloride (mg/l) By Enseco
1	0	14.0	11.0
	1.5	9.56	
	3	4.96	
	6	0.99	0.83
2	0	15.7	
	1.5	14.7	
	3	8.50	
	6	2.12	
3	0	17.6	
	1.5	13.1	
	3	6.13	
	6	2.25	

FULL-SCALE TREATMENT CONDITIONS

Treatment Criteria

The criteria used to project full-scale treatment conditions for the **perox-pure**^{tm} Process are summarized in Table 3. The treatment cases specified by RTG were: (I) treatment of DNAPL Zone water following air stripping, (II) treatment of Site Boundary water, (III) treatment of streams I & II combined. The flow rate and effluent TTO criteria for each case were specified by RTG. The influent TTO for each case was taken to be the influent MeCl concentration after air stripping because MeCl is expected to be the only significant contaminant remaining.

Table 3

Criteria for Full-Scale Treatment
of the Bell Aerospace Well #87-13 Groundwater

	Case I	Case II	Case III
Flow Rate (gpm)	6	40	46
Influent Total Toxic Organics to the **perox-pure**^{tm} Unit (mg/l)	10	10	10
Effluent Total Toxic Organics (mg/l)	2	2	2

Recommended Process Conditions

Full-scale **perox-pure**^{tm} Process conditions are projected in Table 4 for each treatment case. The full-scale oxidation times were calculated from the treatment criteria in Table 3 using the full-scale rate data from Test 1. The oxidation times were then used along with the flow rates from Table 3 to determine the appropriate **perox-pure**^{tm} models and power demands. The H2O2 consumption from Test 1 was used to calculate the full-scale dosages in Table 4, accounting for the changes in oxidation time and equipment size.

Table 4

Full-Scale **perox-pure**^{tm} Process Conditions
for Treatment of the Bell Aerospace Well #87-13 Groundwater

	Case I	Case II	Case III
Oxidation Time (min.)	3.2	3.2	3.2
perox-pure^{tm} Model	LV 30/60	CW 120	CW 120
Power Demand (KW)	15	105	120
50% H2O2 Dosage (lbs./1000 gal)	1.3	1.3	1.3

CAPITAL AND TREATMENT COST PROJECTIONS

Capital Costs

The recommended **perox-pure**^{tm} Models for Cases I, II, and III were presented in Table 4. The budgetary capital costs for both a customer owned system, and a PSI owned system with a PSI Full Service Agreement for each case are shown below. The customer is responsible for freight costs, site preparation and foundation, power to the battery limit, and influent/effluent pipes, pumps and tanks.

	Customer Owned and Operated System	PSI Owned System with Full Service Agreement
Case I (DNAPL Zone)		
Model LV 30/60	$87,850	Included
H2O2 Storage and Feed System	Included with H2O2 Contract	Included
Start-up Services & Training	5,000	$5,000
Case II (Site Boundary)		
Model CW 120	$155,100	Included
H2O2 Storage and Feed System	Included with H2O2 Contract	Included
Start-up Services & Training	5,000	$5,000
Case III (I and II Combined)		
Model CW 120	$155,100	Included
H2O2 Storage and Feed System	Included with H2O2 Contract	Included
Start-up Services & Training	5,000	$5,000

Treatment Costs

The projected costs' for **perox-pure**^{tm} treatment of each of the groundwater cases are shown below. The energy cost was assumed to be $0.07/KWH. Amortization of capital is estimated at 20% of the capital investment per year. The PSI Technical Service Fee includes repair/replacement parts and labor. The PSI Full Service Fee includes equipment lease, chemical supply and repair/replacement parts and labor.

	Customer Owned and Operated System ($/month)	PSI Owned System with Full Service Agreement ($/month)
Case I (DNAPL Zone)		
UV Energy @ $0.07/KWH	$ 756	$ 756
50% H202 @ $0.84/lb. (delivered)	283	Included
Amortization of Capital	1,460	Included
PSI Technical Service Fee	2,830	---
PSI Full Service Fee	---	3,845
Totals	$5,329	$4,601
Case II (Site Boundary)		
UV Energy @ $0.07/KWH	$ 5,290	$ 5,290
50% H202 @ $0.65/lb. (delivered)	1,460	Included
Amortization of Capital	2,585	Included
PSI Technical Service Fee	3,731	---
PSI Full Service Fee	---	6,484
Totals	$13,066	$11,774
Case III (I and II Combined)		
UV Energy @ $0.07/KWH	$ 6,048	$ 6,048
50% H202 @ $0.65/lb. (delivered)	1,680	Included
Amortization of Capital	2,585	Included
PSI Technical Service Fee	3,731	---
PSI Full Service Fee	---	6,704
Totals	$14,044	$12,752

SUMMARY

This bench-scale testing program has demonstrated that the perox-pure^{tm} Process is an effective method of treating the contaminated groundwater to meet the required treatment objectives. Specific test results and cost projections are as follows:

1) The groundwater as received contained 1,040 mg/l of MeCl, 844 mg/l of TCE, and 84 mg/l of TCA. After air purging, the groundwater contained approximately 15 mg/l of MeCl and no detectable amounts TCE or TCA.

2) Testing on the air purged groundwater demonstrated destruction of MeCl to less than 1 mg/l. The best destruction rate was achieved with 150 mg/l of H2O2 in solution and no pH adjustment.

