WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

EXISTING CONDITIONS
REPORT

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MADISON
WI

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3/20/90

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FEBRUARY 1990

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April 25, 1990

Wisconsin Department of Natural Resources
Southeast District Headquarters
2300 North Martin Luther King Drive
P.O. Box 12436
Milwaukee, WI 53212

Attention: Ms. Sharon Schaver, Project Manager

Re: Cedarburg Groundwater Investigation
Final Existing Conditions Report

Dear Ms. Schaver:

We are pleased to submit three copies of the final Existing Conditions Report for the Cedarburg Groundwater Investigation. Two copies of the report have also been submitted to the Bureau of Solid Waste Management in Madison, in accordance with the scope of work.

It has been a pleasure working with you and other DNR staff on this project. We hope to work with you again on future projects.

Sincerely,

STRAND ASSOCIATES, INC.

Jane M Carlson

Jane M. Carlson

Heidi K Crowe

Heidi K. Crowe, Hydrogeologist

Michael D. Doran, P.E.

JMC/HKC/MDD:AJ/104-025

ACKNOWLEDGEMENTS

This project was funded by the Wisconsin Environmental Repair Fund.

Appreciation is given to Cedarburg Light and Water Commission personnel, particularly Mr. Dennis Hintz, for their time and for providing data.

Appreciation is also given to the DNR Southeast District personnel, some of whom volunteered their time, for assistance with the pumping test.

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EXECUTIVE SUMMARY

This report presents findings of an investigation performed on a contaminated groundwater supply in the City of Cedarburg, Wisconsin. This investigation was authorized by the Department of Natural Resources (DNR) in order to gain information on the local hydrogeology and the source and extent of volatile organic chemical contamination in two municipal wells.

The field investigations consisted of a soil gas survey, soil borings, and installation of groundwater monitoring wells. Samples were collected from the soil gas, soils, and groundwater and were analyzed for chlorinated alkanes and alkenes. A pump test was conducted on City of Cedarburg well 3, and water levels in the monitoring wells were monitored.

The results of this investigation indicate the following:

1. The water table lies primarily within glacial till or weathered dolomite bedrock in the area of city well 3, and is at an average elevation of 777.4 feet relative to mean sea level.

2. The Niagara (unconsolidated and dolomite bedrock) Aquifer appears to have a low vertical hydraulic conductivity, such that the shallower unconsolidated aquifer behaves independently of the deeper Niagara Aquifer. There is a strong potential for recharge from the shallow portion into the deeper portion of the aquifer. However, vertical contaminant movement from the surface into the deeper aquifer would occur slowly due to the low conductivity.

3. The piezometric elevation of the Niagara Aquifer is 70 to 100 feet above the piezometric elevation of the Sandstone Aquifer in the vicinity of well 3. Since city wells 3, 4 and 5 are open to both aquifers, water and contaminants from the Niagara Aquifer would tend to cascade down these wells into the Sandstone Aquifer when the respective pumps are off.

4. Low level chlorinated alkane and alkene contamination exists in the shallow groundwater near the former Mercury Marine Plant 2 site.

5. The shallow groundwater at the Scot Pump site is contaminated with concentrations of chlorinated alkanes and alkenes ranging from about 90 to 5,000 mg/L. The deeper groundwater at this site is contaminated with lower concentrations of chlorinated alkenes. The primary alkene at the site, TCE, is also the primary contaminant in city wells 3 and 5.

6. The potential for further degradation of the Niagara Aquifer is high. Potential also exists for degradation of the Sandstone Aquifer.

7. Recommendations are made for further investigation, particularly in the vicinity of the Scot Pump site.

8. Remediation at the source of contamination may prove feasible, particularly if the source is within the unconsolidated soils and weathered bedrock of the shallow Niagara Aquifer.

SECTION 1
INTRODUCTION

1.01 PURPOSE AND SCOPE

This study was authorized by the Department of Natural Resources and funded by the Wisconsin Environmental Repair Fund. The purpose of the study was to investigate the local hydrogeology and source of contamination at two City of Cedarburg municipal water supply wells, wells 3 and 5.

Volatile organic carbon (VOC) contamination in city wells 3 and 5 was first observed in 1982, during sampling conducted by the DNR. Since then, the wells have been regularly sampled with fairly consistent VOC detection. The contamination consists primarily of trichloroethylene (TCE), with traces of 1,2-dichloroethylene (DCE) detected sporadically. The concentration of TCE in the two wells has ranged from "not detected" (N.D.) to as much as 89 ug/L. The safe drinking water standard for TCE is 5 ug/L.

The objectives of the investigation, as outlined in the Scope of Work prepared by the DNR (Appendix L), were as follows:

1. Determine the extent of volatile organic chemical (VOC) contamination in the unconsolidated and dolomite aquifers.
2. Determine the geologic and hydrogeologic conditions of the study area.
3. Document the direction of groundwater flow in the unconsolidated and dolomite aquifers.
4. Identify the location of potential sources of the VOC contamination.
5. Present preliminary needs for remedial actions.
6. Recommend options for a Phase II investigation.

In order to accomplish the above objectives, geochemical and geophysical investigations were conducted using soil gas monitoring, soil borings, and groundwater monitoring wells.

The soil gas survey consisted of collecting and analyzing approximately 30 samples of soil gas from the unconsolidated soils above the groundwater. The purpose of the soil gas monitoring survey was to provide information for locating the borings and monitoring wells.

Eight soil borings were performed as part of this investigation (B-1 through B-8). Five of the soil borings were converted to water table monitoring wells (MW-1, MW-2, MW-5, MW-6, and MW-7). In addition, two monitoring well piezometers were constructed in nests with MW-5 and MW-6 (P-5 and P-6). The monitoring wells provided information on groundwater quality as well as direction of flow and gradient.

In addition to the above studies, a pumping test was conducted on well 3 to provide further information on the aquifer characteristics. This pumping test was conducted primarily by DNR personnel.

This report provides an analysis of the data gathered from the above investigations, as well as a discussion of the extent, implications and possible remediations of contamination in city wells 3 and 5. Recommendations for further investigation are also made. A plan set containing drawings numbered 104-025-1 through 104-025-6 accompanies this report.

1.02 ABBREVIATIONS

The following abbreviations are used in this report:

°C - degrees centigrade
DCA - dichloroethane
DCE - dichloroethylene
DNAPL - dense, non-aqueous phase liquid
DNR - Wisconsin Department of Natural Resources
eV - electron volt
gpm - gallons per minute
IDLH - Immediately Dangerous to Life and Health
K_{oc} - sediment/water partition coefficient
MCL - maximum contaminant level
mg/L - milligrams per liter
ml - milliliter

min - minutes
N.D. - Not detected
NIOSH - National Institute of Occupational Safety and Health
OSHA - Occupational Safety and Health Administration
PCB - polychlorinated biphenyl
PEL - permissible exposure limit
PER - perchloroethylene (tetrachloroethylene)
ppb - parts per billion
ppm - parts per million
QA - quality assurance
RMCL - recommended maximum contaminant level
SA - Strand Associates, Inc.
SES - Soils and Engineering Services, Inc.
TCA - trichloroethane
TCE - trichloroethylene
TLV - threshold limit value
ug/L - micrograms per liter
USGS - United States Geological Survey
VOCs - volatile organic chemicals
WGNHS - Wisconsin Geological and Natural History Survey

SECTION 2
SITE DESCRIPTION

2.01 HISTORICAL REVIEW OF CONTAMINATION

This section provides a brief review of the events leading to this investigation, and background information on City of Cedarburg wells 3 and 5.

Contamination in wells 3 and 5 was first detected in 1982, during DNR sampling. At that time, TCE was detected in wells 3 and 5 at concentrations of 4 and 2.5 ug/L, respectively. Also detected were 1,2-DCE and p-dichlorobenzene. Sampling was then conducted by the DNR approximately twice a year through 1988; TCE was detected fairly regularly at concentrations between 2 and 8 ug/L, and DCE was detected occasionally at concentrations of 1.3 ug/L or less. Dichlorobenzene was not detected after the first sampling event in 1982, and did not appear to be analyzed for on a regular basis. After 1986, the City of Cedarburg began sampling wells 3 and 5 more frequently. The samples were generally analyzed by the city's consultant, Donohue and Associates, Inc. Trichloroethylene was detected in both wells consistently, and 1,1- and 1-2-dichloroethylene were also detected. Ethyl benzene and 1,1,1-trichloroethane were tested for and were detected in June of 1988. Tables 2.01-1 and A-1 provide a summary of the well contamination from 1982 through 1989. Appendix A contains results of DNR and Donohue sampling through 1989.

The levels of TCE have appeared to increase dramatically in well 3 in early 1989 and have also increased in well 5 (Table 2.01-1 and Appendix A) . The apparently higher concentrations could be a result of different sampling procedures; City of Cedarburg employees could have collected the water samples immediately after turning the pump on rather than waiting several minutes. It has been found in the past that TCE concentrations in well 3 decrease considerably after the well has been run for 20 minutes to 4 hours, which is when the DNR typically has collected samples in the past.

The level of contamination in wells 3 and 5 was not a great concern to the DNR or the city during the period from 1982 through 1986, since the Suggested No-Adverse Response Level for TCE was 45 ug/L. However, the DNR set the health

TABLE 2.01-1

SUMMARY OF DNR AND CITY OF CEDARBURG SAMPLING

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

	Well No. 3					Well No. 5				
		TCE ug/L		1,2-DCE ug/L			TCE ug/L		1,2-DCE ug/L	
Year	No. Samples	Range	Average*	Range	Average*	No. Samples	Range	Average*	Range	Average*
1982	2	2.7 - 4.0	3.4	N.D.- 0.2	0.1	2	2.5 - 5.4	4.0	0.1 - 1.0	0.6
1983	2	3.2 - 4.2	3.7	N.D.	N.D.	2	4.3 - 4.6	4.5	---	1.2
1984	3	2.3 - 4.3	3.2	---	N.D.	2	5.2 - 7.5	6.4	1.2 - 1.8	1.5
1985	1	---	3.5	---	N.D.	1	---	6.3	---	2.1
1986	12	N.D.- 18	3.5	N.D.- 2	0.2	21	N.D.- 18	3.7	N.D.- 2	0.2
1987	5	2 - 8	4.8	N.D.	N.D.	6	3 - 6	4.7	N.D.- 1.3	0.4
1988	13	N.D.- 11	4.0	N.D.	N.D.	13	N.D.- 11	4.8	N.D.- 4	0.7
1989	22	1 - 71	15.5	N.D.- 2	0.3	28	N.D.- 89	9.7	N.D.- 3	0.6
OVERALL	60	N.D.- 71	8.1	N.D.- 2	0.2	75	N.D.- 89	6.3	N.D.- 4	0.5

* N.D. was assumed to be 0 ug/L.

advisory level for TCE at 5 ug/L in 1986, and advised the city to take appropriate action since well 5 was then out of compliance. Also, the TCE safe drinking water standard was reduced to 5 ug/L in 1989, which resulted in wells 3 and 5 being out of compliance.

The City of Cedarburg is currently in the design phase for construction of an air stripping tower at the well 5 pumping station. Water from wells 3 and 5 will be pumped to this location and treated by the air stripping tower, which removes VOCs from the water by changing the phase of the volatile compound from liquid to gaseous. This method has been proven effective for compounds such as TCE and DCE, which have a high Henry's constant and vapor pressure, indicating a high tendency to volatilize.

2.02 SITE DESCRIPTION AND HISTORY

Wells 3 and 5 are located in Section 34, T 10 N, R 21 E, Cedarburg Township in Ozaukee County. Well 5 is approximately 2,400 feet south and slightly west of well 3, as shown on Drawing 104-025-2. The City of Cedarburg currently has five municipal water supply wells serving the city. According to the city's engineer, wells 3 and 5 have the two highest yields of the five wells at about 850 gpm and 700 gpm, respectively.

A. Industries

The area surrounding city wells 3 and 5 consists of industrial, commercial, and residential zones. Drawing 104-025-2 is a map showing the location of the city wells in relation to specific industries. Well 3 is situated just west of Scot Pump Division of Ardox Co. and Karak Machine Shop, which is the former location of Mercury Marine Plant 1. Industries to the north of well 3 include Kelch Corporation and a warehouse which was formerly Mercury Marine Plant 2, located approximately 2,000 feet from the well. North and east of well 3, in the commercial district of the city is One Hour Martinizing, a dry cleaner. To the west of well 3 is a residential area including a new subdivision currently under construction. The site of the new subdivision was formerly a mink farm, with a small machine shop located on the north end of the site. The machine shop is now vacant.

There are no major industries to the west of Well 5. To the north is Scot Pump and Karak machine shop. To the east is a commercial district along Washington Avenue, including the Cedarburg Dry Cleaners approximately 1,600 feet away. To the south and east of well 5 along Pioneer Road is an industrial zone including Pioneer Container, Doerr Electric, Carlson Tool and Die, and Allen-Bradley Company. These industries are located around 3,000 feet or more away. To the east of the city wells and close to Cedar Creek are Cedar Tool and Die and Meta Mold Division of Amcast, around 2,500 feet away from the wells.

An additional industrial zone is located on the northeast side of the city, on Highland Drive and Portland Avenue between the street and the railroad right-of-way. These industries include the Scot Pump warehouse, Federal Tool and Engineering and Filter Oil Company, to name a few. This area is 2,500 feet northeast and downgradient from city wells 3 and 5.

Several industrial sites were identified as being potentially related to the Cedarburg city well contamination due to their proximity to the contaminated wells, type of activity, and known or suspected use of solvents. Information on these industries was gathered during a field inspection of the area performed by SA, conversations with City of Cedarburg Water and Light Commission personnel, and information provided by the DNR. Data sheets on the industries, provided by the DNR Bureau of Hazardous Waste, are contained in Appendix B. Table 2.02-1 is a list of the pertinent industries and the type of manufacturing or services provided. The location number of the industry is shown on Drawing 104-025-2 and is provided in Table 2.02-1 as well as in parenthesis below. A brief discussion of several of these industries is provided below.

1. Kelch Corporation (2)

Kelch Corporation is located north of the site of the former Mercury Marine Plant 2. The site was formerly used by Doerr Electric Company until around 1970, which is now located on Pioneer Road. Kelch Corporation produces aluminum molds, and formerly produced traffic cones, according to DNR personnel. A recent video camera inspection of the city storm sewers near Kelch Corporation indicates a possible hook-up from the Kelch property to the storm sewers (Baker, 1990). A survey by the DNR hazardous waste bureau

TABLE 2.02-1

DESCRIPTION OF LOCAL INDUSTRIES

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

Business	Location	Products or Services
Kelch Corp.	2	Manufactures aluminum molds
Mercury Marine Plant 2	3	Formerly manufactured marine motors
Scot Pump	4	Manufactures small pumps
Karak Machine Shop	5	Machine shop
Cedarburg Dry Cleaners	11	Clothing dry cleaner
One Hour Martinizing	1	Clothing dry cleaner
Cedar Tool and Die	8	Machine shop
Meta Mold	9	Aluminum die casting
Doerr Electric	15	Manufactures electric motors and gear drives
Pioneer Container Corp.	16	Manufactures cardboard boxes
Allen-Bradley Co.	13	Manufactures small motors
Pioneer Tool and Die	22	Machine shop
Carlson Tool and Manufacturing	14	Machine shop
Scheer Die Casting	23	Die casting
Graphic, Inc.	12	Printing
ForMart Containers	19	Paper products

indicates that ignitables and solvents are used in the manufacturing process, with spent solvent being recycled and returned to the plant by a chemical supplier.

2. Warehouse at Mercury Marine Plant 2 Site (3)

The warehouse is located adjacent to and south of Kelch Corporation. The building is owned by Madison Avenue Joint Venture of Grafton, Wisconsin. City of Cedarburg personnel indicate that the property was formerly the location of Mercury Marine Plant 2, an aluminum die cast facility, until 1982. Sanborn Insurance maps for the city indicate that the property was used as a rail car repair barn by Milwaukee Northern Electric Railroad from around 1910 until some time after 1927. A report on PCB contamination in the Cedar Creek (Wawrzyn and Wakeman, 1987) indicates that the Mercury Marine Plant No. 2 discharged cooling water from the die cast machines into an open drain and then into a storm sewer discharging to the Cedar Creek. A recent video camera inspection of the sewer confirms a connection from the building to the storm sewer system (Baker, 1990). In 1987 an underground storage tank containing PCB contaminated oil was removed from the east side of the building, between the building and sidewalk on the south part of the property. Soils contaminated with PCBs were also removed at that time, indicating that the tank or the piping was leaking to some degree. Chemical analyses of the soil samples indicate that xylenes, mineral spirits, and petroleum hydrocarbons were detected in addition to PCBs. The tank removal contractor's report is contained in Appendix B. DNR Bureau of Solid Waste personnel performed a walk-through inspection of this warehouse in 1989. A report of this inspection was unavailable for inclusion in this report. During several SA site visits it was noted that vegetation in the area just south of where the tank was removed was brown and apparently stressed.

3. Mercury Marine Company (3), (4)

Mercury Marine owned or leased two or more properties including two manufacturing plants until 1982. The north plant, Plant 2, was a die casting facility. Small marine engines were cleaned, manufactured and tested at the south plant, Plant 1. Information on raw materials used and waste generated by the plant is limited; the DNR PCB report indicated that die cast cooling water, parts cleaning wastes, machining wastes, and outboard motor test tank water were all discharged to the Cedar Creek at some time prior to plant closings in 1980 and 1981. City personnel also indicate that there may have been a large parts washer containing solvents at Plant 1, which was located at the site where Scot Pump and Karak Machine Shop are now located.

4. Scot Pump (4)

Scot Pump Division of Ardox Corporation is located at the former Mercury Marine Plant 1 site. Scot pump has manufactured small pumps at the site since around 1981, according to an employee. During a site visit by SA it was noted that an in-ground test tank filled with fluid is inside the building, which could possibly be the test tank that was reportedly used by Mercury Marine for marine motors. It was also noted that the driveway inside the fence in the northwest area of the site had been sawcut and replaced since the rest of the pavement was placed. This could indicate the placement or removal of an underground storage tank, or else work done on piping or underground utilities in that area. The DNR hazardous waste survey did not indicate the type of service or materials used at the plant.

This property has a well on site which was constructed such that it was open to the Sandstone Aquifer only. This well has not yet been properly abandoned. Its condition is unknown.

5. Karak Machine Shop (5)

This machine shop is located on the south end of the Scot Pump building, at the site of the former Mercury Marine Plant 1. The DNR survey did not indicate use of solvents at the shop.

6. Cedarburg Dry Cleaners and One Hour Martinizing (11), (1)

Both of these industries are dry cleaners, which commonly use solvents in the cleaning process. The DNR survey of industries indicates that both dry cleaners use halogenated and toxic solvents. No information is available on disposal of these solvents.

7. Cedar Tool and Die, Ltd. (8)

Cedar Tool is a machine shop located east of wells 3 and 5. According to the DNR survey, the shop uses TCE and solvents. A spouse of a former employee advised the DNR in May of 1988 that Cedar Tool and the shop next to Cedar Tool, Meta Mold, used large quantities of TCE (see Appendix B).

8. Meta Mold Division of Amcast Industrial Corporation (9)

Meta Mold is an aluminum die casting shop, located across the street from Cedar Tool and Die. The DNR survey did not indicate solvents as a waste generated by the plant. However, the May 1988 report to DNR on the use of TCE at Cedar Tool also indicated that Meta Mold allegedly used TCE.

9. Doerr Electric Company (15)

Doerr Electric manufactures, assembles, and paints electric motors and gear drives. The plant was formerly located north of well 3 where Kelch Corporation is, but moved to the location on Pioneer Road around 1970. The DNR survey indicates that solvents and paint thinners are used during the manufacturing and assembly processes. The Pioneer Road Plant formerly had a septic tank on the property, which was sealed in early 1986. A wastewater pretreatment system was implemented around August 1986, as required by new DNR regulations. The DNR records for the pretreatment program indicate that a negligible amount of total toxic organics (TTO) is discharged to the sanitary sewer system, and that Doerr is not required to monitor TTOs. During a site visit by SA and DNR personnel, ground staining and stressed vegetation were noted on the northwest corner of the site near the railroad track. An investigation is currently underway to determine the nature of the potential contamination.

10. Pioneer Container Corporation (16)

Pioneer Container manufactures cardboard boxes, according to city personnel. The DNR survey indicates that toxic and halogenated solvents are utilized at the plant, and are treated or disposed of by Milwaukee Solvents. An anonymous spill report filed with the DNR on October 10th of 1986 claimed that trucks from another industry, Cedarburg Assembly Incorporated, would unload waste drums at Pioneer Container, where Pioneer Container employees would dump the waste at the railroad tracks to the east of the site without the knowledge of the owners. This report was never confirmed. The spill report form and a location map are contained in Appendix B.

11. Allen-Bradley Company (13)

Allen-Bradley manufactures and assembles small motors, according to city personnel. The DNR survey indicates that the company utilizes halogenated and toxic solvents. Spent solvent is reportedly recycled and re-used. City personnel indicate that the site was formerly occupied by Thermal Products, Inc., manufacturers of control panels and capacitors.

12. Pioneer Tool and Die, Carlson Tool and Manufacturing (22), (14)

Both of these machine shops are located on Pioneer Road. The DNR survey of industries did not target either of these machine shops; however, it is possible that either place could use solvents based on the nature of their processes.

13. Scheer Die Casting (23)

Scheer Die Casting was formerly located in what is now an apartment complex, close to well 3 (see Drawing 104-025-2). During a site survey by SA a resident reported that trees are unable to grow in a certain area of the site. However, vegetation in the indicated area did not seem to be stressed at the time of the site survey.

