ORGANIC AND INORGANIC CONTAMINANTS IN SHALLOW GROUNDWATER AT SIX MUNICIPAL LANDFILLS IN NORTH DAKOTA

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Edward C. Murphy

REPORT OF INVESTIGATION NO. 94

NORTH DAKOTA GEOLOGICAL SURVEY

John P. Bluemle, State Geologist

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CONTENTS

ILLUSTRATIONS

Table		Page

ABSTRACT

A total of 110 sanitary landfills were operating within the State of North Dakota when this project began in 1987. This number has dropped to 46 due to the closure of some poorly located and poorly operated landfills and also because of concern for the upcoming rule changes in the EPA Solid Waste Program.

Six sanitary landfill sites were chosen for study in North Dakota. Five of these sites had previously been identified as poor geologic settings, the sixth site was believed to be well suited geologically for waste disposal. The landfills ranged from 70 to 10 years in age. The purpose of this study was to determine the environmental impact of these six landfills. The results of this study may be used to predict the extent of groundwater degradation at landfills situated in similar geologic settings within the state.

A total of 83 monitoring wells were installed at the six study sites. The average depth of the monitoring wells was 25 feet. Water samples were obtained during September, 1987, May, 1989, and June, 1990. Each sample was analyzed for major ions, selected trace metals, and total organic carbon (TOC). Selected samples were also tested for volatile organic compounds (VOCs) and 16 various pesticides.

The results of the water analyses indicate that refuse leachate is being produced at each of the landfill sites. The leachate is generally characterized by low to moderate increases of major ion concentrations, little to no increase in the selected trace metal concentrations, and moderate to high increases in the organic carbon content. The best indicators of leachate are the chloride ion and the TOC.

In the future, solid waste disposal sites must be sited in the best possible geologic setting. These sites must be properly designed and operated to minimize the amount of leachate that is generated.

AUTHOR'S NOTE

The North Dakota State Department of Health regulates solid waste disposal in North Dakota. Information on waste reduction, reuse, and recycling can be obtained by writing to the Solid Waste Program, Division of Waste Management, North Dakota State Department of Health, 1200 Missouri Avenue, P.O. Box 5520, Bismarck, North Dakota 58502-5520, or by calling (701) 221-5166.

ACKNOWLEDGEMENTS

This project was funded by the North Dakota Geological Survey and the North Dakota State Department of Health and Consolidated Laboratories. The North Dakota Water Resources Research Institute provided a $15,000 grant to defray the costs of the organic analyses (ND 88-01).

A number of individuals were extremely helpful and played a vital role in this project. Jeff Maletzke wrote an excellent Master's Thesis at the University of North Dakota on his investigation of the Hillsboro landfill. Eric Graney is currently in the process of completing his Master's Thesis on the Devils Lake landfill. Steve Tillotson was instrumental in getting this project off the ground and assisting me in the initial phases of the project. I would also like to thank the following people for their help with this project: Dave Lechner, the late Gene Christianson, Francis Schwindt, Martin Schock, Dave Cameron, Jim Pearson, Ken Kary, Kenan Bullinger, Rod Reetz, Kim Wehner, Jim Sinkula, Myra Kosse, Gene Emery, Monte Meiers, and Dave Derragon. Dr. Ed Hagan of Williston, Ms. Marjorie Raitshleger and Dr. N. L. Montaniel of Harvey, Mr. Cliff Herr of Wishek, Mr. Eugene Malsom and the Linton Gun Club, and Mr. Philip Barendt of Devils Lake graciously allowed access to their land during this study.

INTRODUCTION

General Information

The U.S. Environmental Protection Agency (EPA) is scheduled to introduce new rules governing solid waste disposal in 1993. These much anticipated rule changes are expected to - and have already begun to - dramatically change the present-day methods of landfill siting and operation. The economic constraints that these new rules will place on landfill operation is expected to reduce the total number of landfills operating throughout the country by 40 to 60%.

In 1987, when this project began, North Dakota had a total of 110 operating landfills (figure 1). This number has dropped to 46, a decrease of 60% (Solie, 1992). The number of

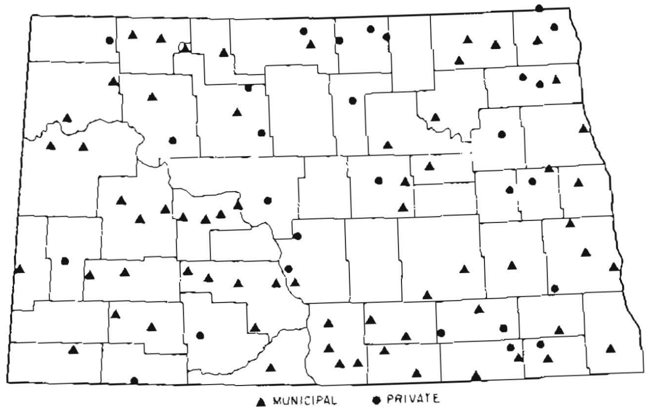

Figure 1. Municipal and private landfills operating in North Dakota during 1987. Source: Health Department.

landfills in North Dakota is expected to stabilize at 15 to 18 active landfill sites by the time the new EPA regulations go into effect (Solie, 1992). This decline is attributable to the long-term efforts by the North Dakota State Department of Health and Consolidated Laboratories (Health Department) to close substandard landfills; it also reflects the concern of municipalities and private operators for the upcoming EPA rule changes, and the resulting increased costs of operating a landfill and the increased liabilities for environmental damage.

Prior to 1976, solid waste in North Dakota was generally disposed of in open dumps. Solid waste management regulations and permitting procedure guidelines for disposal of wastes in North Dakota were established by the State Legislature in 1976. The Health Department was given principal responsibility to regulate solid waste in North Dakota. The State Geological Survey and State Water Commission were mandated to provide technical support to the Health Department in assessing permit applications to construct and operate waste-disposal facilities in the State. (Tillotson and Murphy, 1988).

Beginning in 1976, the Health Department began issuing landfill permits to all applicants with only minimal consideration of the geological or hydrogeological suitability of the sites. This was done to identify all existing facilities and to educate the operators in proper landfill construction and operation techniques.

Between the years of 1976 and 1979, the Health Department closed 106 open dumps (Schock, 1989).

In 1977, North Dakota Geological Survey geologist Alan Kehew evaluated the geologic suitability of the 76 active landfills operating within the state (Kehew, 1977). In 1983, Jon Betcher (a University of North Dakota geology graduate student) reviewed the 46 landfills which had become active since Kehew's review (Betcher, 1983). Both of these were cooperative projects between the State Geological Survey and the Health Department. As a result of these evaluations, landfills located in poorly suited areas were identified and targeted for closure by the Health Department.

In addition to Kehew's (1977) and Betcher's (1983) site reviews, the Health Department, North Dakota Geological Survey, and the U.S. Environmental Protection Agency have monitored individual landfills throughout the state (approximately 18 landfills have been monitored during the last 18 years). Given these studies, there was still a recognized need for a comprehensive detailed study of landfills in various geological provinces of the state to determine if groundwater pollution is occurring.

Little is known of the movement of organic and inorganic contaminants in the shallow groundwater adjacent to municipal landfills in North Dakota. Prior to this study, it was difficult for the state to determine what may be an acceptable geologic and hydrologic setting for waste disposal due to our limited understanding of the environmental impacts of buried municipal waste within North Dakota.

Purpose

During the summer of 1987, the North Dakota Geological Survey and the Health Department began a detailed study of six sanitary landfills within the state. Five of the six (Williston, Linton, Wishek, Harvey and Hillsboro) were chosen because they had previously been identified as being located within geologic settings that were poorly suited for waste disposal (figure 2). The sixth site (Devils Lake) had previously been identified as having excellent geologic conditions for solid waste disposal (Kehew, 1977 and Betcher, 1983).

