HYDROGEOLOGIC INVESTIGATION
PHASE III

FRONTIER CHEMICAL WASTE PROCESS, INC.
NIAGARA FALLS, NEW YORK

APRIL 1990

ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY

VOLUME 7

APPENDIX I

OFF-SITE TOTAL CONTAMINANT LOADING REPORT

OFF-SITE
CONTAMINANT LOADINGS

FRONTIER CHEMICAL WASTE PROCESS, INC
NIAGARA FALLS, NEW YORK

April 1990

OFF-SITE
CONTAMINANT LOADINGS

FRONTIER CHEMICAL WASTE PROCESS, INC
NIAGARA FALLS, NEW YORK

Prepared for:

Frontier Chemical Waste Process,Inc.
47th Street and Royal Avenue
Niagara Falls, New York 14303

Prepared by:

ECCO, Inc.
Suite 515
Brisbane Building
Buffalo, New York 14203

April 1990

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 PREVIOUS INVESTIGATIONS/STUDIES 3
- 2.1 Previous Site Investigations 3
- 2.2 Previous Studies 8

3.0 APPROACH OVERVIEW 10

4.0 SITE ANALYSIS 12
- 4.1 Hydrogeology 12
- 4.2 Chemical Data 14
- 4.3 Total Loading Calculations 15
- 4.4 Supplemental Considerations 15

5.0 SUMMARY 17

APPENDICES

- Appendix A - In-situ Permeability Test Results
- Appendix B - Figures
- Appendix C - Ground water Flow Calculations
- Appendix D - Contaminant Loading Calculations/Total
- Appendix E - Contaminant Loading Calculations/Four Compounds

1.0 INTRODUCTION

Results of previous investigations have identified the presence of chlorinated and non-chlorinated volatile organic constituents in the uppermost portion of the ground water system underlying the Frontier Chemical Waste Process, Inc.'s, site. The site is located in the northwest quadrant at the intersection of 47th Street and Royal Avenue in Niagara Falls, New York, (Figure 1). The above constituents have been detected in elevated concentrations within the overburden and the underlying "A" and to a lesser extent in the "B" bedrock fracture zone monitoring wells.

Underlying the site, the only major water-bearing horizons within approximately fifty feet of ground surface are the "A" and "B" bedrock fracture zones. Recharge of the "A" fracture zone, which is also referred to as Zone 1, underlying the site would occur from downward percolation of water within the overburden deposits. Any horizontal movement of water within the overburden would likely be intercepted by the on-site buried gravity sewer lines. Ground water flow direction within the "A" and "B" bedrock fracture zones is generally across the site from the north, exiting the site beneath the eastern and southern property lines.

At depth, an underlying water-bearing fracture zone, designated as the "C" fracture zone exists. Ground water quality within this zone and the vertical hydraulic relationship between the "C" zone and the overlying zones does not indicate degradation of water quality as a result of past site activity.

Adjacent and parallel to the eastern property line is the New Road Tunnel. Along the southern property line, the Falls Street Tunnel exists. Ground water flow beneath the site within the "A" and "B" bedrock fracture zones is strongly influenced by the presence of these two tunnel systems. Ground water flow within these two uppermost bedrock zones beneath the eastern and southern property lines is towards and subsequently discharges into the adjacent tunnels. In other words, these two tunnel systems intercept ground water flow within the uppermost bedrock zones as it flows off the Frontier site.

An understanding of the potential effect the existing ground water quality underlying the Frontier site may have on these two tunnel systems is important in the identification of off-site concerns. Hence, at the request of Frontier Chemical Waste Process, Inc., an evaluation was undertaken to determine the potential total organic contaminant contribution (i.e. chemical loading) from the Frontier Chemical Waste Process, Inc.'s, site to the adjacent tunnels. Subsequently, in order to provide data for a baseline cancer risk assessment, loading rates for known and probable human carcinogens were also determined. The following sections present the methodology and findings of this study.

2.0 PREVIOUS INVESTIGATIONS/STUDIES

2.1 Previous Site Investigations

Several investigations have been conducted at the Frontier site, beginning in 1981 and extending to the present. The findings of these investigations were reviewed and pertinent data/information selected for inclusion into this evaluation. Following is a brief synopsis of each investigation.

WEHRAN ENGINEERING (December 1981)

The initial hydrogeological investigation performed in December 1981, was conducted by Wehran Engineering Corporation of Middletown, New York. The purpose of the Wehran investigation was: to define the nature of the subsurface geologic materials at the site; to determine the existence, direction, and rate of flow of ground water; and establish a ground water monitoring system for the Frontier facility. The scope of the investigation included the drilling of eight (8) boreholes and the subsequent installation of monitoring wells in each of the boreholes. These wells were installed in one of two configurations: (1) as a top of clay/silt well or (2) as a top of bedrock well.

Ground water was encountered in the overburden lacustrine soils (i.e., clays and silts) and is generally perched. Ground water was also encountered in the upper fractured bedrock unit under semi-confined conditions. This fractured bedrock unit was encountered below the confining, overlying glacial till unit, directly below the overburden lacustrine silts and clays.

Water levels were monitored for a period of six (6) months after the well installations. Water level measurements indicated that the direction of ground water flow, encountered in the fill and lacustrine silts, was primarily to the northwest. Ground water flow encountered in the semi-confined bedrock exhibited a general flow direction to the southeast.

Chemical analysis of ground water samples was not performed during the Wehran investigation. Additional monitoring wells were recommended by Wehran Engineers to provide for an adequate ground water monitoring system.

THOMSEN ASSOCIATES (June 1985)

Thomsen Associates was retained by Frontier to conduct a hydrogeological investigation at the project site. Thomsen proposed and installed nine (9) monitoring wells at strategic locations across the site. All nine (9) wells were installed as top of rock wells. Ground water was encountered in the upper fractured bedrock aquifer. Water level measurements indicated that the ground water flow direction in the upper bedrock unit is from the northwest to the southeast. Monitoring wells MW-9, MW-11, MW-12, and MW-13 required redrilling and installation at greater depths due to insufficient ground water being encountered in the initial installations.

A concerted weekly monitoring program was instituted which involved measurements of pH, specific conductance, TOC (total organic carbon), phenol and water elevations in all installed wells for a four (4) week period. During the fourth weekly sampling event, a volatile organic scan was added to the above noted parameter list. The ground water samples were submitted to Ecology and Environment, Inc., (E & E) for the volatile analysis. Problems were encountered with the quantification of certain chemical species which necessitated the resampling of the wells. The ground water samples from the resampling event were submitted to Zenon Environmental for analysis.

The findings of the investigation indicated that water quality in downgradient wells was elevated in concentrations of volatile organics, phenols, TOC, pH and specific conductance as compared to upgradient wells MW-14 and MW-17. Analytical results of ground water samples obtained from monitoring wells installed near the former sludge settler indicated that the settler was apparently not the source of elevated concentrations of organics in the remaining downgradient wells (i.e., MW-9, MW-11, MW-12, MW-15, and MW-16). Continued monitoring of the wells for a one-year period was recommended by Thomsen Associates. No investigation of the overburden ground water system was performed during this investigation.

GOLDER ASSOCIATES (NOVEMBER 1985)

Golder Associates of Mississauga, Ontario, was retained by Frontier Chemical Waste Process to continue the hydrogeological investigation of the site.

Golder reviewed the previous investigations performed by Wehran and Thomsen and proposed a four (4) point investigation as follows:

- An on-site historical review
- A regional review
- On-going routine monitoring
- Additional boreholes and monitoring wells

The report made a preliminary review of the historical aspects of the Frontier Chemical Waste Process site. This review presented information about the site usage and of the previous hydrogeological investigations conducted by Wehran and Thomsen. Golder reiterated the discrepancies encountered in the analytical data presented by Thomsen Associates (i.e., from E & E and Zenon).

Surrounding sites and utilities were also briefly examined as possible sources of part of the contamination encountered at the Frontier Chemical Waste Process site. Possible contamination was surmised to be originating from surcharging of the Falls Street Tunnel, situated on Royal Avenue, immediately south of the Frontier plant site. An ongoing ground water monitoring plan, consisting of analysis via a Gas Chromatography/Mass Spectrophotometer (GC/MS) scan, was recommended to be performed on samples obtained from each well. The sampling was to be completed after the drilling and installation of additional borings and monitoring wells.

GOLDER ASSOCIATES (OCTOBER 1986)

This report presented a detailed historical review of the Frontier Chemical Waste Process site and the surrounding facilities. The Falls Street and New Road sewer tunnels were examined as potential sources of contaminants in the vicinity of the Frontier Chemical Waste Process site. It was noted that, of the contaminants encountered in the ground water at the Frontier site, many are present upgradient of the site as discharges to the Falls Street and New Road sewer system.

Potential on-site sources were also examined. It was indicated that certain storage tanks, leased to various off-site facilities such as Hooker Chemical (now Occidental Chemical Corporation) and Solvent Chemical Corporation, Sobin Chemicals and the IMC Chemical Group (the latter three now defunct), may have impacted the ground water of several of the monitoring wells. No data was presented to substantiate any leaks from

in the vicinity

the former storage tanks. Little information was available for the on-site practices prior to ownership by Frontier.

EARTH DIMENSIONS, INC. (FEBRUARY AND NOVEMBER 1986)

Earth Dimensions of East Aurora, New York, was contracted by Frontier Chemical Waste Process in November 1985 to obtain soil samples from borings located around the perimeter and a boring in the center of a former sludge settler lagoon. Five borings were advanced to auger refusal on presumed bedrock at approximately eleven and thirteen feet. The remaining four borings were advanced by a hand auger to a depth of 8.5 feet to 9.5 feet. All borings were continuously sampled and logged. Subsequently, selected samples were submitted for analysis via EP Toxicity Leachate Test procedure and EPA Methods 624 and 625. The purpose of the February report was to identify the geology underlying the site and submit final boring logs.

In October 1986, Earth Dimensions was again retained to advance eight borings located in the area of the former lagoon. The borings were hand augered to a maximum depth of 8.5 feet below the bottom of the former lagoon. Two composite samples were prepared from each boring for subsequent analysis. One composite represented the two (2) to three (3) foot depth interval below the base of the former lagoon. The second composite represented the bottom one (1) foot of each boring.

As was noted in Earth Dimension's November 1986 report both within the text and on the boring logs, a dark-brown oily type film was observed on the soil samples from five (5) to six (6) feet below the bottom of the lagoon in the borings located in the northern half of the former lagoon area. This oily-type film was not observed in the upper five (5) feet below the base of the lagoon nor at depth in the southern half of the lagoon. It should be noted that this observation of an oily film was not observed during the February 1986 sampling.

No evaluation of the analytical data was presented in the text of this report.

GOLDER ASSOCIATES (DECEMBER 1986)

The December 1986 Golder report presented the results of the interim ground water monitoring program conducted at the Frontier Chemical Waste Process site in October 1986. Ground water samples were jointly collected by Golder and Frontier and submitted to Zenon Laboratory for analysis. The ground water samples were analyzed for EPA Method 624 priority pollutants, chlorotoluene, dichlorobenzene, total halogenated organics (TOX), and phenol. A dense non-aqueous phase liquid (DNAPL) was encountered in well MW-11 and was analyzed for EPA Method 625 extractable compounds. The analysis of the DNAPL from well MW-11 revealed the presence of fifteen (15) organic compounds, the most salient being dichlorobenzene, 1,1,1, trichlorobenzene, tetrachloroethylene, and chlorotoluene. It was concluded that the analysis from the October 1986 sampling event was found to be similar in the range of concentrations to the sampling and analysis performed in April 1985.

Water levels were also measured in the monitoring wells and, according to Golder, ground water flow directions are influenced by the Falls Street Tunnel and New Road Tunnel on Royal Avenue and 47th Street, respectively.

GOLDER ASSOCIATES (APRIL 1988)

A draft report detailing the geology and hydrogeology of the Frontier site was prepared by Golder in April 1988 which encompassed the results of the advancement of 28 overburden organic vapor analysis (OVA) boreholes (Phase I study) and six (6) clustered bedrock monitoring wells (Phase II Study). The bedrock wells were advanced to depths that range from 22 feet to 55 feet below the ground surface. The draft report also included the analytical results obtained from ground water sampling performed in March 1988 on wells installed by Golder in the summer of 1987 and other existing wells. Based on the results of the Phase I and II investigations, Golder provided recommendations for an additional investigation to define the source(s) of the contamination.

ECCO, INC. (APRIL 1989)

A draft report detailing the geology, hydrogeology and ground water quality underlying the site was prepared by ECCO, Inc., in April 1989. The report encompassed the findings to date from previous investigations and the results of the Phase III investigation conducted by ECCO. The Phase III investigation involved the installation of 39 new wells screened in the overburden, "A," "B" and "C" bedrock fracture zones. Subsequent to the installation of the new wells, 66 on-site wells were sampled. The sampled wells included the majority of the existing wells and all the newly installed wells. The ground water samples were analyzed for the previously fingerprinted constituents of concern on site. The fingerprinted constituents were the Priority Pollutant Volatile Organics plus Acetone, 2-Butanone, 4-Methyl-2-Pentanone, Total Xylenes, and Total Monochlorotoluenes.

Elevated concentrations of chlorinated solvents, benzene, toluene, chlorobenzene species and monochlorotoluene were detected in the overburden and "A" fracture underlying the central and southern portions of the site and to a lesser degree in the eastern and northern portions of the site. Although the same constituents are present in the "B" fracture zone, they were detected at lower concentrations. Within the "C" fracture zone, the same four constituents were detected at approximately the same concentration in all three wells. This would suggest that this zone has not been affected by past activities on site. The detection of the four constituents in the hydraulically upgradient well, MW-88-4C, at levels equal to or slightly above the downgradient suggests an off-site source for the detectable constituents. The vertical hydraulic relationship between the "C" fracture zone and the above "B" fracture zone (i.e., upward vertical hydraulic gradient) also suggests that past activities on site have not affected the ground water quality in the "C" fracture zone.

The data to date suggested several on site sources and possible off-site source(s) have impacted the waters within the overburden and the ground water quality in the underlying "A" and "B" fracture zones. The "C" fracture ground water quality appears to be reflective of off-site source(s). The presence of the unlined sewer tunnels at an elevation coinciding with the "B" fracture zone downgradient of the site and along the southern and eastern property line would intercept the flow within this zone. A report prepared by Camp Dresser & McKee for the City of Niagara Falls dated December 1982 and entitled "Report on Falls Street Tunnel Visual Inspection and Infiltration, Air and Sediment Evaluation" noted ground water infiltration along the ceiling of the tunnel. This indicates that ground water within the "A" fracture may also be percolating down and into the unlined tunnels.

2.2 Previous Studies

In addition to the above site specific investigations, several investigations/studies have been performed in the vicinity of the site. The findings of these investigations were reviewed to obtain any pertinent information relating to the Falls Street Tunnel, New Road Tunnel, regional hydrogeology and ground water quality.

The investigations/studies reviewed were:

- "Draft Report-Falls Street Tunnel Visual Inspection and Infiltration, Air and Sediment Evaluation, Niagara Falls, New York," Camp Dresser & McKee, December 1982.
- "Phase 1 Falls Street Study, City of Niagara Falls, New York," O'Brien and Gere, October 1987.
- "Potential Contaminant Loadings to the Niagara River From U.S. Hazardous Waste Sites," Gradient Corporation and GeoTrans, Inc., February 1988.
- "City of Niagara Falls, Sewer Contract No. 1588, Sewer Repairs at Four (4) Locations, Project Initiation Report-Final," Tallamy, Van Kuren, Gertis & Associates, November 1988.

3.0 APPROACH OVERVIEW

As a matter of course, the estimated contaminant loading (L) from a site is defined as the average ground water contaminant(s) concentration(s) across the downgradient site boundary (C) times the average ground water flow exiting the downgradient site boundary (Q). This definition is represented by the equation:

$$\mathbf{L}\ (\text{lb/d}) = \mathbf{C} \times \mathbf{Q}\ ;\ \text{lb/d - pounds/day}$$

Specifically for the Frontier Chemical Waste Process, Inc., site, the estimated total contaminant loading was calculated for the eastern boundary adjacent to the New Road Tunnel and for the southern boundary adjacent to the Falls Street Tunnel. Each of these two estimated total contaminant loadings were the result of the summation of the individual loadings calculated for the "A" and "B" fracture zones at these downgradient boundaries.

Initially, representative monitoring wells screened within the "A" and "B" fracture zones at the downgradient boundaries were selected. The most recent analytical results for volatile organics were totalled for each well. A mean concentration from the representative wells for the two uppermost water bearing zones at both downgradient boundaries was then calculated. These calculations provided a mean of **C** for both the "A" and "B" fracture zones at the southern and eastern property lines.