B. Records Review and Interviews

The City of Cedarburg wastewater treatment plant superintendent, Mr. Terry Ingraham, was consulted for information on industries discharging solvents or other hazardous wastes to the sanitary sewer system (Ingraham, 1989). Mr. Ingraham knew of no industries which formerly or currently discharged solvents. A sampling survey for VOCs had never been conducted by the utility; however, sludge sampling over the past year or so has not resulted in detection of VOCs except one detect of toluene. The wastewater treatment utility may be conducting VOC sampling in the future, due to recent changes in air pollution regulations.

According to Mr. Ingraham, the city's sanitary sewer system was first constructed in 1921 and 1922. There are no industries in the city that currently have septic systems. Doerr Electric had a septic system until around early 1986, when their industrial pretreatment program went on line. Mr. Ingraham knew of no other industries that may have had septic systems in the past, but said it was unlikely that plants located in the city such as Mercury Marine or Kelch Corporation would have had septic systems.

A discussion with the fire department inspector, Mr. Stephen Quam, indicated that there are no records available at the fire department indicating past or present solvent storage tanks, or storage tanks containing other than petroleum products in the City of Cedarburg.

A review of Sanborn fire insurance maps for the City of Cedarburg through 1927 did not show any solvent tanks or tanks containing other than gasoline or oil in the area.

Some DNR records were reviewed for information on landfills in the area. Information on landfills is presented in Appendix B. The City of Cedarburg landfill is located over four miles north of city well 3, in Section 2 of Cedarburg Township. The landfill is situated in a former gravel pit close to the groundwater table. Leachate from the landfill is monitored, and DNR records indicate that there is potential for migration of leachate from the site.

A private landfill owned by Marvin Procknow is located on the northwest side of the city, in the NE 1/4 of Section 21, Cedarburg Township. The landfill is approximately 2 miles north-west of city well 3. The landfill received wastes including garbage, commercial, and industrial wastes. The DNR records indicate that there is potential for groundwater contamination from the landfill. This landfill has since been closed, but is apparently not monitored.

Another private landfill is located over a mile northwest of the Marvin Procknow site, in Section 8. This site is owned by John Blank. The Cedar Creek floodplain was filled with unknown wastes. Potential for contamination of the groundwater is not documented; however, VOC sampling of private wells southeast of the site resulted in no detects.

C. Review of Previous Studies

A study was conducted for the City of Cedarburg Light and Water Commission by Donohue and Associates, Inc., on remedial action for the VOC contamination in wells 3 and 5 (Donohue, 1987). The study included pumping tests and VOC sampling at both city wells. The conclusions of the report indicated contaminant concentrations at well 3 appear to decrease with increasing pumpage of well 3 and well 5, while concentrations in well 5 appear to increase with increasing pumping of the well, and tend to decrease with increasing pumpage of well 3. The report also concludes that well 5 contamination concentrations have appeared to increase with time, and that the wells are probably impacted by the same source(s) of contamination.

A study was undertaken by the DNR on polychlorinated biphenyl (PCB) contamination in the Cedar Creek basin in Cedarburg (Wawrzyn and Wakeman, 1987). This report indicated that PCBs appeared to be entering Cedar Creek from several industrial storm sewer outfalls located along the creek. Although the behavior of PCBs in the environment is considerably different from that of VOCs, and the compounds are fairly unrelated as far as industrial uses are concerned, the report provides information on potential routes for groundwater contamination.

Another PCB investigation is currently underway by Mercury Marine Corporation, according to City of Cedarburg personnel (Drew, 1990) and DNR personnel (Baker, 1990). Mercury Marine's consultant recently hired a firm to film the storm sewers at the former Mercury Marine Plant #2. A report by a city inspector on the filming is in Appendix B. Two laterals were found entering a manhole located between the plant and Kelch Corporation that were not on the City of Cedarburg maps of the storm sewer system. One of the laterals appeared to be from the Mercury Marine building and the other entered the manhole from the north; this may have been from the Kelch building, according to Mr. Baker. Mr. Baker was present during the filming of the sewers and indicated that the sewers were corrugated metal and appeared to be in very good condition. The catch basins at the properties appeared to be constructed of dirt. The portion of the sewer system built by the city had been constructed during World War II.

Mr. Baker had conducted some investigations on the history of the sites where Mercury Marine Plants 1 and 2 and Kelch Corporation were located. He said that there were four underground storage tanks at the Mercury Marine Plant 2 site, according to an interview with a former employee. One of the tanks was 4,000 to 6,000 gallons and contained ethylene glycol, another was 1,500 gallons and contained Stoddard Solvent (mineral spirits which are straight chained, non-halogenated hydrocarbons), another was 30,000 gallons (according to the employee) and contained either hydraulic fluid or waste oil, and the fourth was 2,500 gallons and served as a holding tank for wastes. This last tank was removed in 1987 and appeared to contain PCB contaminated waste oil, as discussed earlier (see Appendix B for the removal report). Mr. Baker's investigation did not indicate whether or not there were underground storage tanks at the Mercury Marine Plant 1 site or at the Kelch site.

Mr. Baker also said that the discharge to the storm sewer from Mercury Marine Plant 2 was 10,000 gallons per day in 1979 and the records indicate several oil and grease complaints and violations due to the discharge into the Cedar Creek. The Mercury Marine Plant 1 discharge to the storm sewer was 31,000 gallons per day in 1979 and was permitted under the WPDES since 1974.

2.03 REGIONAL SETTING

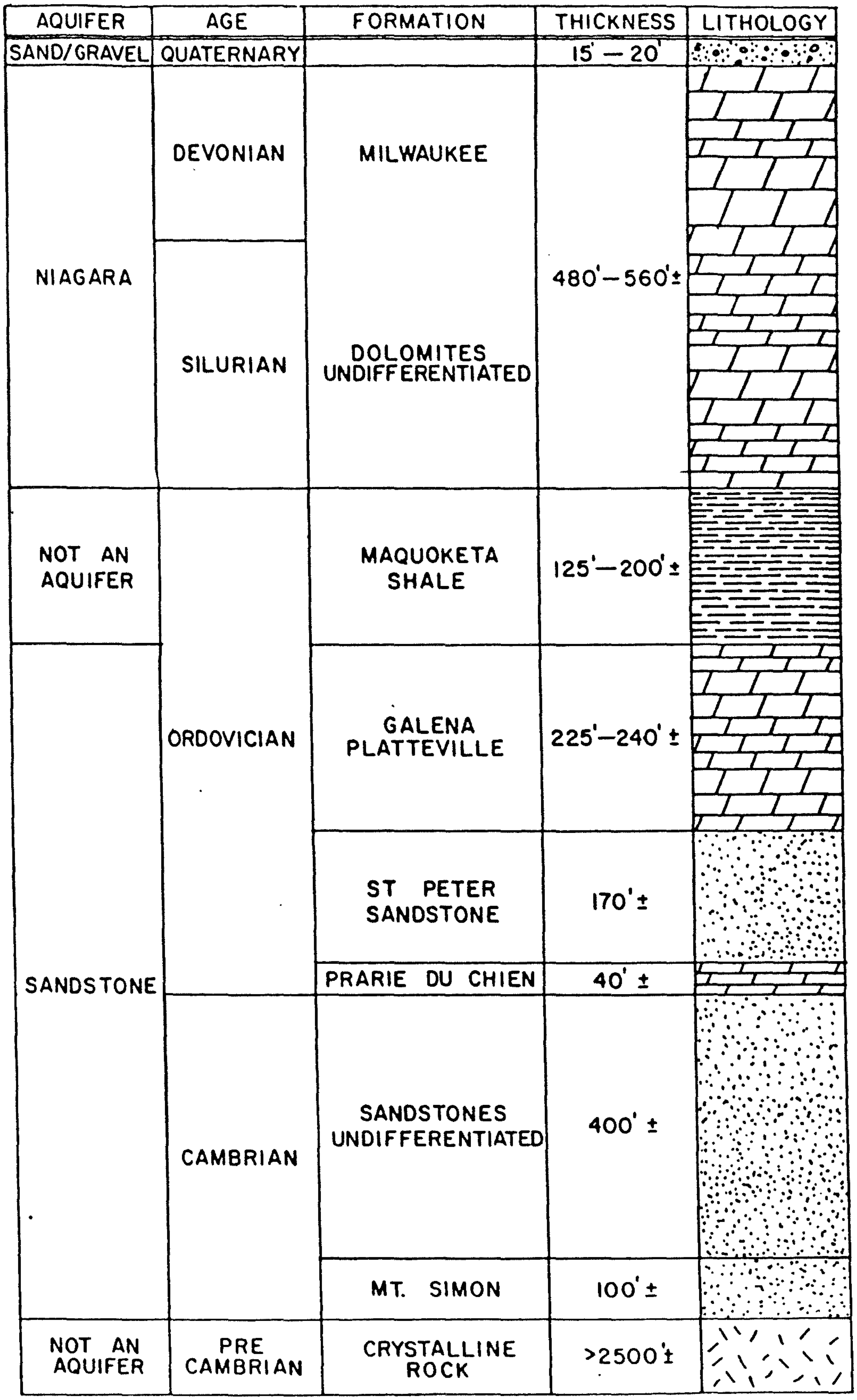
This section provides a discussion of the geology and hydrogeology of the southeast region of Wisconsin, where the City of Cedarburg is located. Information in this section was gathered primarily from USGS and Wisconsin Geological and Natural History Survey publications on the Wisconsin Lake Michigan Basin and Washington and Ozaukee Counties (Skinner & Borman, 1973 and Young and Batten, 1980).

A. Regional Geology

Ozaukee County lies in the Lake Michigan basin. The rocks and soils range in age from Precambrian basement rocks to the Quaternary glacial deposits, alluvium and soils. The bedrock, from oldest to youngest, includes Precambrian crystalline rock; Cambrian sandstone; Ordovician dolomite, sandstone and shale; Silurian dolomite; and Devonian dolomite. Many of these units underlie only parts of the area. A stratigraphic column is shown in Figure 2.03-1.

Low permeability crystalline rocks of Precambrian age prevent further downward movement of groundwater and underlie all of Ozaukee County. The surface slopes to the east and ranges in elevation from 500 feet above sea level in western Washington County to more than 1,200 feet below sea level along the Lake Michigan shore. A major fault in the Precambrian surface extends from Port Washington through the southwest corner of Ozaukee County to the Illinois State Line and the surface may be more than 2,000 feet below sea level southeast of the fault.

Cambrian rocks overlie the Precambrian rocks and are present throughout Ozaukee County. These rocks are primarily sandstone, but include some shale, siltstone and dolomite. The sandstones are comprised of the Dresbach Group, including the Mt. Simon, Eau Claire and Galesville formations, the Franconia sandstones, and the Trempealeau Formation, which includes the Jordon sandstone and the St. Lawrence Formation. The Cambrian sandstone thickens eastward from zero at locations in western Washington County to several hundred feet along the Lake Michigan shore.



AQUIFER	AGE	FORMATION	THICKNESS	LITHOLOGY
SAND/GRAVEL	QUATERNARY		15' — 20'	
NIAGARA	DEVONIAN	MILWAUKEE	480'–560'±	
	SILURIAN	DOLOMITES UNDIFFERENTIATED		
NOT AN AQUIFER	ORDOVICIAN	MAQUOKETA SHALE	125'—200'±	
SANDSTONE		GALENA PLATTEVILLE	225'–240' ±	
		ST PETER SANDSTONE	170'±	
		PRARIE DU CHIEN	40' ±	
	CAMBRIAN	SANDSTONES UNDIFFERENTIATED	400' ±	
		MT. SIMON	100' ±	
NOT AN AQUIFER	PRE CAMBRIAN	CRYSTALLINE ROCK	>2500'±	

DONOHUE, 1987

FIGURE
2.03-1

CEDARBURG GROUNDWATER
INVESTIGATION
STRATIGRAPHIC COLUMN

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Ordovician rocks overlie the Cambrian rocks and are present, in part, throughout the entire area. From oldest to youngest, they are the Prairie du Chien Group, which is discontinuous due to erosion; the St. Peter Sandstone; the Platteville and Decorah Formation and Galena Dolomite, which is undifferentiated and commonly referred to as the Galena-Platteville unit; and the Maquoketa Shale.

The Ordovician rocks dip generally eastward with known thicknesses ranging from 500 feet to 700 feet. The surface of the Galena-Platteville unit ranges in altitude from more than 750 feet above sea level in western Washington County to more than 150 feet below sea level along the Lake Michigan shore.

Silurian dolomite overlies the Ordovician rocks. The Silurian dolomite is the uppermost bedrock unit, except in areas along the Lake Michigan shore where it is overlain by younger Devonian rocks. The Silurian rocks dip generally eastward and their thickness increases eastward to a maximum of about 500 feet at Lake Michigan.

The bedrock surface ranges in elevation from approximately 600 to 900 feet in Ozaukee County and was probably shaped by preglacial stream erosion indicated by several bedrock valleys sloping eastward toward Lake Michigan.

The unconsolidated Quaternary deposits consist of glacial sediments with some alluvium and surficial marsh deposits. End moraines, ground moraines, outwash plains, and lake plains are the prominent landforms produced by glacial deposition. The thickness of these deposits ranges from zero in several areas where the bedrock outcrops, mainly in the southeast quarter of Washington County, to more than 600 feet where glacial materials fill bedrock valleys and in areas of topographic highs formed by end moraines.

B. Regional Hydrogeology

Large supplies of water are produced from the sand and gravel, Niagara, and Sandstone Aquifers, which are the three principal aquifers in the Ozaukee County area.

1. Sand and Gravel Aquifer

The sand and gravel aquifer is comprised of unconsolidated sand and gravel deposits of outwash, alluvium and glacial lake deposits and tends to exist in areas of deep bedrock valleys. Figure 2.03-2 shows the limit of the aquifer's areal extent within Washington and Ozaukee Counties. The sand and gravel aquifer is generally absent from the Cedarburg area where the thickness of unconsolidated material is generally around 50 feet.

Yields from the sand and gravel aquifer have been found to be as high as 1200 gpm with specific capacities as high as 50 gpm/ft (Skinner, Earl L. and Ronald G. Borman). The yields are adequate for municipal, industrial, and domestic uses, yet this aquifer is not used extensively.

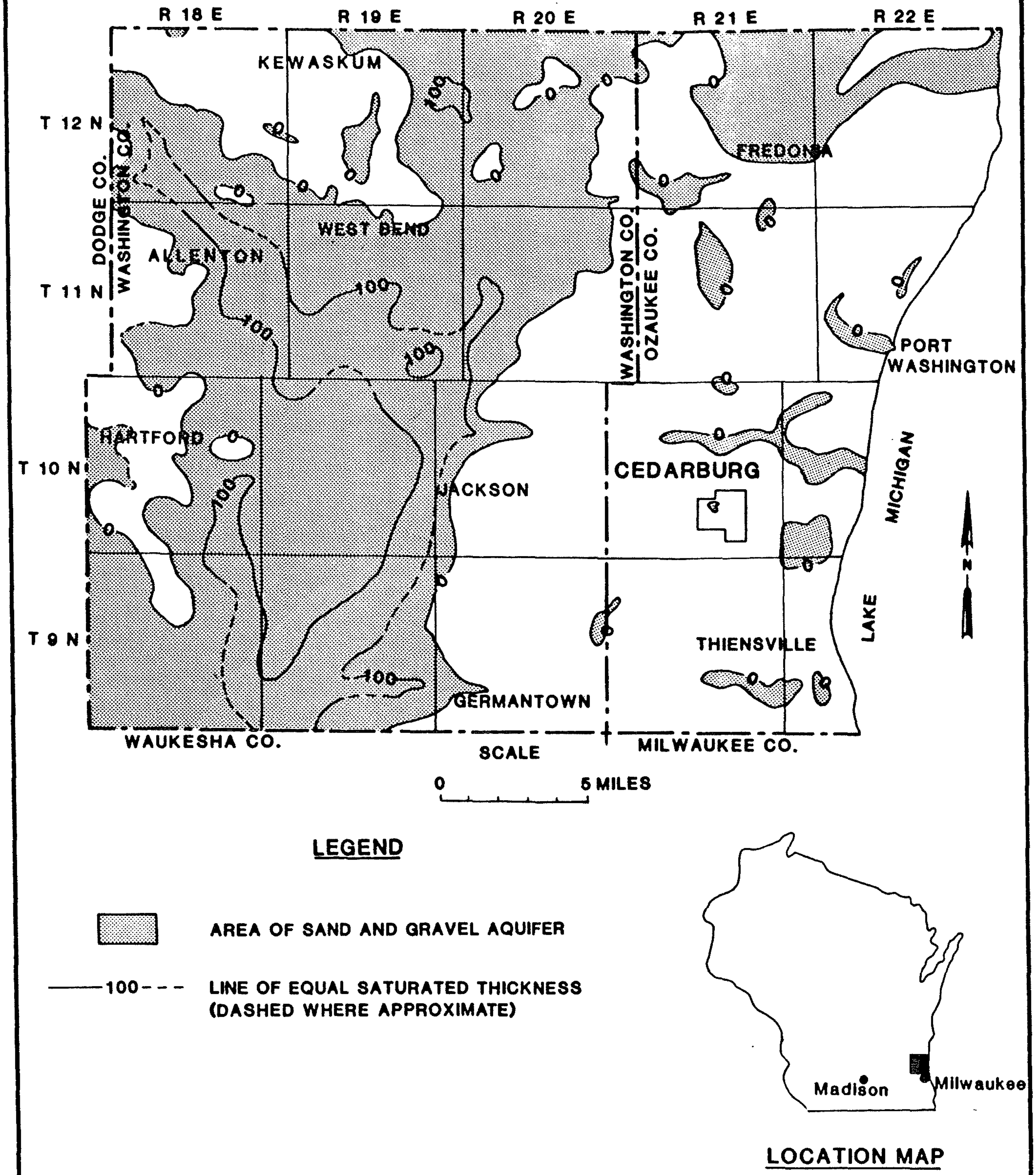
Water quality is generally good, however hardnesses of greater than 180 mg/l have been found in some areas (Skinner, Earl L. and Ronald G. Borman). The water table is shallow and easily polluted by surface wastes.

Hydraulic conductivity values ranging from 20 to 1,500 ft/d (150 to 11,267 gpd/ft^2) have been determined from wells screened in this aquifer in Washington and Ozaukee Counties (Young, H.L. and W. G. Batten).

2. Niagara Aquifer

The Niagara Aquifer consists of undifferentiated Devonian and Silurian Dolomite overlying the Maquoketa Shale. It is present throughout the area except in deep bedrock valleys in Washington County. The aquifer is predominantly unconfined, however because much of the overburden is clay till many areas of the Niagara are locally confined. The aquifer thickness is the same as the combined saturated thickness of the Devonian and Silurian Dolomite.

Small to large yields of 10 gpm to 1200 gpm are found in wells throughout the area. Specific capacities range from 0.2 to 400 gpm/ft (Skinner, Earl L., and Ronald G. Borman). Most municipal wells in Washington and Ozaukee Counties yield 150 to 500 gpm (Young, H. L., and W. G. Borman). The wide



YOUNG, H. L. AND W. G. BATTEN, 1980

FIGURE
2.03-2

CEDARBURG GROUNDWATER
INVESTIGATION

LIMITS OF SAND AND GRAVEL AQUIFER

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range of specific capacities probably reflects the differences between wells that penetrate relatively uncreviced dolomite and wells that penetrate cracks or crevices.

Hydraulic conductivity values ranging from 0.01 to 585 ft/d (7.5 x 10^{-2} to 4,394 gpd/ft^2) were determined from area wells. The median is 3.2 ft/d (24 gpd/ft^2) (Young, H. L., and W. G. Batten). Interconnecting fractures, joints, and solution openings formed during preglacial erosion are responsible for generally greater hydraulic conductivity values in the upper few feet of the aquifer (Skinner, Earl L., and Ronald G. Borman).

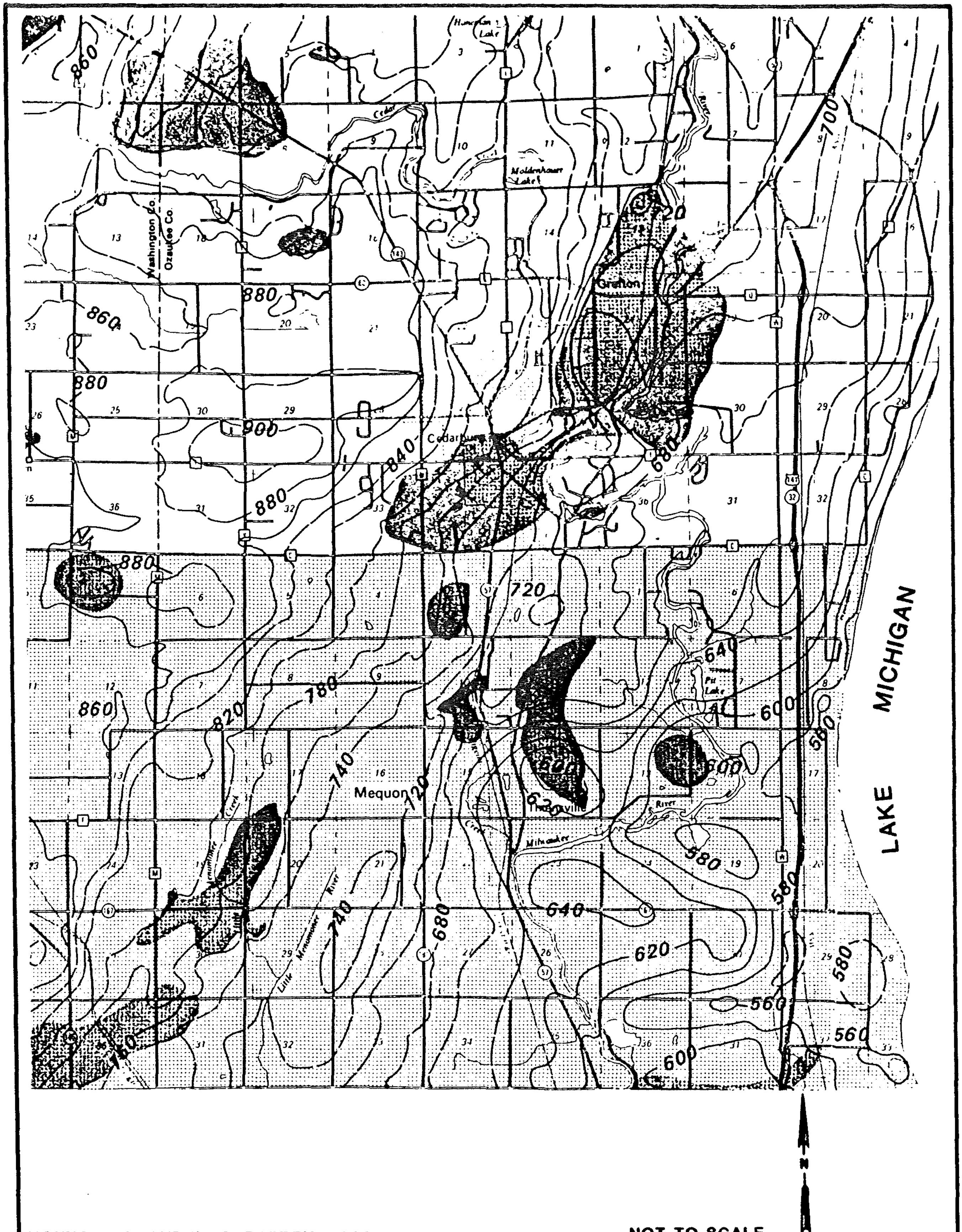
Water quality in the Niagara Aquifer is generally good, but locally is very hard and highly mineralized.