The purpose of this study was to evaluate the movement of contaminants within shallow groundwater at these sanitary landfills and, from this, to make a better determination as to the suitability of the various geologic settings for solid waste disposal. The research objectives of this project were to: 1) search for selected major ions, trace metals, pesticides, total organic carbon (TOC), and volatile organic compounds (VOC) that may be present in the shallow groundwater at these landfill sites; 2) to trace the movement of these contaminants in the upper saturated zone; 3) to assess the health risk posed by consumption of shallow groundwater (under study); and 4) to recommend, as appropriate, corrective measures to be taken. The results may be used to predict the extent of groundwater degradation at municipal landfills situated in similar geologic settings within the state.

Field and Laboratory Methods

Resistivity surveys were conducted at all six study sites using a Soil Test R-50 Stratameter and R-65 voltmeter. The Wenner Electrode Configuration, in conjunction with the Vertical Electrical Sounding (VES) Method, was used at each of the landfills. These resistivity surveys were run prior to monitoring well installation to provide information on monitoring well placement.

The North Dakota Geological Survey's Mobil B-50 auger truck was used to install the

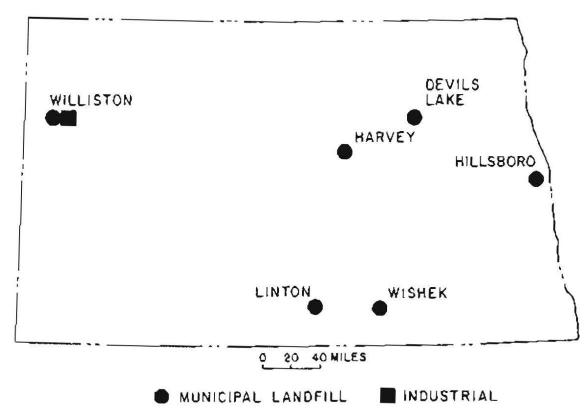

Figure 2. The six landfill study sites.

wells. The Mobile B-50 uses 8-inch hollow stem auger flights and is capable of retrieving shelby tube core. The monitoring wells consist of 2-inch (inner diameter) schedule 40 PVC casing and 2 to 5 foot sections of factory slotted .010-inch PVC screen. Each monitoring well was installed using a dry auger system. In addition, no solvents or cements were used during well installation in order to avoid organic contamination of the wells. The screened intervals were filled with pea gravel and the remainder of the borehole was filled with bentonite chips, cuttings, and grout.

The Geological Survey installed 65 monitoring wells during the summer of 1987 and an additional 18 wells during 1988. The maximum depth of well placement was 78 feet and the average depth was 25 feet. A total of 3,129 feet was drilled during the course of this project.

The sites were surveyed with plane table and alidade. An elevation for the first station was approximated from 7.5 minute USGS quadrangle maps. The elevations recorded are therefore approximations.

The Health Department performed the major ion, trace metal, and organic analysis on the water samples. The laboratory used the following methods to analyze for the various constituents:

1. Trace Metals: Zinc, copper, barium, and manganese were analyzed by emission spectroscopy using a Perkin-Elmer Plasma II inductively coupled plasma emission spectrometer. This system uses two-point background correction and vacuum monochrometers. Chromium, arsenic, and selenium were analyzed on a Perkin-Elmer 5100 atomic absorption spectrometer using stabilized temperature platform furnace technology and Zeeman background correction to control interferences from high chloride content. Lead and cadmium were analyzed on a Perkin-Elmer Model 5000/500 atomic absorption spectrophotometer using stabilized temperature platform furnace technology. All analyses were performed using EPA methodology. Spikes and duplicates were performed on a minimum of 10 percent of all samples. Known EPA reference samples were run with all metal analyses.

2. Organic Compounds: Method for acid extractable compounds: a measured volume of samples was extracted with methylene chloride at a pH less than 2 using a separatory funnel. The methylene chloride was concentrated to a volume of 1 ml and analyzed by GC/MS. The extract was then exchanged to hexane and dervitized with BF_3. The extract was then analyzed by gas chromatography using an electron capture detector.

3. Purgeable Organic Carbon: Method for purgeables: helium gas was bubbled through a water sample contained in a specially designed purging chamber at ambient temperature. The purgeables were transferred from the aqueous phase to the vapor phase. The vapor was swept through a sorbent trap where the purgeables were trapped. After purging was completed, the trap was heated and backflushed with helium to desorb the purgeables onto a gas chromatographic column. The gas chromatographic separated the purgeables which were then detected with a mass spectrometer.

4. Pesticides: Method for organochlorine pesticides: a measured volume of the sample was extracted with methylene chloride using a separatory funnel. The methylene chloride extract was dried and exchanged to hexane during concentration to a volume of 10 ml or less. The extract was separated by gas chromatography and the parameters then measured with an electron capture detector and confirmed with a mass spectrometer.

The following groundwater sampling procedure was used: 1) two to three well volumes of water were removed from each well; 2) water samples were collected with a teflon bailer; 3) the samples for organic analysis (TOC) were placed in glass vials with teflon lids; 4) the samples for VOC analysis were placed in brown glass vials with teflon lids; 5) the samples for pesticide analysis were placed in brown glass gallon jugs; 6) the samples for major ion and trace metal analysis were passed through a 0.45 micron filter and the trace metal sample was acidified; 5) all of the water samples were placed on ice and transported to the lab within the recommended time frames.

Three rounds of water samples were taken at each of the landfills (four at Hillsboro) (Table 1). Initially, the volatile organic compound (VOC) analyses and pesticide scan were to have been performed on these samples in June of 1988. However, due to the drought of 1988, the analyses were postponed and rescheduled for the spring of 1989. Equipment problems within the Health Department necessitated further postponement of the organic analyses until June, 1990.

Climate

The study sites are spread across the state of North Dakota (figure 2). The climate for the state of North Dakota is continental, subhumid (Ruffner, 1985). The average annual precipitation varies from 15 inches in the west to 21 inches in the east (Goodman and Eidem, 1976). The average annual snowfall is 30 inches. The average length of the growing season is 110-130 days (Goodman and Eidem, 1976).

PREVIOUS STUDIES

Scientists began to study the impact of municipal landfills on shallow groundwater in the United States at least as far back as the 1930s (Calvert, 1932). Over the years, there have been numerous studies documenting the major ion and trace metal concentrations of various landfill leachates (California Pollution Control Board, 1954, Cartwright et al., 1956, and Anderson and Dornbush, 1966). The use of organic compounds has greatly increased since the Second World War. In the last 10-15 years scientists have also begun looking for and occasionally finding high levels of organic contaminants in groundwater near sanitary landfills (Zenone et al., 1975, Kunkle and Shake, 1976, and Baedecker and Apgar, 1984).

There have only been a few reported studies that have investigated groundwater quality beneath municipal landfills in North Dakota (Butler, 1973, Arndt, 1977, and Kehew and Knudsen, 1979). These studies found that leachate was being produced and entering the groundwater at each of the landfills. The authors did not test for organic compounds in the landfill leachate.

Table 1. Sampling schedule of the six selected landfill study sites

CITY	9-10/87	12/87	8/88	6/89	6/90
Williston	T&M			A	O
Linton	T&M			A	O
Wishek	T&M			A	O
Harvey	T&M			A	O
Devils Lake			T&M	A	O
Hillsboro		T&M	T&M	A	O

T&M = trace metals and major ions
A = trace metal, major ion, and TOC
O = TOC, VOC and pesticide scan

WILLISTON LANDFILL

Introduction

The Williston landfill is situated on the edge of a hillside overlooking Sand Creek, approximately 1 mile west of the city of Williston (Township 154 North, Range 101 West, ne/nw section 16) (figure 3). The landfill is located in a large south-trending ravine approximately 1,000 feet north of Sand Creek. The landfill covers an area of 18 acres and has received an estimated 562,000 cubic yards (190,000 tons) of solid waste, including some oilfield wastes (Tillotson, 1990) (figure 4). The Williston landfill was in operation from 1969 to 1987.