Secondly, the volume of ground water per time flowing across the southern and eastern property lines within both the uppermost bedrock zones was determined via Darcy's equation (i.e., $\mathbf{Q} = k\ i\ A$). These calculations required the average length times the saturated thickness of both zones at the downgradient boundaries (A), the hydraulic gradients (i) within both zones upgradient of the boundaries, and, the permeabilities (hydraulic conductivities, k) of both bedrock zones. This information was obtained from previous site investigations and recently performed in-situ permeability tests. The results of these calculations provided **Q**'s for the "A" and "B" fracture zones at the southern and eastern property lines.

In addition to performing total contaminant loading calculations, loading calculations were also performed for several individual organic constituents. The purpose of these calculations was to provide data for a baseline cancer risk assessment. The specific organic compounds were: benzene, chloroform, dichorobenzene and trichloroethylene. Of specific interest, was the loading rate of these compounds west of Regulator 8 south of the property. The rationale for this identified data need is discussed in a report entitled "Baseline Cancer Risk Assessment: Frontier Chemical Waste Process, Inc., Niagara Falls, New York" dated April 25, 1990, prepared by Health & Environmental Sciences Group, Washington, D.C.

Several constraints posed by data limitations existed during this determination of total contaminant loading to the adjacent tunnel systems. These constraints were related to the existence of only one set of analytical data for the newly installed wells and only two sets for the existing wells at the downgradient boundaries. Also, ground water levels were not available for the selected wells over a minimum one year time frame. The limited data base for both analytical and water levels does not allow for the identification of the presence or absence of variation in the data and subsequent inclusion into the calculations. Realizing the existence of constraints in the data base, the resultant contaminant loading values, both total and specific compounds, are best estimates based on the existing data base.

4.0 SITE ANALYSIS

4.1 Hydrogeology

Based on information obtained to date, ground water occurs in the overburden deposits and the underlying bedrock. Within the overburden, ground water occurs in the silt and fine sand strata in the upper part of the glaciolacustrine deposits. The underlying clayey silt deposits, although saturated, tend not to yield water due to their low permeability. Horizontal movement of ground water within the overburden would discharge into the on-site gravity sewer lines. Vertical flow of ground water would be downward, recharging the "A" fracture zone.

The "A" fracture zone occurs in the upper portion of the underlying Lockport Dolostone. This zone consists of a highly weathered gypsiferrous bed overlain by weathered, porous dolostone to the bedrock/overburden interface. Based on in-situ permeability tests performed on two (2) "A" fracture wells (Appendix A), a permeability (hydraulic conductivity) of 10^{-4} cm/sec was determined. Underlying the "A" fracture zone is approximately six (6) feet of massive, thickly bedded dolostone. The thickly bedded strata lacks the interconnected void spaces present in the overlying "A" fracture zone. From Freeze and Cherry, 1979, the range of permeability for limestone and dolomite is 10^{-3} cm/sec to 10^{-7} cm/sec. A conservative estimate for the permeability of this massive dolostone would be 10^{-4} cm/sec.

Beneath this massive, thickly bedded dolostone, another highly weathered gypsiferrous bed was encountered. This zone has been designated the "B" fracture zone. Based on in-situ permeability tests performed on two (2) "B" fracture wells (Appendix A), a permeability (hydraulic conductivity) of 10^{-3} cm/sec was determined.

Beneath the "B" fracture zone, the dolostone again becomes massive and is unfractured. This massive unfractured unit which is approximately eight (8) feet thick overlies a slightly porous section of bedrock with a permeability of 10^{-3} cm/sec to 10^{-4} cm/sec. This zone is designated the "C" fracture zone.

Ground water within the "C" fracture zone is under artesian or confining conditions with an upward vertical flow component. As noted in the ECCO draft report submitted in April 1989, the upward component of flow and the ground water quality within the "C" fracture zone suggest the absence of an impact to the waters within this zone due to previous site activity. Therefore, "C" fracture zone has not been included in any of the loading calculations.

The major water bearing zones underlying the site are the "A" and "B" fracture zones. These two water bearing zones are potential pathways for off-site contaminant migration. The reader is asked to refer to drawings illustrating the potentiometric surface on March 27, 1989, for the "A" and "B" fracture zones. These drawings are Drawings 9 and 12 presented in Appendix H of the document to which this report is an appendix. Generally, ground water flow within both these zones is towards the south and east exiting the site beneath the eastern and southern property lines, subsequently discharging into the adjacent unlined 47th Street and Falls Street tunnels. Hence, the following downgradient wells have been selected for inclusion into the contaminant loading evaluation.

- "A" Fracture Monitoring Wells
  East Border - BH87-5C and BH87-28
  South Border - BH87-3B, MW88-6A and MW88-13A
  West of Regulator 8 - BH87-3B and MW88-6A
- "B" Fracture Monitoring Wells
  East Border - MW84-13, BH87-5A and MW84-12
  South Border - BH87 -3D, MW84-9, MW84-11, MW88-6B and MW84-12
  West of Regulator 8 - BH87 -3A and D, MW84-9, MW84-11, MW88-6B

Note that monitoring wells, MW84-9, MW84-11 and MW84-12 screened in the "B" fracture along the southern property line have been included in the above list. Because of the well construction technique used at these locations, it is difficult to ascertain if the resultant water levels and analytical results for these wells reflect a combination of both the "A" and "B" fracture zone. Although this cannot be determined, the analytical results from these wells have been incorporated into the actual loading calculations for the "B" fracture zone.

Two cross-sections have been constructed and are presented in Appendix B. The cross-sections illustrate the subsurface conditions underlying the east and south property lines adjacent to the 47th Street and Falls Street tunnels, respectively. Both cross-sections depict the relationship between the two fracture zones and the tunnel systems.

As can be seen in the cross-section along 47th Street, the water level obtained from the "A" fracture wells occurs below the "A" fracture zone except in the vicinity of well BH87-28. The rock strata below the "A" fracture zone and above the "B" fracture zone is massive dolostone with few interconnected voids for the transmission of water. The permeability within this strata is estimated conservatively to be several orders of magnitude less than the permeability in the overlying "A" fracture zone. The estimated permeability for this massive dolostone is 10^{-4}cm/sec.

The above condition also occurs along the southern property line. The Royal Avenue cross-section shows the "A" fracture zone (Zone 1) as saturated in the vicinity of well BH87-3B, dewatered (not saturated) at well 88-6A and partially saturated at MW88-13A and BH87-28. Of interest, is that the saturated thickness of the "A" fracture zone is greater upgradient along the northern property lines than along the downgradient property lines. In fact, based on the March 1989 water levels, the "A" fracture zone (Zone 1) is unsaturated along most of the eastern property line and the central portion of the southern property line. This downgradient boundary condition may be the result of ground water within this zone discharging downward into the adjacent tunnel system.

The volume per time (**Q**) of ground water flowing across both property lines was calculated using a hydraulic gradient for the "A" fracture zone of 0.03 ft/ft and for the "B" fracture zone of 0.01 ft/ft. A conservative permeability of 10^{-3} cm/sec was used for both the "A" and "B" fractured zones. A permeability of 10^{-4} cm/sec was used for the massive dolostone strata between the two fracture zones. The cross-sectional areas used for the "A" fracture zone was the saturated area in the "A" fracture zone and the saturated area in the underlying massive dolostone down to the potentiometric surface for the underlying "B" zone. The cross-sectional area for the "B" fracture zone was the average thickness of the "B" fracture times the horizontal distance between wells along the east and south property lines. Calculations for **Q**'s are presented in Appendix C.

4.2 Chemical Data

The total detected volatile organic and four selected organic compound analytical results from the November 1988 sampling event have been summed. The results of this summation and the average between wells along the eastern and southern property lines are presented on Table 1 for both the "A" and "B" fracture zones.

TABLE 1

VOC

SUMMARY OF CONTAMINANT CONCENTRATION

	# of compounds	Σ of concentrations (ppb)	Average (ppb) between well locations
"A" FRACTURE WELLS			
EAST BORDER:			
BH87-5C	7	6205	
BH87-28	4	37	3121
SOUTH BORDER:			
BH87-3B	12	43262	
MW-88-6A	15	99850	71556
MW-88-13A	19	127140	113495
BH87-28	4	37	63589
"B" FRACTURE WELLS			
EAST BORDER:			
MW-84-13	8	1526	
BH87-5A	10	4162	2844
MW-84-12	15	70460	37311
SOUTH BORDER:			
BH87-3D	4	43	
MW-84-9	16	36300	18172
MW-84-11	18	196250	160915
MW-88-6B	18	125580	80940
MW-84-12	15	70460	133355

NOTE: All analytical data from November 1988 sampling event

TABLE 1
(cont.)

SUMMARY OF CONTAMINANT CONCENTRATION
WEST OF REGULATOR 8

	# of wells	Σ of concentrations (ppb)	Average (ppb) between well locations
"A" FRACTURE WELLS			
BENZENE	2	14.12	7.06
CHLOROFORM	2	0.056	0.028
DICHLOROBENZENE	2	43.3	21.6
TRICHLOROETHYLENE	2	4.41	2.2
"B" FRACTURE WELLS			
BENZENE	5	12.3	2.47
CHLOROFORM	5	0.74	0.15
DICHLOROBENZENE	5	56.3	11.26
TRICHLOROETHYLENE	5	44.7	8.95

NOTE: All analytical data from November 1988 sampling event

4.3 Total Loading Calculations

The calculations for the total contaminant loading, **L**, along the eastern and southern property lines are presented in Appendix D. The estimated total contaminant loading from both the "A" and "B" fracture zones along the 47th Street property line is 0.04 lbs/day. The estimated total contaminant loading from both the "A" and "B" fracture zones along the Royal Avenue property line is divided into two entities. One contaminant loading rate has been calculated for the segment along Royal Avenue west of Regulator 8. Another loading rate has been calculated for the segment east of Regulator 8 along Royal Avenue. The estimated total contaminant loading from both the "A" and "B" fracture zones west of Regulator 8 is 0.32 lbs/day. East of Regulator 8, the estimated total contaminant loading is 0.26 lbs/day. The estimated total contaminant loading along the entire length of the southern property line is 0.58 lbs/day. Estimated total contaminant loading exiting the Frontier facility is 0.62 lbs/day.

The rationale for dividing Royal Avenue property line into two segments is that during dry weather flow, water in the Falls Street Tunnel east of Regulator 8, inclusive of water within the New Road Tunnel, is diverted into the South Side Interceptor Sewer Line. Therefore, any contaminant loading to the Falls Street Tunnel east of Regulator 8 is diverted into the South Side Interceptor to the Niagara Falls treatment plant. West of Regulator 8, any contaminant loading to the Falls Street Tunnel remains in the tunnel west of the site. Hence, the estimated total contaminant loading west of Regulator 8 is 0.32 lbs/day. The estimated total contaminant loading exiting the site which could subsequently be diverted into the South Side Interceptor Sewer Line during dry weather flow is 0.30 lbs/day.

4.4 Supplemental Considerations

The calculations for the contaminant loading of the following known and probable human carcinogens west of Regulator 8 are presented in Appendix E. The known and probable human carcinogen compounds detected in the downgradient wells west of Regulator 8 and their respective loading rates are:

- benzene - 0.02 lbs/day
- chloroform - 0.0003 lbs/day
- dichorobenzene - 0.08 lbs/day
- trichloroethylene - 0.02 lbs/day

Further calculations were performed based on the above loading rates. These calculations (Appendix E) entailed the determination of an estimated concentration for each of the compounds at two locations hydraulically downstream of the Frontier site. These estimated concentrations were subsequently used in the performance of a baseline cancer risk assessment. The two (2) locations were: the Falls Street Tunnel outfall into the Niagara River upstream of the Rainbow Bridge and the mouth of the Niagara River where it empties into Lake Ontario (i.e., Niagara on the Lake, Canada). The conservative flow rates which were obtained from the Corp of Engineers and used in the calculations were:

- Rainbow Bridge - 54,000 cfs
- Niagara on the Lake - 200,000 cfs

The estimated concentrations at the above two locations were:

- Rainbow Bridge - benzene - 8.2×10^{-8} mg/l
  chloroform - 9.0×10^{-10} mg/l
  dichorobenzene - 2.6×10^{-7} mg/l
  trichloroethylene - 6.0×10^{-8} mg/l
- Niagara on the Lake - benzene - 2.2×10^{-8} mg/l
  chloroform - 2.5×10^{-10} mg/l
  dichorobenzene - 7.1×10^{-8} mg/l
  trichloroethylene - 1.6×10^{-8} mg/l

5.0 SUMMARY

The total contaminant loading exiting the Frontier facility of 0.62 lbs/day is an estimate. The calculations were performed assuming that the analytical results of the November 1988 sampling event were characteristic of the water quality underlying the site. The reliability of the assumption that the results of one sampling event is characteristic of the water quality beneath the site cannot be quantified.

Understanding that the total loading calculations are estimates and may be conservative, the loading calculations appear to suggest several important site conditions. Based on the loading calculations performed for the eastern and southern property lines, ninety-four percent (94%) of the total off-site loading is exiting the site along the Royal Avenue property line. This off-site loading is weighted more towards the "A" fracture zone than the "B" fracture zones (i.e., 0.4 lbs/day versus 0.2 lbs/day). Of the total off-site loading exiting the site, fifty percent (50%) is diverted into the South Side Interceptor upstream of Regulatory 8 during dry weather flow. The estimated loading rate downstream of Regulatory 8 of approximately 0.32 pounds per day is less than the dry weather loading rate of five (5) pounds per day reported in the previously referenced O'Brien and Gere (October 1987) report at Drop Shaft 13A. This fact suggests that although past activities on the Frontier site are contributing to the detected total organics at Drop Shaft 13A, other off-site sources are also contributing.

APPENDIX A

IN-SITU PERMEABILITY TEST RESULTS

IN SITU PERMEABILITY TESTING

Estimates of in situ permeability were calculated from standard methods, developed by the U. S. Department of the Navy, Naval Facilities Engineering Command, for variable head tests by means of piezometer observation wells.

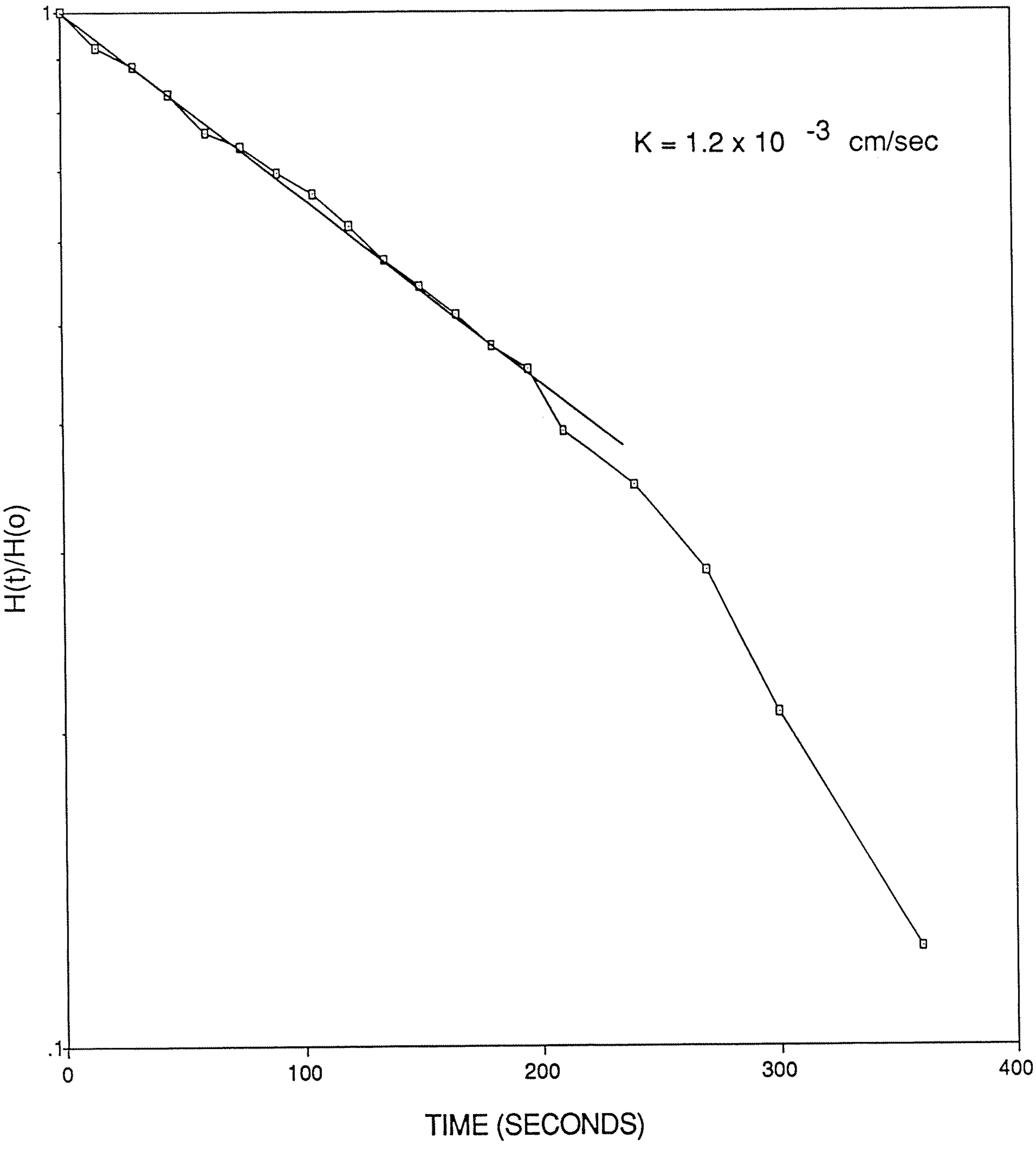
The methodology utilized for performing the variable head tests at the Frontier Chemical Waste Process, Inc. site involved the displacement of the static water level in an uncased monitoring well borehole and observing the recovery of the water level, as a function of time, to its pre-displacement (i.e., static) level. The ratio of the static head (H_o) to the head reading (H_t) at an elapsed time (t) is then plotted on a log-arithmetic scale and the permeability factor, "K", is calculated in accordance with the above noted standard methods, presented in the following publication:

<u>Reference:</u>

Cedergren, Harry R., "Seepage, Drainage and Flow Nets," John Wiley & Sons, Third Edition, 1989.