The groundwater flow direction is generally to the east towards Lake Michigan. The flow direction and potentiometric surface is shown in Figure 2.03-3.

3. Sandstone Aquifer

The Sandstone Aquifer, confined by the Maquoketa Shale, consists of Ordovician and Cambrian rocks composed of sandstone and dolomite formations, and overlies impermeable Precambrian crystalline rocks. The aquifer is continuous throughout the area and ranges in total thickness from 300 feet in southwest Washington County to more than 900 feet in southwest Ozaukee County.

Within the Sandstone Aquifer, the ability of the Cambrian sandstones to store and yield water make it an important source. The St. Peter Sandstone is the major water-yielding Ordovician rock. No wells are known to pump water from the Galena-Platteville or Prairie du Chien Dolomites exclusively, however these formations are considered part of the Sandstone Aquifer and are commonly used in combination with this and the Niagara Aquifer. Yields from the Sandstone Aquifer are as high as 1,500 gpm with specific capacities of as much as 14 gpm/ft. Most municipal and industrial wells yield 300 to 600 gpm. Higher specific capacities are in wells that penetrate greater



YOUNG, H. L. AND W. G. BATTEN, 1980

NOT TO SCALE

FIGURE
2.03-3

CEDARBURG GROUNDWATER INVESTIGATION WATER TABLE ELEVATIONS OF NIAGARA AQUIFER

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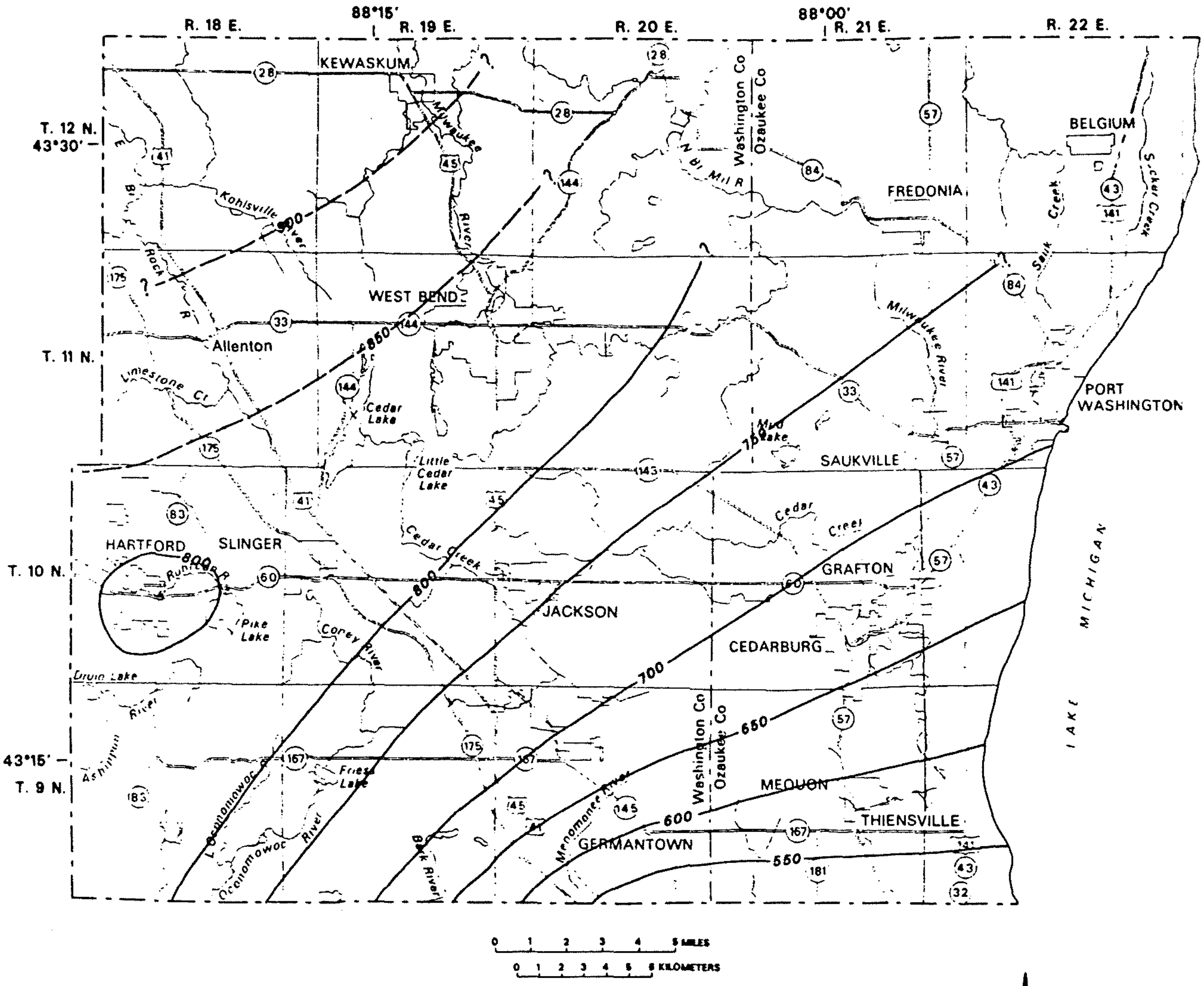
thicknesses of the aquifer. Since many wells in southern Ozaukee County are uncased in both the Sandstone and Niagara Aquifers, water from the Niagara may constitute 20 to 40 percent of the yield from these wells (Young, H. L., and W. G. Batten).

Hydraulic conductivity values have been estimated to be approximately 2.4 ft/d (18 gpd/ft^2) in this area, however good aquifer test data are not available (Young, H. L., and W. G. Batten). Water quality is generally good, but is hard to very hard and saline in some areas.

Figure 2.03-4 shows the potentiometric surface of the Sandstone Aquifer in Washington and Ozaukee Counties during the winter of 1976-77. The direction of flow is to the southeast. Groundwater discharge is at wells located in the area of Milwaukee and Chicago and into Lake Michigan. In this hydrogeologic system, the potentiometric surface of the Sandstone Aquifer used to be higher than the overlying water table, once resulting in discharge from the sandstone to the Niagara Aquifer. The direction of flow used to be generally due east toward Lake Michigan; however, large quantities of water have since been pumped from this aquifer over the last century, and since 1880, the surface has declined as much as 250 feet in southwestern Ozaukee County (Young, H. L., and W. G. Batten). As a result, the water table is now higher than the potentiometric surface. Water moves downward through inconsistencies in the Maquoketa Shale and through wells open to both the Niagara and Sandstone Aquifers. Additional recharge of the Sandstone Aquifer is from the west in Dodge County where the shale has been removed by erosion.

2.04 LOCAL SETTING

This section provides a discussion of surface hydrology and local hydrogeology in the City of Cedarburg area.



EXPLANATION

——————700——————?

Potentiometric contour

Shows altitude at which water level would stand in tightly cased wells. Dashed where location is approximate. Queried where doubtful. Contour interval 50 feet. Datum is mean sea level

N

YOUNG, H. L. AND W. G. BATTEN, 1980

FIGURE 2.03-4

CEDARBURG GROUNDWATER INVESTIGATION

POTENTIOMETRIC SURFACE OF CONFINED SANDSTONE AQUIFER

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A. Surface Hydrology

The three major surface water systems influencing the Cedarburg area are Cedar Creek, the Milwaukee River and Lake Michigan. Figure 2.04-1 shows the location of Cedarburg with respect to these three systems.

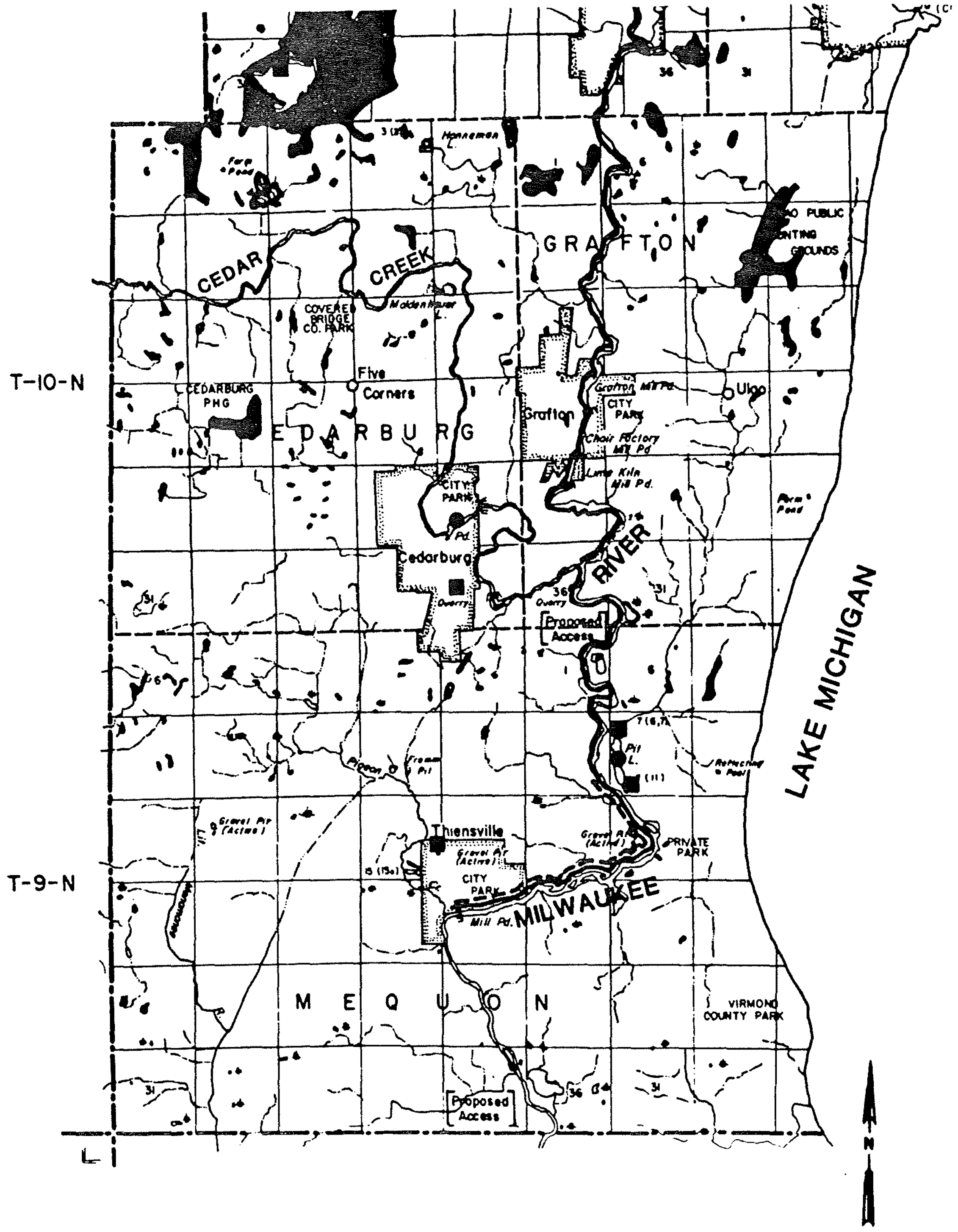
Cedar Creek and it's watershed is located in the Milwaukee River Basin. Cedar Creek is formed at the outlet of Big Cedar Lake in Washington County and flows south by southeast through Washington and Ozaukee Counties for approximately 31.5 miles before it's confluence with the Milwaukee River downstream of the City of Cedarburg. Cedar Creek has an average daily discharge of 66.4 cfs at Cedarburg. The average stream gradient is 9.6 ft/mile (Wawrzyn and Wakeman, 1987).

The Milwaukee River has a mean daily flow equalled or exceeded 99.5% of the time of 10 cfs. A flow of 100 cfs may be equalled or exceeded 68% of the time. The average discharge of the Milwaukee River is 384 cfs. The actual flow may be affected by its fifteen dams. The average stream gradient is 4.4 ft/mile (Skinner, Earl L., and Ronald G. Borman).

Approximately 17 mgd enters the Lake Michigan basin through the Sandstone Aquifer. Approximately 12 mgd enters through the Niagara and sand and gravel aquifers from the west. About 20 mgd leaves the basin from the Sandstone Aquifer and 46 mgd from the Niagara and sand and gravel aquifers to the east and north. This accounts for a total loss of approximately 37 mgd or about 0.2 inches per year. Generally underflow water, entering or leaving the basin through the groundwater system, enters the basin from the west and moves towards Lake Michigan or pumpage centers in Green Bay, Milwaukee or Chicago. Approximately 480 billion gallons of water leave the basin each year as stream flow (Skinner, Earl L., and Ronald G. Borman).

B. Local Hydrogeology

Local hydrogeology was investigated using the well logs of city wells 1,3,4,5 and 6 and USGS publications. The location of these wells are shown on Figure 2.04-2, and the well logs can be found in Appendix C.



NOT TO SCALE

FIGURE
2.04-1

CEDARBURG GROUNDWATER
INVESTIGATION
SURFACE HYDROLOGY

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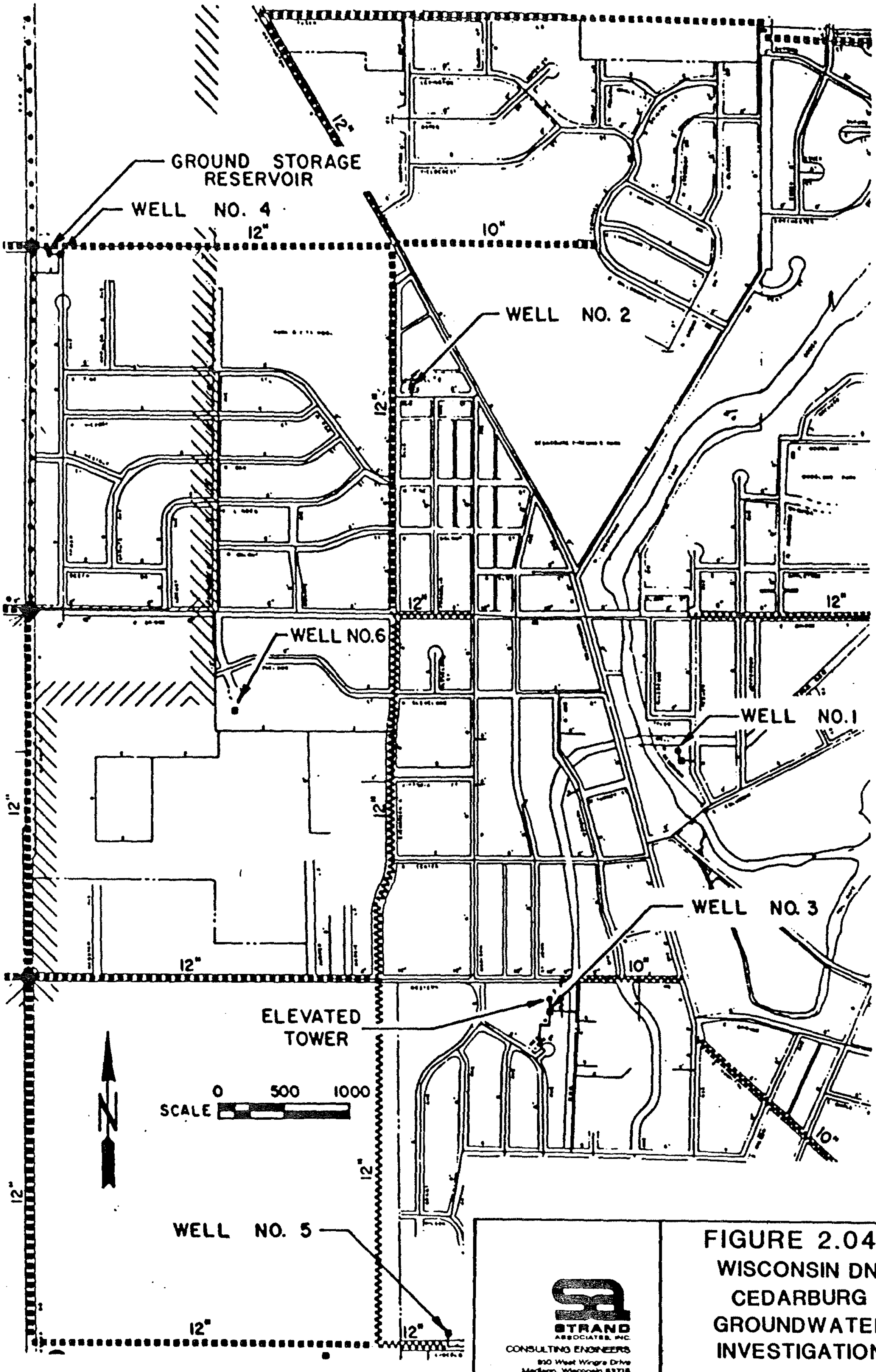

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CONSULTING ENGINEERS
910 West Wingra Drive
Madison, Wisconsin 53715
Tel. (608) 251-4843

FIGURE 2.04-2
WISCONSIN DNR
CEDARBURG
GROUNDWATER
INVESTIGATION

CITY WELL LOCATIONS

reported upon completion of the well in 1985. The estimated operating capacity is 650 gpm. This well also does not appear to be contaminated with VOCs.

City well 3 is drilled to a depth of 1,002 feet and is constructed such that it is open to and draws water from both the Niagara and Sandstone Aquifers. The estimated operating capacity of the well is 850 gpm. City well 3 had a specific capacity of 16.7 gpm/ft and a static water elevation of 718 feet at the time of completion in 1956.

City well 5 is drilled to a depth of 965 feet and, like W-3, draws water from both the Niagara and Sandstone Aquifers. Its estimated operating capacity is 700 gpm. City well 5 had a specific capacity of 3.8 gpm/ft and a static water elevation of 715 feet at the time of completion in 1967.

The water distribution system in Cedarburg is such that any well may theoretically supply water to any point in the system (i.e., there are no isolated wells or portions of the system). Elevated storage tanks are located at city wells 1 and 3, and a ground storage reservoir at city well 6. Wells 4 and 5 pump directly to the distribution system.

The Niagara and Sandstone Aquifers are the principal water producers in Cedarburg. The average thickness of the Niagara Aquifer is 501 feet. Thickness of the Sandstone Aquifer in the area is unknown.

The general direction of groundwater flow in the water table aquifer is to the southeast where shallower groundwater discharges into Cedar Creek. The deeper Sandstone Aquifer also flows to the southeast and discharges to Milwaukee wells and Lake Michigan.

C. Cedarburg Municipal Wells

The five municipal water supply wells in Cedarburg are shown on Figure 2.04-2. The following is a description of the individual city wells:

City well 1, located approximately 0.4 miles north-northeast of city well 3 (W-3), is drilled to a total depth of 1210 feet and penetrates 290 feet into the St. Peter Sandstone. The well is cased through the Niagara Aquifer and Maquoketa Shale and draws water solely from the Sandstone Aquifer. The normal static water elevation is 685 feet. The estimated operating capacity is 580 gpm. The specific capacity of the well was reported as 13.6 gpm/ft at well completion in 1922. This well does not appear to be contaminated with VOCs.

City well 4, located approximately 1.25 miles northwest of W-3, is drilled to a total depth of 1210 feet and penetrates 175 feet into the St. Peter Sandstone. The well is cased from +2 to 110 feet and from 573 feet to 829 feet. It is open to and draws water from both the Niagara and Sandstone Aquifers. The static water elevation was recorded at 725 feet and the specific capacity was recorded at 1.5 gpm/ft at well completion in 1965. The estimated operating capacity is 550 gpm. This well is located between city wells 3 and 5 and the Marvin Procknow landfill on the northwest side of Cedarburg. It does not appear to be contaminated with VOCs.

City well 6, located approximately 0.6 miles northwest of W-3, is drilled to a total depth of 635 feet. It is terminated in the Maquoketa Shale and draws water solely from the Niagara Aquifer. The well is cased from +1 to 170 feet. It has a specific capacity of 2.6 gpm/ft and a static water elevation at 692 feet, as

SECTION 3
SITE INVESTIGATIONS

Investigations conducted at the site included a soil gas survey, soil borings, and monitoring well installation and sampling for VOCs. This section provides a discussion of the methods used for each investigation.