3) The full-scale oxidation time to destroy 10 mg/l of MeCl in the groundwater to 2 mg/l is projected to be 3.2 minutes. Based on this oxidation time, treatment costs for the DNAPL Zone, the Site Boundary, and both of these waters combined were estimated to be $4,601, $11,774, and $12,752 per month, respectively, for PSI owned systems with Full Service Agreements.

4) Pretreatment of the groundwater for solids removal is required.

8.0 COMMERCIAL PLANT PROCESS FLOW SHEET

Based on the pilot air strip tower, UV Oxidation, and dynamic bench scale carbon column test data, the process flow sheet for the commercial plant was developed. This flow sheet is shown in Figure 8.1. The description of the process, process design criteria and equipment sizing and selection for the commercial plant are briefly discussed as follows:

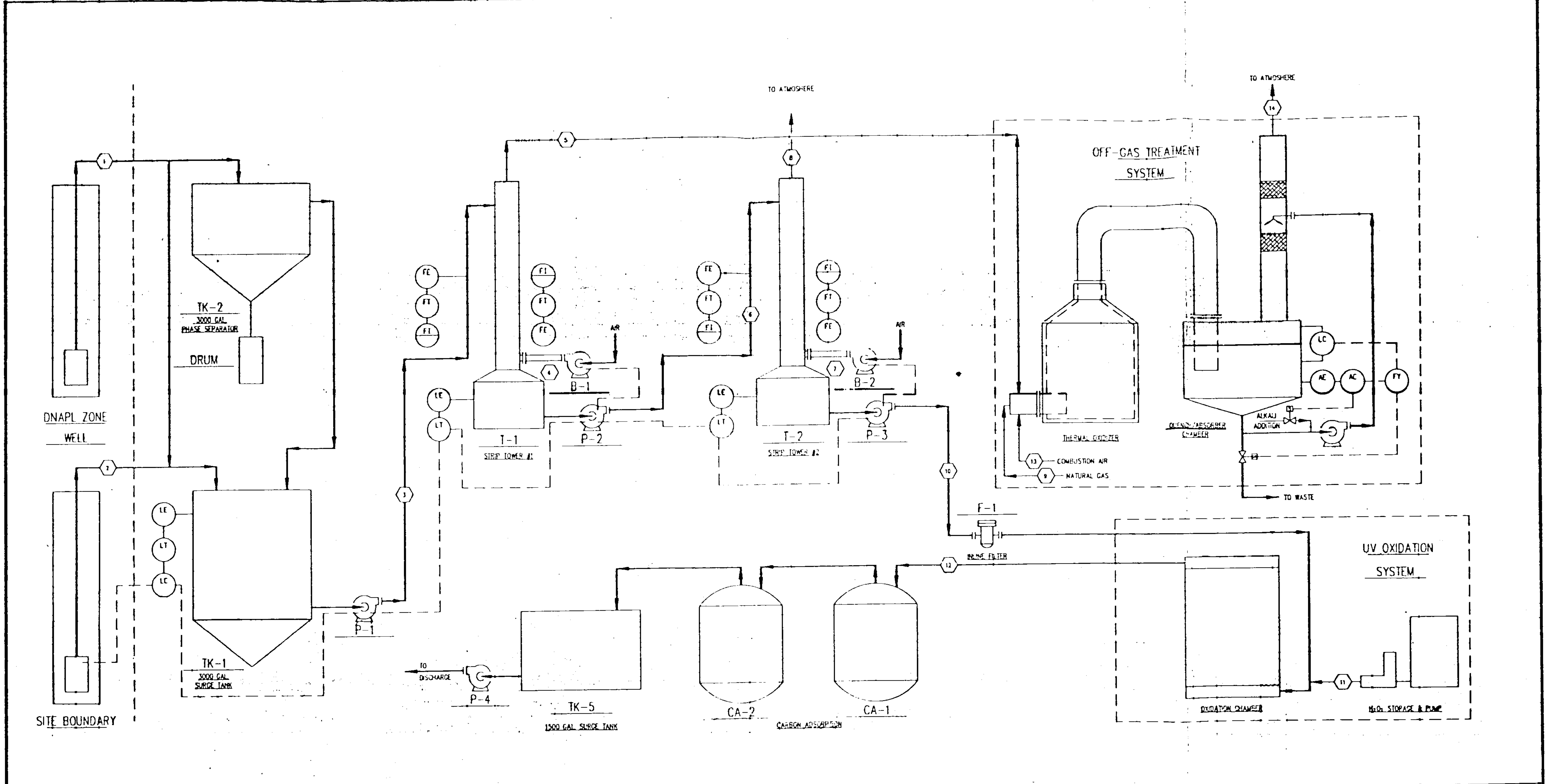
8.1 Process Description

The process uses four main unit operations. These are:

- Air stripping for removal of most of the volatile organics in the feed water.
- UV Oxidation for PCBs and residual volatile organics removal in the effluent from the air stripping step.
- Carbon columns for polishing the effluent before it is discharged.
- Air strip tower off-gas treatment system for removal of contaminants in the air exiting from the strip tower.