Geology

The Williston landfill is situated within glacial sediments that have a maximum thickness of 70 feet. These sediments are thickest along the north edge of the landfill and thin to the south (figures 5 and 6). The glacial sediments are comprised of 10 to 40 feet of till, underlain by glaciofluvial sand and gravel deposits. The glaciofluvial deposits consist primarily of sand and gravel throughout most of the landfill area, but fine to silt along the western edge of the landfill. A large sand and gravel pit is located just north of the landfill boundary. Large scale trough-cross stratification is visible in the walls of the gravel pit. Fractures are visible (due to mineral staining) within the till, which also outcrops along the walls of the gravel pit.

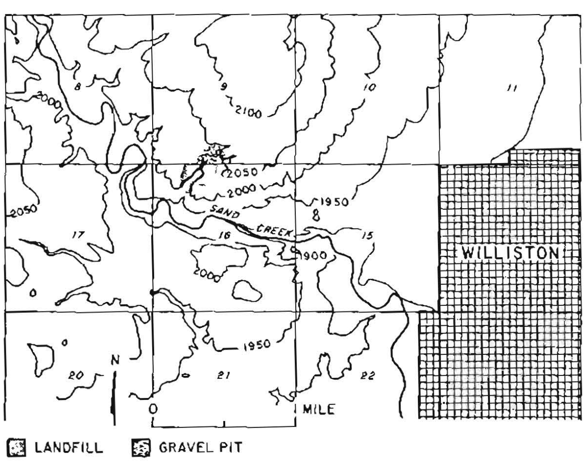

Figure 3. The location map for the Williston landfill.

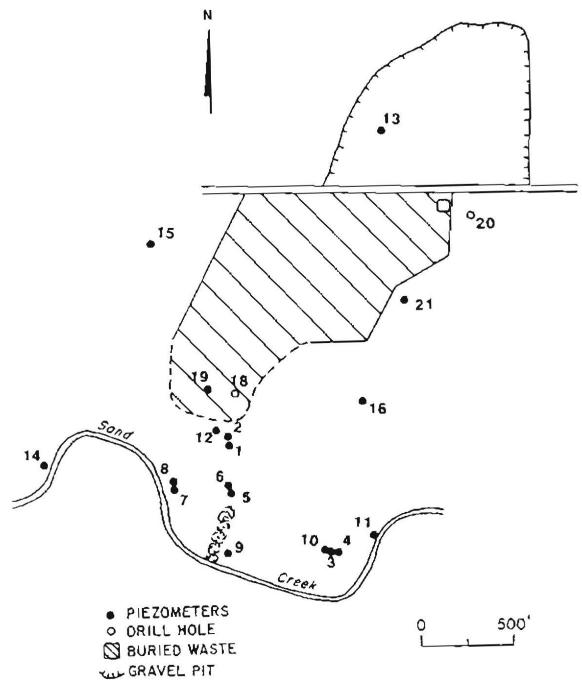

Figure 4. Location of monitoring wells at the Williston landfill.

The glacial sediments overlie the Sentinel Butte Formation of Paleocene age. The Sentinel Butte Formation consists of alternating beds of sandstone, siltstone, claystone, and lignite (Freers, 1970) (figures 5 and 6). The dominant lithology within the Sentinel Butte Formation at this site is claystone. Siltstone was the dominant lithology encountered along the southeast edge of the study area in monitoring wells 3 and 4. At least two thin lignite beds (less than three feet thick) were identified within 50 feet of the base of the landfill. A thick layer of weathered coal is present at the base of the outwash deposits beneath the gravel pit.

South of the landfill boundary, on the floodplain of Sand Creek, the Sentinel Butte Formation is overlain by 10 to 20 feet of alluvium (sand and gravel) (figure 5). Interbedded within these alluvial deposits are lenses of colluvial sediments which were eroded out of the large

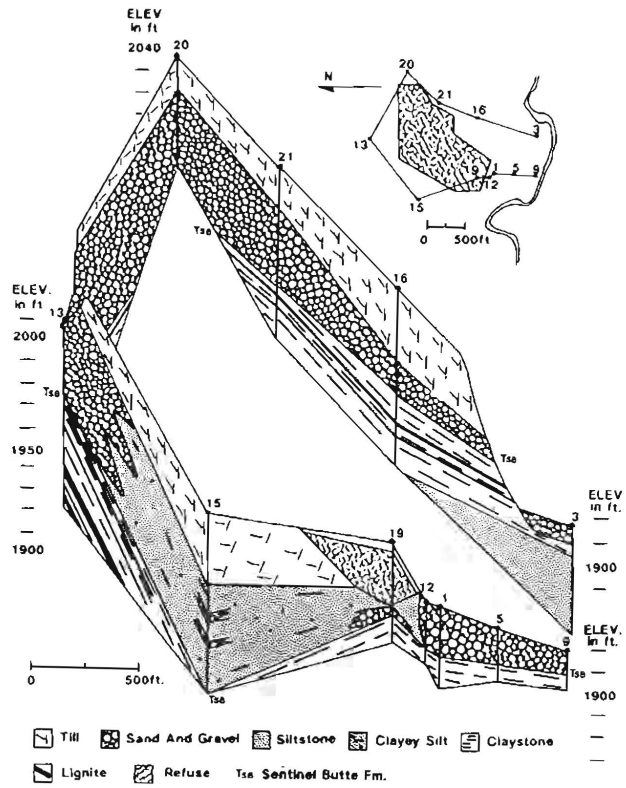

Figure 5. Geologic fence diagram of the Williston landfill.

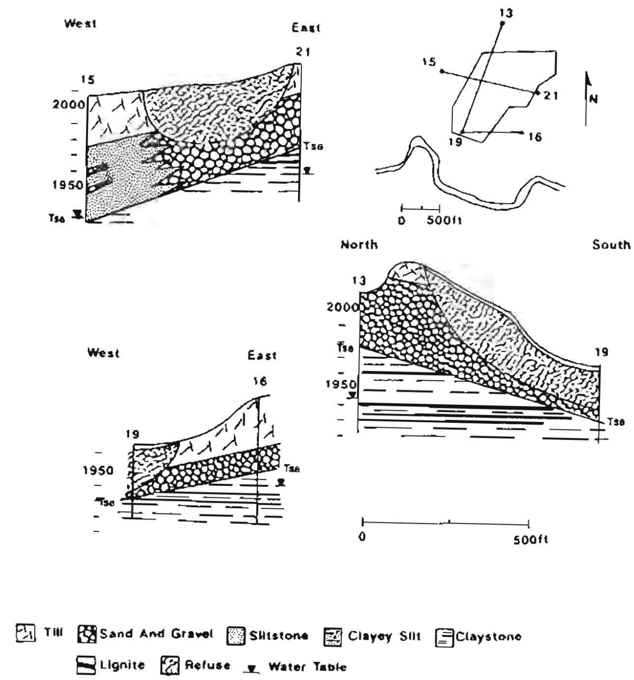

Figure 6. Geologic cross-sections of the Williston landfill.

ravine situated where the landfill stands today.

Monitoring Wells

Several wells (13, 15, 16, and 21) were screened at depths of 70-80 feet beneath the surface (Appendix B). Monitoring wells installed south of the landfill, within the Sand Creek floodplain, were generally nested in pairs. The deeper well was generally screened 10 to 15 feet below the alluvium/bedrock contact and the shallower well was screened through the alluvium/bedrock contact. The shallower well was designed with 3-10 feet of solid pipe below the screen in an effort to catch any perched water migrating along this contact (Appendix B).

Hydrogeology

Two major near-surface aquifers, the Muddy and the Trenton, occupy the area around Williston. The Williston landfill is approximately 4 miles west of the Muddy Aquifer and 7 miles north of the Trenton Aquifer (Armstrong, 1969). The Sand Creek Aquifer is located along the southern boundary of the landfill. This aquifer locally may be of some importance, but the saturated thickness is generally too thin to be of use at the landfill site.

The depth to the water table varies from 80 feet below the surface along the north end of the landfill to 30 feet along the southern end. The water table occurs within the Sentinel Butte Formation in the highland area surrounding the landfill and is at, or very close to, the alluvium/bedrock contact within the Sand Creek floodplain (figure 6). The groundwater flow direction is to the west-southwest beneath the landfill and to the southeast along the Sand Creek floodplain (figure 7). The gradient on the water table is approximately 5 x 10^{-2} in the study area.