3.01 SOIL GAS INVESTIGATION

A soil gas investigation was conducted in the vicinity of wells 3 and 5 in late April of 1989. The purpose of the investigation was to determine the placement and construction of monitoring wells and soil borings, according to the DNR Scope of Work. The specified method used for the investigation was the active soil gas extraction method. The results of this investigation are discussed in Section 4.

A. <u>Theory</u>

Soil gas investigations are used for locating volatile organic compounds present in the soil or groundwater. VOCs which have high vapor pressures and Henry's Constants (Table 4.04-1) will tend to vaporize more quickly and to a greater extent than those with lower values. In theory, a concentration gradient may be established in the vadose (unsaturated) zone with the highest contaminant concentration in the soil gas near the source (groundwater plume or contaminated soil) and the lowest at the ground surface. The concentration of the compound at any point in the soil gas will depend on the vapor pressure of the compound and the gas-liquid-soil partition coefficients for the compound, as well as the distance from the source of contamination. Several geological or hydrogeological factors may also effect the concentration of contaminants in the soil gas. For instance, Lappala and Thompson (1984) indicate that it is necessary for there to be a fluctuation in the groundwater table level in order for contaminants to be released from the capillary zone of the groundwater table into the vadose zone. Also, at sites where tight, saturated or near-saturated clays are present, or where the contaminated aquifer lies below a clean aquifer, the soil gas extraction method may not be effective at locating contamination.

During a soil gas investigation, soil gas is generally extracted from the vadose zone by driving a probe into the ground and using a vacuum pump to remove a known quantity of gas. The gas may be collected in a syringe and directly analyzed in the field, or the VOCs may be concentrated onto carbon or other sorbent matrix and analyzed at a later time in a lab.

B. Sampling Methods

The soil gas sampling locations were chosen such that a grid was established, with sampling points becoming more concentrated near industries that were considered possible users of TCE. The grid points were located at approximately every eighth-section corner (1,320 feet by 1,320 feet) across an area of approximately two square miles. Industries that were targeted for additional sampling points were generally those industries listed in Table 2.02-1. Forty-one sampling points were chosen originally, and were reduced to 32 points in the field due to time constraints. The locations of the sampling points are shown on Drawing 104-025-3.

Steel probes with teflon liners were used for extracting soil gas from the ground. Soils and Engineering Services, Inc. (SES) of Madison, WI provided the drill rig and steel probes with teflon liners. The SES crew drove 2-1/2 inch OD, steel probes in five foot long sections with a steel well point to a depth of 15 feet or to hardpan or bedrock, whichever occurred first. Then the steel probe was withdrawn approximately 2 inches from the well point, to allow a space for soil gas entry. A teflon liner was then inserted into the steel probe. The teflon liner consisted of 3/4-inch teflon tubing in five foot sections with threaded ends. The end-point where soil gas was drawn from consisted of a slotted endpiece to allow soil gas to enter without soil entering, and o-rings for sealing the outside of the teflon liner against the inner surface of the steel probe to prevent vapor from entering or leaving along the side of the teflon pipe.

Once the probe was in place, the sampling train was hooked up. The sampling train consisted of 3/8-inch teflon tubing with a vacuum pump, vacuum gauge, sampling port, and port for photoionization detector (HNu meter) hook-up. The vacuum pump was a Dupont Alpha-1 air sampler, capable of sampling flow rates from

5 to 5,000 ml/min. The HNu meter was a model PI-101, equipped with an 11.7 eV lamp. Tygon tubing was used downstream of the sampling port for hookup to the vacuum pump and HNu meter. In general, stainless steel compression fittings were used upstream of the sampling port and polypropylene compression fittings were used downstream. Where threaded fittings were used, teflon tape was used to prevent leakage. The total volume of the sampling train was approximately 1.4 liters. A schematic diagram of the soil gas probe and sampling train is shown in Figure 3.01-1.

The train was purged with approximately 5 volumes (8 liters) of soil gas at a rate of 2 liters per minute prior to sampling. After purging, the valve upstream of the sampling pump was closed and the HNu meter valve was opened and a reading taken. Then the valve immediately downstream of the sampling port was closed and a sample withdrawn. As a general rule, if the HNu reading was greater than approximately 0 or 1 ppm, two samples were taken; one 100 ml sample and one 50 ml sample. If there was no response on the HNu meter, only one 100 ml sample was taken.

Samples were withdrawn with a 50 or 100 ml glass syringe with a needle and teflon syringe valve on the end. The needle was inserted through a teflon lined septum on the sampling port, a small volume of gas (around 20 to 50 ml) was withdrawn and wasted to account for dead space in the port, and then the sample was collected. The sample was injected into a 1/4 inch diameter, stainless steel carbon-packed sample tube at a rate of about 50 to 100 ml/min. This was accomplished by removing the needle and using a small piece of silicone tubing to seal the syringe to the tube, opening the syringe valve, and allowing the weight of the syringe and sample tube to slowly push the syringe plunger down and inject the sample. The sample tube was then immediately capped and placed in a carbon filled desiccator.

Once sampling was completed at each location, the steel and teflon probe was withdrawn and the hole was backfilled with soil. Cold patch was used to cap the hole in cases where the probe was driven through bituminous pavement.

Samples were shipped in the carbon desiccators approximately every three days to Enviroscan, Inc. for analysis. Sample tubes were thermally desorbed and analyzed

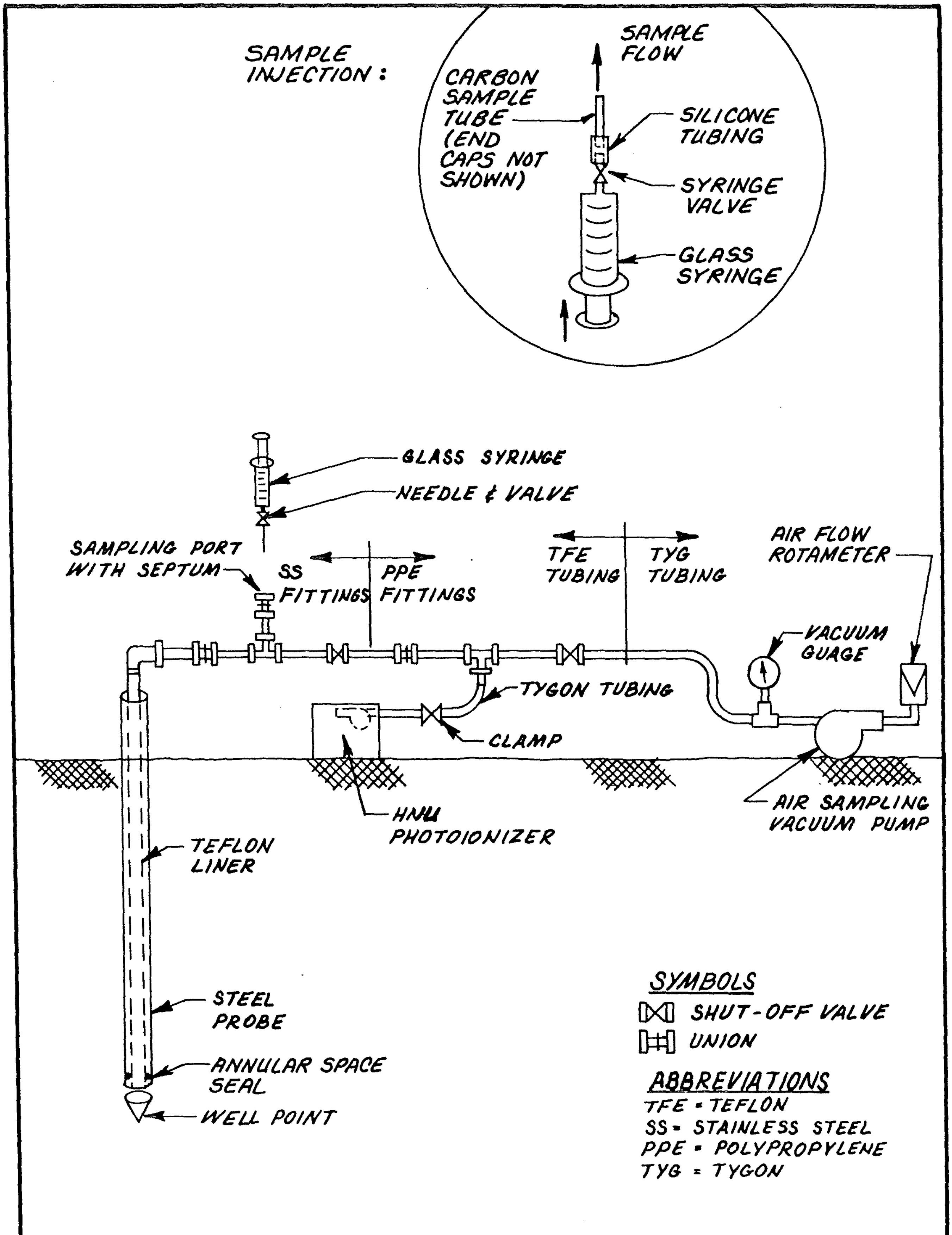

FIGURE 3.01-1

CEDARBURG GROUNDWATER INVESTIGATION
SOIL GAS SAMPLING APPARATUS

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by gas chromatography (GC) using a Hall (halogenated VOC) detector. The samples were analyzed for 1,1-dichloroethane, cis-1,2-dichloroethylene, trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), tetrachloroethylene, and 1,2-dichloroethane (DCA). Field data from this investigation is in Appendix D. The lab report is contained in Appendix E.

C. Quality Assurance (QA)

1. Field QA

Care was taken during sampling to assure that cross contamination or contamination from ambient sources was avoided, and that samples were taken in a representative manner. Two trip blanks were included with the first shipment of sample tubes and remained in the field until the last samples were shipped to the lab. The teflon sampling train was purged with soil gas prior to sampling and with nitrogen gas after each sampling event. The glass syringes were purged with approximately 20 volumes of atmospheric air, up-wind from the drill rig, prior to sampling. Needles and septa were disposed of after each sample was collected. Equipment blanks were collected once a day to ensure that contamination did not carry over from one sample point to the next. Steel probes were steam cleaned at the beginning or end of each day, while portions of the steel probe that were needed more than once a day were detergent washed and rinsed with City of Cedarburg water from an uncontaminated well (well 1). Teflon liner points were detergent washed and rinsed with distilled water and dried, or purged with nitrogen prior to each sampling. Also, duplicate samples of a smaller volume were taken at each location where an HNu detect above 1 ppm occurred.

Field equipment was calibrated on a regular basis. The HNu meter had been calibrated at Hazco Services on April 18, 1989, and was field calibrated by SES daily with 5% benzene, in accordance with the manufacturer's instructions. The vacuum pump was calibrated on the first field day using a 0 to 5,000 ml/min gas rotameter. The calibration was verified about every other day in the field.

2. Lab QA

In general, five standards were run for each compound that was analyzed in the lab. The standard concentrations ranged from approximately 0.04 ppb to approximately 1.4 ppb. According to a phone conversation with Enviroscan personnel, the standards were prepared and analyzed in a manner similar to the samples; the compound was injected into a carbopac sample tube, thermally desorbed, and analyzed by GC using a Hall detector. The standard curves for the soil gas sample analysis are included with the lab report in Appendix E.

3.02 SOIL BORINGS

Eight soil borings were performed by Soils and Engineering Services, Inc., in the vicinity of wells 3 and 5. The borings were performed on July 11 and 12 and August 21, 1989. The purpose of the soil borings was to sample and classify the soils and determine groundwater levels, as well as to monitor the soils for contamination. Five of the eight borings were later developed into monitoring wells. The results of the soil borings and soil testing are discussed in Section 4.

A. Location

Soil boring locations are shown on Drawing 104-025-2. The soil boring locations were determined based on results of the historical investigation and the soil gas survey. The intent was to locate the five borings that were to be developed into monitoring wells fairly close to city well 3. Since only a limited number of borings and wells were proposed in the Scope of Work, and two city wells were contaminated, it was felt that it would be best to gain as much information as possible on one of the city wells rather than gaining a little information on both of the wells. This approach was supported by previous studies (Donohue, 1987), which indicated that the two wells were probably contaminated from the same source(s). Well 3 was chosen as the well to concentrate on over well 5 since previous studies indicated that the source of contamination could be closer to well 3 than well 5 (Donohue, 1987).

The five borings closest to well 3 were generally located to provide good information on up- and down-gradient groundwater quality, groundwater flow direction, and "suspect" industries surrounding well 3. Review of available hydrogeological information indicated that the groundwater table aquifer flow direction was most likely to the east or south-east (Section 2.04); therefore, three borings were located in the presumed up-gradient direction from well 3. These were located down-gradient of the mink farm shop (B-5); down-gradient from the former Mercury Marine Plant 2/Kelch Corporation area (B-1), and between the One Hour Martinizing dry cleaner and well 3 (B-3). Borings down-gradient of well 3 included one between Scot Pump and well 3 (B-6), and one south of well 3 but north of well 5 (B-7).

The remaining three borings were originally located close to industries that were implicated due to past use of TCE, yet were farther away from the contaminated wells. The intent was also to locate at least two of these borings close to the Cedar Creek to provide additional information on groundwater level and flow direction. Two of these boring locations were revised, however, when City of Cedarburg personnel, through discussions with DNR personnel in other Bureaus, became aware of the existence of the DNR PCB study report (Section 2.02). The DNR project manager subsequently decided to locate borings B-2 and B-4 close to the Creek, at locations where sources of PCB contamination were found during that study. Although TCE use is not necessarily related to PCB use, it was felt that the contamination could have occurred through a similar route, in this case through storm sewers. Also, the industries suspected of causing a portion of the PCB contamination were also suspected of using TCE in the past. Boring B-2 was located close to where a storm sewer outfall from the Mercury Marine Plant 1 was, and boring B-4 was located close to the Mercury Marine Plant 2 storm sewer outfall.

B. Methods

The soil borings, soil sampling, field VOC testing, and logging of soils were all performed by SES. The standard soil borings were performed using hollow stem augers to either the depth of bedrock or to approximately 10 feet below the groundwater table, whichever occurred first. Where the bedrock was encountered, drilling continued by using tri-cone rotary drilling bits for the highly weathered bedrock, followed by coring with diamond bits where installation of deeper wells into the bedrock was required. Borings were backfilled upon completion, after the stabilized groundwater level had been recorded. A copy of the SES report for the soil borings is contained in Appendix F. Field notes from the soil borings are also in the Appendix.

Soil sampling was conducted during soil borings using split spoon samplers and small diameter hollow stem augers. Soil samples were collected every five feet. The soils and bedrock were classified visually in the field by the drilling crew. Standard penetration tests were also conducted in the field. Laboratory soil tests were conducted on selected split spoon samples recovered from different soil layers. The tests included natural moisture determination, Atterberg limits, and gradation analysis. The results of these tests are contained in the SES report in Appendix F and are discussed in Section 4. Split spoon samplers were detergent washed and rinsed with water from the City of Cedarburg well 1 after completion of each boring. Augers were steam cleaned at the beginning of the project and at the end of each day.

Soil samples were tested for VOCs with an HNu photoionizer immediately after recovery of the sample. In general, samples with a detectable HNu reading (i.e. above approximately 0.5 ppm) were saved in soil jars for lab analysis of VOCs. At boring B-8, however, all soil samples had readings of 2.5 to 4.0 so only two soil samples were collected for lab analysis of VOCs. Soil VOC samples were packed tightly into soil jars and stored in a cooler or refrigerator, and were shipped to the lab within two days of collection. The samples were analyzed for TCE, TCA, cis-1,2-DCE, 1,1-DCA, 1,2-DCA, tetrachloroethylene, and vinyl chloride by Enviroscan, Inc. using the low level EPA method 5030. A copy of the Enviroscan lab report and chain of custody sheet is contained in Appendix E.

3.03 MONITORING WELL INSTALLATION

A total of seven monitoring wells were installed in the vicinity of wells 3 and 5 in July and August of 1989. Five of the wells were developed from soil borings and screened at the water table. These were numbered consistently with the borings they were developed from: MW-1, MW-3, MW-5, MW-6 and MW-7. Two of the monitoring wells were screened at a depth below the water table to act as piezometers. These wells were constructed in nests with MW-5 and MW-6 and were numbered P-5 and P-6, respectively. The monitoring wells were sampled in three rounds after development; the results from the groundwater investigation are presented in Section 4.

A. Location

Water table monitoring wells were located as described for soil borings. The intent was to surround city well 3 with monitoring wells to gain as much information as possible on the hydrology and water quality near well 3. Piezometers were located in nests with wells 5 and 6, in what was considered the approximate groundwater up-gradient direction and down-gradient direction from the city well, respectively.

B. Methods

Monitoring wells were installed by SES in accordance with the Bureau of Solid Waste 1985 Monitoring Well Installation Guidelines, as specified in the Scope of Work. The wells were installed using large diameter hollow stem augers to bore through the soils to the point of auger refusal. The larger diameter auger was used so that the use of drilling mud was avoided. Where bedrock was encountered, drilling was continued using tri-cone rotary drilling bits followed by coring with diamond bits. The water table wells and piezometers were installed in the bored or cored hole using two inch diameter, schedule 80 PVC pipe and screens. The screen and pipe sections were threaded to prevent the use of solvents, and were sealed with teflon tape to prevent leakage. The screens varied in length but were generally 10 feet long for water table wells and 15 feet long for piezometers, with slots 0.006-inch wide. The longer screen length for piezometers was approved by the DNR and was used to lessen the possibility of a dry piezometer, since the bedrock at the depth of the screen was not highly fractured.

The depths of the piezometers were generally selected to correspond with the portion of the aquifer that city well 3 draws water from. Since city well 3 was cased to 130 feet and had a static water level of approximately 110 feet, it was expected that a piezometer cased to approximately the same depth might have a similar water level. Therefore, P-5 and P-6 were cored until the water level in the core hole began to drop below the water table elevation.

The backfill of the annular space for the wells generally consisted of silica sand or flint sand followed by silica sand, followed by a bentonite seal and a steel protector pipe. The protector pipe was flush mounted in some cases, and was concreted in place. A description of the methods used for installation and drawings of each monitoring well are part of the SES report, in Appendix F.

Wells were developed by SES by surging and pumping until a change in water appearance from muddy to cloudy, milky, or clear was noted. The total amount of water removed from each well during development varied between 3 well volumes for piezometer P-6 to 84 well volumes for monitoring well MW-5, and is reported in the SES report.

3.04 WELL 3 PUMP TEST

After monitoring well installation was complete and prior to the first groundwater sampling event in September, a pumping test was conducted on well 3. Since this portion of the investigation was beyond the Scope of Work outlined by the DNR, the DNR provided most of the personnel for conducting the pumping test, while Strand Associates provided two additional people. The purpose of the pumping test was to gain more information on the nature of the dolomite aquifer in the vicinity of wells 3 and 5. It had previously been noted during monitoring well installation that the shallower wells did not appear to be affected by well 3 pumping while the deeper wells did, and it was felt that this should be explored more thoroughly.

For approximately 24 hours preceding the pumping test, well 3 was not pumped and the water level was allowed to approach "static," or non-pumping conditions. At the same time, well 5 was pumped continuously at a rate of about 750 gpm for the 24 hours preceding the test, since the City of Cedarburg needed at least one of the two wells for peak water demands. Static water levels were recorded on the morning of September 14, as well as the pumping level in city well 5, and then well 3 was turned on and pumped at about 960 gpm and well 5 was turned off. Water level data was collected at each monitoring well and city well at intervals of time decreasing in frequency from 1 to 2 minutes between measurements to once every 20 to 30 minutes. Data was collected for approximately seven and one-half hours of pumping at well 3. Wells P-5, P-6, and city wells 3 and 5 were monitored the most intensely, with the water table wells being monitored less frequently.

A schedule for the pumping test and the data sheets are contained in Appendix H. The results of the pumping test are discussed in Section 4.

3.05 GROUNDWATER SAMPLING

A. Methods

The seven monitoring wells and city wells 3 and 5 were sampled in three rounds, one month apart, in accordance with the DNR Scope of Work. The WDNR Groundwater Sampling Guidelines, PUBL-WR-153, February 1987, were followed. Sampling occurred on September 14 and 15, October 17, and November 17, 1989. Groundwater sampling field data and notes are in Appendix J. Well 3 was pumped for as long as possible prior to and during sampling (generally 8 to 12 hours minimum), so that dynamic conditions would be approached and the portion of the VOC plume influenced by city well 3 would begin moving toward the well. Well 5 was generally off during this time so that it would have minimal influence on plume movement during sampling. Attempts were made to duplicate the sampling procedure and pumping schedule during each sampling event.

During the groundwater pumping test on September 14, it was noted that the water table well water levels did not drop any significant degree after city well 3 had been pumping for approximately eight hours. The piezometers, on the other hand, did seem to be influenced by city well 3. Since dynamic conditions were desired during sampling, piezometers P-5 and P-6 were sampled the evening of the 14th, after city well 3 had been pumping for eight to ten hours at a rate of about 800 to 1,000 gpm. The monitoring wells were sampled the following day, since they did not seem to be influenced by city well 3 pumping. During the October and November sampling events, city well 3 was turned on by city personnel early in the morning, water table well samples were collected first, and piezometer samples were collected in the afternoon after the well had been pumping for six to ten hours. Wells were generally sampled in order from least to most contaminated. Water table monitoring wells MW-1,3,5,6, and 7 were bailed with a 1-1/4 inch diameter, 6 foot long all teflon bailer prior to sampling. Wells P-5 and P-6 were generally bailed with the same bailer with an additional 6 foot long section attached. Stainless steel cable on a downrigger reel was used for lowering and raising the bailer. Approximately four well volumes of groundwater were removed from the water table wells and two well volumes removed from the piezometers prior to sampling. It was felt that bailing two well volumes from each piezometer would be sufficient since the screen was at 160 to 180 feet depth and water was being bailed from around 30 to 35 feet depth, causing fresh water to flow upward in the piezometer as the stale water was removed.