The proposed flow sheet has been designed to treat waters from both dense non-aqueous phase liquid (DNAPL) zone and from site boundaries. The water from the DNAPL zone is received in a phase separator TK-2, whereas the water from the site boundary is received in a surge tank TK-1. Both TK-1 and TK-2 are provided with level controllers. The level controllers on high high signal turn the well pumps off. The low low level signal from TK-1, however, stops the TK-1 pump so that it does not run dry. This pump turns on again when a pre-determined

Figure 8.1



STREAM # / ITEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TOTAL POUNDS/HOUR	3004	20,027	23,031	2,100	2,110	23,021	2,100	2,100	44	23,021	3.5	23,025	1584	3738
FLOW RATE (GPM)	8.0	40.0	48.0	460 SCFM	460 SCFM	46	460 SCFM	460 SCFM	18.7 SCFM	46	7 gal/day	46	347 SCFM	824 SCFM
MeCl POUNDS/HOUR	8.0	0.2	8.2	-	8.168	0.031	-	0.031	-	0.00018	-	-	-	-
TCE POUNDS/HOUR	3.8	0.2	3.8	-	3.799	0.0004	-	-	-	-	-	-	-	-
TCA POUNDS/HOUR	0.22	-	0.22	-	0.2198	0.00003	-	-	-	-	-	-	-	-
PPM MeCl	2000	10	269	-	2923	1.35	-	14.8	-	0.0067	-	-	-	-
PPM TCE	1200	10	165	-	1800	0.0174	-	-	-	-	-	-	-	-
PPM TCA	72	-	9.6	-	104	0.0013	-	-	-	-	-	-	-	-

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BAT WASTEWATER TREATMENT FACILITY
FLOW DIAGRAM

SCALE: NONE | DRAWN BY: NOB | 6/24/90 | PROJECT LOCATION: NIAGARA FALLS, NY | PROJECT #

RTG RESOURCE TECHNOLOGIES GROUP, INC.

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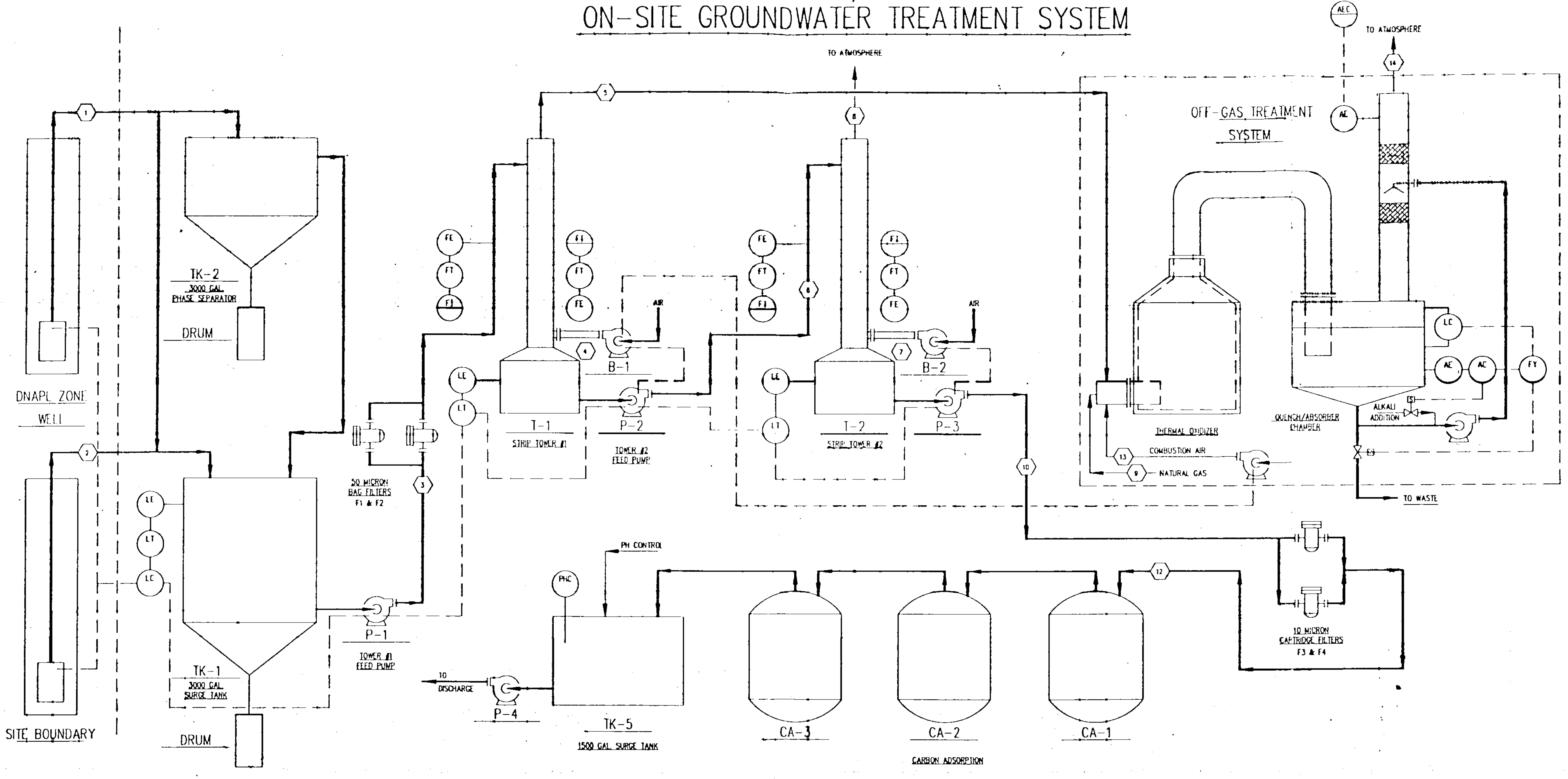
CLIENT: BELL AEROSPACE TEXTRON
NIAGARA FALLS, NY