Perched water, of varying quantity, was encountered at the bedrock/glacial and bedrock/alluvium contact (contact of sand and gravel over claystone) in many of the drill holes. This contact generally slopes to the south-southwest (figures 5 and 6). As previously mentioned, a number of wells were screened through this interval to intercept any water migrating along this horizon. It was determined during the drilling program that this would be the primary route for leachate migrating from the landfill.

In general, the water levels in the monitoring wells at this site declined during the three-year monitoring period. The magnitude of this decline was generally between 2 and 3 feet (figure 8). Water levels in the monitoring wells screened in bedrock in the highlands (13, 15, 16, and 21) remained fairly constant over this same period. The water levels in these wells generally declined through the end of 1988 and began recovering in the beginning of 1990 (figure 8).

Groundwater Quality

A comparison of isoconcentration maps for selected parameters within the groundwater adjacent to the Williston landfill indicates that a plume of degraded groundwater extends downgradient from the buried refuse for approximately 500 feet (figures 9 to 11). This plume is well defined in the TDS map and is evident in a comparison of the major ion concentrations, especially the chloride ion (figure 9).

Trace metal concentrations within the degraded plume of groundwater are generally at or near the same levels as background concentrations and do not exhibit the same distinct pattern as seen with the major ions (figures 9 and 10). Two exceptions to this appear to be barium and zinc. A groundwater plume, enriched in these two metals, eminates from the southern end of the landfill (figures 10 and 11).

Well number 13 (figure 4) was drilled north of the landfill as a means of obtaining information on background groundwater quality. A comparison of groundwater quality in well 13 to that in wells 1 and 2 (75 feet downgradient of the landfill) shows an increase in concentrations of several ions, e.g. (TDS, Cl, Ca, and Fe) up to 10 times that of the background levels (figures 9 and 10).

Two of the wells tested contained detectable amounts of VOC's (wells 1 and 19). The sample in well 19 contains perched water migrating along the base of the sand and gravel, near the base of the refuse. Well 1 is located 75 feet south of the boundary of buried refuse and

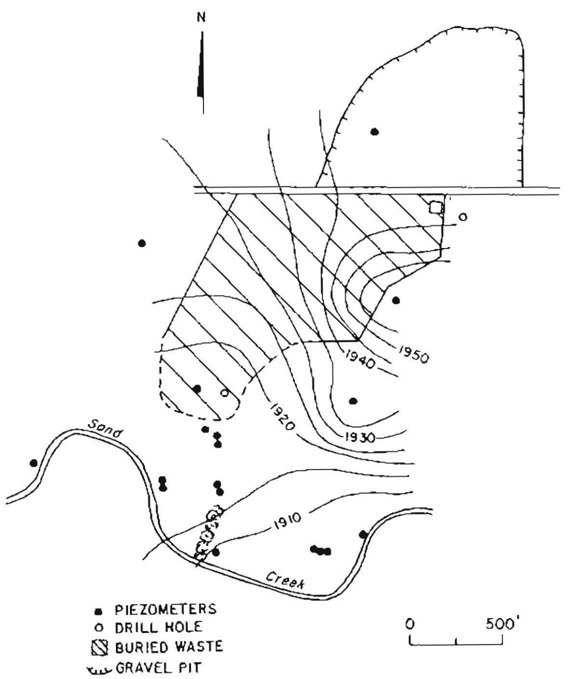

Figure 7. Contour map of the water table at the Williston landfill. Data collected on May 15, 1989.

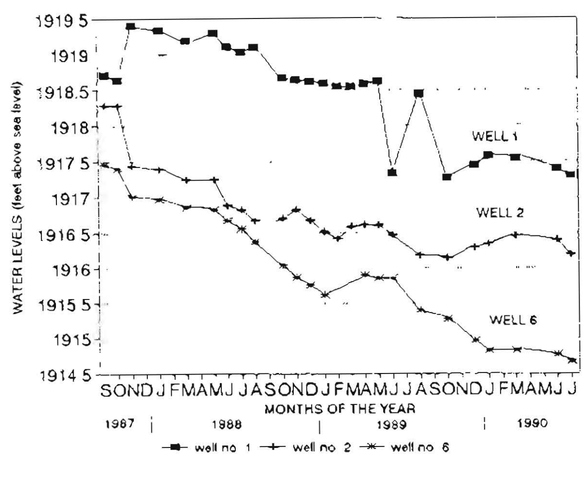

Figure 8. Water level profiles for wells 1, 2, and 6 at the Williston Landfill.

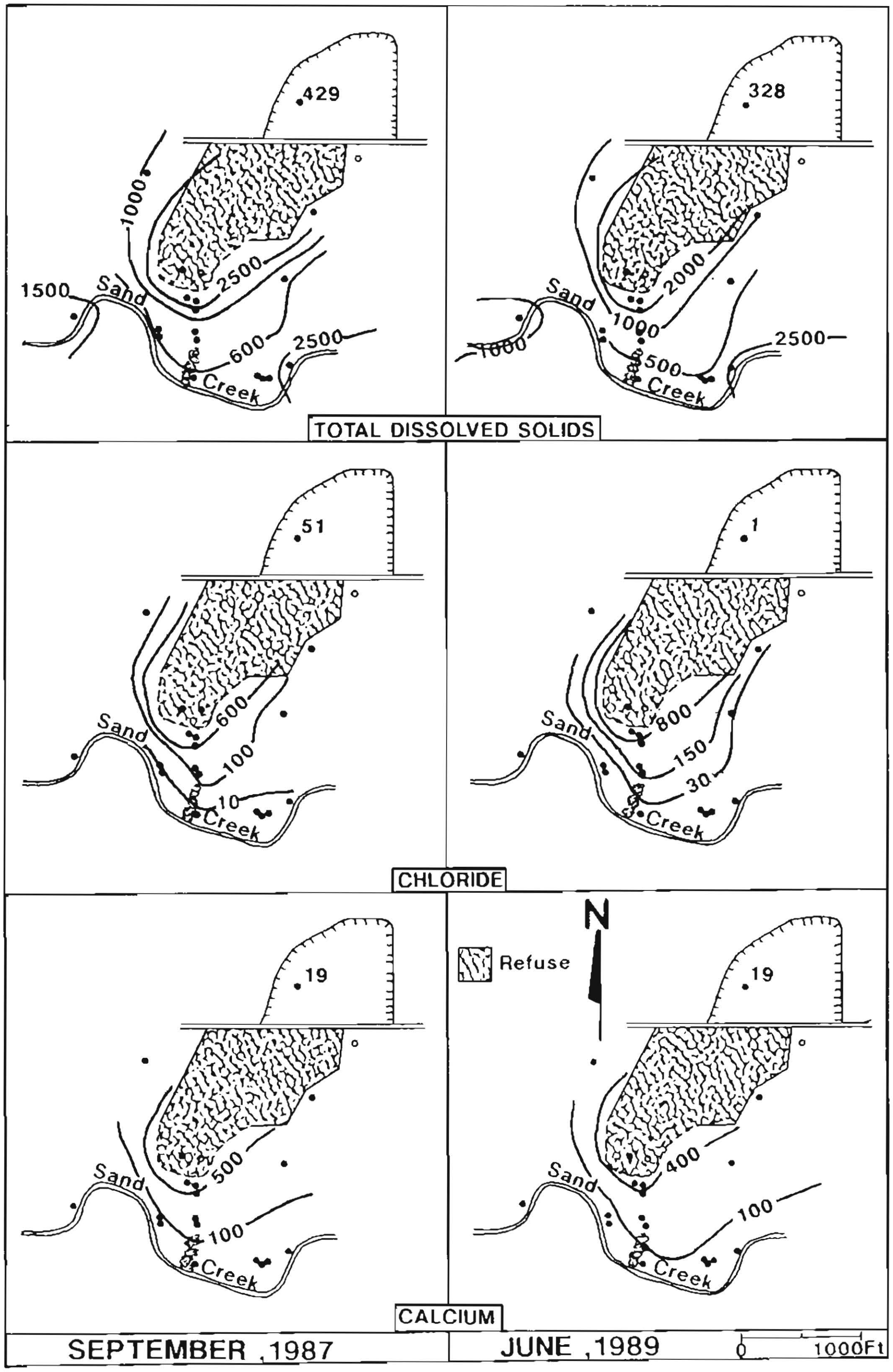

Figure 9. Isoconcentration maps for TDS, chloride, and calcium at the Williston landfill.