Samples were obtained by carefully lowering, filling and raising the bailer and then filling two VOC sample vials at each well. Care was taken not to cause aeration of the water in the well or in the sample. City wells were sampled by allowing the well to run for a few minutes to remove standing water, and filling two VOC vials from a faucet in the well house, taking care to keep the flow into the sample vial laminar.

Prior to bailing and sampling MW-1 on the first sampling event, DNR personnel obtained samples from the top few inches of water in the well for PCB analysis. This well was close to the location of the removed underground storage tank containing PCB laden oil, at the former Mercury Marine Plant 2. After these samples were obtained, the well was bailed and sampled again for PCBs as well as VOCs.

Sample vials were stored in coolers with ice packs until sampling was complete. The samples were shipped to Enviroscan for analysis within a few days of sampling. Samples were analyzed by GC, using EPA Method 502.2. Samples which were noted by the lab as having a strong hydrocarbon odor were diluted in the lab and detection limits were adjusted by the same factor as the dilution. The results from each sampling event are discussed in Section 4.

B. Quality Assurance

Trip blanks were provided by Enviroscan for each of the three sampling events. These samples were brought into the field with the sampling crew and then returned to Enviroscan with the groundwater of the samples. In the field, duplicate samples were taken by retrieving a second bailer full of water and filling VOC vials from it after the original sample was taken. The bailer and stainless steel cord were flushed with distilled water after each well was sampled. Bailer blanks were collected once per sample day, by filling the bailer with distilled water and filling two VOC vials with this water. Lab QA data is contained in Appendix E, as well as Chain of Custody sheets for the groundwater samples.

3.06 SITE CONTROL

Locations and elevations of soil gas sampling points, soil borings, and monitoring wells were determined by Strand Associates using standard surveying techniques. Bench marks used were U.S. Public Land Survey Control Stations, which had been set up by Aero-Metric Engineering, Inc. in 1986 and 1987. The horizontal datum was the Wisconsin State Plane Coordinate System, South Zone and the vertical datum was the National Geodetic Vertical Datum of 1929. The Control Stations, hereafter referred to as "bench marks", were located at quarter section corners throughout the City of Cedarburg. The control accuracy of each bench mark was Third Order, Class I for horizontal and Second Order, Class II for vertical.

Where bench marks were not available due to paving of roadways or other changes since the survey was made, the bench marks were either located by witness points or a different quarter section corner was used. To assure accuracy of the survey, loops were made locating the well or sample point using one bench mark and verifying the location with another bench mark.

Site control data and records of monitoring well and boring elevations are contained in Appendix I.

SECTION 4
RESULTS AND DISCUSSION

4.01 SITE GEOLOGY

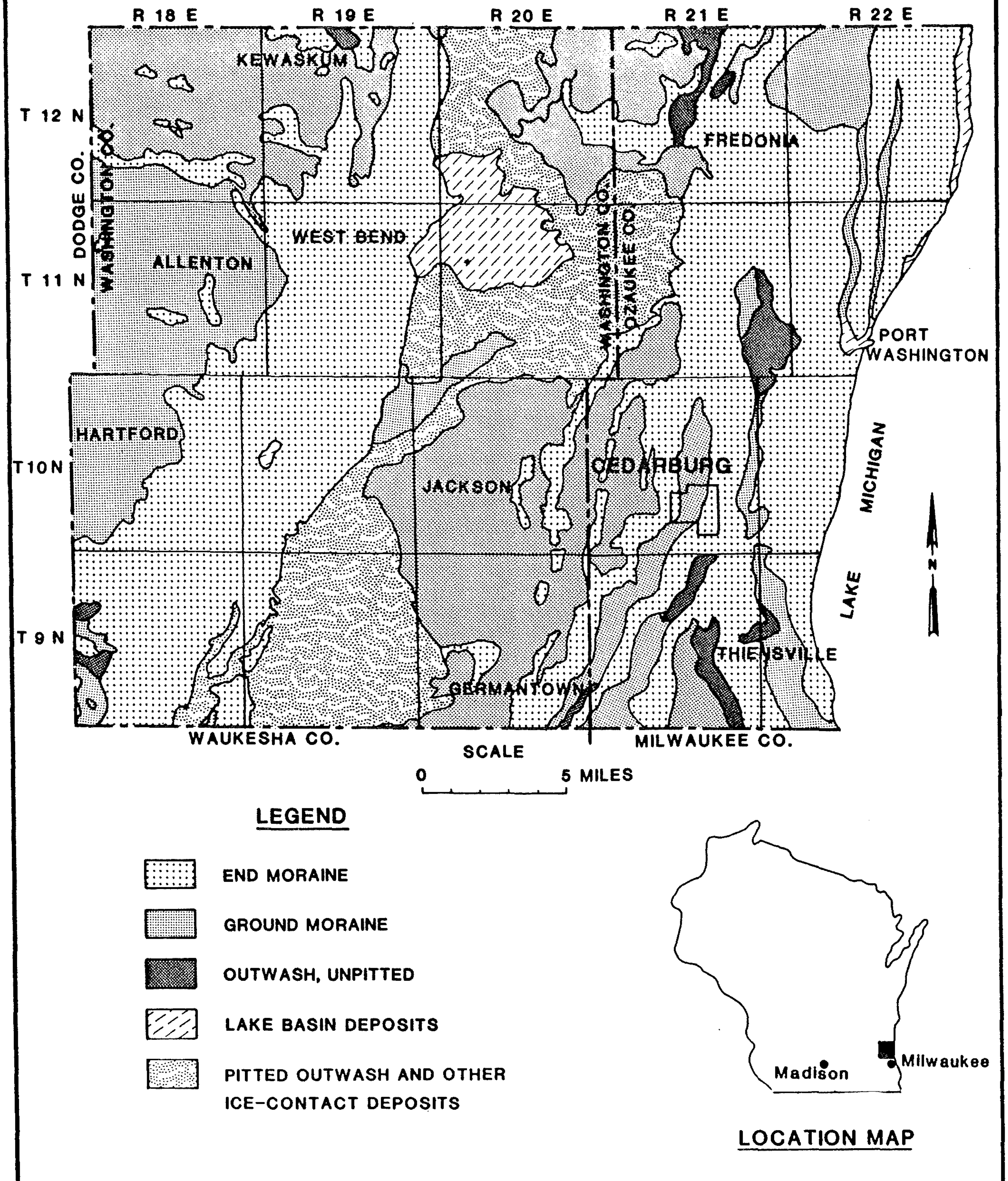
Information on site geology was obtained from eight shallow borings, two deep piezometers and four city wells. The locations are shown on Drawing No. 104-025-2. The results of the soil borings and installation of the piezometers are contained in the SES report in Appendix F. A fence diagram and cross section are shown on Drawing No. 104-025-4 and 104-025-5, respectively. The fence diagram illustrates the unconsolidated surficial deposits. Lithologic characteristics of the bedrock are illustrated in the cross section.

A. Unconsolidated Surficial Deposits

The unconsolidated deposits at the site are glacial in origin and overlie dolomite bedrock. These deposits are variable and non-continuous, exhibiting the complex stratigraphy typical of glaciated areas. The area consists of ground and end moraine, glacial lake, and outwash deposits laid down during the last Wisconsinan glacial period.

Figure 4.01-1 shows the boundary between ground moraine and elongate end moraine that parallel Lake Michigan at the City of Cedarburg. End moraines are formed by deposition of glacial debris at the margin of a glacier. They may form at the point of maximum ice advance or during recession of the glacier. Ground moraines are deposited beneath moving glacial ice or as a residue after the ice melts. Both ground and end moraines consist of unsorted and unstratified glacial deposits ranging in size from clay to boulders. Enclosed depressions called kettles are typical. Glacial lakes formed in these kettles contain stratified deposits of well sorted sand, silt and clay. Typically stratified, well sorted sand and gravel outwash is deposited at the terminus of the glacier. Outwash is laid down by water from melting ice fronts.

Borings 2 and 4 contain very poorly sorted deposits of silty, fine to course sand and gravel. This type of deposit is typical of ground or end moraine deposits.



YOUNG, H. L. AND W. G. BATTEN, 1980

FIGURE 4.01-1	CEDARBURG GROUNDWATER INVESTIGATION GLACIAL DEPOSITS	STRAND ASSOCIATES, INC. ENGINEERS

Most of the remaining borings at the site appear to penetrate glaciolacustrine[1] sediments. Borings 7 and 8 consist of typical stratified lake deposits of clay and sand, and partings, lenses and seams of silty fine sand and lean clay. Lake deposits appear to overlay morainal deposits in borings 3,5 and 6, and city well 5. Boring 5 may contain stratified sand and silt outwash sediments.

Topsoil or fill material, probably produced during preparation of the ground surface prior to development, overlies the entire area. Topography of the area is shown in Figure 4.01-2.

B. Bedrock

Undifferentiated Devonian and Silurian dolomite bedrock directly underlies the unconsolidated glacial drift. A stratigraphic sequence of these dolomites, the Maquoketa Shale, the Galena-Platteville Dolomite and the upper portion of the St. Peter Sandstone are shown in the cross section located on Drawing No. 104-025-5. The cross section is taken through city well 1, city well 3, piezometer P-5 and city well 5.

Drill core from piezometer P-5 was available for detailed study. The drill logs of city wells 1, 3 and 5 were made available by the Wisconsin State Geological Survey (Appendix C). Due to the less detailed information contained in these logs it was not possible to correlate specific characteristic changes in the dolomite between P-5 and the city wells. A detailed description of the dolomite as seen in P-5 is as follows:

> There are four distinct lithologic differences seen in the drill core from 21 feet to 180 feet below ground surface.
>
> From 21 to approximately 33 feet is a rubbly, fractured zone of slightly recrystallized, very fine to medium grained tan to gray sparry[2] micrite[3].

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[1] Glaciolacustrine: Pertaining to sediments deposited in glacial lakes.

[2] Sparry: Defines almost any transparent or translucent, readily cleavable, crystalline mineral having a vitreous luster.

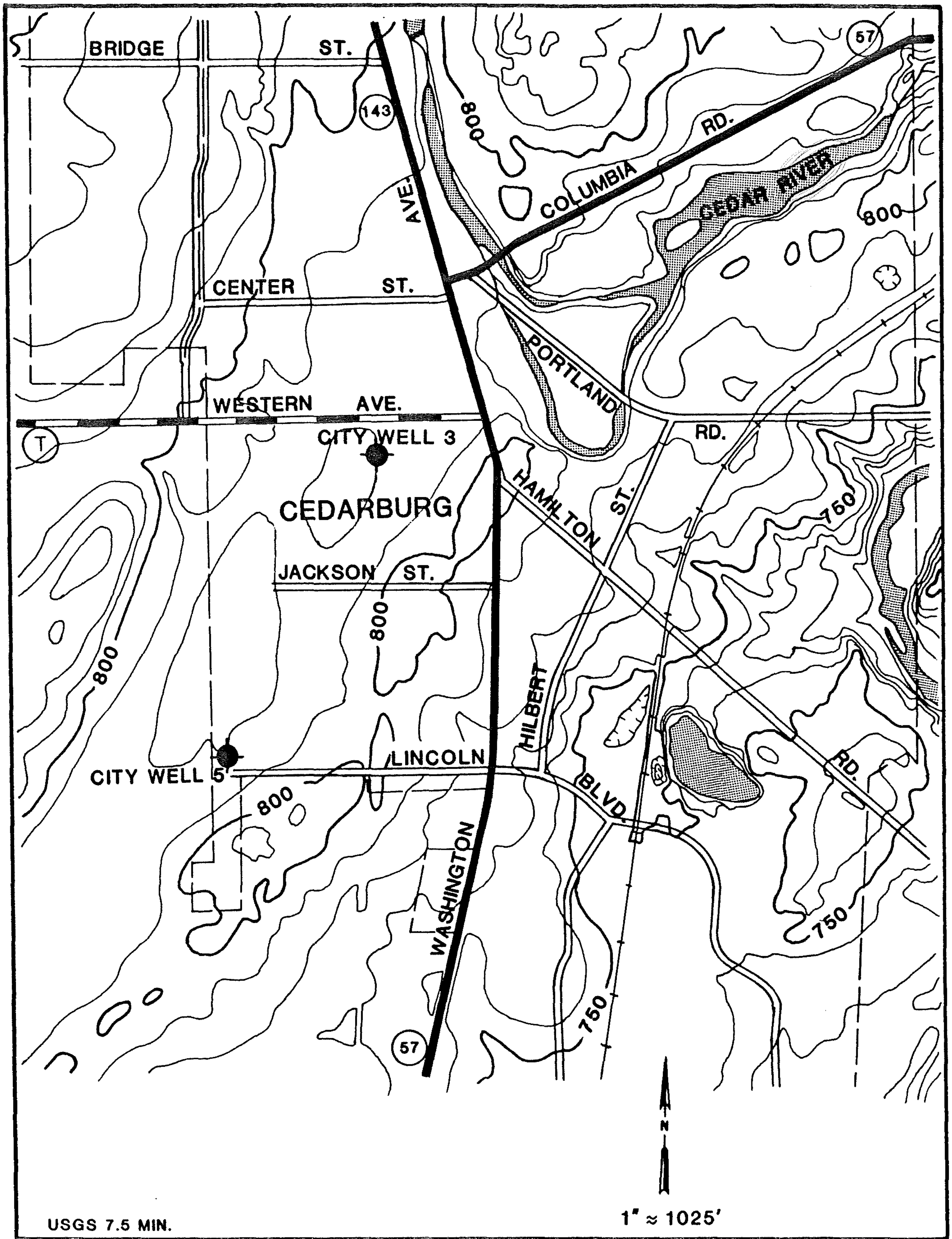

FIGURE
4.01-2

CEDARBURG GROUNDWATER
INVESTIGATION
SITE TOPOGRAPHY

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Two to three inch thick deposits of dense, gray clay fill the fractures at this depth.

From approximately 33 to 51 feet is a light gray to tan zone of more competent dolomite. This unit exhibits a greater degree of recrystalization. The unit is fine to medium grained sparry micrite. Greater compaction in this zone is evidenced by the increasing occurrence of pressure-solution stylolites[4]. Fractures occur every 1.0 to 1.3 feet and are not infilled with clay.

A transitional zone exists between the above described lithology and a more porous, medium grained sparry micrite. This transitional zone extends from approximately 51 feet to 60 feet. It is tan to light gray and contains traces of pyrite. Fractures occur every 1.0 to 1.3 feet.

The dolomite from approximately 60 feet to a very distinct lithological contact at 126 feet is a medium grained, moderately recrystallized sparry micrite which contains traces of pyrite and is tan to gray in color. The core is very mottled and occurrences of drusy[5] quartz in vugs[6] is common. Some fracture points show the elongated column like characteristics of the stylolitic fronts[7]. Fractures in this zone occur every 1.3 to 5.5 feet. The distance between fractures increases with depth.

---

[3] Micrite: Rock composed of fine mud size carbonate grains.

[4] Stylolite: A term applied to parts of certain limestones which have a column-like development as a result of pressure solution. The "columns" being generally at right angles or highly inclined to the bedding planes, having grooved, sutured or striated sides, and irregular cross-sections.

[5] Drusy: The appearance of a crystalline aggregate whose surface is covered with a layer of small crystals.

[6] Vugs: A cavity, often with a mineral lining of different composition from that of the surrounding rock.

[7] Stylolitic Front: Solution front due to stylotolization.

The remaining portion of the core penetrates a compact, highly banded, very fine to fine grained micrite. The bands are gray to dark gray in color and probably represent organic-rich zones. Small, chalky white micritic lenses, some containing chert nodules, exist throughout the unit. The absence of stylolites and evidence of significant recrystalization indicate this unit was not highly compacted during burial. However fractures still exist at spacings of 0.5 to 1.5 feet.

There was a 100 percent recovery of the core indicating no large fractures or solution channels existing to the depth drilled. The existing fractures are distinct hairline fractures probably resulting from the weight of the ice when glaciers inundated this portion of Wisconsin, as well as movement during subsequent isostatic rebound.

The following is a description of the remainder of the stratigraphic sequence as interpreted from the city well logs:

The Devonian and Silurian dolomites extend to depths of between 495 and 510 feet with a thickness of 480 to 498 feet. The dolomite remains a light gray, containing white chert and traces of pyrite and fossil fragments.

The Maquoketa Shale directly underlies this dolomite, at a depth between 695 and 705 feet with a thickness between 195 and 205 feet. It is gray to blue-gray in color. City well 1 reports it as calcareous[8] and city well 5 reports traces of pyrite, chert and fossil fragments.

Directly underlying the shale at depths of 835 to 920 feet is the undifferentiated Galena-Platteville Dolomite. This formation is 215 to 225 feet thick. It is light brown to gray in color with white chert and traces of pyrite and fossil fragments. The grain size is reported as fine to course sand. The fracture density is unknown.

Underlying the Galena-Platteville Formation is the St. Peter Sandstone. It is described as white to gray in color with traces of white chert and

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[8] Calcareous: Containing calcium carbonate.

dolomite-pyrite cement. The grain size is reported as very fine to very course sand. All city wells terminate in this formation, except for city well 6. The stratigraphic sequence shown in the well log for city well 1 indicates the St. Peter Formation is approximately 205 feet thick and is underlain by undifferentiated formations belonging to the Dresbach Group. It is apparent from this well log that, in this area, the Prairie du Chien, Trempealeau and Franconia Formations have been removed by erosion.

4.02 SITE HYDROGEOLOGY

The hydrogeology of the site was investigated using monitoring wells MW-1,3,5,6 and 7, piezometers P-5 and P-6, city wells 3 and 5, and results of the pump test performed on city well 3. The wells and piezometers were installed to investigate subsurface materials, subsurface contamination, and groundwater vertical and horizontal hydraulic gradients. The pump test was performed to investigate the aquifer response to pumping; specifically, the hydrogeologic influences between the unconsolidated materials and the deeper dolomitic bedrock of the Niagara aquifer, and to estimate the local hydrogeologic parameters. Subsection A presents the results found prior to commencing test pumping from well 3, which are referred to as "pre-pump test" conditions. Subsection B presents results found during the pump test. Pre-pump test water elevations and dynamic water elevations are presented in Table 4.02-1. Drawing No. 104-025-6 presents cross sections showing the changes in water levels in response to pumping. Sample calculations are provided in Appendix K. Pump test data and DNR calculations are provided in Appendix H. A discussion of the site hydrogeology involving fractured dolomite and the inherent limitations of the calculated results are presented in subsection C.

A. Pre-pump test conditions

The site groundwater flow direction, shown in Figure 4.02-1, is generally to the east-southeast toward Cedar Creek. Pre-pump test water level elevations show an average water table elevation of 777.43 hosted primarily in glacial till. The average horizontal gradient of the water table surface is 0.006. Piezometers P-5 and P-6 show pre-pump test water elevations of 755.81 and 751.60, respectively. Apparent vertical hydraulic gradients of 0.156 at P-5 and MW-5 and 0.185 at P-6

TABLE 4.02-1

SUMMARY OF WATER LEVELS

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

Well No.	Ground Elevation	Water Elevation[1]	Depth of Water	Pre-Pump Test Water Level Elevation	Dynamic[2] Water Level Elevation
MW-1	789.96	789.65	7.51	782.14	782.04
MW-3	782.68	782.38	7.77	774.61	774.61
MW-5	788.05	789.84	9.88	779.96	779.93
MW-6	787.37	787.15	10.85	776.30	776.46
MW-7	794.88	796.62	22.46	774.16	774.30
P-5	787.96	789.80	33.99	755.81	755.14
P-6	787.30	787.15	35.55	751.60	750.54
W-3	795.0	797.46	113.00	684.46	663.46
W-5	792.0	794.70	108.5	686.20	522.7

NOTES:

1. Well elevations for city wells refer to centerline of pressure gauge on air-line depth measuring device. Well elevations for monitoring wells and piezometers refer to top of PVC.
2. Dynamic water levels, except for in city well W-5, were taken after 7-1/2 hours of well W-3 pumping at approximately 960 gpm. The W-5 dynamic water level was taken after about 24 hours of W-5 pumping at approximately 750 gpm.
3. Elevations in feet referenced to USGS MSL 1929 datum.
4. Depth of water in feet referenced to well or pressure gauge elevation.