PERMEABILITY TEST NO. 1 / MW-88-6B
STATIC WATER LEVEL: 28.10'
H-H(o)= 28.10'- 26.57' = 1.53'

TIME	READING	H-H(t)	H(t)/H(o)
15	26.57	1.53	1.000
30	26.69	1.41	0.922
45	26.75	1.35	0.882
60	26.83	1.27	0.830
75	26.93	1.17	0.765
90	26.97	1.13	0.739
105	27.03	1.07	0.699
120	27.08	1.02	0.667
135	27.15	0.95	0.621
150	27.22	0.88	0.575
165	27.27	0.83	0.542
180	27.32	0.78	0.510
195	27.37	0.73	0.477
210	27.41	0.69	0.451
240	27.5	0.6	0.392
270	27.57	0.53	0.346
300	27.66	0.44	0.288
360	27.78	0.32	0.209
420	27.91	0.19	0.124

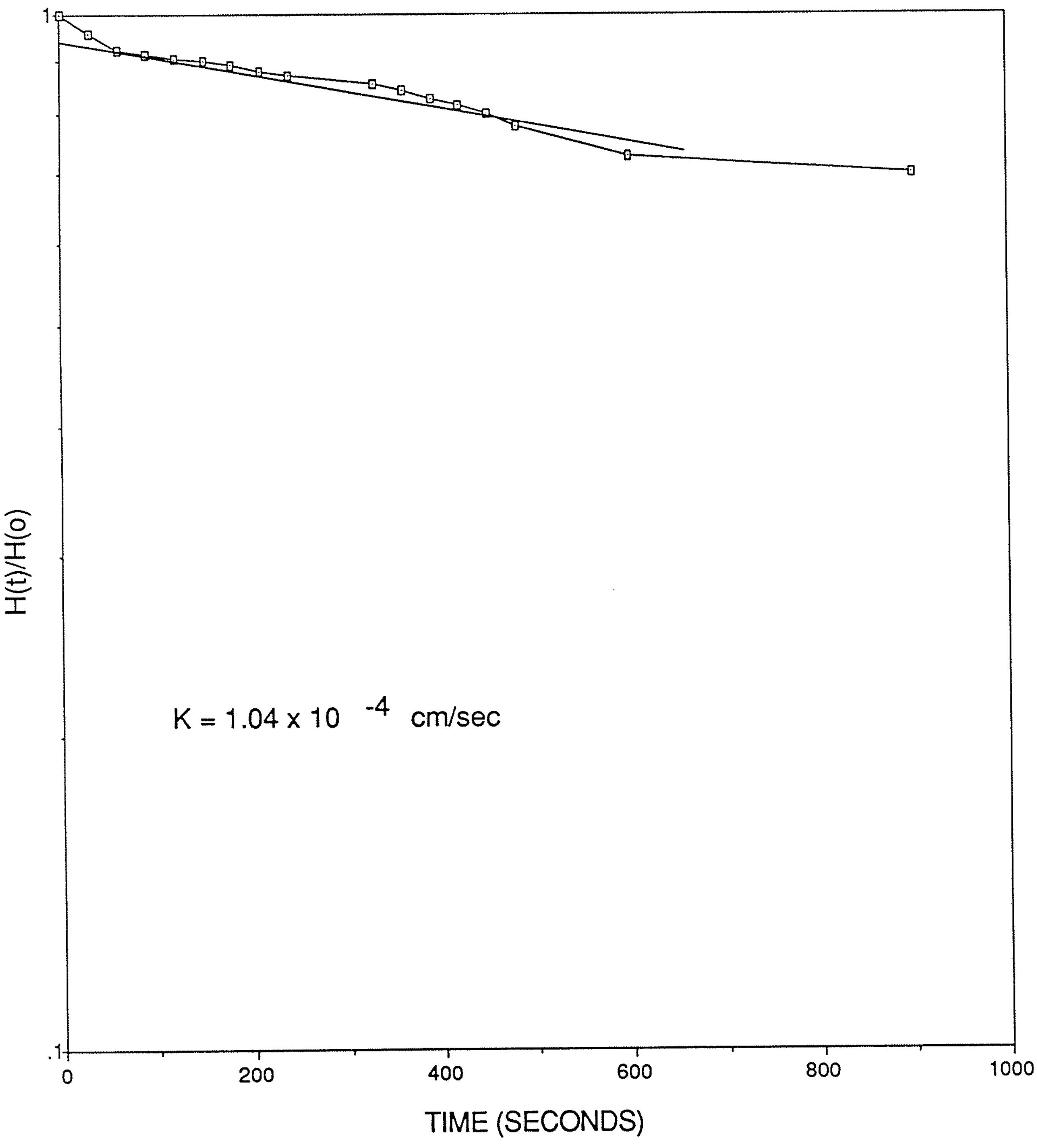


ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 1
MONITORING WELL MW-88-6B
PERMEABILITY TEST
MARCH 1990

PERMEABILITY TEST NO. 2 / MW-88-11A
STATIC WATER LEVEL: 19.73
H-H(t)= 19.73-18.33=1.40

TIME	READING	H-H(t)	H(t)/H(o)
30	18.33	1.40	1.000
60	18.39	1.34	0.957
90	18.44	1.29	0.921
120	18.45	1.28	0.914
150	18.46	1.27	0.907
180	18.47	1.26	0.900
210	18.48	1.25	0.893
240	18.5	1.23	0.879
330	18.51	1.22	0.871
360	18.53	1.20	0.857
390	18.55	1.18	0.843
420	18.57	1.16	0.829
450	18.59	1.14	0.814
480	18.61	1.12	0.800
600	18.64	1.09	0.779
900	18.71	1.02	0.729
1200	18.75	0.98	0.700



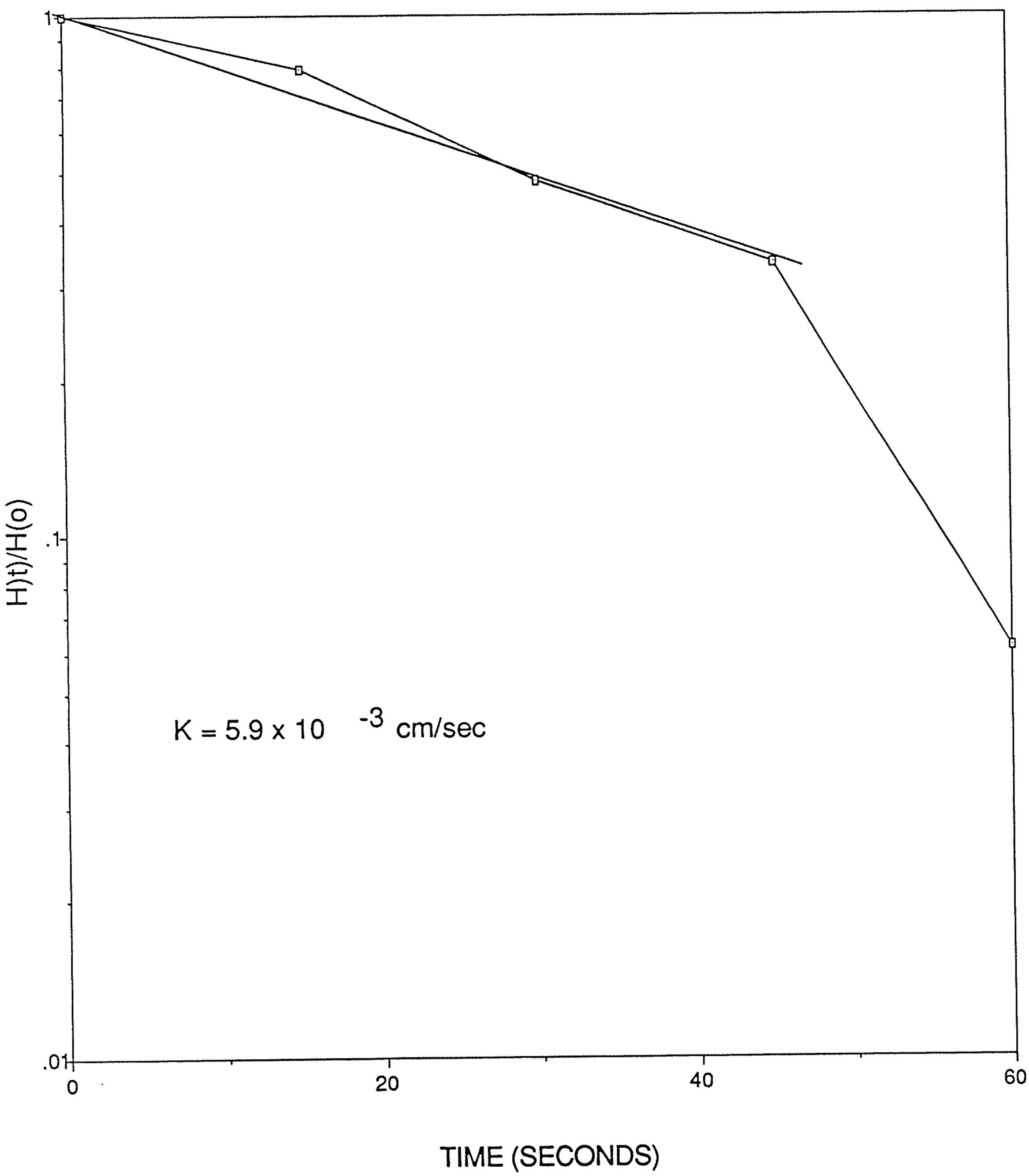
ecco INC.

THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 2
MONITORING WELL MW-88-11A
PERMEABILITY TEST
MARCH 1990

PERMEABILITY TEST NO. 3 / MW-88-11B
STATIC WATER LEVEL: 23.25'
H-H(o)= 23.25'- 22.92' = 0.33'

TIME	READING	H-H(t)	H(t)/H(o)
15	22.92	0.33	1.000
30	22.99	0.26	0.788
45	23.09	0.16	0.485
60	23.14	0.11	0.333
75	23.23	0.02	0.061
90	23.25	0	0.000



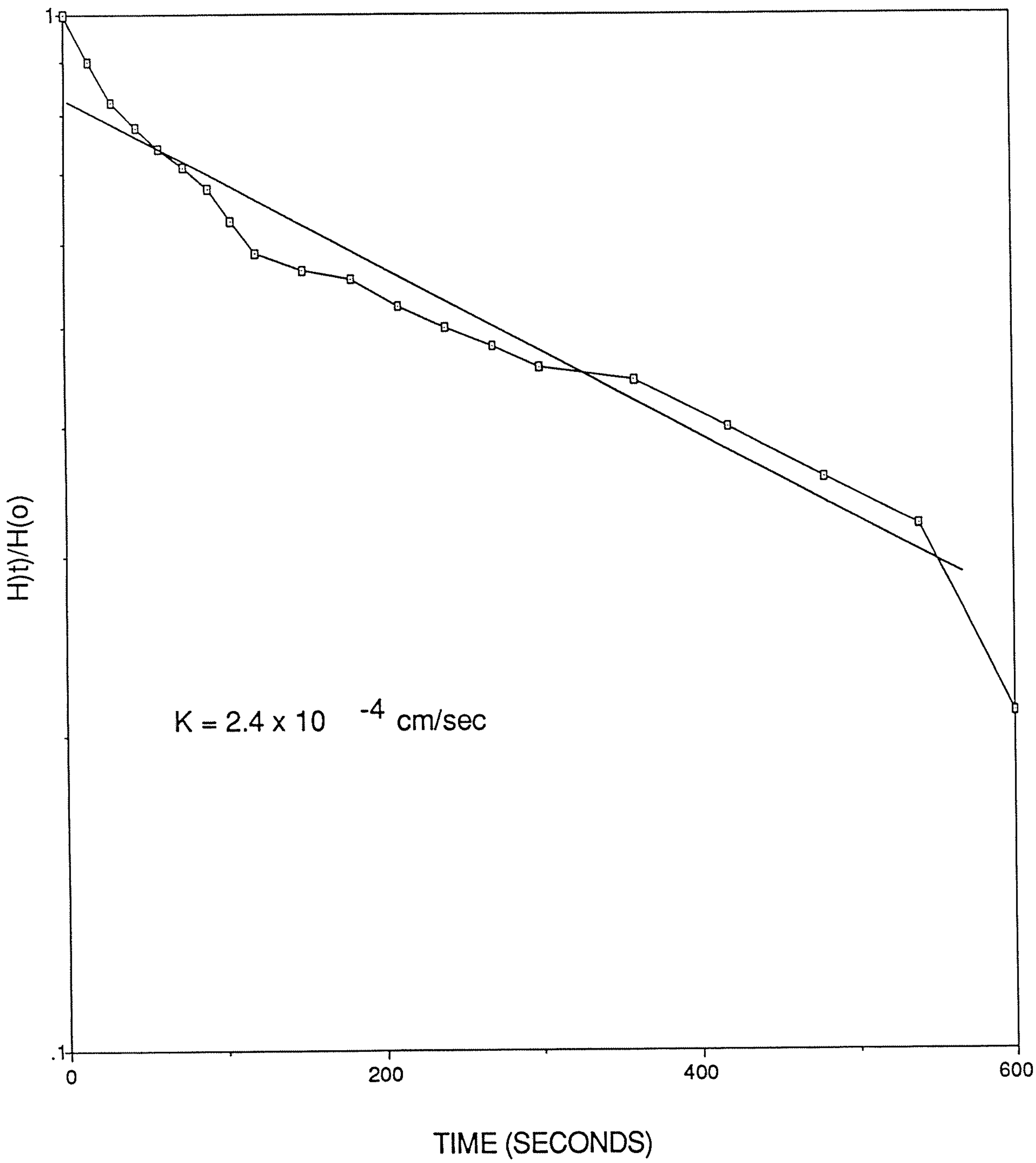
ecco INC.

THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 3
MONITORING WELL MW-88-11B
PERMEABILITY TEST
APRIL 1990

PERMEABILITY TEST NO. 4 / 84-12
STATIC WATER LEVEL: 28.50'
H-H(t)= 28.50-27.60=0.90

TIME	READING	H-H(t)	H(t)/H(o)
15	27.60	0.90	1.000
30	27.69	0.81	0.900
45	27.76	0.74	0.822
60	27.80	0.70	0.778
75	27.83	0.67	0.744
90	27.86	0.64	0.711
105	27.89	0.61	0.678
120	27.93	0.57	0.633
150	27.97	0.53	0.589
180	27.99	0.51	0.567
210	28.00	0.50	0.556
240	28.03	0.47	0.522
270	28.05	0.45	0.500
300	28.07	0.43	0.478
360	28.09	0.41	0.456
420	28.10	0.40	0.444
480	28.14	0.36	0.400
540	28.18	0.32	0.356
600	28.21	0.29	0.322
900	28.31	0.19	0.211

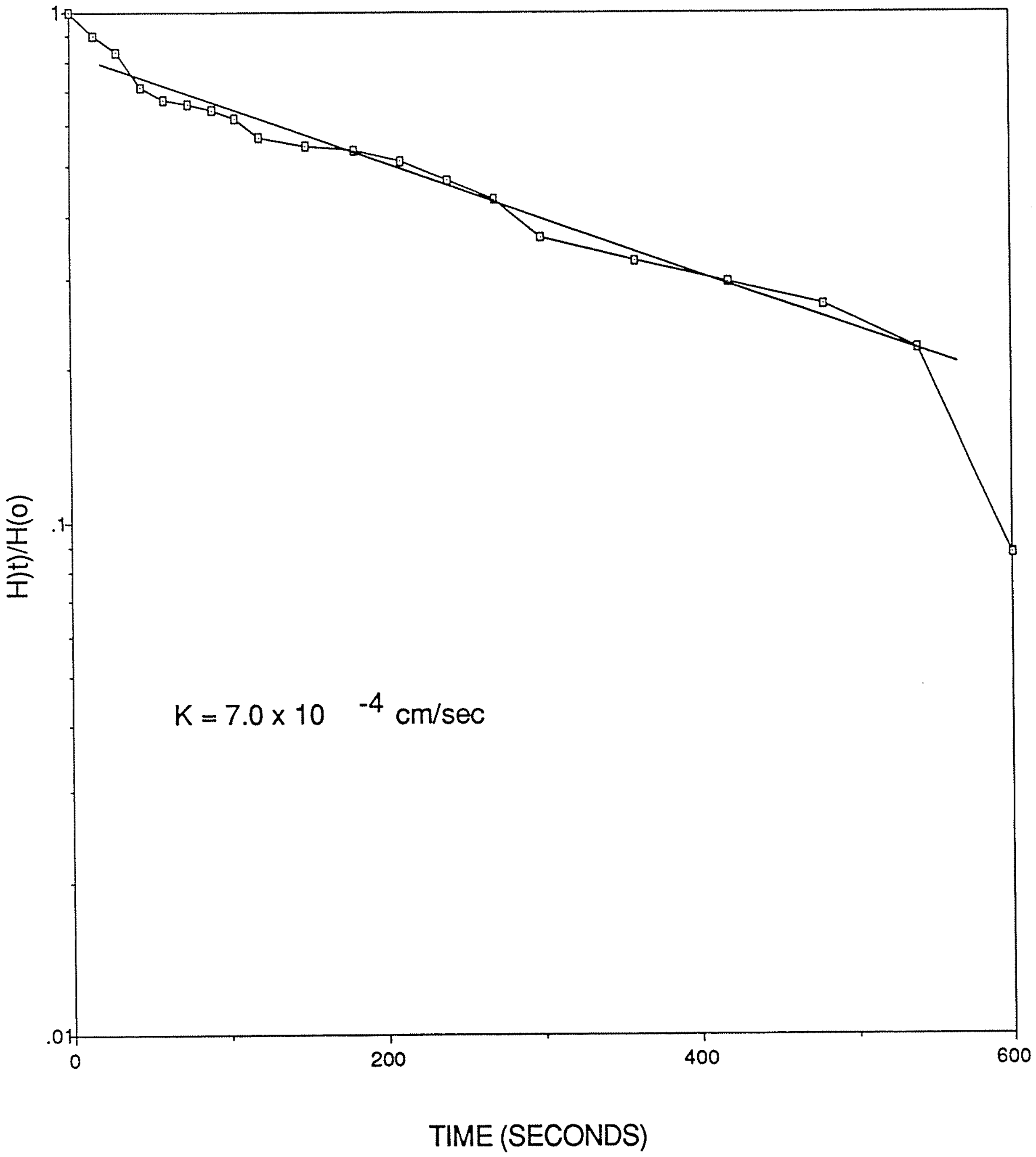


ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 4
MONITORING WELL 84-12
PERMEABILITY TEST
APRIL 1990

PERMEABILITY TEST NO. 5 / MW-88-13A
STATIC WATER LEVEL: 21.81'
H-H(t)= 21.81'-20.77'=1.04'

TIME	READING	H-H(t)	H(t)/H(o)
15	20.77	1.04	1.000
30	20.87	0.94	0.904
45	20.94	0.87	0.837
60	21.07	0.74	0.712
75	21.11	0.70	0.673
90	21.125	0.69	0.659
105	21.14	0.67	0.644
120	21.17	0.64	0.615
150	21.22	0.59	0.567
180	21.24	0.57	0.548
210	21.255	0.56	0.534
240	21.28	0.53	0.510
270	21.32	0.49	0.471
300	21.36	0.45	0.433
360	21.43	0.38	0.365
420	21.47	0.34	0.327
480	21.5	0.31	0.298
540	21.53	0.28	0.269
600	21.58	0.23	0.221
900	21.72	0.09	0.087

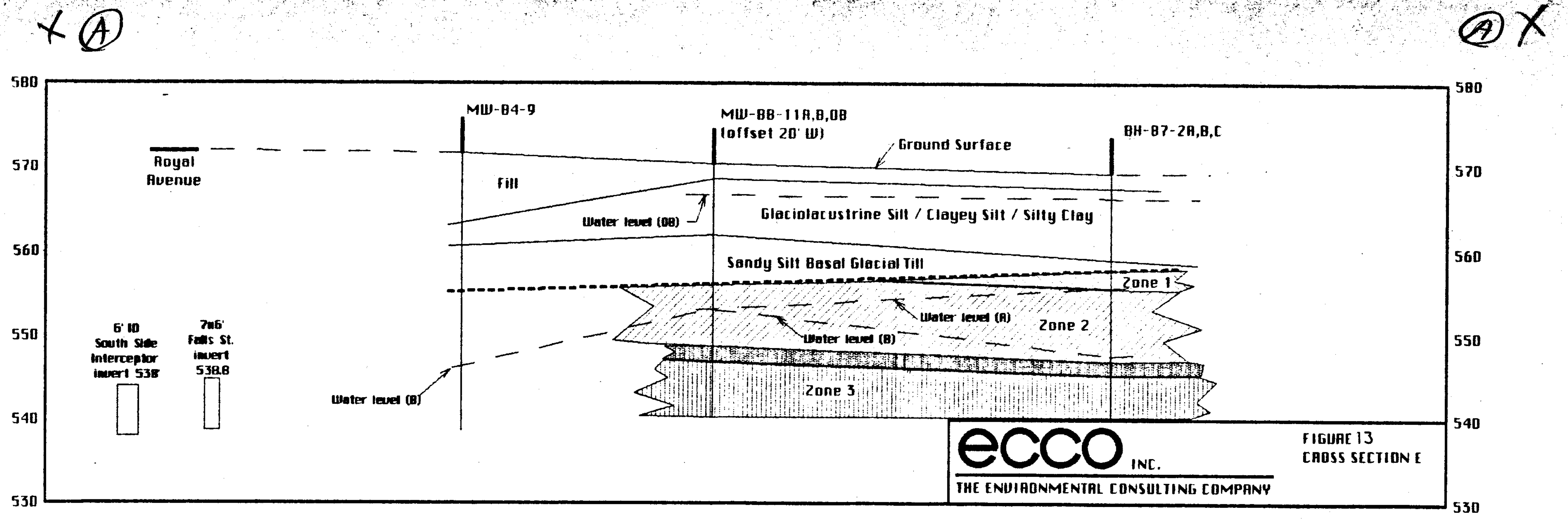


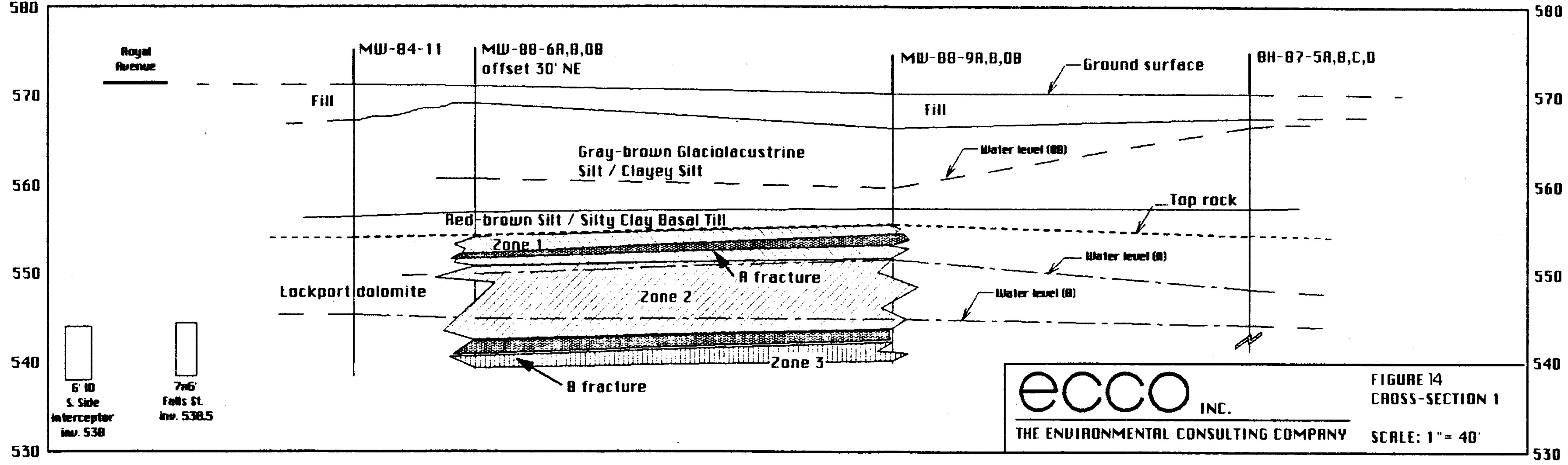
ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 5
MONITORING WELL MW-88-13A
PERMEABILITY TEST
APRIL 1990

APPENDIX B

FIGURES


A
A
580
570
560
550
540
530
MW-84-9
MW-88-11A,B,OB
(offset 20' W)
BH-87-2A,B,C
Ground Surface
Royal
Avenue
Fill
Water level (OB)
Glaciolacustrine Silt / Clayey Silt / Silty Clay
Sandy Silt Basal Glacial Till
Zone 1
Water level (A)
Zone 2
Water level (B)
Zone 3
Water level (B)
6' ID
South Side
Interceptor
invert 538
7x6'
Falls St.
invert
538.8
ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY
FIGURE 13
CROSS SECTION E



ecco INC.

THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 14
CROSS-SECTION 1

SCALE: 1" = 40'

FIGURE 16
CROSS-SECTION 3
SCALE: 1" = 40'

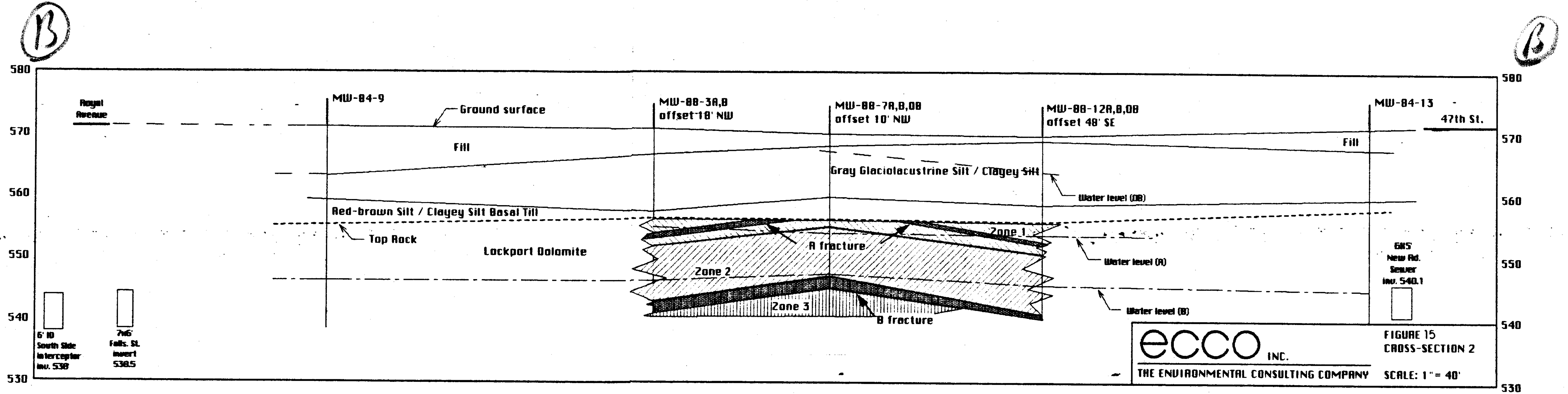


FIGURE 15
CROSS-SECTION 2
SCALE: 1" = 40'

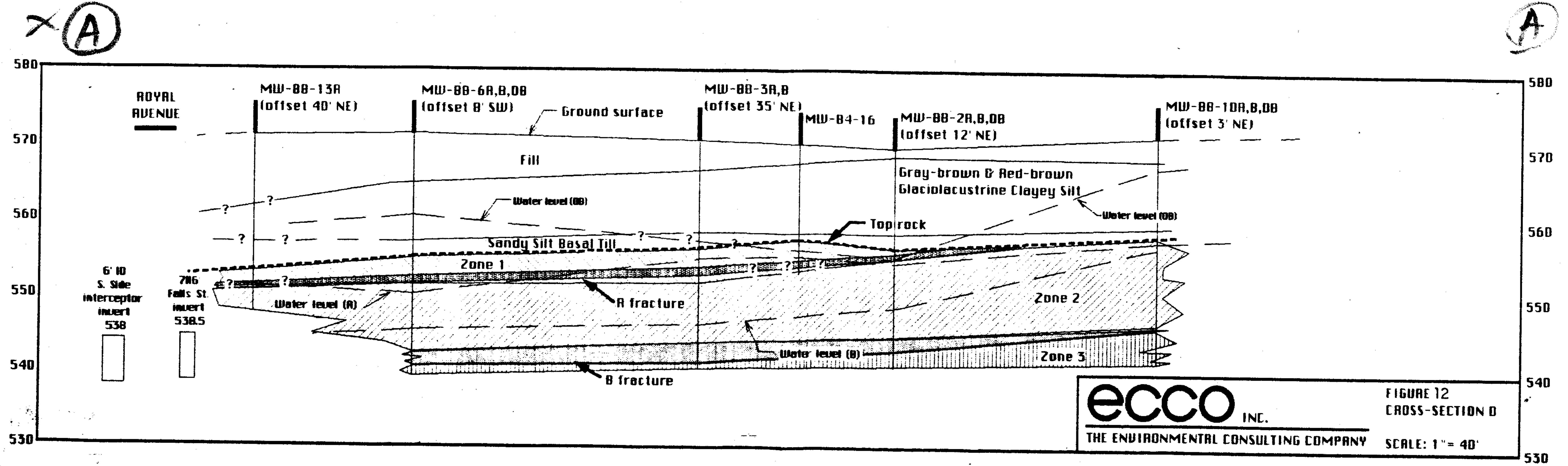
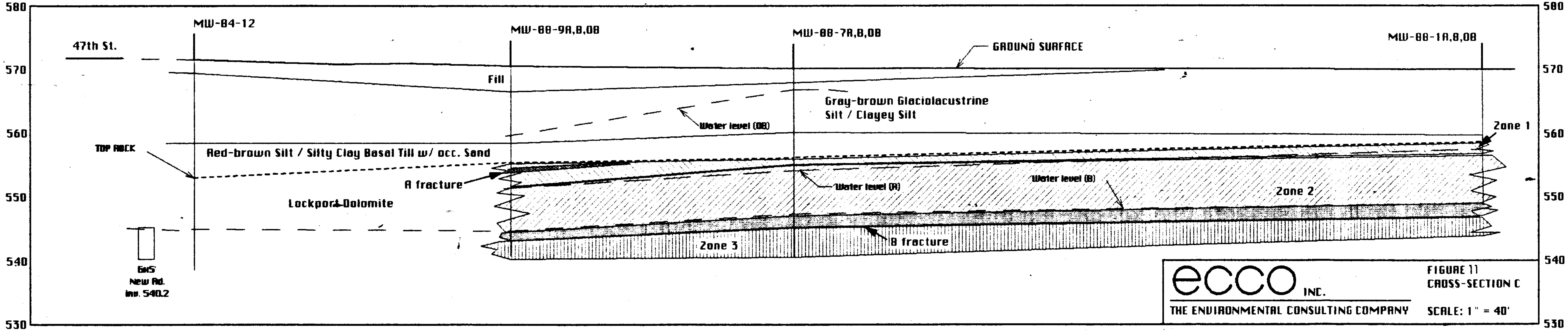