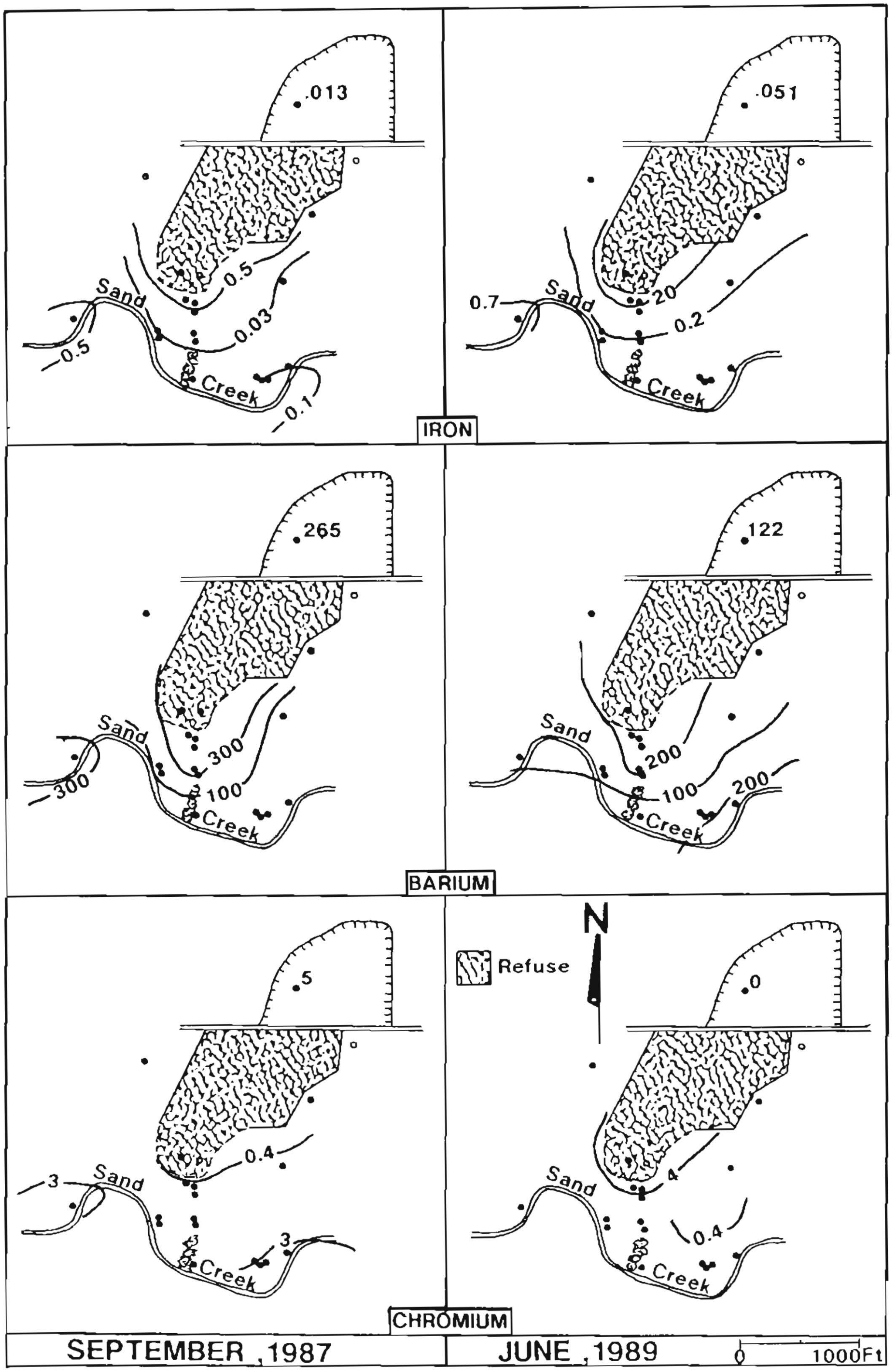

Figure 10. Isoconcentration maps for iron, barium, and chromium at the Williston landfill.

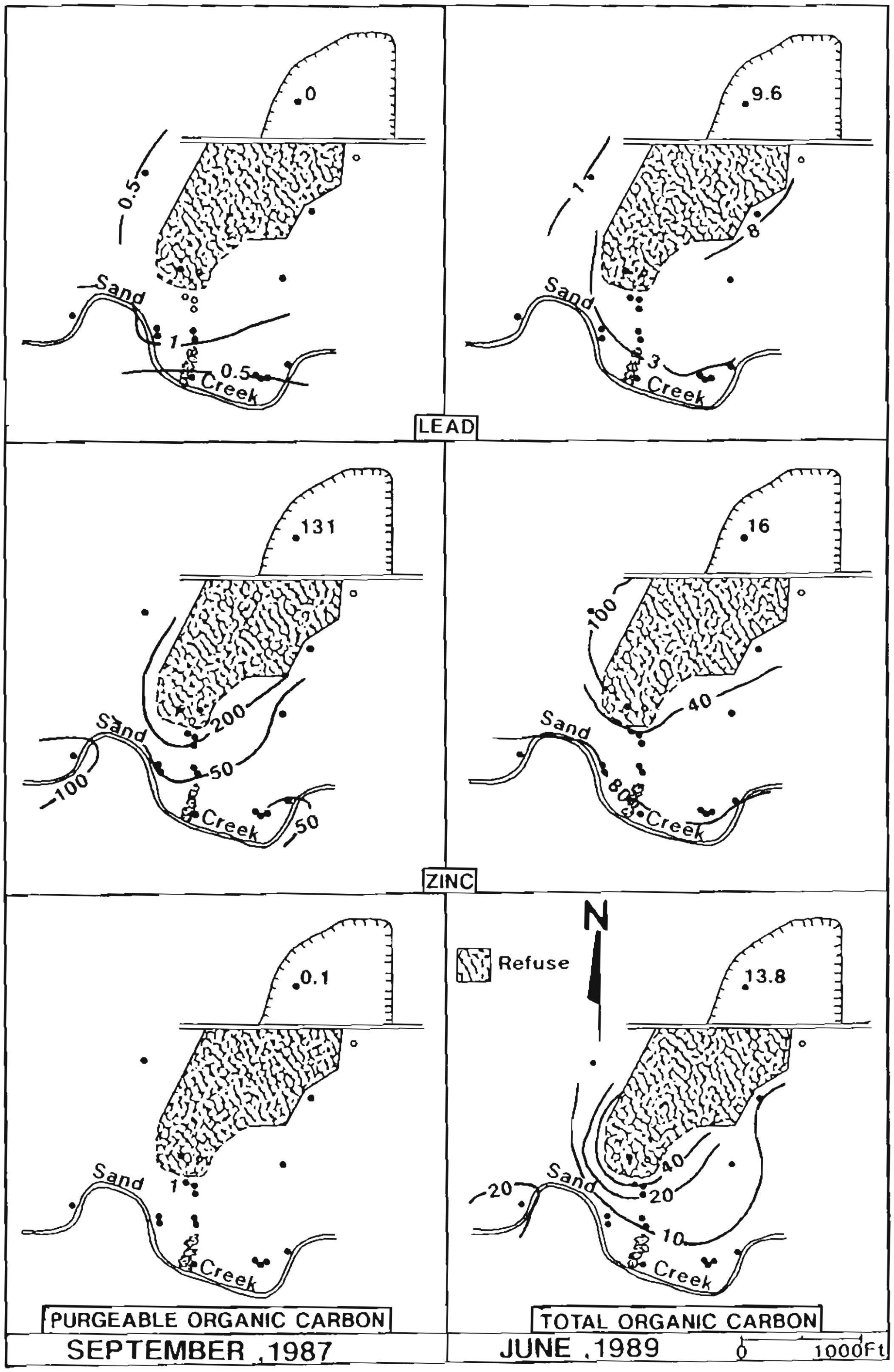

Figure 11. Isoconcentration maps for lead, zinc, and organic carbon at the Williston landfill.