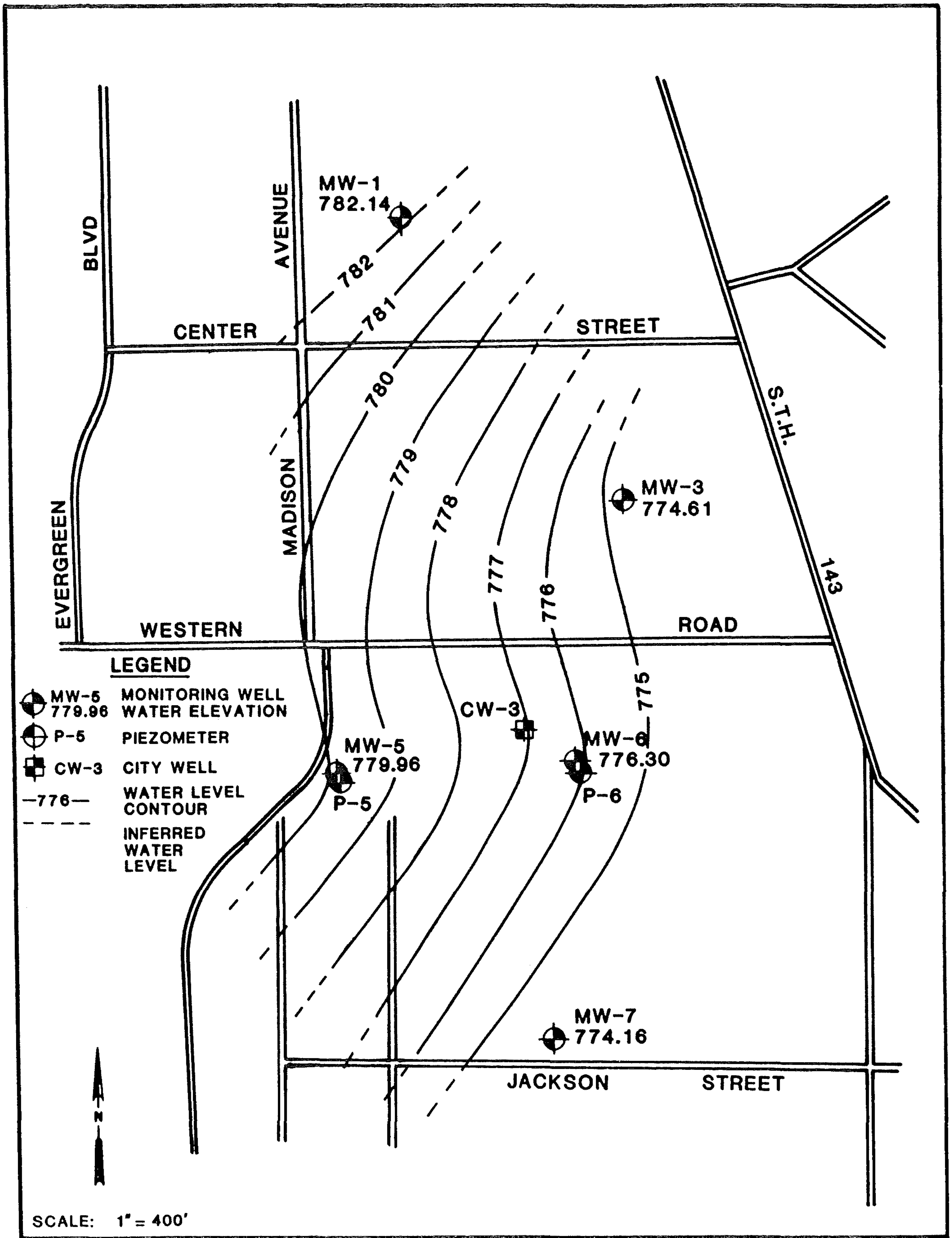

FIGURE
4.02-1

CEDARBURG GROUNDWATER INVESTIGATION

WATER TABLE SURFACE IN GLACIAL DRIFT

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and MW-6 were determined. Pre-pumping water elevations at city well 3 and 5 was 648.46 and 681.70, respectively. The difference in water levels between city well 3 and the adjacent piezometers P-5 and P-6 were 107.35 feet and 103.14 feet respectively.

B. Pumping conditions

The total drawdown observed in P-5 and P-6 was 0.67 feet and 1.06 feet, respectively, after approximately 7.5 hours of pumping. This resulted in a slight increase in vertical gradient at these locations to 0.164 and 0.193, respectively, between the piezometers and the shallow monitoring wells. No significant drawdown was observed in the shallow monitoring wells.

State DNR personnel performed the Thies curve matching method and Cooper-Jacob straight line method to determine local transmissivity and storativity values. The drawdowns in P-5 and P-6 were used for the analysis.

The Thies curve matching analysis on P-6 drawdown resulted in a transmissivity value of 2.84 x 10^5 gpd/ft and a storativity value of 0.043. Using the Cooper-Jacob straight line method, determined transmissivity values were 3.09 x 10^5 gpd/ft, 6.67 x 10^5 gpd/ft and 3.34 x 105 gpd/ft with storativity values of 0.03, 0.03 and 0.06. Using the Cooper-Jacob straight line method on P-5 data, transmissivity values of 3.96 x 10^5 and 3.84 x 10^5 gpd/ft, and storativity values of 0.01 and 0.01 were obtained. The average transmissivity and storativity by these methods were 3.96 x 10^5 gpd/ft and 0.03, respectively.

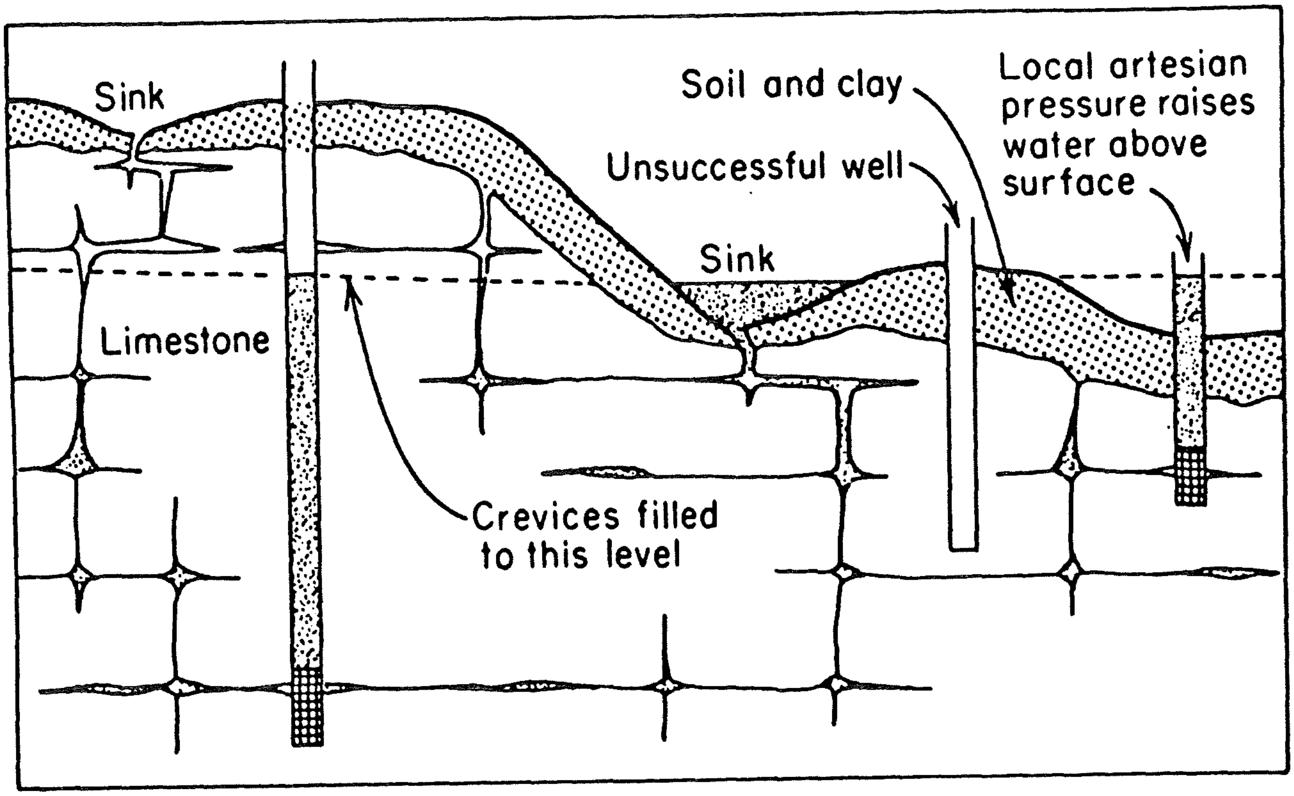
Hydraulic conductivity values were estimated by SA based on the calculated transmissivity values for the Niagara aquifer. The local average Niagara aquifer thickness, based on the local city well logs, of 489 feet was used for the calculation. The average determined horizontal hydraulic conductivity value was approximately 809 gpd/ft^2. Using the horizontal hydraulic gradient of the drift hosted pre-pumping water levels and estimated hydraulic conductivity of the dolomite, a local average velocity was estimated at 0.62 ft/day.

C. Discussion of results

It is important to bring into perspective the heterogeneity of fractured dolomitic strata with respect to groundwater flow. Permeability, or conductivity, indicates the ease with which water can move through the rock, and is determined by the size, shape, and interconnection of pore space, fractures, and solution channels in the rock. The primary permeability of limestone or dolomite is commonly less than 0.212 gpd/ft (Freeze and Cherry, 1979). Permeabilities of this magnitude are not significant sources of groundwater supply. However, dolomite has appreciable secondary permeabilities as a result of fractures or openings along bedding planes allowing considerable conductivity of water to area wells. Due to the nature of these bedding planes, there is a greater density of horizontal fractures versus more widely spaced vertical fractures resulting in greater groundwater movement parallel than perpendicular to the rock's bedding. Rock strata having low permeability, such as dolomite, can retard the vertical movement of water. Water can move through these strata, but much more slowly than through sand, gravel, and sandstone. There is a higher probability of wells encountering horizontal openings than vertical fractures and successful and unsuccessful wells can exist in close proximity depending on the frequency and interconnection of fractures encountered by the well bore. A schematic illustration of the occurrence of groundwater in carbonate rock is presented in Figure 4.02-2. This inherent nature of fractured dolomite is displayed in wells of close proximity having significant differences in water levels (Freeze and Cherry, 1979).

At Cedarburg, potential reasons for the significant differences in water levels, and the calculation limitations inherent in the estimated hydrogeologic parameters are explained in the following discussion:

There appears to be a considerable vertical hydraulic gradient between the unconsolidated drift and the fractured dolomite. Although the unconsolidated drift and the dolomitic strata are considered as one groundwater reservoir (the Niagara aquifer), at some places the units may act as separate, but closely related, aquifers between which leakage takes place. Differences in head between the units are large in the vicinity of city well 3 and the well nests, and may occur where steep hydraulic gradients, induced by pumpage or by groundwater flow



FREEZE AND CHERRY, 1979

FIGURE 4.02-2	CEDARBURG GROUNDWATER INVESTIGATION SCHEMATIC ILLUSTRATION OF FRACTURED CARBONATE ROCK	STRAND ASSOCIATES, INC ENGINEERS

down a non-pumping well into the Sandstone Aquifer, move groundwater much more rapidly along the bedding than the water can move vertically across the bedding. The separate nature of these two units is further substantiated by the lack of response of water levels in the shallow monitoring wells during the pump test.

The differences in water levels between the piezometers and the city wells open to both the Niagara and the Sandstone aquifers, are probably due to water from the Niagara cascading down through the city wells to the Sandstone aquifer. It is possible that the pre-pump test water levels in the piezometers do not represent actual static conditions but may in fact reflect a drawdown due to the constant downward discharge of water through wells 3 and 5. This would further explain the substantial water level differences between the water table monitoring wells and the piezometers. If it were possible to plug this "drain", it is possible that the piezometric surface, as seen in the city wells and piezometers, would rise and stabilize reflecting the head at some depth within the unconfined aquifer.

Difficulty is found when attempting to determine the transmissivity, hydraulic conductivity and velocity of groundwater movement within the Niagara aquifer. The determination of transmissivity requires one to know the rate of discharge and the drawdown response in a nearby well during pumping. The problem lies with the fact that the pumping well, city well 3, is open to both the Niagara and the Sandstone aquifers and the piezometers, P-5 and P-6, are open only to the Niagara aquifer. The rate of discharge used in the calculation is a combined discharge from both aquifers; however, the drawdown observed in the piezometers was in response to water being discharged from only the Niagara to the well, and this discharge is unknown. If the rate of discharge used in the calculation (960 gpm) reflected discharge from the Niagara only, the drawdowns in the piezometers would increase. In turn, if the drawdown in the piezometers is held constant it would be necessary to decrease the value of discharge. This indicates that the rate of discharge used in the calculations for transmissivity is falsely high with respect to drawdown. Since discharge is directly proportional to drawdown and transmissivity is inversely proportional to drawdown, this may suggest that the transmissivities, determined from this pump test, are falsely high. For example, if transmissivity values are calculated based on previous investigator's conclusions that wells open to both the Niagara and Sandstone aquifers in Ozaukee County receive approximately 20% to 40% of their water from the Niagara aquifer (Young H. L. and W. G. Batten), the rate of discharge from the Niagara Aquifer during this pump test would range from 192 gpm to 384 gpm, and the resulting transmissivities would range from 7.86×10^4 gpd/ft to 1.15×10^5 gpd/ft.

Hydraulic conductivity was determined from transmissivity values and as a result, may also be high. Also, due to the apparent separate groundwater systems between the drift and dolomite, the estimated velocity, based on surface water hydraulic gradients and possibly high horizontal hydraulic conductivities, may or may not represent actual velocity of water moving through the secondary fractures and openings. It would be necessary to test the separate, distinct geologic strata to determine a more accurate estimate of transmissivity, storativity, hydraulic conductivity, and velocity of the Niagara aquifer.

Each of the analytical methods presented in this section describe the response to pumping in a very idealized representation of actual confined aquifer configuration. Since very few aquifers approach the idealized configurations, the predictions that can be carried out with the analytical solutions presented in this section must be viewed as estimates only.

In the case of this pump test, the plotted points form a time-drawdown curve that closely resembles the theoretical Thies type curve even though it is, theoretically, an unconfined system and there may be leakage from the glacial drift to the Niagara, and from the Niagara to the Sandstone aquifer. It is probable that early drawdown due to pumping, as observed in the piezometers, approaches an ideal response. A pump test conducted over a longer period of time may produce type curves representing leaky aquifer conditions or a delayed yield response typical of unconfined conditions.

4.03 ENVIRONMENTAL MONITORING

A. Soil Gas Monitoring

The soil gas investigation yielded only one detect of VOCs when the carbon tubes were desorbed and analyzed for halogenated volatile organics in the lab (see lab report, Appendix E). This detect occurred at soil gas point 39, in the parking lot just west of the One Hour Martinizing (see Drawing 104-025-3). The compound detected was tetrachloroethylene, also known as perchloroethylene or "PER", at a concentration of 0.5 ug/L. This relatively low concentration of PER would not seem unusual so close to a dry cleaner; the PER could have entered the soil gas through a drain, a vent, or a past spill of perchloroethylene either at the site or upgradient from the site. It is difficult to determine whether or not the groundwater or soil below the dry cleaner is contaminated with PER since it is inherently difficult to formulate a reliable relationship between groundwater contamination and soil gas concentrations of VOCs.

The lab report from Enviroscan also mentions several detects of methylene chloride, and no detects of any other halogenated contaminants. The lab report indicates that the most likely reason for the methylene chloride detects is the use of that solvent in the lab.

A photoionization detector (HNu) was used during the survey to screen soil gas samples. The readings from the HNu meter are in raw form in Appendix D and are presented on Drawing 104-025-3 for each soil gas point. During all but one of the survey days, background HNu readings in the fresh, upwind air at each location tended to range from 0.5 to 0.8 ppm. Since this background reading seemed to be consistent no matter where the sample was taken, the background reading at each soil sampling point was subtracted from the sample HNu reading prior to reporting the results on the drawing.

There did not appear to be a trend in the HNu readings obtained during this study. All of the readings were quite low, generally below 1 ppm, except for sample #3 taken near an apartment building north of Bridge Road (not shown on the drawing), which was around 5 ppm. This reading may have been caused by sewer gas, petroleum hydrocarbons, or another source since no halogenated VOCs were detected in the lab. Point 4 had an HNu reading of 1.8 ppm; a petroleum odor was noted at this location and halogenated VOCs were not detected in the lab. The low readings noted at other points could have been caused by organics in the soil or air other than halogenated VOCs.

There could be several reasons why TCE was not detected during the soil gas survey. The most obvious of these is that there may have been no TCE in the upper (water table) portion of the aquifer. Another possible factor is that there was too much wet to saturated clay in the area where many of the points were taken, and therefore the void volume of the soil above the groundwater table was not sufficient for obtaining a good sample. The presence of clay or another relatively impermeable barrier could also cause the TCE vapor to move in a non-uniform manner, since the vapor would move through a path of least resistance such as a sandy layer of soil. The soil boring results indicate that there is an apparently continuous layer of clay from around city well 3 extending south and east through borings B-7 and B-8 (See Drawing 104-025-4).

B. Soil Sampling

Photoionization detector (HNu) readings taken during the performance of soil borings are recorded on the boring logs in the SES report, Appendix E. These readings are summarized in Table 4.03-1, along with the VOC analysis results from the lab. The lab VOC results are contained in the Enviroscan report for soil samples in Appendix E.

Detections of volatile organics were obtained with the HNu meter at borings B-1, 4, 5, 6 and 8. Soil samples were collected at all of these locations except B-6, which had an HNu reading of 1 ppm at a depth of 10 feet, but was 0 ppm at depths of 5 and 15 feet. The highest HNu reading was 154 ppm at B-1, which was located close to where the underground storage tank had been removed from the Mercury Marine Plant 2 site. This reading was obtained at a depth of about ten feet, which was the approximate level of the water table. The driller's report indicates that the HNu reading in the top of the open bore hole upon completion was 100 ppm at B-1.

TABLE 4.03-1

SOIL SAMPLE RESULTS

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

No.	Depth (ft)	HNu Reading (ppm)	Lab VOC Results
1	5	0	N.A.
	10	154	N.D.*
2	5,10	0	N.A.
3	5,10,15	0	N.A.
4	5	0.5	N.D.
	10,14	0	N.A.
5	5	0.5	N.A.
	10	1.3	N.D.
	15,20,25	0	N.A.
6	5,15	0	N.A.
	10	1.0	N.A.
7	5,10,15,20,25	0	N.A.
8	5	4.0	N.D.
	20	2.5	N.D.
	15,25,30,35	2.5	N.A.

N.A. = Not Analyzed

N.D. = Not Detected

* Lab reported many late eluting peaks which could indicate fuel or other hydrocarbons.

The soil VOC results from the lab indicates that TCE and related VOCs were not detected in the five samples that were analyzed. However, the lab reported many late eluting peaks in the sample from B-1. These peaks could indicate the presence of fuel, mineral spirits, or other hydrocarbons in the soil. The hydrocarbons could have entered the soil from the leaking underground storage tank that was removed in 1987; however, the tank removal contractor's report indicates that soils having HNu readings greater than 10 ppm were removed at that time.

C. Groundwater Monitoring

The results from the three groundwater sampling events are presented in Table 4.03-2. The groundwater sampling field notes and city well 3 pumping data for the sampling events may be found in Appendix J. Lab results are in Appendix E. Water elevations were measured prior to bailing each well and are presented in Table 4.03-3. A VOC sample was not collected at monitoring well P-5 in November due to the loss of the bailer prior to sampling that location.

Three of the seven monitoring wells were found to be contaminated during the groundwater monitoring program: MW-1, MW-6 and P-6.

The contamination at MW-1 consisted of TCE, 1,1,1-TCA, 1,1-DCA, and PER. The 1,1,1-TCA was present at the highest concentration, which averaged about 13 ug/L. TCE was detected at only 0.7 ug/L. The concentrations of all four contaminants increased from the September to the November sampling event by a factor of 2 to 6. It is interesting to note that PER was detected at concentrations averaging around 8 ug/L in this well, and PER was also detected in the soil gas downgradient from MW-1, at the dry cleaner. However, PER was not detected in MW-3, which is also considered to be downgradient from MW-1 based on the groundwater direction and gradient calculated from the pumping test results.

The contamination at the MW-6/P-6 nest consisted of TCE, 1,1,1-TCA, and 1,2-DCE. The 1,1,1-TCA was not detected in the piezometer during any of the sampling events and 1,2-DCE was not detected in either well after the first sampling event. The TCE and TCA concentrations at the water table were quite high, averaging around 3,600 ug/L and 490 ug/L, respectively.

TABLE 4.03-2

GROUNDWATER SAMPLING RESULTS

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

		VOC Concentration, (ug/L)			
Well No.	VOC	September 1989	October 1989	November 1989	Average
MW-1	TCE	0.4*	0.7	0.9	0.7
	1,1,1-TCA	6.9*	16.3	17.0	13.4
	1,1-DCA	0.6*	2.6	3.6	2.3
	PER	1.9*	8.8	12.2	7.6
MW-3	---	N.D.	N.D.	N.D.	N.D.
MW-5	---	N.D.	N.D.	N.D.	N.D.
P-5	---	N.D.	N.D.	N.S.	N.D.
MW-6	TCE	4960	2340	3440*	3580
	1,1,1-TCA	670	440	357*	490
	1,2-DCE	88	N.D.	N.D.*	≈29
P-6	TCE	280	269	221	257
	1,1,1-TCA	N.D.	N.D.	N.D.	N.D.
	1,2-DCE	2.1	N.D.	N.D.	≈0.7
MW-7	---	N.D.	N.D.	N.D.	N.D.
W-3	TCE	4.4	5.1	8.4	6.0
W-5	TCE	7.7	5.5	11.0	8.1

N.D. = Not Detected

N.S. = Not Sampled

* Average of duplicate samples.

TABLE 4.03-3

WATER ELEVATIONS IN MONITORING WELLS

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

	September 1989	October 1989	November 1989
MW-1	781.8	781.2	780.8
MW-3	774.6	774.2	774.2
MW-5	779.9	779.1	778.7
P-5	755.0	754.4	---
MW-6	776.5	775.9	774.7
P-6	750.6	749.6	749.4
MW-7	774.3	773.7	773.1

Note: Elevations in feet referenced to USGS MSL 1929 datum.

The results from the MW-6/P-6 well nest indicate the possible presence of a vertical concentration gradient at this location. Contaminant concentrations tended to be higher near the water table in the unconsolidated portion of the aquifer and seemed to decrease with depth. The TCE concentration was an average of 93% lower in P-6 than MW-6, the 1,2-DCE averaged 98% lower, and the 1,1,1-TCA was not detectable in the piezometer.