DRAWING NUMBER: FIG - 8.1

BELL AEROSPACE TEXTRON
WHEATFIELD, NEW YORK
ON-SITE GROUNDWATER TREATMENT SYSTEM



STREAM # / ITEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TOTAL POUNDS/HOUR	3004	20,027	23,031	2,100	2,110	23,021	2,100	2,100	44	23,021	3.5	23,025	1584	3738
FLOW RATE (GPM)	6.0	40.0	46.0	460 SCFM	460 SCFM	46	460 SCFM	460 SCFM	18.7 SCFM	46	7 gal/day	46	347	824
MeCl POUNDS/HOUR	6.0	0.2	6.2	–	6.169	0.031	–	0.031	–	0.00016	–	–	–	–
TCE POUNDS/HOUR	3.6	0.2	3.8	–	3.799	0.0004	–	–	–	–	–	–	–	–
TCA POUNDS/HOUR	0.22	–	0.22	–	0.2199	0.00003	–	–	–	–	–	–	–	–
PPM MeCl	2000	10	269	–	2923	1.35	–	14.8	–	0.0067	–	–	–	–
PPM TCE	1200	10	165	–	1800	0.0174	–	–	–	–	–	–	–	–
PPM TCA	72	–	9.6	–	104	0.0013	–	–	–	–	–	–	–	–

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BY

BAT ONSITE WASTEWATER TREATMENT
FLOW DIAGRAM

SCALE: NONE
DRAWN BY: MOB 4/24/90
PROJECT LOCATION: NIAGARA FALLS, NY
PROJECT #

RTG RESOURCE TECHNOLOGIES GROUP, INC.

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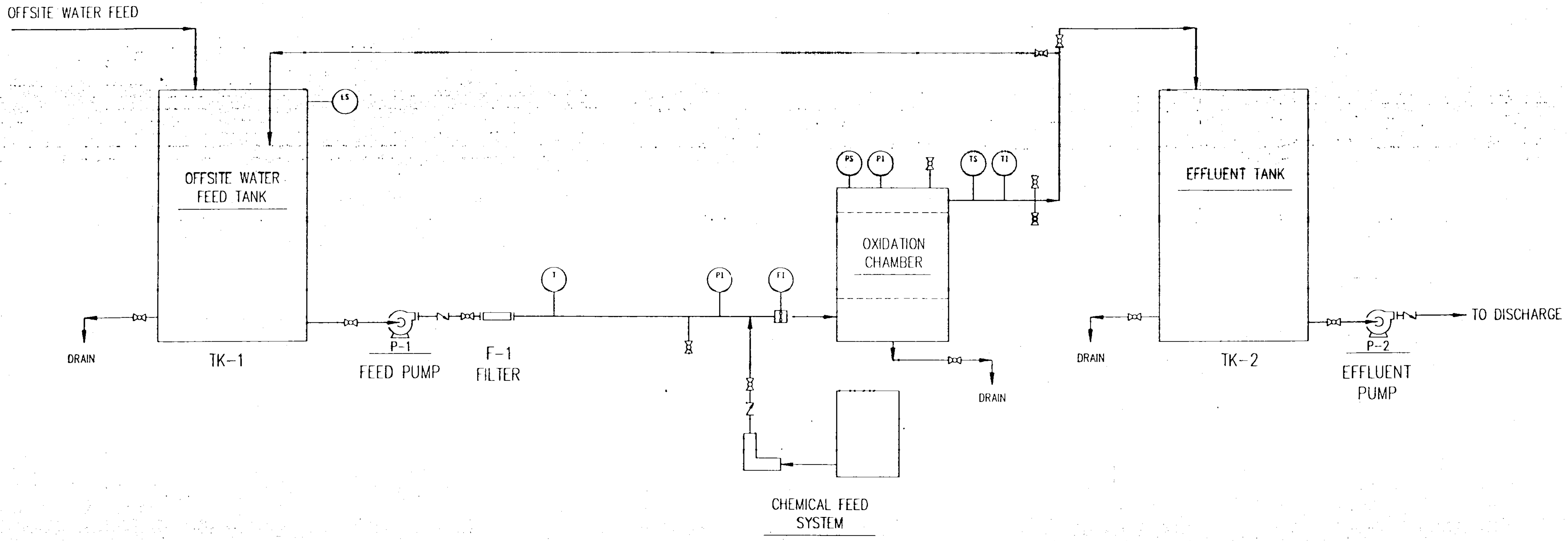
CLIENT
BELL AEROSPACE TEXTRON
WHEATFIELD, NY

DRAWING NUMBER
Fig. 8.2

BELL AEROSPACE TEXTRON
WHEATFIELD, NEW YORK
OFF-SITE GROUNDWATER TREATMENT SYSTEM



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BY:

BAT OFF-SITE GROUNDWATER TREATMENT SYSTEM

SCALE: NONE | DRAWN BY: JEP 6/14/90 | PROJECT LOCATION: NIAGRA FALLS, NY | PROJECT #

RTG RESOURCE TECHNOLOGIES GROUP, INC.

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CLIENT: BELL AEROSPACE TEXTRON
WHEATFIELD, NY

DRAWING NUMBER
Fig. 8.3

level is reached in TK-1. The phase separator is provided for the DNAPL zone water in order to separate any DNAPL that might be present in this water. If DNAPL is present in this water, it will sink to the bottom of the separator, because it is heavier than water. It is manually drained periodically from the bottom of the separator into a drum. The DNAPL free water from the separator overflows into the surge tank TK-1, which receives water from the wells on the site boundaries also. Water from the site boundary wells is not expected to contain any DNAPL and is, therefore, not treated in the phase separator.