FIGURE 12
CROSS-SECTION D



580
570
560
550
540
530
47th St.
MW-84-12
MW-88-9A,B,OB
MW-88-7A,B,OB
MW-88-1A,B,OB
GROUND SURFACE
Fill
Gray-brown Glaciolacustrine
Silt / Clayey Silt
Water level (OB)
Zone 1
TOP ROCK
Red-brown Silt / Silty Clay Basal Till w/ occ. Sand
A fracture
Water level (A)
Water level (B)
Zone 2
Lockport Dolomite
Zone 3
B fracture
GMS
New Rd.
Inv. 540.2
ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY
FIGURE 11
CROSS-SECTION C
SCALE: 1" = 40'

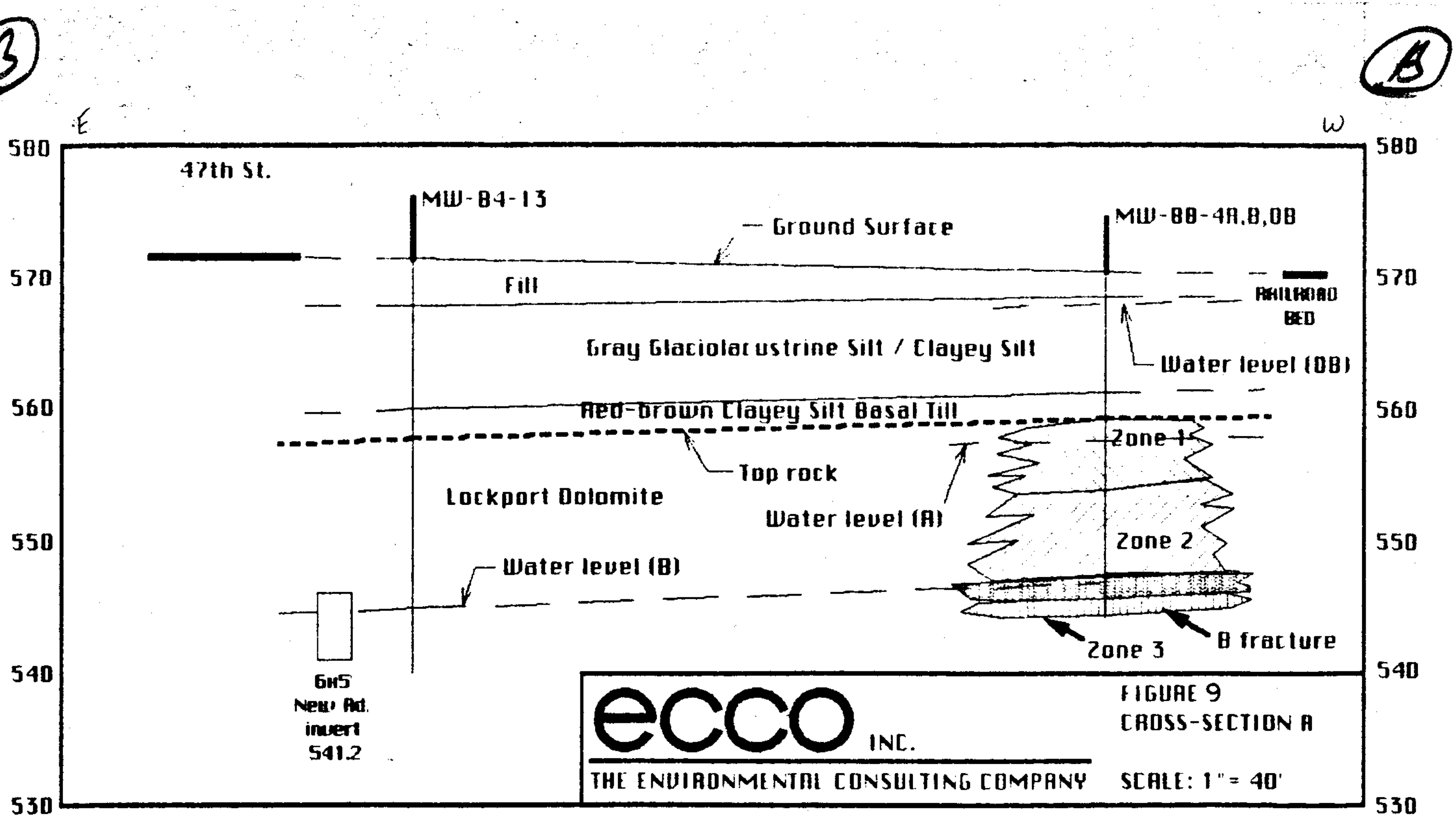


FIGURE 9
CROSS-SECTION A

SCALE: 1" = 40'

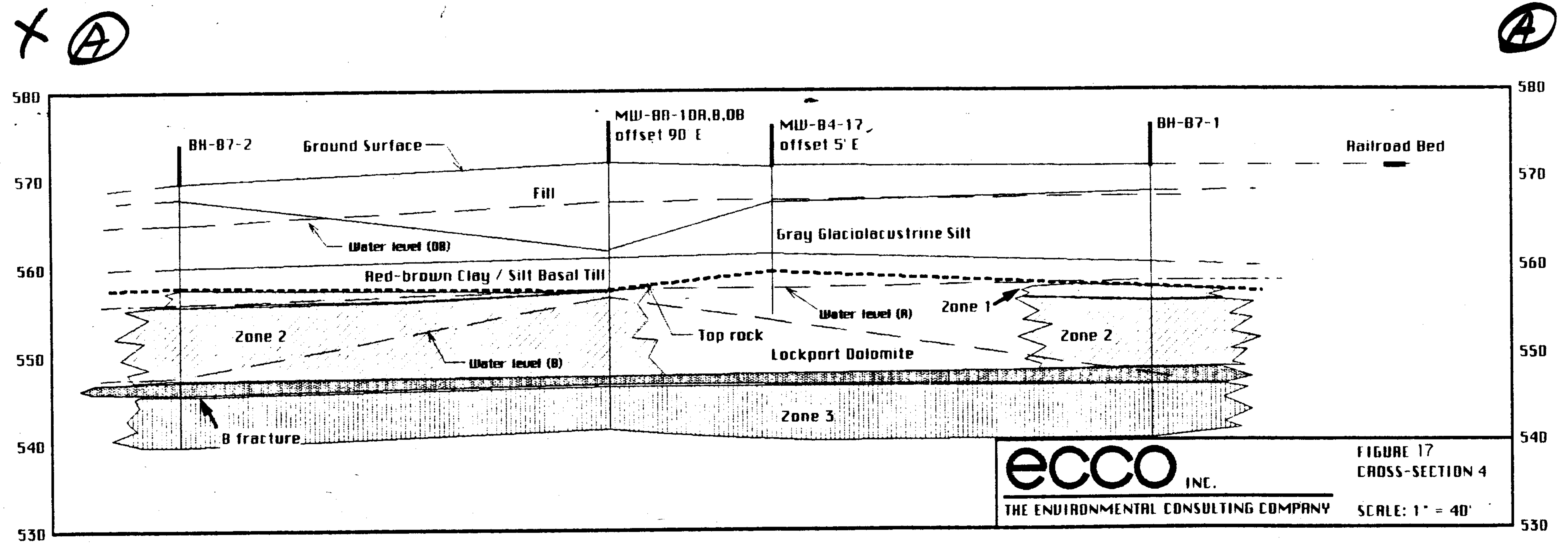
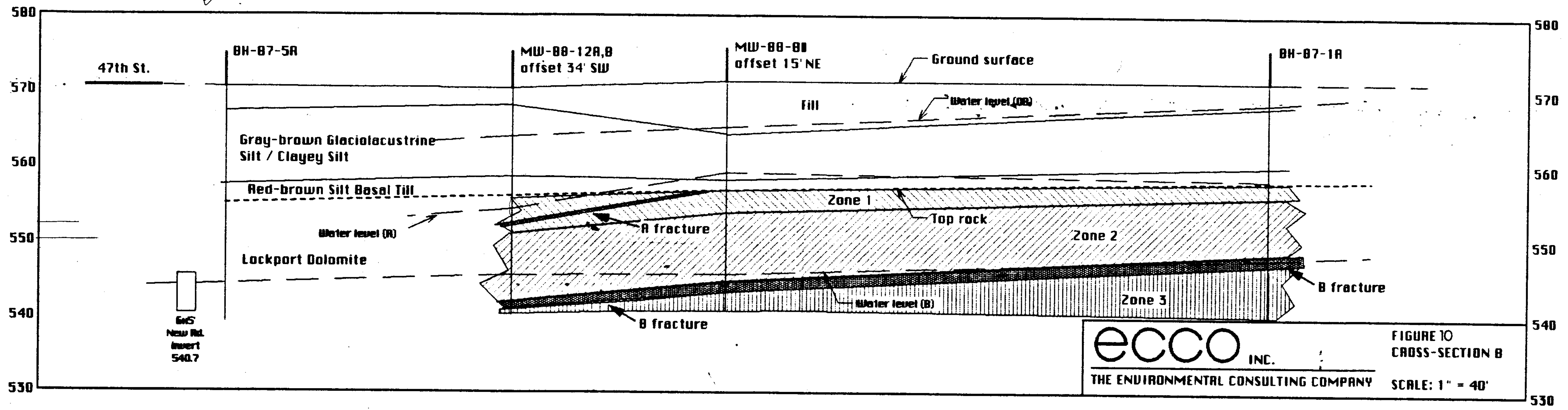


FIGURE 17
CROSS-SECTION 4
SCALE: 1" = 40'



ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY

FIGURE 10
CROSS-SECTION B
SCALE: 1" = 40'

CROSS-SECTION ALONG 47TH STREET
S
N
MW-84-12
offset 23' to W
BH-87-28
offset 27' to W
Ground Surface
BH-87-5 A,B,C,D
offset 22' to W
MW-84-13
offset 22' to W
MW-81-4
offset 50' to W
Water level
Overburden
3/27/89
Top rock
Zone 1
Water level
Zone 1 / A Fracture
3/27/89
Zone 2
B fracture
6'x5' NEW ROAD SEWER TUNNEL (Unlined)
8'x10' shaft
Inv. 541.7
6' Lined
South Side
Interceptor
Falls Street
8'x10' shaft
No.15
Inv. 539.1
8'x10' shaft
Inv. 540.2
Water level
B Fracture
3/27/89
TO 515.48'
LEGEND
: Ground Surface
: Top Rock
: Zone 1
: B Fracture
: Sewer Tunnels & Shafts
: Potentiometric Surface
(dashed is extrapolated)
ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY
SCALE
1" = 40' Horizontal
1" = 10' Vertical
580
570
560
550
540
530
520

CROSS-SECTION ALONG ROYAL AVENUE
W
E
BH-87-3 A,B,C,D
offset 67' to N
MW-84-9
offset 87' to N
MW-84-11
offset 46' to N
MW-88-6 0B,A,B 2
offset 96' to N
MW-88-13A
offset 63' to N
MW-84-12 offset 43' to N
BH-87-28 offset 47' to N
Ground Surface
Water level
Overburden
3/27/89
Zone 1
Water level
Zone 1 / A Fracture
3/27/89
Top Rock
Zone 2
Water level
B Fracture
3/27/89
Shaft 14A
B Fracture
Weir
Elev. 542.1
Regulator *8
Shaft 14B
Connection to
South Side
Interceptor
Inv. 538
6' Lined
South Side
Interceptor
8'x10' shaft
No.15
Inv. 539.1
7'x6' Falls Street
Sewer Tunnel (Unlined)
LEGEND
: Ground Surface
: Top Rock
: Zone 1
: B Fracture
: Sewer Tunnels & Shafts
: Potentiometric Surface
(dashed is extrapolated)
SCALE
1" = 40' Horizontal
1" = 10' Vertical
ecco INC.
THE ENVIRONMENTAL CONSULTING COMPANY
580
570
560
550
540
530
520

APPENDIX C

GROUNDWATER FLOW CALCULATIONS

CROSS-SECTIONAL AREA CALCULATIONS

	A (a frac) (square feet)	A (dolostone) (square feet)
Royal Ave. (W to E)		
Area 1		
PL / MW-84-9	220.4	1724.8
MW-84-9 / MW-88-6	0	1239
	220.4	2963.8
Area 2		
MW-88-6 / MW-88-13	22	523.6
Area 3		
MW-88-13 / PL	222	1419
Total:	464.4	4906.4
47th Street (S to N)		
Area 1		
PL / BH-87-5	56.2	982.4
Area 2		
BH-87-5 / MW-84-13	0	1384
MW-84-13 / PL	0	1394
	0	2778
Total:	56.2	3760.4

GROUND WATER FLOW CALCULATIONS

DARCY'S LAW

$Q = kiA$

k = PERMEABILITY / HYDRAULIC CONDUCTIVITY

i = HYDRAULIC GRADIENT

A = CROSS-SECTIONAL AREA

"A" FRACTURE

ROYAL AVENUE (W TO E)

AREA 1 : PL TO MW 88-6

$Q_1 = (10^{-3}\ cm/sec)(0.03)(220)$

$Q_1 = 148.1\ gal/day$ ✓

$Q_2 = (10^{-4}\ cm/sec)(0.03)(2964)$

$Q_2 = 202\ gal/day$ ✓

AREA 1 $Q \cong$ 350 gal/day

AREA 2 : MW 88-6 TO MW 88-13

$Q_1 = (10^{-3}\ cm/sec)(0.03)(22)$

$Q_1 = 14.8\ gal/day$

$Q_2 = (10^{-4}\ cm/sec)(0.03)(523.6)$

$Q_2 = 35\ gal/day$

AREA 2 $Q \cong$ 50 gal/day ✓

AREA 3: MW 88-13 TO ℄

$Q_1 = (10^{-3} \text{ cm/sec})(0.03)(222)$

$Q_1 = 149.6$ gal/day

$Q_2 = (10^{-4} \text{ cm/sec})(0.03)(1419)$

$Q_2 = 96$ gal/day ✓

AREA 3 $Q \cong 246$ gal/day

47th STREET (S TO N

AREA 1: ℄ TO BH-87-5

$Q_1 = (10^{-3} \text{ cm/sec})(0.03)(56.2)$

$Q_1 = 38.1$ gal/day

$Q_2 = (10^{-4} \text{ cm/sec})(0.03)(982)$

$Q_2 = 66$ gal/day

AREA 1 $Q \cong 104$ gal/day

AREA 2: BH 87-5 TO ℄

$Q_2 = (10^{-4} \text{ cm/sec})(0.03)(1394)$

$Q_2 = 94$ gal/day

AREA 2 $Q = 94$ gal/day

NOTE: A CONVERSION FACTOR OF 3×10^3 WAS USED TO CONVERT FROM cm/sec TO ft/day

"B" FRACTURE

ROYAL AVENUE (W TO E)

AREA 1: PL TO MW 88-6B 756

Q = (10^{-3} cm/sec) (0.01) (664.5)

Q = 148.8 gal/day → 160 gal/day

AREA 2: MW 88-6B TO MW 84-12

Q: (10^{-3} cm/sec) (0.01) (457.5) 515

Q = 102.5 gal/day ~110 gal/day

47TH STREET (S TO N)

AREA 1: PL TO BH 87-5

Q: (10^{-3} cm/sec) (0.01) (375) 487

Q: 83.8 gal/day ~103 gal/day

AREA 2: BH 87-5 TO MW 84-13

Q: (10^{-3} cm/sec) (0.01) (375) 478

Q = 83.8 gal/day 101 gal/day < saturated

AREA 3: MW 84-13 TO PL

Q = (10^{-3} cm/sec) (0.01) (255) 328

Q: 57.6 gal/day

APPENDIX D

CONTAMINANT LOADING CALCULATIONS FOR TOTAL ORGANICS

3.785

TOTAL CONTAMINANT LOADING CALCULATIONS

$L = CQ$

C: AVERAGE CONCENTRATION OF TOTAL DETECTED VOLATILE ORGANICS

Q: VOLUME OF GROUNDWATER/TIME

PPM ÷ 1000 ⇒ g/l × 3.785 l / g ⇒ g/gal

g/day

ROYAL AVENUE

"A" FRACTURE

AREA 1

$L = (0.271\ g/gal)(350\ gal/day)$

$L = .21\ lbs/day$ ✓

AREA 2

$L = (0.428\ g/gal)(50\ gal/day)$

$L = .05\ lbs/day$ ✓

AREA 3

$L = (0.241\ g/gal)(246\ gal/day)$

$L = 0.13\ lbs/day$ ✓

TOTAL "A" FRACTURE L ALONG ROYAL AVENUE

$L = 0.39\ lbs/day$

WEST OF REGULATOR 8 ✓

$L = 0.21\ lbs/day$

EAST OF REGULATOR 8 ✓

$L = 0.18\ lbs/day$

"B" FRACTURE

AREA 1

L = (0.339 g/gal)(148.8 gal/day)