If the hypothesis of a vertical concentration gradient at this well nest was true, however, it would be expected that 1,1,1-TCA would have been detected in P-6 at least during the September sampling event when 1,2-DCE was detected, since 1,1,1-TCA, TCE, and 1,2-DCE have similar physical and chemical properties (Table 4.04-1). It is possible yet it would not seem likely that the 1,1,1-TCA was biologically transformed to TCE between MW-6 and P-6, since the expected transformation products would be 1,1-DCA, which was not detected, and then 1,2-DCE and vinyl chloride (Montgomery and Welkom, 1990). The TCE and 1,2-DCE detected in P-6 may be from a different source than the contaminants detected in MW-6. It is also possible that the contaminants in the two wells are related although not by a direct vertical pathway through the aquifer.

Trichloroethylene was detected in City of Cedarburg wells W-3 and W-5 during all three sampling events, while no other contaminants were detected that were tested for. The average concentration of TCE in W-3 and W-5 was 6.0 and 8.1 ug/L, respectively. These concentrations tended to correspond well with historical data. The well 3 concentration was slightly lower than the average concentration shown in Table 2.01-1, perhaps because the well had been running for 6 to 8 hours prior to sampling. The well 5 concentration was slightly higher than average, possibly because the well had been operating for 24 or more hours prior to sampling, and had only been off for 6 to 8 hours.

The water levels in all the monitoring wells, including the two piezometers, decreased by one to two feet from mid-September to mid-November. The trend in VOC concentrations from September to November did not appear to necessarily vary consistently with the water table level change. The VOC concentrations in MW-1 increased as the water level decreased, while the VOC concentrations at the MW-6/P-6 nest tended to decrease overall. An increase in VOC concentrations under low recharge conditions could be caused by less dilution, while a decrease in VOC concentrations could indicate that the source is in the unsaturated zone and is not flushed into the aquifer during low recharge conditions.

The TCE concentrations in city wells W-3 and W-5 also appeared to increase from September to November, although this may have been caused by variations in pumping and sampling conditions rather than variations in VOC concentrations in the aquifer.

The DNR indicated that PCBs were detected in MW-1 during the September sampling, but the concentrations were quite low, around 2 ug/L. An oily sheen was noted on the surface of the water purged out of this monitoring well during well development, but this sheen was not as noticeable during sampling in September. One reason for this could be that the water table elevation was a few inches above the top of the monitoring well screen in September, when the PCB oil sample was collected. Thus, if a floating product was present at the water table, it may not have been possible to obtain a representative sample of it in the well in September. On the other hand, the PCB concentration could have been low simply because it has a low solubility in water. It may be desirable to obtain another sample from this well at a time when the groundwater level intersects the well screen.

4.04 CHARACTERISTICS AND POTENTIAL SOURCES OF CONTAMINATION

A. Characteristics and Behavior of Contaminants

1. Properties of Dense Chlorinated Hydrocarbons

The contaminants which were tested for during this study included chlorinated alkanes, 1,1,1-trichloroethane (TCA), 1,1-dichloroethane (1,1-DCA), and 1,2-dichloroethane (1,2-DCA); and chlorinated alkenes, tetrachloroethylene (PER), trichloroethylene (TCE), 1,2-dichloroethylene (DCE), and vinyl chloride (VC). These compounds are sometimes referred to as "dense, non-aqueous phase liquids" (DNAPLs), or more commonly as "sinkers", since they are generally denser than water and are relatively immiscible in water.

Trichloroethylene is an industrial solvent commonly used for dry cleaning, degreasing and drying metals and electronic parts, extraction of fats and oils, as a refrigerant and heat exchange fluid, thinner for paints and adhesives, and other purposes. Trichloroethylene is a suspected human carcinogen. Mice fed large amounts of TCE over a short period of time were found to develop cancer. It is suspected that humans consuming TCE at lower rates over a long period of time could also develop cancer. The Immediately Dangerous to Life and Health (IDLH) level, which is a 30 minute maximum level set by NIOSH, for TCE is 1,000 ppm and the permissible exposure limit (PEL) in air is 100 ppm, or 25 ppm on a 10 hour time weighted average. Trichloroethylene may be biodegraded to 1,2-DCE and vinyl chloride in an aquifer (Montgomery and Welkom, 1990).

A 1,2-dichloroethylene is used as a solvent for fats and as a coolant or refrigerant, among other uses. 1,2-DCE may biodegrade to vinyl chloride in an aquifer (Montgomery and Welkom, 1990). There is less data available on health effects of exposure for 1,2-DCE; the threshold limit value (TLV) set by OSHA for the mixture of *cis* and *trans* isomers has been established at 200 ppm and the IDLH at 4,000 ppm (Montgomery and Welkom, 1990).

Other compounds which were tested for during this investigation included tetrachloroethylene (perchloroethylene or PER), a carcinogen with uses similar to those for TCE plus ink and textile processing; 1,1,1-trichloroethane, a metal cleaning or textile processing fluid; 1,1-dichloroethane, used as an extraction solvent, insecticide, paint and finish remover, degreaser, and fire extinguisher; 1,2-dichloroethane, a potential human carcinogen used as a lead scavenger in gasoline and as a paint and finish remover and metal degreaser; and vinyl chloride, a potential human carcinogen used in the manufacture of polyvinyl chloride and as an adhesive, refrigerant, and extraction solvent.

Table 4.04-1 contains a summary of several pertinent physical and chemical properties of the VOCs tested for during this investigation. All of the compounds are denser than water except for vinyl chloride, and all are relatively immiscible in water.

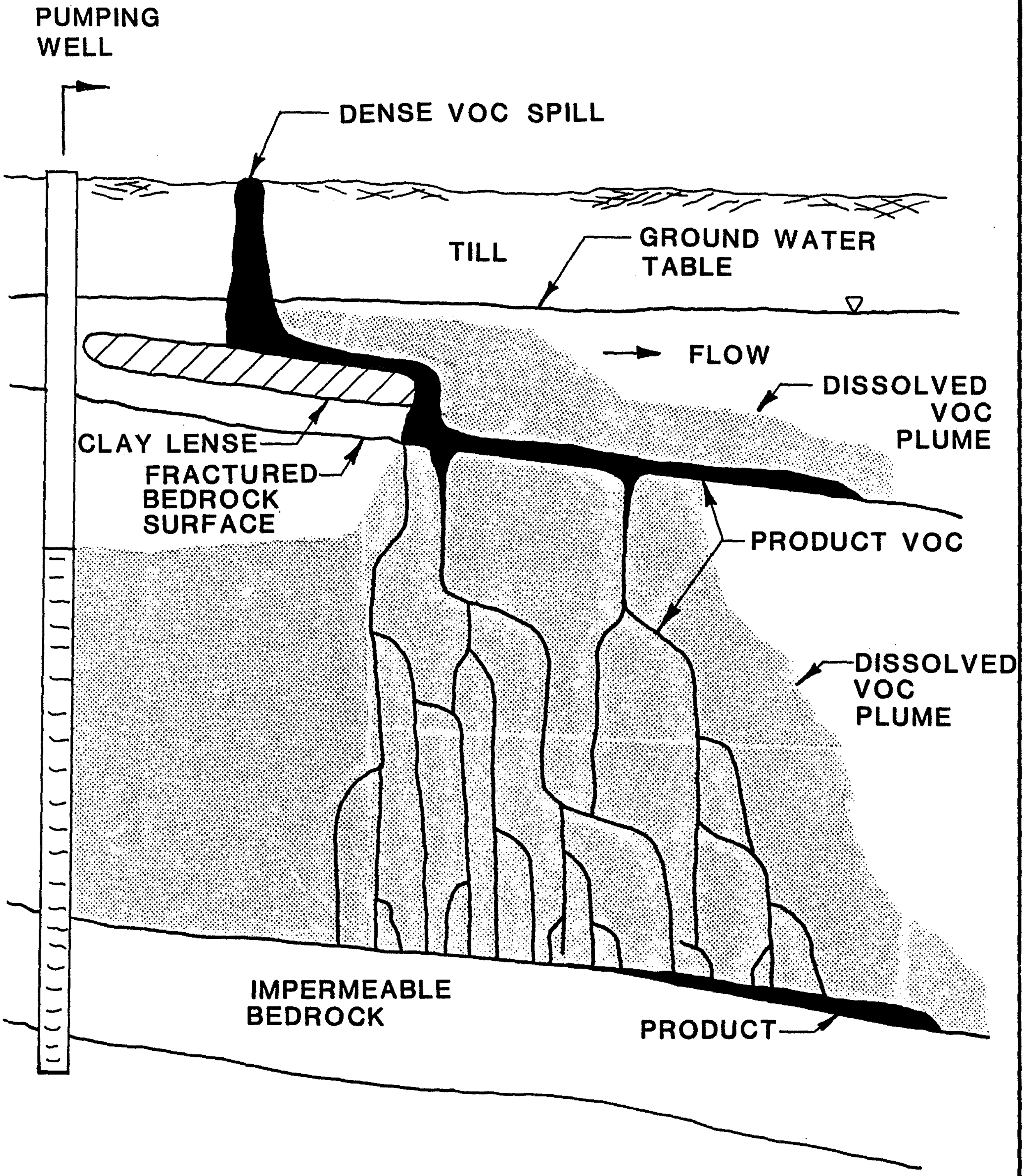


FIGURE 4.04-1

CEDARBURG GROUNDWATER INVESTIGATION
SCHEMATIC OF A DENSE VOC SPILL

STRAND ASSOCIATES, INC.
ENGINEERS

TABLE 4.04-1

PHYSICAL PROPERTIES OF VOCs[1]

WISCONSIN DNR
CEDARBURG GROUNDWATER INVESTIGATION

	Specific Density[2] g/cc	Solubility in Water[2] mg/L	K_{oc}[3] ml/g	H[4]
trichloroethylene (TCE)	1.46	1,100	126	0.31
1,2-dichloroethylene (DCE)[5]	1.27	800/600	59/N/A	0.12/3.1
tetrachloroethylene (PER)	1.63	200	364	0.56
1,1,1-trichloroethane (TCA)	1.35	720	152	0.56
1,1-dichloroethane	1.17	5,500	30	0.19
1,2-dichloroethane	1.26	8,690	14	0.039
vinyl chloride	0.91	1,100	2.5	111

[1] Adapted from Schwille, 1988, and Montgomery and Welkorn, 1990.

[2] Solubility and density generally given for 20°C.

[3] K_{oc} = sediment/water partition coefficient.

[4] H = Henry's constant, expressed as (mg/L in water)/(mg/L in air) at 10°C.

[5] Density given for mixture of *cis* and *trans* isomers, all other constants given for *cis/trans*.

2. Behavior of dense VOCs in an aquifer

Considering the local hydrogeology and chemical nature of the contaminants studied during this investigation, the VOCs detected in the monitoring wells would be expected to move through the aquifers in a fashion similar to that depicted in Figure 4.04-1. Since the chemicals detected are all denser than water (Table 4.04-1), pure or "product" chemical entering the groundwater would tend to sink down through pores in the soil or cracks in the bedrock until a confining layer of low permeability was encountered. Some of the pure or "product" TCE could remain trapped in pores or cracks above the confining layer, and some would move by gravity along the slope of the confining layer. Meanwhile, a portion of the chemical would dissolve up to a theoretical concentration equal to its solubility in water. A portion would also be adsorbed onto the organic carbon in the soil or rock in the saturated zone, as defined by the constant K_{oc} (Table 4.04-1).

The dissolved portion of the TCE, or "plume", would be expected to move with the bulk of the groundwater and be adsorbed to some degree onto soil particles. This absorption and desorption would result in retardation of the movement of the chemical in relation to the groundwater flow. The plume of contamination would be influenced by the pumping of well 3 or 5 in approximately the same manner that the bulk groundwater is influenced, except that again the chemical movement would be retarded to some degree. Thus, in the vicinity of wells 3 and 5, the plume could move east to southeast with the aquifer flow, downward with recharge into the Niagara or Sandstone Aquifers, or toward the city wells during pumping of the wells or because of the tendency for groundwater to flow into the sandstone through the wells when the wells are not pumping.

From the discussion of hydrogeologic conditions in the vicinity of city well 3, it appears that contamination in the upper unconsolidated portion of the Niagara Aquifer would not move easily into the deeper portions of the aquifer in the vicinity of P-5 and P-6, due to the apparent zone of low vertical conductivity in the bedrock at these locations. Therefore, it is possible that contamination in the unconsolidated materials and upper dolomite of the aquifer could move horizontally a considerable distance before finding a vertical pathway into the deeper portions of the Niagara Aquifer. City wells 3 and 5 would not likely be effected by surface contamination until the contaminants reached this deeper portion of the aquifer.

B. Potential Sources

Several potential sources of contamination will be considered in this section, based on historical information and the results of the investigations presented in this section. These possible sources of contamination are discussed in approximate order from most likely to least likely causing contamination as follows:

1. Scot Pump/Karak Machine Shop site
2. Kelch Corporation/Mercury Marine Plant 2 site
3. Storm sewer outfalls to the Cedar Creek
4. One Hour Martinizing dry cleaner
5. Cedarburg Dry Cleaners
6. Mink farm machine shop
7. Area landfills
8. Former Scheer Die Casting site
9. Other industries east of wells

1. Scot Pump/Karak Machine Shop Site

The Scot Pump/Karak Machine Shop site appears to be a likely source of the VOC contamination in city well 3. Historical information indicated the use of "parts cleaning fluid" at the site when Mercury Marine Plant 1 was in operation, and city personnel indicated that a large parts washer containing solvents was on site. It has also been reported that the Mercury Marine plant discharged test tank water, parts cleaning fluid, and other fluids to the storm sewer. Scot Pump has not reported the use of solvents, but it is not known whether or not Karak Machine Shop uses solvents such as TCE or TCA. Although no records indicate the presence of a septic system or underground storage tank on site, it is possible that one or the other existed or that solvents were spilled or discharged to the ground at some point in the history of the site.

Monitoring well MW-6 indicates a high level of VOC contamination in the shallow groundwater and lower levels in the deeper groundwater as indicated by P-6. The contamination in P-6 is primarily TCE with one detect of 1,2-DCE. The 1,1,1-TCA that was detected at high concentrations in MW-6 was not detected in P-6. Historically, TCA was detected in the city wells only once at W-5, although it appears that it was only analyzed for on three occasions at well 3 and four occasions at well 5.

Assuming this site is the source of contamination of the city wells, there are several possible reasons why TCA was not detected at P-6 while 1,2-DCE was, even though TCA was present at higher concentrations than DCE near the surface. One possibility is that the DCE detected in P-6 during the first sampling event was an artifact, possibly carried down during drilling of P-6. Another is that 1,1,1-TCA was transformed to 1,2-DCE or another compound prior to reaching the depth of the piezometer. A third possibility is that since TCA migration is retarded more than TCE and 1,2-DCE (see K_{oc} values, Table 4.04-1), the TCA may have become adsorbed onto carbon in the soils near the surface and not yet migrated into the lower portions of the aquifer. This last hypothesis is further supported since there does not appear to be a direct hydraulic connection between the water table portion and the deeper portion of the Niagara Aquifer, which would also slow vertical migration.

More information would be required to conclude that the contamination in P-6 and in the city wells is, indeed, from the shallow source at the Scot Pump site. At a minimum, one or more additional monitoring wells would be required at the site to better characterize the extent and source of contamination in the unconsolidated and deeper aquifers. The condition of the existing Sandstone Aquifer well at this site should be examined to determine whether it might be a route for vertical migration of contamination.

2. Kelch Corporation/Mercury Marine Plant 2 Site

The results of soil borings and groundwater samples, as well as historical information, indicate that the site where Mercury Marine Plant 2 was and Kelch Corporation is located is contaminated with VOCs. The site is old, is believed to have three underground storage tanks on site and perhaps two connections from the buildings to the storm sewers. Soil boring HNu readings indicated a very high level of volatile organics in the soil on the south east corner of the property, although the chemical(s) causing these readings have not been identified. This contamination could be from the mineral spirits which were detected at the site during the underground tank removal, or from the oily substance which was in the underground tank that was removed. Mineral spirits generally consist of straight-chain hydrocarbons which are not chlorinated.

Groundwater sample results at this location indicate the presence of PCBs and chlorinated VOCs. Although the concentrations of chlorinated VOCs at this site were low and TCE was not detected in concentrations above 1 ug/L, sampling results and historical information indicates some potential for this site to have caused contamination of the Niagara Aquifer. The water table lies within the bedrock at this location, and it is therefore possible for contamination to enter the Niagara Aquifer and move along fractures to the city wells without necessarily being detected at high concentrations in MW-1. The apparent strong downward gradient in the aquifer combined with the sinking nature of TCE could contribute to the inability to detect the contamination at the groundwater table. However, it is more probable that the contamination detected at this site is not from the same source as the contamination in the city wells.

Installation of deeper wells up and down gradient could provide better information on the extent and direction of contaminant migration at this site.

3. Storm Sewer Outfalls

Several storm sewer outfalls on the Cedar Creek were indicated as being the source of PCB contamination in the creek, as discussed in Section 2. The industries suspected of the PCB contamination were also suspected users of solvents such as TCE which could have entered the stream and been adsorbed onto the sediments or carried with the stream water. Groundwater elevations gathered during this investigation indicate that the Cedar Creek is a groundwater discharge area for the water table aquifer. Furthermore, it would be expected that VOCs would be stripped from the stream water fairly rapidly, due to the turbulent nature of the streamflow and the presence of dams along the creek. Also, soil borings indicate that VOCs were not present in the soils in the vicinity of the storm sewer discharges. However, these borings were not taken in the stream itself. It may be possible that VOCs adsorbed to sediments in the creek could gradually seep into the lower Niagara Aquifer, since there is a strong potential for downward vertical flow of groundwater in this area. This would not appear to be a likely route for chlorinated VOC contamination, however.

4. One Hour Martinizing Dry Cleaner

The dry cleaner located northeast of city well 3, One Hour Martinizing, was suspected of being a potential source due to the soil gas PER detect and the use of dry cleaning solvents. However, MW-3, located between the dry cleaner and city well 3, indicated no shallow VOC contamination. Also, the dry cleaner is located close to the Cedar Creek, a local discharge area. Therefore, it is unlikely that the dry cleaner is the source unless the VOCs are directly entering the deeper portions of the Niagara Aquifer and being drawn to the wells during pumping or during static conditions when groundwater flows into the Sandstone Aquifer through the wells. It is possible that the PER detect in the soil gas was either from the Mercury Marine Plant 2 site, which is generally upgradient, or from an isolated source at the dry cleaner.

Tetrachloroethylene could be biologically broken down to trichloroethylene through the removal of one chlorine atom (dehalogenation) by bacteria in the soil or groundwater. Therefore, it is possible that the source of TCE in the municipal wells could be the same as the PER source near the dry cleaner. This is not considered likely, however, since it is not likely that all of the PER would be converted to TCE and since PER has never been detected in the city wells, except for one detect of 0.8 ug/L in well 5.

5. Cedarburg Dry Cleaners

Little information is available on the Cedarburg Dry Cleaner, except that the dry cleaner is known to use halogenated solvents. This site is downgradient from the city wells, but may be within the zone of influence of the wells when pumping. It was originally hoped that MW-7 would provide information on possible plumes being pulled toward city well 3 from sources southeast of the city well, but MW-7 is finished in the glacial till and is probably not deep enough to provide information of this nature, since the city wells appear to draw water primarily from the deeper bedrock portion of the Niagara Aquifer.

6. Mink Farm

The mink farm machine shop was suspected as being a potential source due to its proximity to both wells and the fact that surface drainage and groundwater appear to flow from this site toward the two city wells. The site also appeared to be in poor condition with piles of refuse and rubble, a partially demolished building and an apparently unabandoned water well on site. However, the shallow and deep wells (MW-5 and P-5) downgradient of the mink farm and upgradient from city well 3 did not indicate VOC contamination coming from any sources west of city well 3.

7. Area Landfills

The historical survey indicated potential contamination migrating from landfills on the northwest side of Cedarburg. The Marvin Procknow site had been known to accept industrial wastes, and is documented by the DNR as having the potential for migration of contamination from the site. However, contamination migrating from this site would be expected to move southeast past city wells 4 and 6 prior to reaching wells 3 and 5. Since the former two wells completely penetrate the Niagara Aquifer and do not appear to be contaminated with VOCs, it is unlikely that the landfills are the source of contamination in wells 3 and 5.

It is possible that the contamination in city wells 3 and 5 is from a landfill that was not in the DNR records and was not found during the site visits.

8. Scheer Die Casting Plant

Another potential source of the groundwater contamination is the former Scheer Die Casting plant, now an apartment complex. Little information is available on the site; however, it is located fairly close to city well 5. It is probable that any underground tanks or other storage structures located at the site would have been removed during construction of the apartment buildings. This site is downgradient of the city wells, but may be within the zone of influence during pumping of the wells.

9. Other Industries East of Wells

Several industries along Pioneer Road could also be potential sources of contamination, although this is not likely since they are downgradient and farther away from the city wells. Again, a deeper well finished in the bedrock downgradient of well 3 or 5 would be required to gain information on any contamination originating from this area.

SECTION 5
SUMMARY AND RECOMMENDATIONS

5.01 NATURE AND EXTENT OF CONTAMINATION

The results of the groundwater sampling program may be used to draw limited conclusions concerning the extent of groundwater contamination in the vicinity of city wells 3 and 5. Further inferences may be made regarding the source and extent of contamination through information gathered during the well 3 pumping test. This information may be used to help locate additional groundwater monitoring points to confirm predictions of contaminant migration.