- **Air Stripping of Volatile Organics**

The combined water from the surge tank TK-1 is pumped to two air strip towers arranged in series. Two towers are recommended because test data show that one tower is not likely to remove volatile organics to the desired levels (99.99%) with a practical packing height of 25 feet. The contaminated water is pumped to the top of the first tower and it is allowed to flow down by gravity through a packing of pre-determined height, whereas, air supplied by the blower B-1, is introduced into the tower through the bottom opening as shown in the flow sheet. The air flow rate is controlled to get the desired air-to-liquid flow ratio. The packing provides surface area for water and air to come in contact with each other. Due to counter-current flow of water to air, water flowing down the tower loses it's volatile organic contaminants to the air rising from the bottom of the tower to the top. The water collected in the bottom section of the tower called sump, is pumped to the second tower. Air for stripping the volatiles in this water is provided by the blower B-2. Removal of approximately 99.5% of the volatile organics takes place in the second tower. It is expected that the water exiting from the second tower will have less or equal to 5 ppb of methylene chloride. This water is further treated for PCBs and volatile organics removal in a UV/Oxidation unit, whereas, air exiting from the top of the first tower is sent to the off-gas treatment system before it is exhausted into the atmosphere. The air from the second tower is discharged into the atmosphere without any treatment as air from this tower is expected to have only slight amounts of contaminants.

The strip towers operate automatically. The water level in the well of each tower is controlled by a level controller which turns Pumps P-1, P-2, and P-3 on and off as required to maintain a given level of water in the well. Pressure drop across the packing in each tower is measured and indicated by a locally-mounted indicator. This measurement helps in evaluating the performance of the strip tower; channelling or plugging of the bed.

Air needed for the operation of the towers can be an inside air (heated building air) or an outside air. The performance efficiency of a strip tower is greatly affected by the water temperature and not so much by the air temperature because mass and heat capacity of air are both quite small as compared to the mass and heat capacity of water under the conditions the towers will be operated. If it is assumed that the performance of the towers is not affected by the air temperature, then some savings in the heat could be realized by using outside air instead of inside air. Preliminary calculations show that this savings could be in the range of $2,000 - $2,500/year. Use of outside air, however, would require additional ductwork, wall penetration, filter/s, louver installation, etc. For this reason, it appears that the inside air will be more convenient and simpler to use in the towers than the outside air.

- **UV Oxidation**

The purpose of providing an UV Oxidation unit is to remove any PCBs and small quantities of volatile organics that might still be present in the water exiting from the second air strip tower. The pH of this water is adjusted, with sulfuric acid if necessary. The water is then pumped into a reactor provided with UV lamps. Hydrogen peroxide is added to the water in pre-determined quantities to ensure that the solution is adequately oxidized. This method is expected to destroy PCBs and any residual volatiles left over in the water from the second air strip tower to their MCL levels.

- **Carbon Adsorption**

The effluent from the UV Oxidation step is further treated in carbon columns. The purpose of this step is two-fold; (1) to polish the effluent before it is discharged and (2), to provide insurance against discharge of contaminated water in case unit operations ahead of carbon adsorption (Air Strip and UV/Oxidation) malfunction due to some reason.

The process uses two downflow fixed bed carbon columns arranged in series. The effluent from the first column is fed into the second column. When carbon in the first column reaches its saturation capacity, as determined by the assay results, the column is taken off the line and its loaded carbon is replaced with the regenerated carbon. Once filled with the regenerated carbon, the column is brought back on-stream again, not as a lead column but as a follow-up unit. The effluent from this step is received in a surge tank TK-3, where the pH is adjusted if necessary, and water is then pumped and discharged. The only instruments used by the system are the locally-mounted pressure gauges to indicate pressure drop across the columns.

- **Air Strip Tower Off-Gases Treatment**

The air exiting from the first air strip tower is likely to have unacceptable levels of contaminants. This air will, therefore, require some treatment before it is discharged. The treatments available are 1) carbon adsorption followed by desorption with steam and 2) thermal oxidation. Both methods were evaluated and the evaluation showed that thermal oxidation would be a more cost-effective method and, hence, it was selected for the 46 gpm plant.

The thermal oxidizer used to control VOC emissions will oxidize the VOCs to carbon dioxide, water and hydrochloric acid. The hydrochloric acid will be removed by an alkaline scrubber and the final exhaust from the scrubber will be acid and VOC-free. Monitors may be installed in the exhaust stack to assure that the exhaust is acid and VOC-free.

If PCBs are present in the water, they will not be removed by air stripping due to the extremely low vapor pressure of PCBs. Physical carryover of water containing PCBs will be prevented by a dual demister section installed at the top of the air strip towers. Thus, no PCBS will go into the thermal oxidizer system.

It is estimated that the flue gases from the oxidizer will be at approximately 1500°F temperature. At this temperature, the heat content of the gases is estimated at approximately 1 million BTU/hr. This heat can be utilized to heat the feed water to the strip towers. Preliminary calculations show that the feed water can be heated from 55°F to 100°F with a double pipe U-shaped heat exchanger. In this heat exchanger, the flue gases at high temperature (1500°F) flow in one direction in an inside pipe, whereas the feed water to be heated flows in the annular space between the outer and inner pipes in the opposite direction. The installed cost of this equipment is estimated at $60,000. At 100°F temperature instead of 55°F, the expected performance of the strip towers should be greatly enhanced due to the increase in the overall mass transfer coefficient for methylene chloride, which is almost twice as much at 100°F as it is at 50°F. Because of this, the packing height required for the towers would be 13 - 15' instead of 23'. So if the feed water is heated with the waste heat in flue gases leaving the oxidizer, the performance of the strip towers should be better than the performance for which they have been designed. While the towers could use a smaller packing height at 100°F feed water, (13' instead of 23') it is recommended that the packing height be kept at 23' (height for feed water at 55°F), because it would ensure designed performance of the towers even if the feed water quality turns out to be worse than the quality for which the towers have been designed.