Table 2. Hydraulic Conductivity of Sediments Adjacent to Monitoring well Screens at Williston landfill.

Well No.	Hydraulic Conductivity	Lithology
2	7.3×10^{-5} cm/s	silty claystone
3	4.8×10^{-3} cm/s	siltstone
4	2.5×10^{-3} cm/s	siltstone
6	2.2×10^{-4} cm/s	sand*
8	1.8×10^{-4} cm/s	siltstone

* denotes Pleistocene deposit.

screened just below the water table in sand and gravel. No pesticides were detected in the four wells that were tested at this site (table 3).

The chemical concentrations in Paleocene bedrock groundwater in North Dakota are generally extremely variable. Although the increased concentrations seen at this site indicate leachate, part of the increase may also be attributable to the natural variation in groundwater quality.

Perched Water and Surface Water Quality

One of the initial concerns at this site was the possibility that contaminated water was entering Sand Creek either via surface runoff from the landfill or from degraded groundwater discharging into the creek. A comparison of the water quality in Sand Creek both upgradient and downgradient from the Williston landfill demonstrates no discernible impact upon the creek (table 4). However, in order to judge the impact of runoff from the landfill on the water quality of the creek, one would have to sample during the runoff event. This was not done during this project.

As previously mentioned, a large gravel pit (approximately 14 acres) is present just north of the landfill site. Water has been observed ponding two to three feet deep in a portion of this pit following snow melt or a heavy rain. The ponding of this water increases the amount of water that will infiltrate into the subsurface. This water will either travel down to the water table (65 feet below base of pit) or it may travel as perched water through the buried waste. Further, the refuse at this site was buried, in part, in a large south-trending ravine. This ravine slopes to the south, and it is reasonable to assume that any perched water migrating laterally into this site, or any water percolating down through the refuse, will likely flow south along the waste/ravine contact.

Table 3. Monitoring wells tested for VOC's and pesticides at the Williston landfill.

Well No.	VOC's	Pesticides
1	X	
2	X	X
4	X	X
5	X	X
9	X	X
10	X	
12	X	
15	X	
19	X	

Table 4. Water Quality at the Williston Landfill.

WELL NO.	LOCATION	TDS	Cl	Fe	Ba	Cr	TOC
19	within landfill	1550	500	3.42	896	2.76	19.4
12	50' south of landfill	1365	189	2.53	187	0	43.3
1	75' south of landfill	470	692	11.6	207	2.12	23.1
5	350' south of landfill	1135	283	.242	40	41.2	9.4
9	700' south of landfill	1495	5.0	.072	84	0	8.7
10	850' se of landfill	1490	70.1	.01	71	0	9.8
Sand Creek	upgradient	2810	16.5	.392	45	.95	34.2
Sand Creek	downgradient	2770	16.1	.057	47	4.25	28.2

Note: Values are the mean of two analyses. Ba and Cr in ug/l; all others in mg/l.

The perched water sampled during this study was found to be highly degraded within the landfill. Perched water was also found to be degraded at least 350 feet south of the landfill and possibly up to 850 feet southeast of the landfill boundary (table 4). The chloride ion as well as iron and barium appear to be the best inorganic indicators of landfill pollution. The chloride ion was found at a level of 791 mg/l in groundwater immediately south of the landfill boundary. This is 20 to 50 times higher than the normal concentrations of chloride found in groundwater in this area.

The total organic carbon (TOC) concentrations were found to be high (43.3 mg/l) in perched water 50 feet south of the landfill (Table 3). This sample also contained 1 mg/l of purgeable organic carbon. Perched water collected 350 feet south of the landfill was found to contain normal concentrations of organic carbon, although it contained close to 15 times the normal background levels of the chloride ion (table 4).

Conclusions

1. The landfill is situated within a south treading ravine which leads to Sand Creek.

2. Waste at this site was buried within glacial sands and gravels or till. The glacial deposits are 40 to 70 feet thick and overlie alternating sandstones, siltstones, claystones, and lignites of the Sentinel Butte Formation.

3. The Williston landfill is degrading groundwater at least 350 feet downgradient from the site boundary (figure 12). This leachate plume is characterized by high concentrations of some major ions (Ca, Cl, Fe), slight to moderate increases of one or two trace metals (Ba and Zn), and high concentrations of organic carbon.

4. Perched water migrating out of the Williston landfill is degraded to a higher degree than is the groundwater. The zone of contaminated or degraded perched water appears to extend for at least 350 feet south and 850 feet southeast of the landfill boundary.

5. No appreciable impact was observed on the water quality of Sand Creek down-gradient of the landfill.

Recommendations

The Williston landfill was closed during the summer of 1987. The site was capped the following fall and spring. The recontouring and capping of the site should help reduce the amount of water infiltrating through the buried waste. The city has had difficulty in establishing vegetation on the cap due to the extended drought in this area. Further, since the landfill is situated in an old ravine, the topography in this area tends to route surface runoff into the landfill area. As a result, the cap has experienced erosion problems, especially along the southern boundary of the landfill. Deep, narrow gullies have been carved

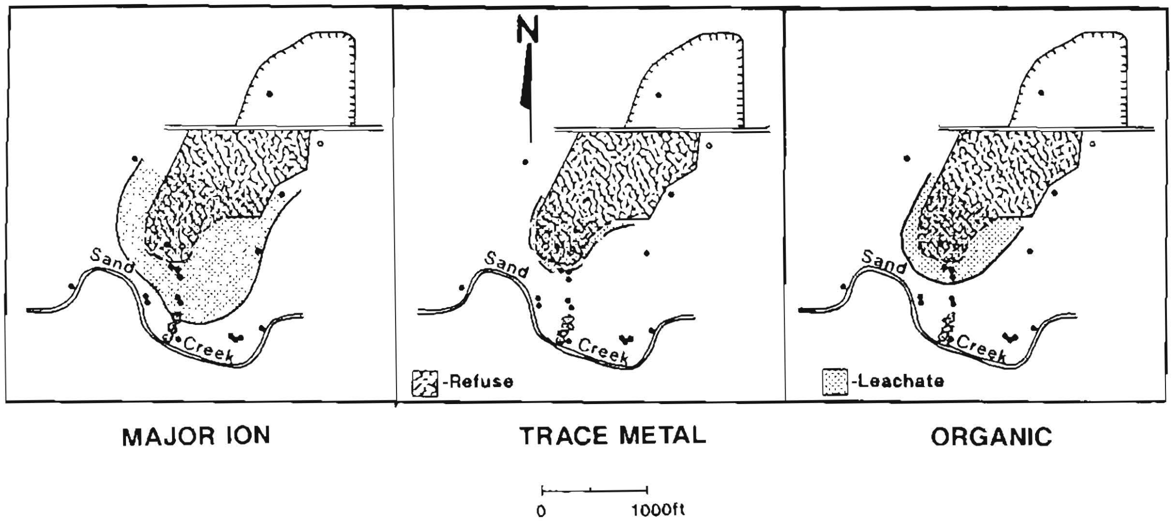

Figure 12. Extent of leachate migration at the Williston landfill.

into the cover, in some places exposing refuse. The city has been periodically repairing the cap and is hopeful that the erosion rates will subside once the vegetation has been established.

Any refuse exposed along the south boundary of the landfill may produce leachate when in contact with runoff. This runoff recharges Sand Creek. To prevent this from occurring, the city of Williston will have to maintain the integrity of the cover at this site for the foreseeable future.

The adjacent gravel pit also poses a serious problem because it drains a large area and allows water to pond and eventually infiltrate into the subsurface. It is likely that a portion of this infiltrating water migrates south along the dip of the outwash/bedrock contact and may come in contact with buried refuse, thereby increasing the volume of leachate eminating from the landfill (figure 4). The construction of a surface drainage divide, a drainage ditch, a culvert, or any other means of eliminating the ponding of water upgradient of the landfill would reduce the adverse impact of the Williston landfill on the surrounding area.