L = 0.11 lbs/day ✓

AREA 2

L = (0.371 g/gal)(102.5 gal/day) .406

L = 0.08 lbs/day .092

TOTAL ROYAL AVENUE "B" FRACTURE

L = 0.19 lbs/day

WEST OF REGULATOR 8

L = 0.11 lbs/day

EAST OF REGULATOR 8

L = 0.08 lbs/day

ROYAL AVENUE TOTAL LOADING

"A" + "B" FRACTURES = 0.58 lbs/day

ROYAL AVENUE TOTAL LOADING

WEST OF REGULATOR 8 : L = 0.32 lbs/day

EAST OF REGULATOR 8 : L = 0.26 lbs/day

47TH STREET

"A" FRACTURE

AREA 1

L = (~~0.12~~ 0.012 g/gal)(104 gal/day)

L = .003 lbs/day

AREA 2

L = (.023 g/gal)(94 gal/day)

L = 0.005 lbs/day

TOTAL "A" FRACTURE LOADING

L = .008 lbs/day

"B" FRACTURE

AREA 1

L = (0.14 g/gal)(83.8 gal/day)

L = .026 lbs/day

AREA 2

L = (.011 g/gal)(83.8 gal/day)

L = .002 lbs/day

AREA 3

L = (.006 g/gal)(57.6 gal/day)

L = 0.0008 lbs/day

TOTAL "B" FRACTURE LOADING

L = .029 lbs/day

47TH STREET TOTAL LOADING = .037 lbs/day

TOTAL LOADING EXITING SITE = 0.621 lbs/day

APPENDIX E

CONTAMINANT LOADING CALCULATIONS FOR FOUR ORGANIC COMPOUNDS

SPECIFIC COMPOUND LOADING CALCULATIONS (WEST OF REGULATOR 8)

$L = CQ$

"A" FRACTURE

BENZENE

$L = (0.027\ g/gal)(350\ gal/day)$

$L = 9.45\ g/day$

CHLOROFORM

$L = (0.00011\ g/gal)(350\ gal/day)$

$L = 0.038\ g/day$

DICHLOROBENZENE

$L = (0.082\ g/gal)(350\ gal/day)$

$L = 28.7\ g/day$

TRICHLOROETHYLENE

$L = (.0083\ g/gal)(350\ gal/day)$

$L = 2.9\ g/day$

"B" FRACTURE

BENZENE

$L = (.0093\ g/gal)(149\ gal/day)$

$L = 1.38\ g/day$

CHLOROFORM

$L = (.00056\ g/gal)(149\ gal/day)$

$L = 0.083\ g/day$

DICHLOROBENZENE

$L = (0.0426\,g/gal)(149\,gal/day)$

$L = 6.35\,g/day$

TRICHLOROETHYLENE

$L = (0.034\,g/gal)(149\,gal/day)$

$L = 5.07\,g/day$

TOTAL LOADING WEST OF REGULATOR 8

BENZENE: $L = 10.83\,g/day$

CHLOROFORM: $L = 0.121\,g/day$

DICHLOROBENZENE: $L = 35.05\,g/day$

TRICHLOROETHYLENE: $L = 7.97\,g/day$

FLOW RATES AS OBTAINED FROM CORP OF ENGINEERS

@ RAINBOW BRIDGE

SUMMER MONTHS: DAY - 100,000 cfs
NIGHT - 56,000 cfs

REMAINDER OF YEAR: 54,000 - 60,000 cfs

@ NIAGARA ON THE LAKE

SUMMER MONTHS: DAY - 220,000 cfs
NIGHT - 190,000 cfs

REMAINDER OF YEAR: 200,000 cfs - 215,000 cfs

APPENDIX J

BASELINE CANCER RISK ASSESSMENT REPORT

Baseline Cancer Risk Assessment:
Frontier Chemical Waste Process, Inc.
Niagara Falls, New York

Prepared for:

ECCO, Inc.
Buffalo, New York

Prepared by:

Health & Environmental Sciences Group
Washington, D.C.

April 25, 1990

TABLE OF CONTENTS

I. Introduction

A. Background: Frontier Chemical Waste Process Site

B. Risk Assessment Principles

II. Methodology

A. Risk Assessment Rationale

B. Quantitative Aspects

C. Qualitative Aspects

III. Results

A. Hazard Identification

B. Dose-response Assessment

C. Exposure Assessment

1. Site inspection

2. Human exposure pathways

D. Risk Characterizations

1. Drinking water - Falls Street tunnel outflow

2. Drinking water - mouth of Niagara River

E. Qualitative Risk Comparisons

1. Ingestion of fish - Falls Street tunnel outflow

2. Ingestion of fish - mouth of Niagara River

3. Ingestion of fish and drinking water - Niagara River at Falls Street tunnel outflow

4. Ingestion of fish and drinking water - mouth of Niagara River

5. Noncarcinogenic effects - oral reference dose

IV. Conclusions

Endnotes

Tables

Introduction

This report describes a baseline cancer risk assessment relative to chemicals identified in the groundwater at the Frontier Chemical Waste Process, Inc. (Frontier) facility at 4626 Royal Avenue, Niagara Falls, New York. The risk assessment is to supplement a hydrogeologic investigation being conducted by ECCO, Inc. for Frontier.

Background: Frontier Chemical Waste Process Site:

Testing, initiated in 1982 and continuing to present, identified detectable concentrations of forty-one organic chemicals and metals at the Frontier site. Testing for metals ceased after April, 1986. Testing for organics continues. The presence of the substances has been attributed both to migration onto the site from upgradient contamination and to historical practices at Frontier. There are currently no active sources at the site generating the identified compounds.[1]

Groundwater has been shown to preferentially migrate along two fracture zones within the upper bedrock underlying the site.[2] The upper fracture has been designated as the A fracture, and the deeper fracture as the B fracture. Water in the overburden above the A fracture shows little lateral migration and water beneath the B fracture appears to be under confining conditions, i.e. artesian.

ECCO, Inc. has determined the direction of the groundwater flow to be southeast and south, toward the Forty-seventh Street sewer tunnel in the east and the Falls Street sewer tunnel in the south, running along Royal Avenue.[3] All of the groundwater reaching the sewer tunnels east of Regulator 8 (midway along the southern border of the Frontier site) and approximately seventy percent of that reaching the Falls Street sewer tunnel west of Regulator 8 is diverted during dry weather flow either at Regulator 8 or at the gorge pump station. This water is processed by the City of Niagara Falls Wastewater Treatment Plant (NFWWTP).[4,5] It follows that thirty percent of the groundwater reaching the Falls Street sewer tunnel west of Regulator 8 is released untreated into the Niagara River. The untreated portion of the effluent was the focus of this baseline cancer risk assesment.

Risk Assessment Principles:

Over the past thirty years, sophisticated methodologies have evolved within the public health and medical communities to identify and control environmental health risks. These methods have evolved within the framework of prevention and preventive intervention, and were adapted from historical approaches to the control of infectious and waterborne diseases.[6] The goal of risk assessment remains the identification of factors influencing the disease process so that illness can be prevented or at least controlled.

Adaptations of these scientific and medical principles have led to a more specific definition of risk assessment applicable to the regulatory context. The United States Environmental Protection

Agency (EPA) currently considers risk assessment to be the definition of the adverse health consequences of exposure to toxic agents.[7] The underlying premise is that the frequency or intensity of disease due to environmental agents is dose related. That is, the greater the exposure to an agent, the greater the adverse impact in terms of public health. Conversely, the absence of significant exposure suggests minimal public health risk.

Methodology

Although there are many possible approaches to assessing the potential health impact of the groundwater contamination at the Frontier site, we have incorporated conservative EPA models in defining the cancer risk posed by the site. The methodology employed relies on assumptions which would tend to overestimate risk and therefore provide a significant margin of public health safety for remedial decisions made pursuant to the results of the risk assessment.

Risk Assessment Rationale:

Consistent with basic scientific principles, our risk assessment began with the premise that human exposure was necessary for exposure-related cancer to be manifested. We considered all logical pathways for human exposure derivative of the groundwater contamination at the Frontier site. These pathways included drinking water, ingestion of fish, and direct contact through recreational activities.

At the point of possible human contact, further conservative assumptions were made to assure that any possible risk would be identified. In the case of drinking water, it was assumed that each individual would consume two liters of water from the contaminated source per day. It was assumed further that the exposure would be sustained daily, and for an entire lifetime, measured as 70 years. In the case of fish ingestion, it was assumed that 6.5 grams of fish from the contaminated waters were consumed daily, over the entire lifetime, measured as 70 years. In the case of exposure through recreational activities, ingestion of the contaminated water was assumed under similar assumptions as for drinking water; therefore, the drinking water risk assessment incorporates recreational exposures as well.

Our approach specifically followed EPA Carcinogen Risk Assessment Guidelines, incorporating the four major components:

1. Hazard identification,
2. Dose-reponse assessment,
3. Exposure assessment,
4. Risk characterization.[8]

Quantitative Aspects:

For those compounds identified as carcinogenic or probably carcinogenic to humans,[9] increased lifetime cancer risks were estimated assuming that there is no threshold for carcinogenic effects in humans.[10] Specifically, the increased lifetime cancer risk was calculated as the product of the exposure measured in units of mg/kg body weight/day and the carcinogenic potency for the oral route of exposure.

Qualitative Aspects:

Concentrations of specific substances at the point of human exposure were compared to the:

1. EPA-established oral reference dose for noncarcinogenic effects,[11]
2. EPA-established maximum contaminant level in drinking water,[12]
3. EPA-established concentration leading to an increased lifetime cancer risk of 1×10^{-6} for consuming organisms from the water,[13]
4. EPA-established concentration leading to an increased lifetime cancer risk of 1×10^{-6} for ingesting both organisms from the water and the water.[14]

Results

Hazard Identification:

We reviewed tables of analytical results for 71 measuring locations (sampled monitoring wells) provided by ECCO, Inc.[15] All detected analytes were evaluated in terms of their potential to cause cancer in humans when ingested, according to the EPA carcinogenic classifications: known, probable, or possible human carcinogens, or nonclassifiable as to potential to cause cancer in humans.[16]

Of the organics identified, two known human carcinogens, and four probable human carcinogens were measured in 1988.[17] Because 1988 was the most recent sampling year, the risk assessment was based on these measurements. Quantitative risk assessments were conducted for benzene and vinyl chloride (known human carcinogens) and chloroform, 1,4-dichlorobenzene, 1,2-dichloroethane, and trichloroethylene (probable human carcinogens).[18]

<u>Dose-response assessment:</u>

Published EPA carcinogenic potency factors for compounds classified as known or probable oral human carcinogens were obtained and incorporated into the later risk assessment steps. These carcinogenic potency factors are based on conservative assumptions which allow that one molecule of the substance is sufficient to produce a cancer risk over the lifetime of an exposed individual.[19] As with the other assumptions incorporated into our risk assessment, a bias toward an overestimation of risk is inherent to the one-molecule theory encompassed by the EPA carcinogenic potency factors.

Exposure assessment:

Based on observations during the site visit, evaluations of the available hydrogeologic data, and discussions with ECCO, Inc. personnel, we developed two scenarios for possible human exposure:

1. Substance flow into the groundwater, along the A and B fracture zones and into the sewer tunnel, down the sewer tunnel into the Niagara River (below Niagara Falls)[20], down the river into Lake Ontario and ingested either through recreational activities involving water or the drawing of drinking water from the lake;
2. Substance flow into the groundwater, along the A and B fracture zones and into the sewer tunnel, down the sewer tunnel into the Niagara River (below Niagara Falls), into the fish swimming there, and ingested with the fish.

We obtained from ECCO, Inc. the estimated concentrations of the six known or probable human carcinogens in the Niagara River at the Falls Street tunnel outflow and at the mouth of the Niagara River.[21] Two of the carcinogens (1,2-dichloroethane and vinyl chloride) were eliminated from consideration at this point because the only downgradient sampling wells on the site in which they appeared led into the sewer tunnel east of Regulator 8. Because of the location, outflow corresponding to these wells should be completely diverted and treated by the city.[22] Table 1 contains the estimated loading concentrations of the compounds at the Falls Street tunnel outflow and at the mouth of the Niagara River.

Risk Characterizations:

In this section, the quantitative risk assessments for the known and probable human carcinogens are presented. Data are stated in terms of excess cancer risk per population. The EPA has established as convention that any risk exceeding one per million is unacceptable. In the sections below, a one in a million cancer risk is expressed as 1E-06.

Drinking water - Niagara River at Falls Street tunnel outflow. In Table 2 are compound-specific excess lifetime cancer risks associated with ingestion of water present in the Niagara River at the Falls Street tunnel outflow. The highest cancer risk is associated with dichlorobenzenes, where ingestion carries a two in 10 billion excess lifetime cancer risk.

Drinking water - mouth of Niagara River. In Table 3 are compound-specific excess lifetime cancer risks associated with ingestion of water present at the mouth of the Niagara River. The highest cancer risk is associated with dichlorobenzenes, where the excess cancer risk is five in a 100 billion population.

Qualitative Risk Comparisons:

In this section, estimated concentrations of specific compounds at the Falls Street tunnel outflow and the mouth of the

Niagara River are compared to EPA guideline concentrations for ingestion of fish and drinking water which carry less than a one in one million cancer risk.

Ingestion of fish - Niagara River at Falls Street tunnel outflow. Table 4 presents compound-specific comparisons for ingestion of fish at the Falls Street tunnel outflow. The lowest margin of safety is associated with trichloroethylene where the concentration is a million times lower than the EPA reference level.

Ingestion of fish - mouth of Niagara River. Table 5 presents compound-specific comparisons for ingestion of fish from the mouth of the Niagara River. The lowest margin of safety is associated with trichloroethylene, where the concentration is a million times lower than the EPA reference level.

Ingestion of fish and drinking water - Niagara River at Falls Street tunnel outflow. Table 6 presents compound-specific comparisons for ingestion of both fish and drinking water from the Niagara River at the Falls Street tunnel outflow. The lowest margin of safety is associated with trichloroethylene, where the concentration is 100,000 times lower than the EPA reference level.

Ingestion of fish and drinking water - mouth of Niagara River. Table 7 presents compound-specific comparisons for ingestion of both fish and drinking water from the mouth of the Niagara River. The lowest margin of safety is 100,000 for trichloroethylene.

Noncarcinogenic effects - oral reference dose. Although this baseline risk assessment focused on carcinogenic risk, we compared the concentrations to the oral reference dose for noncarcinogenic effects for the two compounds for which such information is available. The oral reference dose represents a daily exposure to the human population, including sensitive subgroups, that is likely to be without an appreciable risk of adverse effects. For chloroform, the concentrations are 100 million times lower than the reference dose. For dichlorobenzene, the concentrations are one million times lower than the reference dose.

Conclusion

Overall, the baseline risk assessment conducted for the Frontier site suggests that the concentrations of chemicals contaminating the groundwater do not pose an undue risk of cancer to the public.

Endnotes

1. Scarpelli, R. Frontier. Discussion at site visit, 4/12/90.

2. ECCO, Inc. Draft Hydrogeologic Investigation, 4/21/89.

3. Crouch, R. ECCO, Inc. Discussion at site visit, 4/10/90.

4. Crouch, R. ECCO, Inc. Discussion, 4/19/90.

5. Records indicate this treatment plant to be in compliance with its pollutant discharge permit limits. However, NFWWTP exceeded its permit limit for dichlorobenzenes and trichloroethylene in January, 1990. According to a SPDES self-monitoring report dated October, 1989, NFWWTP is investigating the situation and currently attributes at least the dichlorobenzene excesses to non-aqueous phase liquid found southeast (i.e. downgradient) of the Frontier site.

6. Leavall and Clark. Preventive Medicine. 1970.
   MacMahon and Pugh. Epidemiology Principles and Methods. 1970.

7. U.S. EPA. Guidelines for Carcinogen Risk Assessment. FRL-2984-1. Federal Register 51:185:33993. 9/86.

8. U.S. EPA. Guidelines for Carcinogen Risk Assessment. FRL-2984-1. Federal Register 51:185:33993. 9/86.

9. According to EPA hazard evaluation criteria.

10. The no-threshold model is another of the conservative assumptions incorporated into the EPA approach. There is considerable scientific evidence to suggest that, for at least some carcinogens, thresholds exist.

11. ATSDR. Toxicological Profile for [the agent].

12. ATSDR. Toxicological Profile for [the agent].

13. ATSDR. Toxicological Profile for [the agent].

14. ATSDR. Toxicological Profile for [the agent].

15. ECCO, Inc. Frontier Chemical Waste Process, Inc. Detected Analytical Results. Monitoring Well [well number].

16. U. S. EPA. Health Effects Assessment for [the agent]. Environmental Criteria and Assessment Office. Cincinnati, OH. AND/OR U. S. EPA. Online IRIS file for the agent.