- **Filtration**

The feed water from the wells is likely to contain sand, clays, etc. For this reason, surge tanks with conical bottoms are provided to receive feed water. The conical bottom tank is adequate for removing heavy, large size solids, but is not effective in removing clays and other suspended solids. The clays and suspended solids can be removed by filtration.

Filtration prior to strip towers is not as critical as it is before carbon columns, because carbon columns act like sand filters and can become plugged quite rapidly with the solids in the feed water, whereas, strip towers can tolerate some degree of solids in the feed water.

The choice of filtration equipment available to separate clays and fine suspended solids from the feed water is quite large and it falls into two broad categories viz., (1) backwashable filter and (2), disposable cartridge filters. The advantages of each type are briefly presented below.

- Backwashable Filters

  Advantages:

  - Does not require replacement of filter media.
  - Operation is automatic with little or no operator attention.
  - Better control of operation as frequency of backwashing the media is adjustable.

  Disadvantages:

  - Generates solid/liquid waste for disposal.
  - Requires lined holding pond or similar container type with a large surface area to receive backwash slurry. Large area is required so that water can be recycled back into the process after solids have settled down.
  - May require monitor wells to monitor any loss of contaminants to water table.
  - Because of the ultimate settling density of the solids, there is some loss of water with the solids. If this semi-solid sludge cannot be buried in-place, which might be true for this project, the quantity of sludge that would require disposal could be much higher than the quantity of in-line filter cartridges requiring disposal in case in-line filters are used (instead of backwashable filters), for separating the suspended solids.
  - Higher capital cost than cartridge filters.

- <u>In-Line Filters</u>

  Advantages:

  - Does not require any water for backwashing the solids. The disposal cost would be smaller because of virtually moisture-free solids on the cartridge surface.
  - Does not require large surface area water storage and there is no recycling of water.
  - Lower capital cost - Simple to install.

  Disadvantages:

  - Higher operating cost due to frequent replacement of filter cartridges.
  - Replacement of cartridges is manual.
  - May require disposal of cartridges by incineration.

Based on the comparison presented above, it is more attractive to use in-line filters in the plant rather than the backwashable type filters.

Two in-line filter types are recommended: bag filters (50 micron) for separating the suspended solids before air stripping and smaller pore size in-line cartridge filters (10 microns) before carbon columns. The location of these filters is shown in Figure 8.2. The reason for the smaller pore size filters before the carbon columns is that the carbon columns cannot tolerate suspended solids in water as much as the strip towers can. Therefore, two in-line bag filters, each sized for a 50 gpm of flow, and two in-line cartridge filters (each 50 gpm of flow) are included in the design. Two filters are recommended instead of one, so that when one filter needs replacement of cartridges or bags, the other filter can be brought on-line so that there is no interruption of operation.

Assuming that bag filters would require replacement of bags twice a week and cartridge filters only once a week, it is estimated that approximately two 55 gallon size drums per year would be required to hold the used bags and cartridges prior to their shipment for incineration or disposal.

8.2 Description of Alternate Processes

The process described in Section 8.1, referred to as Base Case, is not the only process which was evaluated in the study. Some alternate processes were also considered.

8.2.1 Alternative One

The base case includes the use of an UV/Oxidation step. This step is justified if PCBs are present in the groundwater. The PCBs are not removed from water by air stripping and if an UV/Oxidation step is not used, it would be necessary to incinerate the carbon rather than regenerate the carbon. The alternative to UV/Oxidation would be the installation of a single additional carbon column in front of the two existing carbon columns. The purpose of this column would be to protect the downstream carbon columns from PCB contamination and allow the downstream carbon to be regenerated. Periodically, the carbon in the lead or sacrificial column would have to be removed and disposed of by incineration or any other approved method. The frequency at which the sacrificial column must be changed would depend on the PCB concentration of the feed which is unknown at this time. The capital cost of a sacrificial column will be small and the operating cost could be less than $10,000/year (assuming one carbon changeout). This alternative has the potential of lowering capital cost and possibly operating cost. A flowsheet showing this alternative is found in Figure 8.2.

Figure 8.2

8.2.2 Alternative Two

This alternative evaluated an alternate process to treat air exiting from the strip tower. In this process, decontamination of air is carried out by treating it with carbon followed by steam stripping of the contaminants instead of treating it by thermal oxidation. The treatment with carbon and steam stripping produces waste water contaminated with methylene chloride due to the high solubility of this compound in water and, therefore, the water needs to be recycled and treated for methylene chloride removal. This alternative also produces almost 3 drums of mixed methylene chloride and trichloroethylene waste every week that requires disposal. This alternative would significantly increase the capital and operating cost with no significant technical benefit and was not evaluated further.