Data from monitoring well MW-6 indicates there is a fairly concentrated (approximately 5 mg/L or more), plume of TCE in the shallow groundwater at the Scot Pump site. The contamination also consists of 1,1,1-TCA and 1,2-DCE. The exact source of this shallow contamination cannot be determined from available data, but is likely to be downgradient of MW-3 and MW-5 since these monitoring wells indicated no contamination. Upgradient MW-1 did show some contamination, but at different concentrations of different chemicals. It is probable that the source is on the Scot Pump site since there appears to be no suspected users of solvents between the clean, up-gradient wells and MW-6.

The extent of contamination downgradient of MW-6 was not determined, although it appears from MW-7 data that the plume does not extend south to that monitoring well. The horizontal velocity of the groundwater in the Niagara Aquifer may be estimated as 0.15 ft/day, based on the average of the lower transmissivity values which were estimated in Section 4.02-C. If it is assumed that this estimated velocity also applies to the shallow water table aquifer, then groundwater in the shallow aquifer would travel approximately 55 feet per year (Note that this velocity was calculated based on a pump test performed on a deeper portion of the aquifer. The velocity in the till may be more or less than this value). Trichloroethylene would travel more slowly due to adsorption onto organic soils in the aquifer. Using the soil to water partition coefficient for TCE of 126 ml/g (Table 4.04-1), and assuming an overall aquifer porosity between 0.3 and 0.5 and an organic carbon content of the aquifer materials between 1% and 5%, the TCE would have an approximate retardation coefficient between 5 and 40. (See Sample

Calculations, Appendix K). This would mean the TCE would travel between 1.4 and 11 feet per year in the aquifer at the calculated groundwater velocity, and could have traveled horizontally between 11 and 100 feet since 1982, when contamination was first noted in the city wells.

This is obviously a wide range of distances for the possible horizontal extent of the plume, and the estimate is further limited because it represents only the movement of the bulk of the plume. Also, the velocity used in the estimate is probably more representative of the groundwater in the lower dolomite rather than in the upper drift and highly weathered dolomite. The actual migration of a small percentage of the mass of the plume could be much greater than this if the contamination is moving along fractures in the bedrock, or much less than this if the actual groundwater velocity is much slower than estimated here.

The contamination in the shallow groundwater at the Scot Pump site may have spread downward into the deeper portions of the Niagara Aquifer, as indicated by P-6 data and the vertical groundwater gradient between MW-6 and P-6. The contamination in the groundwater at P-6 consisted of an average of 670 ug/L of TCE. Eighty-eight micrograms per liter of 1,2-DCE were also detected in P-6 during the first sampling event. Since 1,1,1-TCA was not detected in P-6, this deeper contamination could be from a source other than the shallow contamination, although the upgradient piezometer P-5 did not indicate an upgradient source to the west. Another possibility is that TCA was not detected in P-6 because it was either transformed or its movement is retarded due to adsorption onto soils and rock in the aquifer.

The velocity of the groundwater in the vertical direction was not determined, but may be estimated in order to determine the likelihood of the deeper contamination at Scot Pump coming from the same source as the shallow. The primary permeability of the unfractured dolomite may be estimated as 0.21 gpd/ft^2 (.03 ft/day) (Freeze and Cherry, 1979). Considering the head differential between the water table and the piezometer of about 25 feet and a distance between the MW-6 screen and the P-6 screen of 135 feet, the velocity through the rock under static conditions would be only .006 ft/day by Darcy's law (see calculations, Appendix K). This would mean it could take as long as 60 years for water to travel vertically from the water table through the rock to the level of the piezometer screen, and perhaps hundreds of years for the TCE to reach the piezometer. In actuality it probably takes much less time than this due to vertical fractures or areas of greater permeability, known as "secondary permeability," in the bedrock. Vertical fractures in the bedrock could cause the TCE to reach the deeper aquifer much more quickly than would be predicted by the overall vertical permeability of the aquifer. Another possible vertical pathway could be the deep water well at the site, which could have cracks or holes in the steel casing.

The contamination at the old Mercury Marine Plant 2 and Kelch Corporation site appears to be at a fairly low level (less than 15 ug/L) in the water table aquifer. The contamination consists of 1,1,1-TCA, 1,1-DCA, PER, and TCE. Information on the aquifer would indicate that this contamination would tend to move both horizontally southeast and vertically downward in the aquifer. The source of the contamination is not known, but is likely to be on-site since there are no suspected users of solvents upgradient of this site and downgradient of municipal well 6, which is not contaminated. Data indicates that the plume has not extended downgradient to MW-3 since that well had no detects of VOCs, although this could mean the plume is either deeper than the bottom of the screen at MW-3 or that the contamination is travelling along fractures in the bedrock that are not intercepted by MW-3. It is not likely that the contamination found at MW-6 is from the same source as MW-1, since the types and relative concentrations of VOCs at the two sites are considerably different.

Contamination at the Mercury Marine Plant 2 site is also known to consist of high levels of non-halogenated volatile hydrocarbons other than the compounds investigated here. This contamination is documented by the underground tank removal contractor's report in Appendix B, soil sample HNu readings taken near the water table, and visual observations of an oily film on the water purged from the well during development. Low levels of PCBs in the groundwater were also found during DNR sampling of MW-1.

Trichloroethylene contamination is known to extend to city wells 3 and 5, as well as trace amounts of 1,2-dichloroethylene contamination. The plume does not appear to extend west of W-3, since MW-5 and P-5 showed no contamination. The plume is also not present at upgradient municipal well 6, though it could be between municipal well 6 and W-3. It is not possible to determine how far downgradient the contamination has spread, or how much contamination has entered the Sandstone Aquifer. It is likely that city wells 3 and 5 are providing a route for VOC contamination of the Sandstone Aquifer, particularly if either well is not pumped for a long period of time (see Section 4.02). The pressure head of the deeper Niagara Aquifer is as much as 65 to 85 feet greater than that of the Sandstone Aquifer near the city wells, and since the wells are open to both the Niagara and Sandstone Aquifers, groundwater contamination would tend to move into the sandstone.

5.02 POTENTIAL FOR FURTHER DEGRADATION

The potential for further degradation of the aquifers would depend on the extent of contamination in soils and in the shallow aquifer, whether the source was an isolated spill or a continuous discharge, whether the source is presently continuing to discharge the chemicals to the environment, and many other factors. The data for municipal wells 3 and 5 indicates that concentrations of TCE in the city wells may be increasing since sampling first began in 1982. This could indicate that there is strong potential for further degradation, if the trend in increasing concentrations continues.

If the source of contamination in the city wells is from the shallow contamination found at the Scot Pump site, it would be expected that further degradation of the deeper aquifer from this source would continue, unless the shallow contamination is remedied. This is indicated from the relatively high concentration of TCE near the groundwater table at the site combined with the potential for contamination to move vertically downward into the deeper Niagara Aquifer. Given time, this contamination could also reach the Sandstone Aquifer and cause degradation of that valuable source of drinking water, unless pumping of the city wells is sufficient to keep the contamination from spreading in this aquifer.

The most likely horizontal path of migration of the contaminated plume would indicate little further degradation in terms of threat to public health and welfare, once the plume is outside of the influence of wells 3 and 5. Private wells in the Cedarburg city limits have been abandoned over the past several years. Shallow contaminated groundwater would discharge to the Cedar Creek and

Milwaukee River downgradient of the source, where it would be diluted and VOCs would be stripped by aeration and decomposed by bacteria in the surface water. There are no municipalities east of Cedarburg which would draw water from the deeper Niagara Aquifer, and deeper Niagara groundwater contamination would eventually be diluted, biodegraded, and discharged into Lake Michigan. Any contamination in the Sandstone Aquifer would most likely be diluted or broken down biologically prior to reaching City of Milwaukee water supply wells; however, Mequon and Thiensville are closer and could conceivably draw contaminated water from the Sandstone Aquifer.

5.03 TYPES OF REMEDIAL ACTIONS

The City of Cedarburg has chosen a remedial action to protect its customers from continuing use of a contaminated water supply. The city will be treating water from well 3 and well 5 by air stripping of VOCs prior to distribution. If the contamination in city wells 3 and 5 continues to increase and if surface sources of contamination are not removed, the operating cost and possibly further construction costs for the air stripping remedy could increase significantly over time. Also, future air pollution regulations could increase operating costs of the air stripper considerably. Preventing or reducing further degradation of the aquifer may be feasible if the costs of remediating the source are less than future operation and maintenance costs of treatment at well 3 and 5, or if a private party took on financial responsibility for remediating the source.

Assuming the source of the contamination is known, there are several remedial actions that could be considered to limit further degradation of the aquifer. These could include: A) in-situ treatment of the contaminated groundwater or soils, B) creation of aquifer barriers to prevent or lessen further migration of contamination, C) removal or containment of contaminated soils to prevent further elution of contaminants into the aquifer, and D) pumping and treating of groundwater by either granular activated carbon or air stripping.

A. <u>In-Situ Treatment</u>

In-situ treatment of groundwater by bacterial degradation alone may not be desirable since VOCs such as TCE and 1,1,1-TCA and PER all tend to biodegrade to vinyl chloride in an aquifer environment (see Section 2). Vinyl chloride is toxic and may not break down further into carbon dioxide and water by bacteria normally found in an aquifer. Pilot testing of this alternative would be essential prior to implementation. It may be feasible to treat contaminated soil in-situ depending on the proximity of the groundwater table and the types of soils that are contaminated. Bio-treatment of contaminated soils combined with soil venting to remove the vinyl chloride may be a cost-effective remedy if conditions are favorable.

B. Construction of Barriers to Migration

Creation of aquifer barriers to contain the source is normally considered a temporary remedy in order to protect against an imminent threat to public health and welfare. Such a remedy would probably not be feasible in this situation, since there appears to be no immediate danger to the public in terms of down-gradient exposure to the contamination. If further investigations prove otherwise, then a barrier could be used in conjunction with groundwater and/or soil treatment at the source of contamination.

C. Removal or Containment of Soils

Removal or containment of contaminated soils is generally most cost effective if the volume of soils is relatively small and the concentration of contaminants is relatively high. Evaluation of the actual soil conditions and the containment, disposal or treatment costs would be necessary to determine the effectiveness of this alternative.

D. Pumping and Treatment of Groundwater

Pumping and treating groundwater at the source of contamination could be a feasible alternative, particularly if the contamination was within the unconsolidated water table aquifer above the bedrock and was present in fairly high concentrations, as it appears to be at the Scot Pump site. An evaluation of the extent of the plume in this portion of the aquifer, as well as the characteristics of the groundwater flow, should be made prior to implementing this remediation. Since the bedrock surface appears to limit downward migration, it would appear that the unconsolidated portion of the aquifer could be pumped with little dilution from the deeper portions of the aquifer, and pumping and treatment would, therefore, be more cost-effective.

It is important to note that pumping and treating of deeper portions of the Niagara Aquifer would probably not be feasible, due to the more dilute nature of the contamination and the difficulty in locating contaminated fractures in the bedrock. The need for remediating the deeper groundwater is also lessened by the fact that this groundwater will be drawn toward the city wells and treated by air stripping in the future.

Air stripping of the pumped groundwater would most likely be the most cost-effective treatment alternative in terms of capital costs, and is known to be effective for removing chlorinated VOCs. Operational costs are fairly high, however, and would increase significantly with future changes to air pollution regulations. The amount of time that the air stripper or other treatment alternative would need to be operated should be estimated, and O & M costs included in the cost analysis, prior to selecting this remediation alternative.

It may also be possible to pump groundwater and discharge it to the sanitary sewer system. The chlorinated VOCs would be effectively stripped or degraded during biological treatment at the city's wastewater treatment plant. A discharge permit would most likely need to be obtained, as well as permission from the city wastewater utility.

In summary, there would appear to be no immediate danger to public health from the contamination once air stripping treatment of the water from wells 3 and 5 is commenced. However, it appears that there is potential for further degradation of both the Niagara and Sandstone Aquifers, which could cause increased costs of treatment and make further remediation necessary. Furthermore, the relatively high level of contamination found at the Scot Pump site and former Mercury Marine Plant 2 site may warrant remediation or careful monitoring to ensure that activities carried out at the sites do not endanger persons coming in contact with the contaminated groundwater or vapors.

5.04 RECOMMENDATIONS FOR FURTHER INVESTIGATION

Recommendations are made in this section for further investigation to confirm the source of contamination in the city wells or the extent of contamination at individual sites. As was mentioned in the previous sections, the city has chosen a remedial action for their water supply which will reduce the threat to the health and welfare of water consumers. Therefore, further investigation would only be desirable if the city wished to recover or lessen costs of remediation by identifying the responsible party or by remediating the source.

There is a strong case for the source of contamination being from either the Scot Pump site or the former Mercury Plant 2 site, as discussed in Section 4.04. Furthermore, it has been noted in Section 5.03 that remediation of a shallow source of contamination may prove to be feasible, while for deeper contamination the previously selected remedy of air stripping at the city wells would be the most feasible. Therefore, it may be desirable to focus further investigation on the shallow contamination and routes of migration of shallow contamination into the deeper dolomite aquifer.

Several additional wells should be placed at the Scot Pump site. These may consist of two or three additional downgradient (east and southeast) water table monitoring wells and one or two deep wells to determine the migration of contamination in the horizontal and vertical direction. It may also be desirable to place an additional monitoring well further northwest of the site, to verify that the contamination detected at the Scot Pump site is not from a different, upgradient source.

A deep well located on the southeast corner of the Scot Pump site should also help isolate a potential source from the Cedarburg Dry Cleaner or the Scheer Die Casting site, since a plume of contamination at either of these sites might be pulled toward city well 3 during both non-pumping and pumping conditions.

If it is determined that the plume of contamination at MW-6 and P-6 is from a source at the Scot Pump site, a full assessment should be made of the property. Past employees should be interviewed and company records reviewed from the Mercury Marine Company as well as Scot Pump and Karak Machine Shop. The exact source of the contamination at the site should be determined if possible, and the general time frame that the contamination occurred. The inside and outside of the building should be examined for drains, vents, and other indications of discharge points or holding tanks. It may also be desirable to perform intensive soil sampling around the site.

If it is determined that the source of contamination is not from the Scot Pump site and it is considered desirable to locate the source, a few deeper wells could be constructed to better isolate the source. One of these, at a minimum, should be placed south-southeast of the Mercury Marine Plant 2 site to determine whether contamination is entering the bedrock and is moving toward the city wells with the deeper groundwater. Deeper wells could also be placed near MW-7 or east of city well 5. Data from these wells could indicate whether or not source is the industries to the east of the wells along Washington or Pioneer Roads.

If additional monitoring wells are constructed in the area, it would be helpful to monitor soils and rock cores for VOCs in the field. This could best be done by placing small core samples from every 5 to 10 feet of core into a small jar, allowing the VOCs to equilibrate between the soil, water, and gas phases, and analyzing the headspace for VOCs. The core should also be logged for fracture density, prior to taking VOC samples.

Some additional, relatively low-cost investigations could be conducted to gain useful information on the local aquifer. A pumping test could be conducted on well 5 to determine the extent of influence of that well, and further verify that the source of contamination at well 5 is the same as the source at well 3. This pumping test should be carried out for a longer period of time, perhaps 48 to 72 hours, than the well 3 test, to determine whether well 5 has an influence on the water table monitoring wells when it is allowed to pump for a long time. The monitoring effort would not need to be as intense as the well 3 pump test, however, since the intent would be only to determine the general influence of the well, and not to try to characterize the aquifer system.

Further attempts could be made to determine the transmissivity of the deeper dolomite portion of the aquifer as well as the shallow unconsolidated aquifer by performing bail-and-recovery tests on the monitoring wells and piezometers. This would be accomplished by bailing or pumping water out of the monitoring well and timing the recovery of the water level. This would provide an estimate of the aquifer transmissivity in the immediate vicinity of the particular monitoring well. A more exact, but much more expensive, method of determining the transmissivity of the Niagara Aquifer would be to perform a packer test on city well 3 by sealing off the Sandstone Aquifer and monitoring the water levels in P-5 and P-6 while the well is pumping. This may not be feasible, however, due to the depth of the city well and the cost of the test, compared to the value of the information that would be gained.

Another potential means of investigation would be to run a dye test in the shallow and deeper portions of the Niagara Aquifer. A non-toxic dye or conservative tracer could be injected into monitoring well 6, and samples could be taken from city wells 3 and 5 and monitoring well P-6 over time. This would provide information on the velocity of groundwater flow in the vertical direction and the vertical hydraulic conductivity near well 3, and would confirm or dispute the potential for the TCE detected near the groundwater table at MW-6 to migrate downward to the city wells. There could be a limitation to such a study, however, in that it could take anywhere from hours to years for dye injected near the water table to reach the level of the piezometer and the city wells. Pumping well 3 extensively could lessen the amount of time the investigation would take.

Finally, the fractures in the bedrock in the vicinity of wells 3 and 5 could be mapped at a relatively low cost. It is important to have some knowledge of the density, strike and dip of fractures when studying a bedrock aquifer. Some knowledge of the horizontal frequency of fractures was gained from the P-5 rock core. However, the strike and dip of these fractures and frequency of vertical fractures could not be determined from the cores. Aerial photographs, bedrock outcrops and possibly rock quarries could be examined for this information.

5.05 CONCLUSIONS

The following conclusions may be drawn from this investigation:

1. The soils in the vicinity of wells 3 and 5 consist of glacial till, including mixtures of silt, fine to course sand, gravel and clay, with some topsoil or fill over the entire study area. The soils range in depth from approximately 4 feet to more than 30 feet.

2. The bedrock to a depth of around 500 feet consists of undifferentiated Devonian and Silurian dolomite which contains small horizontal fractures at spacings of 0.5 to 5.5 feet to a depth of 180 feet or more.

3. The bedrock below the dolomite consists of around 200 feet of shale followed by around 220 feet of dolomite. Underlying the dolomite is sandstone of an unconfirmed thickness.

4. There are two distinct bedrock aquifer systems in the study area: the regionally unconfined Niagara Aquifer at depths to about 500 feet, and a confined Sandstone Aquifer at a depth of about 700 feet and more.

5. The Niagara Aquifer in the study area appears to consist of an upper level of unconsolidated and highly fractured bedrock materials near the water table, followed by a deeper level of more competent carbonate bedrock. These two zones do not appear to have a significant hydraulic connection in the areas of the two well nests and city well 3, as is apparent from field observations during construction of P-6 and the well 3 pumping test results. The deeper portion of the Niagara Aquifer in this area probably greatly retards vertical groundwater movement, since recharge into it from the water table zone appears to occur very slowly.

6. The piezometric levels of the respective aquifers indicate that the water table zone of the aquifer recharges the deeper zone of the Niagara Aquifer, although this may occur very slowly, and the Niagara Aquifer recharges the Sandstone Aquifer. Groundwater movement from the water table into deeper portions of the Niagara Aquifer would occur through

vertical cracks and inconsistencies in the dolomite bedrock. City wells 3 and 5 appear to act as a "drain," providing a route for movement of water from the Niagara to the Sandstone Aquifer. This results in a simulated "pumping" condition in the Niagara Aquifer, even when the city wells are not actually pumping. This condition also causes concern relative to potential contamination of the Sandstone Aquifer.

7. Under "static" or non-pumping conditions, the water table aquifer appears to move horizontally in a east-southeast direction with a horizontal gradient of approximately 0.006 ft/ft. The vertical hydraulic gradient between the water table monitoring wells and the piezometers appears to range from 0.156 and 0.185 downward.

8. Under dynamic conditions of pumping well 3, the water table elevation does not appear to be influenced and the deeper Niagara appears to be influenced to distances of about 1,300 feet from well 3 or more. Vertical gradients between the water table wells and the piezometers appear to increase to values between 0.16 and 0.193 under pumping conditions.

9. The soil gas investigation results indicated the presence of tetrachloroethylene near a dry cleaner. No other areas of soil vapor contaminations were apparently penetrated. The soil gas survey failed to locate a "hot spot" of contamination at the Scot Pump site, possibly due to the presence of wet, clayey soils at the site interfering with soil gas sampling, or because the contaminants were not present near the water table at the locations sampled, but had sunk to deeper portions of the aquifer.

10. The data collected from analysis of soil boring samples indicated that the borings did not penetrate any pockets of soils contaminated with chlorinated alkenes or alkanes. However, non-chlorinated hydrocarbons were detected at B-1 at a depth of 10 feet, near the water table.

11. The shallow groundwater in the vicinity of MW-1, at the former Mercury Marine Plant 2, appears to be contaminated with low concentrations of chlorinated alkanes and alkenes.

12. The shallow groundwater in the vicinity of MW-6 and P-6, on the Scot Pump site, appears to be contaminated with chlorinated alkenes and alkanes. The deeper groundwater at this location appears to be contaminated with chlorinated alkenes. The predominant alkene contamination (TCE) observed in MW-6 and P-6 has been the predominant contaminant observed in city wells 3 and 5. The predominant alkane (1,1,1-TCA) in MW-6 has not been observed in P-6 or city wells 3 and 5.

13. Chemical data and hydrogeologic information gathered during this investigation indicate the potential for further degradation of both the Niagara and Sandstone Aquifers.

14. The results of this investigation indicate that further remedial action may be justified, due to the potential for further degradation of the aquifers. It may be desirable to pursue remediation at the Scot Pump site whether or not this site is the source of well 3 and 5 contamination, due to the high concentrations of contaminants at this location. The extent of shallow and deep contamination in the vicinity of the city wells should be further investigated and a cost-benefit analysis of remediation performed prior to implementing remedial actions.

15. Based on the results of this investigation, it is recommended that further investigations be conducted to better identify the source and extent of contamination. The first phase of further investigations should include, at a minimum, installation and sampling of two or three water table monitoring wells and one deep piezometer at the Scot Pump site. This site appears to be the most likely cause of contamination of wells 3 and 5, according to data gathered during this investigation. Soils and rock core should be monitored for VOCs during well installation. Rock cores and outcrops in the area should also be examined for information on the density, strike and dip of the bedrock.

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