17. Only known and probable human carcinogens are regulated on the basis of cancer-causing potential.

18. Frontier measured dichlorobenzene concentrations, which might or might not have included 1,4-dichlorobenzene. We treated the dichlorobenzene measurements as if they were measurements of 1,4-dichlorobenzene as an added measure in providing the widest possible margin of safety.

19. U.S. EPA. Health Effects Assessment for [the agent]. Environmental Criteria and Assessment Office. Cincinnati, OH.

20. The drinking water intake for the city of Niagara Falls, New York, is above Niagara Falls.

21. Crouch, R. ECCO. Telephone conference, 4/19/90.

22. Crouch, R. ECCO, Inc. 4/19/90.

Table 1

Loading Concentrations;
Estimated Concentrations* at Falls Street Tunnel Outflow
and Mouth of Niagara River

	Estimated Concentration, Tunnel Outflow (mg/l)	Estimated Concentration, Mouth of River (mg/l)
Benzene	8.2E-08	2.2E-08
Chloroform	9.0E-10	2.5E-10
Dichlorobenzenes**	2.6E-07	7.1E-08
Trichloroethylene	6.0E-08	1.6E-08

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 2

Risk Characterizations;
Drinking Water at Falls Street Tunnel Outflow;
Estimated Concentrations* and Excess Cancer Risk

	Estimated Concentration (mg/l)	Excess Cancer Risk
Benzene	8.2E-08	1E-10
Chloroform	9.0E-10	2E-12
Dichlorobenzenes**	2.6E-07	2E-10
Trichloroethylene	6.0E-08	2E-11

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 3

Risk Characterizations;
Drinking Water at Mouth of Niagara River;
Estimated Concentrations* and Excess Cancer Risk

	Estimated Concentration (mg/l)	Excess Cancer Risk
Benzene	2.2E-08	3E-11
Chloroform	2.5E-10	5E-13
Dichlorobenzenes**	7.1E-08	5E-11
Trichloroethylene	1.6E-08	5E-12

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 4

Qualitative Risk Comparison;
Ingestion of Fish at Falls Street Tunnel Outflow;
Estimated Concentration* Versus EPA Reference Level

	Estimated Concentration (mg/l)	EPA Reference Level (mg/l)
Benzene	8.2E-08	none established
Chloroform	9.0E-10	1.6E-02
Dichlorobenzenes**	2.6E-07	2.6E+00
Trichloroethylene	6.0E-08	8.1E-02

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 5

Qualitative Risk Comparison;
Ingestion of Fish at Mouth of Niagara River;
Estimated Concentration* Versus EPA Reference Level

	Estimated Concentration (mg/l)	EPA Reference Level (mg/l)
Benzene	2.2E-08	none established
Chloroform	2.5E-10	1.6E-02
Dichlorobenzenes**	7.1E-08	2.6E+00
Trichloroethylene	1.6E-08	8.1E-02

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 6

Qualitative Risk Comparison;
Ingestion of Fish and Drinking Water at Falls Street Tunnel Outflow;
Estimated Concentration* Versus EPA Reference Level

	Estimated Concentration (mg/l)	EPA Reference Level (mg/l)
Benzene	8.2E-08	none established
Chloroform	9.0E-10	1.9E-04
Dichlorobenzenes**	2.6E-07	4.0E-01
Trichloroethylene	6.0E-08	2.7E-03

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

Table 7

Qualitative Risk Comparison;
Ingestion of Fish and Drinking Water at Mouth of Niagara River;
Estimated Concentration* Versus EPA Reference Level

	Estimated Concentration (mg/l)	EPA Reference Level (mg/l)
Benzene	2.2E-08	none established
Chloroform	2.5E-10	1.9E-04
Dichlorobenzenes**	7.1E-08	4.0E-01
Trichloroethylene	1.6E-08	2.7E-03

* ECCO, Inc.
** Estimated concentration for "dichlorobenzenes," which might or might not include 1,4-dichlorobenzene.

APPENDIX K

KEY PERSONNEL RESUMES

Resume

Richard L. Crouch

Hydrogeologist

Education:

1972	B.S. - Engineering Geology	North Carolina State University Raleigh, North Carolina
1975-1978	Post-Graduate Geology & Groundwater Hydraulics	North Carolina State University

CERTIFICATION:

OSHA (29 CFR 1910.120) Hazardous Waste Site Worker Protection Training.

Experience:

July 1987 - Present
Consulting Hydrogeologist
President

ECCO, Inc.
Brisbane Bldg.,Suite 515
403 Main Street
Buffalo, N.Y. 14203

Consulting hydrogeologist for hydrogeologic, contaminant migration and engineering geologic aspects of investigative programs (e.g. site development, uncontrolled waste site assessments, solid and hazardous waste site permits and closures).

June 1986 - June 1987
Senior Hydrogeologist/Associate.

Recra Environmental, Inc.
(Formerly Recra Research,Inc.)
Audubon Business Center
Suite 106
10 Hazelwood Drive
Amherst, N.Y. 14150

Senior technical advisor for hydrogeological and contaminant transport aspects of investigative programs. Designed the scope of work of investigative programs including, but not limited to, geophysical survey methods, test boring/monitoring well siting and installations, soil and aquifer parameter determinations, soil, surface water and groundwater sampling methodologies and analytical programs. Implemented and supervised field activities and data acquisition. Directly involved in data interpretation and report preparation. Assured technical quality control throughout projects. Final reviewer for all reports related to hydrogeological and contaminant migration assessment reports. Interfaced with both industrial and regulator personnel from development of proposed programs to presentation of investigation program results. Responsible for technical development of staff personnel through in-house training seminars and individual instruction.

April 1981 - June 1986
Senior Hydrogeologist

Recra Research, Inc.
4248 Ridge Lea Road
Amherst, N.Y. 14226

Technical advisor for hydrogeological and contaminant transport aspects of investigative programs. Project manager for major investigative assignments. Responsible for program design, implementation, data interpretation and report writing for hydrogeological/ remedial investigations conducted in New York, Pennsylvania, Massachusetts, Connecticut, New Jersey, Illinois, Oklahoma and Texas. Major contributor to the groundwater section in Part B submissions for existing and proposed hazardous waste disposal facilities in New York, Ohio, Illinois, Texas, Louisiana, and Puerto Rico. Technical supervisor and reviewer for Phase I and Phase II activities associated with Recra's New York State Department of Environmental Conservation Superfund Contract. Developed and participated as an instructor in groundwater contamination assessment training seminars for New York State Department of Environmental Conservation, the environmental regulatory agencies of five Mid-Western States including Michigan, Wisconsin, Illinois, Ohio, and Minnesota, and EPA Region V. Participated as an instructor in seminars concerning hazardous waste site investigative/remedial methods presented to representatives of industries in Puerto Rico. Responsible for technical development of staff personnel through in-house training seminars and individual instruction.

Resume

Richard L. Crouch

Hydrogeologist

May 1978 - April 1981
Hydrologist II

North Carolina Dept. of Natural Resources and Comunity Development
Raleigh, North Carolina

Groundwater representative on the North Carolina Water Quality Management Plan Task Force (208 Water Quality Management Plan). Responsible for the design and implementation of hydrogeological/analytical investigations around non-point sources of pollution within North Carolina (e.g. solid waste sites, industrial lagoons, agricultural activites, etc.). Evaluated field data, assessed the relationship between non-point sources of pollution and groundwater, and recommended best management practices for each of the investigated non-point sources. Participated in numerous public hearings across the State detailing the investigative efforts and results from groundwater investigations around non-point sources and the recommended best management practices associated with each non-point source activities.

Sept 1975 - May 1978
Graduate Assistant

North Carolina State University
Department of Geoscience
Raleigh, North Carolina

Taught undergraduate geology laboratory courses and assisted undergraduate geology course lectures. Also worked as a consultant on groundwater and air photo interpretation projects.

May 1969 - June 1972
Geological Technician II

North Carolina Dept. of Transportation
Raleigh, North Carolina

Exclusive of 6 months active service for U.S. Army Reserve, assisted in soil sampling and test boring construction both on land and water for geological and geotechnical characterzation associated with highway and bridge construction. Performed sieve analysis and Atterberg Limit deteminations. Evaluated Standard Penetration Test results, geotechnical properties, geology and groundwater conditions and summarized results for submission to design engineers.

Resume

Andrew J. Kucserik

EDUCATION:

1981	M.A.- 25 credit hours towards Master of Arts Degree	S.U.N.Y. at Buffalo
1977	B.A.- Geological Sciences	S.U.N.Y. at Buffalo

CERTIFICATION:

Asbestos Handler Certification, N.Y.S. Department of Labor.
OSHA (29 CFR 1910.120) Hazardous Waste Site Worker Protection Training.

EXPERIENCE:

August 1988 - Present
Senior Geologist

ECCO, Inc.
Brisbane Bldg., Suite 515
403 Main Street
Buffalo, NY 14203

Hydrogeologic investigations including program development, field implementation, data evaluation and report preparation of the geohydrology aspects; Real Property Environmental Examinations; geophysical surveys; general environmental consulting and assessment work; development and supervision of field, health, and safety plans.

Oct., 1986- Aug. 1988
Senior Geologist

Empire Soils Investigations, Inc.

Hydrogeologic investigations, environmental assessments, geophysical surveys, evaluation of materials, development and implementation of monitoring well and sampling programs.

Dec., 1981- Oct. 1986 **Empire Soils Investigations, Inc.**
Drilling Manager

Managed up to seven drill rigs and crews; coordinated and performed test boring surveys; classified soil and rock samples; conducted hydrogeologic field investigations and subsequent reports; drill rig inspection. Was Assistant Drilling Manager from Dec., 1981- Jan., 1985.

April, 1979- Dec. 1981 **Empire Soils Investigations, Inc.**
Engineering Technician

Performed quality control inspection and testing on earth work and foundation projects.

May, 1978- April, 1979 **Krehbiel Associates, Inc.**
Engineer's Field Representative

Performed quality control inspection on pavement, sewer, and water line projects.

CONTINUING EDUCATION:

"Subsurface Monitoring Technology", April 13-15, 1987
"Site Assessment for Hazardous Waste Sites", October 2, 1987
"Hazardous Waste Regulation Update", December 15, 1987

Resume
Andrew J. Kucserik

PROFESSIONAL SOCIETIES:

Certified Professional Geologist #683, State of Indiana
Licensed Geologist#858, State of North Carolina
Association of Engineering Geologists-Affilate Member
Buffalo Association of Professional Geologists,
President (1988), Vice-President (1987), Treasurer (1986).

GEORGE LOUIS CARLO

1225 Eye Street, N.W. Suite 1210
Washington, D.C. 20005
(202) 289-6800

EDUCATION

B.A. (cum laude) **State University of New York at Buffalo** (Biology)

M.S. Roswell Park **Memorial Institute**, Division of Graduate Studies (SUNYAB), Department of Epidemiology (Epidemiology)

Ph.D. Roswell Park **Memorial Institute**, Division of Graduate Studies (SUNYAB), Department of Experimental Pathology (Experimental Pathology/Epidemiology)

J.D. **George Washington University National Law Center**

CERTIFICATION

American College of Epidemiology

EXPERIENCE

9/88 to present	Chairman **Health & Environmental Sciences Corporation**
2/88 to 9/88	Technical and Legal Consultant **George Carlo & Associates, Inc.**
1/84 to 2/88	Chairman, President and Chief Executive Officer **George Carlo & Associates, Inc.**
1/84 to 2/86	Director of Research **George Carlo & Associates, Inc.**
2/86 to 2/88	Director of Legislative, Regulatory and Litigation Support Projects **George Carlo & Associates, Inc.**
1/84 to present	**Expert Witness and Consultant**

EXPERIENCE (Scientific and Academic)

8/86 to present	Assistant Professorial Lecturer in Medicine **George Washington University**, School of Medicine and Health Sciences
5/86 to present	Clinical Assistant Professor **State University of New York at Buffalo**, School of Medicine.
1/82 to present	Adjunct Faculty **Roswell Park Memorial Institute**, Graduate Division, State University of New York at Buffalo.
4/85 to 5/86	Research Associate **State University of New York at Buffalo**, School of Medicine. Department of Social and Preventive Medicine.
6/81 to 5/84	Research Leader in Epidemiology **Dow Chemical U.S.A.**, U.S. Area Medical Department.
6/81 to 6/82	Adjunct Professor **University of Arkansas for Medical Sciences**, Little Rock, Arkansas.
2/80 to 6/81	Assistant Professor **University of Arkansas for Medical Sciences**, Little Rock, Arkansas. Department of Pharmacology and Interdisciplinary Toxicology.
9/79 to 6/81	Assistant Professor **University of Arkansas for Medical Sciences**, Little Rock, Arkansas. Division of Biometry.
9/79 to 6/81	Assistant Professor **University of Arkansas for Medical Sciences**, Little Rock, Arkansas. Department of Family and Community Medicine.
8/78 to 9/79	Clinical Instructor **State University of New York at Buffalo**, School of Medicine, Buffalo, New York. Department of Social and Preventive Medicine.
8/78 to 9/79	Epidemiologist **State University of New York at Buffalo**, School of Medicine, Buffalo, New York. Research Program in Occupational and Environmental Health.

9/77 to 8/78 Teaching Assistant
Roswell Park Graduate Division, State University of New York at Buffalo. Department of Epidemiology.

PUBLICATIONS

Abstracts

Carlo GL: Painting as a Possible Occupational Cancer Hazard. New York State Department of Health, Mentor, June 1978.

Vena JE, Rogers K, and Carlo GL: Studying the Occupational Health of Auto Workers Using Union Data: Issues and Progress. Proceedings of the 108th Annual Meeting, American Public Health Association, October 1980.

Carlo GL, Arrighi HM, and Vena JE: The Healthy Worker Effect and Contradictory Results in SMR and PMR Analyses. Proceedings of the 17th Annual Meeting of the Society for Epidemiologic Research, June 1981.

Kahn A, Davidson K, and Carlo GL, et al: Chronic Adult Stress Syndrome and the Primary Care Physician. Proceedings of the North American Primary Care Research Group Meeting, 1981.

Davidson K, Kahn A, and Carlo GL, et al: Lifestyle Modification Counseling in the Treatment of the Chronic Adult Stress Syndrome. Proceedings of the North American Primary Care Research Group Meeting, 1981.

Carlo GL, Arrighi HM, and Vena JE: The Healthy Worker Effect and Contradictory Results in SMR and PMR Analyses. American Journal of Epidemiology. Volume 114, No. 3, September 1981.

Carlo GL and Hearn S: Practical Aspects of Conducting Reproductive Epidemiology Studies in Industry. Proceedings of the 5th Annual Rocky Mountain Center for Occupational and Environmental Health Research Symposium, April 1983.

Carlo GL: Systematic Account and Critical Appraisal of Current Epidemiological Approaches for Monitoring Reproductive Outcome in Industry: Industry Viewpoint. Proceedings of the 5th Annual Rocky Mountain Center for Occupational and Environmental Health Research Symposium, April 1983.

Carlo GL, Doemland ML, LeVois ME, and Ponomarenko T: Expanding the Interface Between Epidemiology and the Law: A Model for Settlement of Toxic Torts. American Journal of Epidemiology. Volume 124, No. 3, September 1986.

Carlo GL and Buck GM: Dose-Response Relationships in Exposure to Human Teratogens: The Importance of Timing. American Journal of Epidemiology. Volume 126, No. 3, September 1988.

Articles and Reports

Carlo GL: Organic Drinking Water Contaminants and the Incidence of Selected Gastrointestinal and Urinary Tract Cancers. State University of New York at Buffalo Doctoral Dissertation, 1979.

Carlo GL and Mettlin CJ: Cancer Incidence and Trihalomethane Concentrations in a Public Drinking Water System. American Journal of Public Health, Vol. 70, No. 5, May 1980.

Kimmell C, Carlo G, Hogue C, and Holson J: Suitability of Animal Models for Predicting Hazards to Human Development. Proceedings of the Toxicology Forum I98I Winter Meeting, February 1981.

Bond GG and Carlo GL: An Epidemic of Cancer? The Evidence in Perspective. Dow CRI report B-600-272-8I, July 1981.

Currier MF, Carlo GL, Poston PL, Ledford WE: A Cross-Sectional Study of Employees With Potential Workplace Exposure to Ethylene Oxide. British Journal of Industrial Medicine, 41:492-498, 1984.