8.2.3 Alternative Three

This alternative evaluated increasing the size of the treatment plant to allow treatment of contaminated groundwater from the Zone I DNAPL area, the site boundary wells, and the wells installed off-site. This alternative would increase the size of the on-site treatment plant from a maximum of 46 gpm to a maximum of 80-90 gpm. This evaluation indicated that the capital cost to increase capacity of the on-site plant would be minimal, but it also indicated that the capital cost to install pipelines from off-site to the on-site treatment plant would be high. One of the major components of the pipeline cost was the cost associated with crossing as many as four roads. Due to the high capital cost of pipeline installation, this alternative was not evaluated further.

8.2.4 Alternative Four - Potential Treatment System for Off Site Water

This alternative evaluates an off-site treatment system designed to process water with low levels of contaminants. This system would treat water that may have migrated off-site and the contaminant levels in this water are expected to be between 300 and 600 parts per billion of organic contaminants. The expected flow to the off-site treatment system is 40-50 gpm. A system for treatment of off-site water has also been developed as a result of the treatability study. The proposed preferred alternative to treat off-site water is the use of an UV/OX system using hydrogen peroxide as the oxidant. The UV/OX system can be sized to treat the expected flow from off-site collection wells. A flowsheet showing the proposed off-site treatment system is shown in Figure 8.3.

This system can be located in a small building (maximum size of 20 feet by 20 feet) and would have no effluents other than the treated water. The treated water can be discharged into a nearby manhole after the proper testing has been completed and the proper permits have been obtained.

8.2.5 Preferred Alternative

As a result of the treatability study and pilot plant test, the proposed preferred alternative for treatment of water from the Zone I DNAPL wells and the site boundary wells is the on-site treatment system which utilizes the sacrificial carbon column. This alternative is shown in Figure 8.2.

Figure 8.3

In addition to the on-site treatment system, the slightly contaminated water from the off-site collection wells will potentially be treated using the UV/OX system shown in Figure 8.3

8.3 Design Criteria and Equipment Sizing

The process design criteria are the data, information, and specifications, etc. used for sizing and designing the key equipment used by the plant. It is, therefore, comprised of general data/information and equipment-specific information. Mostly equipment-specific information is obtained or collected by conducting treatability studies, as done for this project. Based on the results of various tests carried out, the design criteria for a 46 gpm plant was developed and it is given in Appendix A. This design criteria was used to size the various equipment.

PROCESS COMBUSTION CORPORATION
PO Box 12866, Pittsburgh, PA 15241 • Phone 412-655-0955 • Telex 81-2389, Fax 412/655-0961

April 26, 1990

Ref: BPO-0490-21-RK

Resources Technology Group, Inc.
3190 S. Wardsworth, Suite 250
Lakewood, CO 80227

Attention: Bart Conroy

Subject: Package Stripper Vent Cleanup System

Gentlemen:

We are pleased to submit PCC budget proposal no. BPO-0490-21-RK for the supply of a package stripper vent cleanup system.

Should you have any questions or require additional information, please contact our area representative at the address below or this office direct.

Very truly yours,

J. Keith McCartney
Manager of Proposals

JKM/cak

cc: Mr. Bruce Merritt
Thermex Co.
P. O. Box 441218
Aurora, CO 80044
(303) 690-6866

cc: Jay Klaus
Klaus Equipment Co.
P. O. Box 13624
Pittsburgh, PA 15243
(412) 221-1355

PROCESS COMBUSTION CORPORATION
PO Box 12866, Pittsburgh, PA 15241 • Phone 412-655-0955 • Telex 81-2389, Fax 412/655-0961

BUDGET PROPOSAL

Reference No.: BP-0490-21-RK

Date: April 26, 1990

To: Resources Technology Group, Inc.
3190 S. Wardsworth, Suite 250
Lakewood, CO 80227

Attention: Bart Conroy

Followup: Please contact our area representative:

Mr. Bruce Merritt
Thermex Co.
P. O. Box 441218
Aurora, CO 80044
(303) 690-6866

SPECIFICATION

To clean up a vent of air from a waste water stripper. The unit is designed to incinerate the stream, cool and quench the gases and scrub with an alkaline solution to deliver a clean, substantially neutral discharge to the sewer.

The inlet stream is designed for 500 scfm of air at ambient temperature, saturated with water and containing a burden of 10 lb/hr of methylene chloride, 6 lb/hr of trichlor-ethylene and 0.35 lb/hr of 1.1.1. trichlorethane.

This proposal has been based entirely upon the specifications, descriptions, data and drawings provided to PCC by Resources Technology Group, which are confirmed above. If these specifications are incomplete or incorrect in any way, PCC is not responsible for any consequences, including but not limited to modifications, additions, repairs, losses, labor costs or damages of any kind, whether PCC requested additional information or not.

The unit is generally illustrated on the enclosed sketch 490-21-SK1.

Proposal Page 2.

EQUIPMENT

A. Thermal Oxidizer

One PCC thermal oxidizer complete with:

1 - PCC/Bloom 146 series burner assembly designed to use the fume as "combustion air" (3" NPT inlet) damper, designed for a maximum 1.2 MM BTU/hr heat release when operating on natural gas.

1 - Refractory lined, (shop installed) combustion chamber with supports, fabricated from A36 carbon steel. Chamber designed to heat waste streams from ambient inlet temperature to 1600 deg F.

The thermal oxidizer will include the following accessories:

1 - Fume blower complete with motor
1 - Pilot system (complete)
1 - Gas control valve with electric actuator
1 - Fuel gas train with safety interlocks
1 - Control panel with flame failure and temperature controller.

B. Radiant Tube Cooler

One PCC designed radiant gas cooler of high alloy construction, complete with connecting flanges and stainless steel shrouds.