LINTON LANDFILL

Introduction

The Linton landfill is located one mile west of the city of Linton (Township 132 North, Range 77 West, sw/se/se Section 12) (figure 13). The landfill is situated on a hill overlooking the valley of Beaver Creek. Refuse was initially buried at the site in a northwest-trending ravine. The landfill began operation prior to 1977 and was closed in 1988 (Tillotson, 1990). The City of Linton's municipal wastewater impoundments are located below the landfill on the Beaver Creek floodplain (figures 14 and 15).

Geology

The landfill is situated within glaciofluvial sand and gravel deposits (figure 16). The glaciofluvial deposits are 10 feet thick along the southeast boundary of the landfill and 25 feet thick along the west edge. The outwash deposits are underlain by lacustrine clay which varies from 5 to 20 feet in thickness across the landfill site (figure 16). These deposits are underlain by sandstones, siltstones, and mudstones of the Fox Hills Formation (Cretaceous). Shale, encountered at an elevation of approximately 1690 feet, may indicate the Pierre Formation.

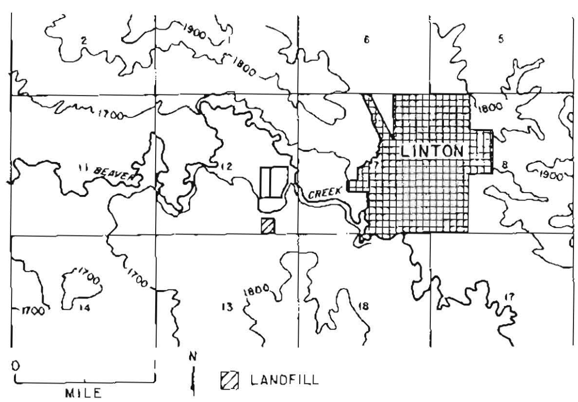

Figure 13. Topographic map of the Linton landfill area.

The Beaver Creek floodplain, within the vicinity of the landfill, is underlain by 30 to 40 feet of fine grained (silty clay) to coarse (sand and gravel) alluvial deposits (figure 16). These deposits may be underlain by shales of the Pierre Formation. A small clastic wedge is present at well sites 3 and 4. This wedge is an alluvial fan that formed at the base of the ravine prior to its filling with refuse.

Hydrogeology

A ten- to twelve- foot-thick zone of perched water exists approximately 20 feet below the surface of the Linton landfill (figure 16). The top of the perched water table is located approximately 7 feet below the base of buried waste throughout most of the landfill, although it may intercept waste along the west end. The water is perched at the base of the outwash by the lacustrine clay bed (figure 16). Water levels in the wells screened in the perched water zone gradually declined during the study period (figure 17). Water levels in the perched water table, and the slope of the clay bed, indicate that the perched water is flowing north toward Beaver Creek valley (figure 17). This perched water may feed an intermittent spring, or series of springs, along the edge of the site.

The primary source of the perched water may be south of the landfill site, but a portion of the perched water has likely infiltrated down through the overlying refuse. During the operation of this site, the open pits collected snow and rain, some of which would have infiltrated down to the clay layer and added to the quantity of the perched water.

The groundwater table is at a depth of approximately 70 feet below the surface of the landfill. There is a water table gradient of 3.36×10^{-3} ft/ft between wells 11 and 2. Water levels in wells 2 and 11 generally rose in winter and spring and declined in the summer and fall (figure 18). A third monitoring well is needed in

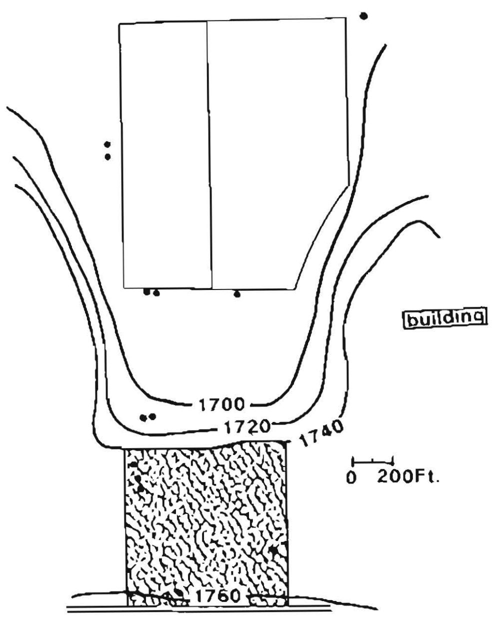

Figure 14. Topographic map of the Linton landfill.

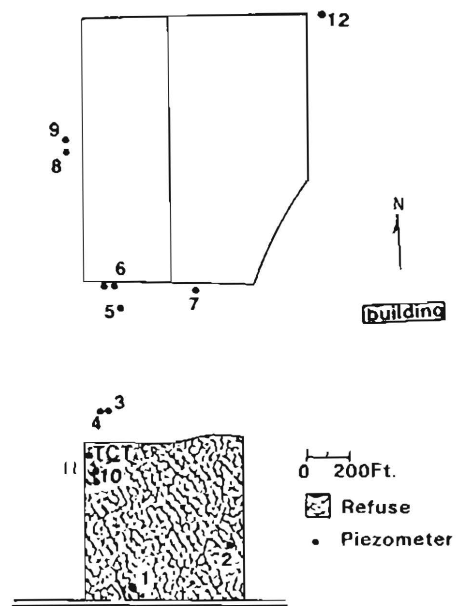

Figure 15. Monitoring wells at the Linton landfill.

the southwest corner of the landfill to accurately determine the overall gradient of the water table beneath the refuse.

The water table is relatively flat and shallow on the floodplain below the landfill, likely as a result of mounding of groundwater beneath the City of Linton wastewater impoundments. Additional wells are also needed along the north side of the municipal impoundments to accurately determine the groundwater flow direction in this area. Wells should be placed farther from the ponds to reduce the effects of groundwater mounding on the water table beneath the site. The general groundwater flow direction beneath the floodplain appears to be to the west-southwest. Groundwater within the Fox Hills Formation is flowing to the northwest at a gradient of 7.4×10^{-4}.

The east cell contained wastewater during the entire 2-year monitoring period. The west cell contained water only during April and May, 1989. During the time that the west cell contained water, the water levels in wells 5, 6, 8, and 9, all rose approximately 5 to 6 feet and were within 2 feet of the surface (figure 19).

In-situ hydraulic conductivities were determined for the sediments adjacent to the screen intervals for several of the monitoring wells at this site (table 5). The hydraulic conductivites were determined from falling head tests (Hvorslev, 1951). The hydraulic conductivities determined from these tests fall within the normal ranges associated with those units for all but one well. The hydraulic conductivity for the shale adjacent to the screen in well 3 was found to be three to four orders of magnitude higher than anticipated (table 5). This may be the result of fracturing in the shale, sand within this interval, or a poor cement job above the top of the screen interval.