Carlo GL, Cook RR, Hearn S, et al: Assessment of Fertility Potential Among Male Employees: Practical Scientific Needs. Dow CRI Report B-492-82, 1982.

Carlo GL: The Clean Air Act and Its Research Initiatives: The Need for Innovative Public Health Research. Dow CRI Report B-446-82, 1982.

Carlo GL, Currier MF, and Flanagan KJ: The Louisiana Cancer Controversy: Some Scientific Perspectives. Louisiana Medical Journal, March 1983.

Carlo GL, Cook RR and Ott MG: Epidemic of Cancer? A Case Study of Cherokee County, North Carolina. North Carolina Medical Journal, December 1983.

Plomer JJ and Carlo GL: The Health Effects of Ozone: An Overview of the Scientific Literature. Dow CRI Report, 1982.

Kimmel CA, Holson J, Hogue CJ, and Carlo GL: Reliability of Experimental Studies for Predicting Hazards to Human Development. National Center for Toxicological Research Technical Report 6015. January 1984.

Ott MG, Carlo GL Bond GG, and Steinberg S: Mortality Experience of Employees Involved in Chemical Manufacturing and Related Activities. American Journal of Epidemiology, Volume 122, No. 2, August 1985.

Carlo GL and Miller MK: Health Surveillance Around Hazardous Waste Sites: A Cost-Effectiveness Analysis for Cancer Mortality. Contract study report, Chemical Manufacturers Association, August 1985.

Vena JE, Sultz HA, Fiedler RC, Barnes RE and Carlo GL: Mortality of a Municipal Worker Cohort: I. Males. American Journal of Industrial Medicine, 7:241-252, 1985.

Carlo GL: Health Surveillance As It Applies to the Hazardous Waste Issue: Conceptual Overview and Assessment. Contracted study report, Chemical Manufacturers Association, November 1985.

Carlo GL: Implementation of Intervention Components of Multi-disciplinary Health Surveillance: Selected Disease Specific Models for Estimating Costs. Contracted study report, Chemical Manufacturers Association, 1986.

Vena JE, Sultz HA, Carlo GL, Fiedler RC, and Barnes RE: Sources of Bias in Retrospective Cohort Mortality Studies: A Note on Treatment of Subjects Lost to Follow-up. Journal of Occupational Medicine, Vol. 29 No. 3, March 1987.

Carlo GL, Doemland ML, LeVois ME, Ponomarenko T, and Conroy C: Birth Rates and Potential for Exposure to Trace Amounts of DBCP Through Groundwater Contamination: A Study of California Counties. Submitted for publication.

Carlo GL, Doemland ML, LeVois ME, Ponomarenko T, and Conroy C: Cancer Mortality and Potential for Exposure to Trace Amounts of DBCP Through Groundwater Contamination: Study of California Counties. Submitted for publication.

Carlo GL and LeVois ME: Mortality Surveillance at the Mobay Chemical Corporation New Martinsville, West Virginia Facility: Report on a General Mortality Survey. February 1988.

Carlo GL, Levois ME and Godfrey LR: Public Health Claims Under Superfund: New Data and Tools for Estimating Liability and Apportioning Claims. Environmental Claims Journal, December 1988.

LeVois ME, Carlo, GL: Diagnostic Suspicion in the Recognition of Early Stage Reye's Syndrome: A Survey of Physicians. Submitted for publication.

Chapters In Books

Carman DD and Carlo GL: Obesity: Prevention and Control. In: Chronic Disease: Concepts and Application, C.V. Mosby Co., 1980.

Carlo GL and Hearn S: Practical Aspects of Conducting Reproductive Epidemiology Studies in Industry. In: Reproduction. The New Frontier in Occupational and Environmental Health Research. New York: Alan R. Liss, 1984.

Carlo GL: Systematic Account and Critical Appraisal of Current Epidemiological Approaches for Monitoring Reproductive Outcome in Industry: Industry Viewpoint. In: Reproduction. The New Frontier in Occupational and Environmental Health Research. New York: Alan R. Liss, 1984.

Carlo GL, LeVois ME and Lang BE: The Public Health Authorities of Superfund: New Areas of Significant cost Liability. In: Insurance Claims for Environmental Damages: Legal and Technical Considerations. Executive Enterprises Publishing Company, 1988.

Editorials, Reviews, Miscellaneous

Carlo GL and Hogue CJ: Analysis of Infant Deaths and Stillbirths in Pope County, Arkansas. Arkansas State Department of Health, October 1979.

Carlo GL and Cook RR: Comments Prepared for the Office of Technology Assessment, Congress of the United States, regarding "Draft Protocol for Epidemiological Studies of Agent Orange." September 1981.

Carlo GL and Barth SJ: The U.A.R.E.P. Study on Hazardous Waste and Human Health: What Does It Tell Us? Chemical Manufacturers Association Report, April 1985.

PROFESSIONAL PAPERS PRESENTED (SELECTED)

Vena JE, Rogers KA, and Carlo GL: Studying the Occupational Health of Auto Workers Using Union Data: Issues and Progress. Presented to American Public Health Association, October 1980.

Carlo GL: Health Monitoring Around Hazardous Waste Management Facilities. Presented to Arkansas Federation of Water and Air Users, October 1980.

Kimmel C, Carlo G, Hogue C and Holson J: Suitability of Animal Models for Predicting Hazards to Human Development. Panel discussion presented at the Toxicology Forum Winter Meeting, February 1981.

Kahn A, Davidson K and Carlo G, et al: Chronic Adult Stress Syndrome and the Primary Care Physician. Presented to North American Primary Care Research Group, March 1981.

Davidson K, Kahn A and Carlo G, et al: Lifestyle Modification Counseling in the Treatment of the Chronic Adult Stress Syndrome. Presented to North American Primary Care Research Group, March 1981.

Carlo GL, Panel Moderator: Assessing Environmental Health Risks: The State of the Art in Arkansas. Arkansas Public Health Association Meeting, April 1981.

Carlo GL, Arrighi HM and Vena JE: The Healthy Worker Effect and Contradictory Results in SMR and PMR Analyses. Presented to Society for Epidemiologic Research, June 1981.

Carlo GL: Health Effects of Ozone. Presented to Chemical Manufacturers Association Environmental Update, May 1983.

Carlo GL, LeVois ME, and Doemland ML: Attributable Risk Under the Health Assessment Framework of Superfund. Chemical Manufacturers Association Symposium on Measures of Risk. June, 1986.

Carlo GL and Buck GM: Dose-Response Relationships in Exposure to Human Teratogens: The Importance of Timing. Presented to Society for Epidemiological Research, June 1987.

Carlo GL, Schumacher RP, and Lang BE: Health Surveillance as an Evolving Concept of Redress: A Legal Remedy in Public Health Currency. Society of Environmental and Occupational Health Annual Conference, Toxic Wastes and Public Health: The Impact of Superfund. April 1988.

RESEARCH PROJECTS (SELECTED)

Project Director, "Mortality Experience of a Municipal Worker Cohort and Subsequent Application of the Methodological Issue of the Healthy Worker Effect," funded by New York State Health Research Council, 1979-1980.

"Mortality Experience of a Cohort of Western New York Auto Workers," funded by New York State Health Research Council, 1980-1981.

Principal Investigator, "Painting as a Possible Occupational Cancer Hazard," funded by Department of Epidemiology, Roswell Park Memorial Institute, 1976-1977.

"Dietary and Selected Health Interview Survey," funded by National Institutes of Health and The University of Arkansas, 1979-1981.

Principal Investigator, "Birth Cohort Infant Mortality and Environmental Insult in Arkansas Counties," funded by U.S. Environmental Protection Agency, 1980.

"Minor Morbidity Due to Diuretic Induced Potassium Depletion in Hypertensive Patients," supported by Department of Family and Community Medicine, University of Arkansas for Medical Sciences, 1981.

"The Incidence and Prevalence of the Chronic Adult Stress Syndrome in a Family Practice Clinic," supported by Department of Family and Community Medicine, University of Arkansas for Medical Sciences, 1981.

"Reliability of Animal Models for Predicting Hazards to Human Development," supported by National Teratology Project, National Center for Toxicological Research, 1980-1981.

Primary Investigator, "Cross-Sectional Study of Employees with Potential Workplace Exposure to Ethylene Oxide," Dow Chemical Company, 1981.

Primary Investigator, "Trends in All Causes and All Cancer Mortality in Western North Carolina Counties: 1960-1981." Dow Chemical Company, 1982.

Primary Investigator, "A Vital Status Registry and General Mortality Survey for the Louisiana Division of Dow Chemical U.S.A." Dow Chemical Company, 1982.

"An Assessment of Clinical Laboratory Test Reference Limits," Dow Chemical Company, 1983.

Primary Investigator, "Development of a Morbidity Reporting System and Cancer Registry for the Louisiana Division of Dow Chemical U.S.A." Dow Chemical Company, 1982.

Primary Investigator, "Health Surveillance Around Hazardous Waste Sites: A Cost-Effectiveness Analysis for Cancer Mortality." 1984.

"Factors Influencing the Recognition of Early Stage Reye's Syndrome Among Physicians in the United States." funded by The Aspirin Foundation of America, 1988.

SEMINARS (SELECTED)

"Methodological Difficulties in Using a Small Subset of a Self-Selected Hospital Population as an Occupational Study Base" to Department of Experimental Pathology, Roswell Park Memorial Institute, Fall 1976.

"Painting: A Possible Occupational Cancer Hazard" to Department of Experimental Pathology, Roswell Park Memorial Institute, Spring 1977.

"Mortality Experience of a Chemical Exposure Cohort" to the Western New York Council on Occupational Safety and Health, June 1978.

"Research Methods in Occupational and Environmental Health" to Department of Social and Preventive Medicine, SUNY at Buffalo School of Medicine, Fall 1978.

"Organic Drinking Water Contaminants and Cancer Incidence" to Department of Epidemiology, University of California at Berkeley School of Public Health, June 1979.

"Occupational Cancer Epidemiology" to National Center for Toxicological Research, Pine Bluff, Arkansas, July 1979.

"Epidemiology and the Art of Medicine" to Department of Family and Community Medicine, University of Arkansas for Medical Sciences, November 1979.

"Epidemiology and Toxic Substances" to State of Arkansas Toxics Public Information Task Force, Fall 1980.

"Routine Surveillance of Reproductive Events" presented to Department of Health and Environmental Sciences, Dow Chemical Company, April 1981.

"An Epidemic of Cancer? The Evidence in Perspective," presented to Department of Health and Environmental Sciences, Dow Chemical Company, July 1981.

"The Health Effects of Chlorinated Dioxins," presented to Department of Epidemiology, Oak Ridge Associated Universities, Oak Ridge, Tennessee, September 1983.

"Epidemiological Studies of Chlorinated Dioxins: An Overview" Roswell Park Memorial Institute Occupational Epidemiology Symposium, November 1983.

MISCELLANEOUS

Invited Participant, "Health Effects of Ozone and Other Photochemical Oxidants," U.S. Environmental Protection Agency Workshop, November 1983.

Invited Participant, "Epidemiology and the Courts," Symposium at the American College of Epidemiology Annual Meeting, 1985.

Invited Participant, "Epidemiology and the Law," Symposium sponsored by the University of Cincinnati at the Cincinnati Epidemiology Forum, November, 1986.

Testimony before the Subcommittee on Health and Safety, Committee on Education and Labor, U.S. House of Representatives, concerning H.R. 162, The High Risk Occupational Disease Notification and Prevention Act of 1987, March 17, 1987.

Invited Participant, "Environmental Risks for Lenders," Infocast Bankers Symposium, Washington, D.C., Fall 1987.

Invited Participant, "Assessment and Management of Public Health Risk: New Areas of Potential Liability," Executive Enterprises, Inc. Symposium, Insurance Claims for Environmental Damages: Technical and Legal Considerations, New York, N.Y., May 1988.

Invited Participant, "Epidemiological, Toxicological, and Clinical Evidence in Toxic Tort Litigation," Erie County Bar Association Spring Meeting, Buffalo, N.Y., May 1988.

Invited Participant, "Health Related Authorities Under SARA", Executive Enterprises, Inc. Oil and Gas Industry Environmental REgulation Conference, Houston, Texas, October 1988.

UNPUBLISHED MANUSCRIPTS AND ARTICLES IN PREPARATION

Carlo GL and Lang BE: The Health Related Authorities under the Superfund Amendments and Reauthorization Act of 1986: RI/FS, Settlement and Cost-Recovery Aspects. May 1987.

Reitze AW and Carlo GL: Federal Legislation to Compensate Disease Victims: An Evolving Concept. May 1987.

Carlo GL: The Use of Disparate Impact Statistics to Infer Intent in Disparate Treatment Cases: An Analysis of Watson v. Fort Worth Bank and Trust. December 1987.

Carlo GL: Evaluating U.S. and U.S.S.R. Strategies for Managing the Risk of Nuclear War: A Comparison Based on an Environmental Risk Management Model. December 1987.

Carlo GL: Aspirin, Reyes Syndrome and the Warning Label: Too Late or Too Early? December 1987.

Carlo GL and Campbell L: Compensating Persons With Diseases Related to Pollution in the United States and Japan: A Synthesis of Approaches and a Recommendation. April 1988.

Carlo GL, Williams SE, Baller J and Lang BE: ATSDR and the Health Related Authorities of SARA: Some Practical and Legal Considerations. March 1988.

Carlo GL: Prevention as an Alternative in the Delivery of Health Care: A Cost-Effectiveness Analysis of Selected Primary and Secondary Preventive Interventions. May 1988.

Carlo GL: Health Surveillance as a Remedy in Latent Injury Cases: A Convergence of Legal, Equitable, and Scientific Principles. May 1988.

Carlo GL and Reitze AW: Medical Surveillance, Superfund and Tort Actions and The Agency for Toxic Substances and Disease Registry. May 1988.

COURSES TAUGHT

Quantitative Epidemiology I - University of Arkansas for Medical Sciences

Clinical Oncology - University of Arkansas for Medical Sciences

Preventive Medicine Seminar - University of Arkansas for Medical Sciences

Clinical Epidemiology - George Washington University, Medical Center

Reproductive Epidemiology - State University of New York at Buffalo, School of Medicine

Epidemiology and the Law - SUNY at Buffalo O'Brian School of Law

PROFESSIONAL ASSOCIATIONS

2/88 to present	Member, The Defense Research and Trial Lawyers Association
11/85 to present	Member, American Association for the Advancement of Science
1/86 to present	Member, New York Academy of Sciences
1/86 to present	Member, Society for Occupational and Environmental Health
2/85 to present	Member, American Bar Association

4/80 to present	Member, Sigma XI, Honorary Research Society
9/77 to present	Member, American Public Health Association
9/77 to present	Member, Society for Epidemiological Research
6/81 to 5/84	Member, Industrial Epidemiologists Professional Group
2/79 to 1/81	Member, Society for Occupational and Environmental Health
9/77 to 9/79	Member, New York State Public Health Association
9/77 to 9/79	Member, Western New York Epidemiology Society
8/78 to 9/79	Member, Western New York Council on Occupational Safety and Health

COMMITTEES (SELECTED)

8/81 to present	Office of Technology Assessment, U.S. Congress, Agent Orange Advisory Panel.
1/82 to 1/85	Society for Epidemiologic Research/American Public Health Association Joint Committee on Governmental Affairs.
1/82 to 2/84	Louisiana Chemical Association Cancer Task Force.
5/82 to 2/84	Chemical Manufacturers Association, Air Pollutant Effects Task Group (Leader), Ozone Health Effects Work Group (Member), Government Research Work Group (Member).
1/82 to 5/84	Ethylene Oxide Industry Council, Member, Epidemiology Committee.
1/82 to 6/83	American Industrial Health Council, Scientific Principles of Causality Subcommittee.
10/80 to 6/81	Toxics Public Information Program, Technical Advisory Committee, State of Arkansas.
9/80 to 6/81	Member, University of Arkansas for Medical Sciences Research Council.
3/80 to 6/81	Chairman, Research Committee, Department of Family and Community Medicine, University of Arkansas for Medical Sciences.

12/79 to 6/81	Member, State of Arkansas Hazardous Waste Technical Advisory Committee.
8/78 to 7/79	Project Director, Research Foundation of the State of New York.
8/78 to 6/79	Consultant, Hazardous Waste Task Force, New York State, Department of Health.
6/76 to 6/77	Administrative Vice-President, Graduate Student Association, SUNYAB.
6/75 to 6/77	University Senate, Roswell Park Memorial Institute, Division of Graduate Studies, SUNYAB.

FELLOWSHIPS

New York State Department of Health (1977)

HONORS

Commendation, Arkansas Commission on Pollution Control and Ecology (1981)

Outstanding Young Men of America (1980)

Who's Who Among American Law Students (1986)