C. Quench System

To cool the exit gas from the radiant cooler, we offer a PCC design "submerged" quench/absorption system complete with the following equipment:

1 - Inlet breeching, carbon steel construction, ceramic fiber refractory lining
1 - PCC dipleg quench tube, constructed of stainless steel with corrosion resistent dipleg
1 - Absorption tank with necessary internals, carbon steel construction with rubber lining
1 - pH controller (to control overboard rate and alkali injection)
1 - Inlet makeup water control valve (bronze) complete with mechanical actuator and float
1 - Local level gauge (polypropylene)
1 - Overboard acid solenoid control valve (PVC)
1 - Set local piping complete with manual valves and fittings (PVC).

D. Scrubber System

To remove HCl from the flue gas to meet local regulations, we offer a packed tower scrubber system complete with:

1 - Packed tower scrubber complete with factory installed packing and demister. FRP body and grids, polypropylene or ceramic packing
1 - Circulating pump complete with motor
1 - Caustic injection solenoid valve
1 - Set of piping complete with manual valves and fittings (PVC)
1 - Stack (FRP) to 15 ft above grade. Stack is fitted with sample ports and support ring but not with guys or fittings.

Note: No platforms or ladders included in this system.

GENERAL

The equipment will be preassembled and "skid" mounted for easy installation.

Proposal Page 4.

SURFACE

All exposed carbon steel surfaces will be painted with one coat of our standard shop primer over wire brushed metal. Stainless steel and plastic items will be left unpainted, and purchased components will have the manufacturer's standard finish.

PRICE

Total budget price is $100,000.00 net f.o.b. manufacturing point (assume Pittsburgh, PA).

TERMS AND CONDITIONS

PCC standard terms and conditions would apply.

FOR PROCESS COMBUSTION CORP.

J. Keith McCartney

9.0 REFERENCES

(1) Dobbs, R.A., Cohen, J.M., "Carbon Adsorption Isotherms for Toxic Organics". EPA-600/8-80-023, April, 1980.

(2) Wood, P.R., Parsons, F.Z., Demarco, J., Harveen, H.J., Lang, R.F., Payan, I.L., Meyer, L.M., Ruiz, M.C., and Ravelo, E.D. "Introductory study of the biodegradation of the chlorinated methane, ethane, and ethene compounds". Cooperative Agreement CR806890-01, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1980.

(3) Patterson, J.W., "Industrial Wastewater Treatment Technology" Second Edition, 1985, Butterworth Publishers, Boston, Massachusetts.

(4) AWWA Seminar Proceedings, "Granular Activated Carbon Installations: Conception to Operation". Presented at the AWWA Conference, June 14, 1987, No. 20018.

(5) Gosset, J.M. et al, "Mass Transfer Coefficients and Henry's Constants for Packed-Tower Air Stripping of Volatile Organics: Measurements and Correlation", Air Force Engineering and Service Center, ESL-TR-85-18, June, 1985.

APPENDIX A

DESIGN CRITERIA

DESIGN CRITERIA

1.0 GENERAL

1.1 Flow rate of water from DNAPL zone: 6 gpm

1.2 Analysis of DNAPL zone water:

Methylene Chloride - 2,000 ppm
Trichloroethylene - 1,200 ppm
Trichloroethane - 72 ppm
Specific Gravity - 1.1

1.3 Flow rate of water from site boundary wells: 40 gpm

1.4 Analysis of site boundary zone water:

Methylene Chloride - 10 ppm
Trichloroehylene - 10 ppm
Dichloroethane - 1 ppm
Specific Gravity - 1.0

1.5 Average temperature of water: 20°C

1.6 Retention time of DNAPL zone water in the separator: 60 minutes

1.7 Retention time of water in surge tank: 60 minutes

2.0 AIR STRIPPING

2.1 Number of towers: 2

2.2 Operation mode: Series

2.3 Tower diameter: 24" each

2.4 Specific flow rate: 15 gpm/ft^2

2.5 Packing height: 25' in each

2.6 Overall height of tower: 33' each

2.7 Air to water ratio: 75 to 1

2.8 Flow rate: 46 gpm

2.9 Removal efficiency for methylene chloride: 99.5% in each

2.10 Material of Construction: FRP

2.11 Packing Type: Tri-Pak

2.12 Packing Size: 2"

DESIGN CRITERIA (Continued)

3.0 UV OXIDATION

3.1 Flow rate: 46 gpm
3.2 Oxidation time: 3.2 minutes
3.3 50% Hydrogen peroxide dosage: 1.3 lb/1,000 gal.
3.4 Power usage: 120 KW/hr.
3.5 Removal efficiency: 80% (total toxic organic)

4.0 CARBON COLUMNS

4.1 Number of columns: 2
4.2 Mode of operation: Series
4.3 Flow rate: 46 gpm
4.4 Empty bed contact time: 9 minutes each
4.5 Specific flow rate: 2.5 gpm/ft^2
4.6 Carbon bed depth: 4 ft. each
4.7 Material of Construction: Steel
4.8 Carbon type and Size: Calgon Filtrasorb 400 - Granular

5.0 AIR STRIP OFF-GAS TREATMENT

5.1 Treatment type: Thermal Oxidation
5.2 Number of units: 1
5.3 Flow rate: 500 cfm
5.4 Est. Contaminants level
Methylene Chloride = 7 #/hr.
Trichloroethylene = 3.5 #/hr.
5.5 Fuel Type: Natural gas
5.6 Fuel Consumption: 1 million BTU/hr.