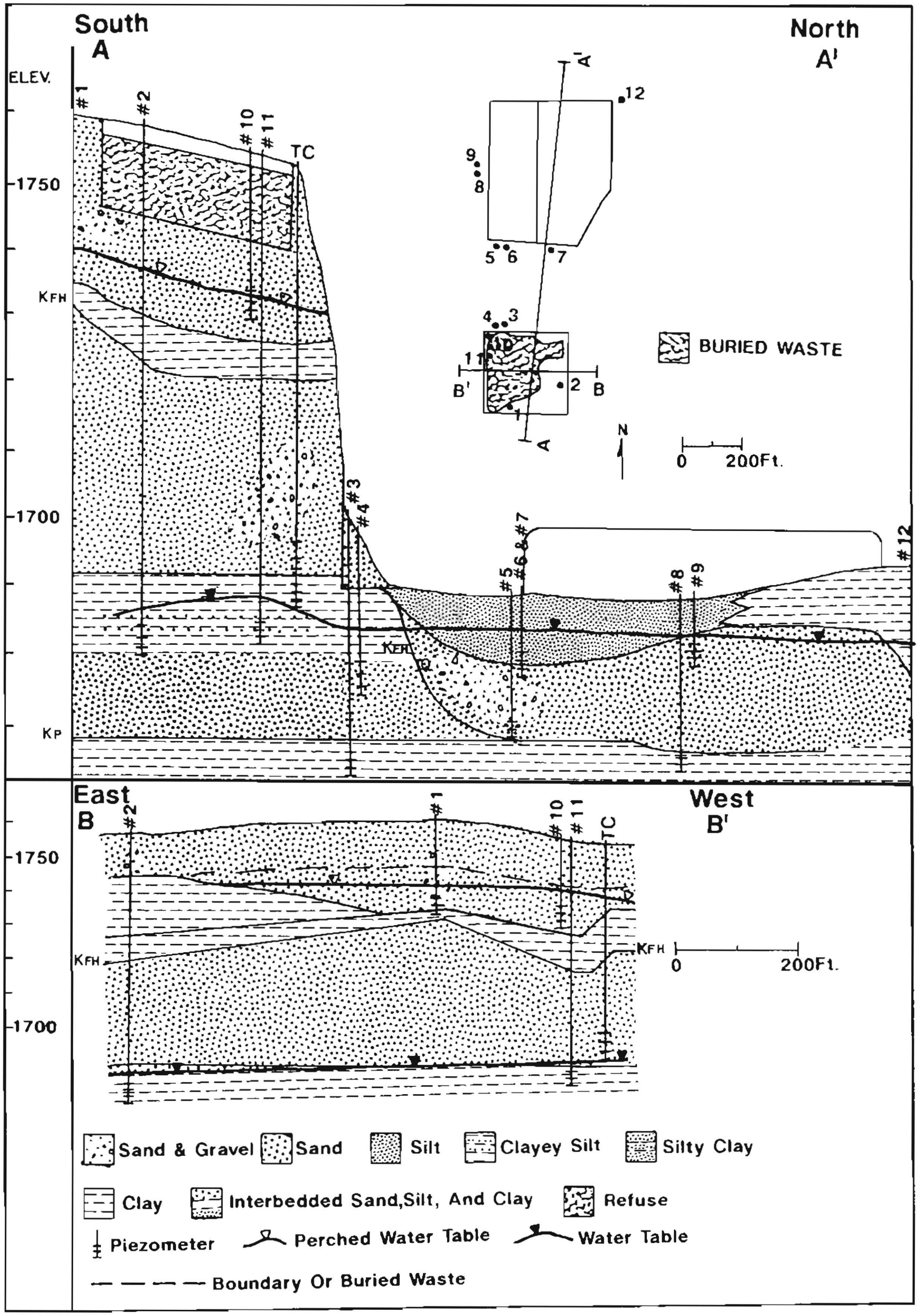

Figure 16. Geologic cross-sections of the Linton landfill.

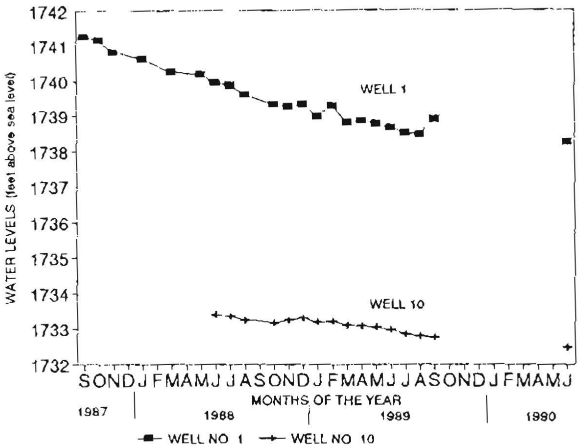

Figure 17. Water levels from perched water at the Linton Landfill.

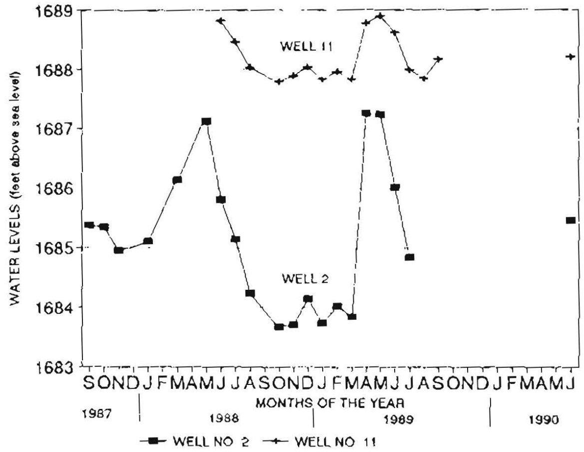

Figure 18. Water levels in well nos. 2 and 11 at the Linton landfill.

Table 5. Hydraulic conductivities of sediments adjacent to the screen of monitoring wells at the Linton Landfill.

Well No.	Lithology	Hydraulic Conductivity
2	silty sand	7.6×10^{-3} cm/s
3	shale	5.6×10^{-4} cm/s
4	sand & gravel	1.7×10^{-3} cm/s
5	sand & gravel	9.7×10^{-2} cm/s
10	fine sand	1.0×10^{-3} cm/s

Monitoring Wells

Monitoring wells were generally placed at three stratigraphic horizons: within the perched water table (wells 1 and 10) within 5 feet of the water table (wells 2, 11, 4, 6, 7, 9, and 12), and 15 to 20 feet below the water table (wells 3, 5, and 8) (figure 16). Several of these monitoring wells were placed around the Linton wastewater impoundment in an effort to determine its influence on the groundwater quality. Time and cost restraints precluded drilling additional deep holes around the landfill at the site.

Groundwater Quality

A sharp decrease in water quality is evident from a comparison of the chemistry from perched water in well 1 to that of well 10 (table 6). The most obvious increases in concentrations occur for the chloride ion and total organic carbon. The high concentrations for some parameters in well 10 confirm the initial speculation that the perched water beneath the landfill is

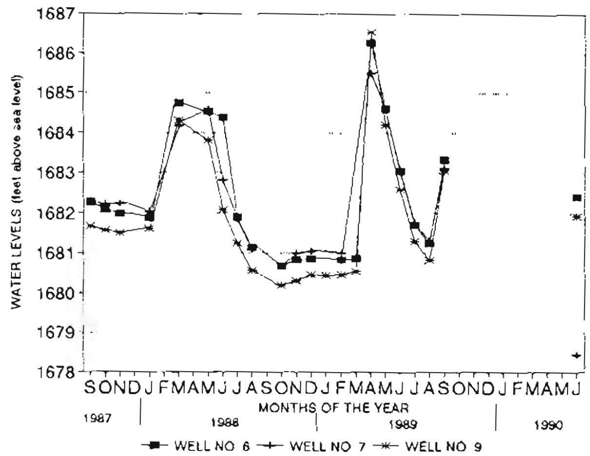

Figure 19. Water levels in three monitoring wells adjacent to the Linton wastewater impoundments.

made up, at least in part, of water that has percolated down through the refuse.

Water quality in the Fox Hills Formation can be compared in the four monitoring wells screened within this unit (wells 2, 3, 4, and 11). The Fox Hills Formation generally contains water of highly variable quality. Armstrong (1978) found the total dissolved solids to range between 183 to 3,660 mg/l. The TDS values from the four monitoring wells is well within this normal range. A general pattern can be discerned by comparing wells 2, 4, 6, and 11. Most chemical concentrations increase in well 11 (beneath the landfill), decrease to near normal concentrations in well 4 (north of the landfill), and increase substantially in the groundwater at well 6 (next to the wastewater impoundments) (table 6).

No pesticides were found in the three wells tested at the Linton landfill (table 7). Only one of the six wells tested for VOC's had concentrations above the detectable limit. Well 5 contained 9.8 ug/l of o-Dichlorobenzene which may have come from a discarded solvent, insecticide, or sweeping compound. This well is adjacent to the west cell of the wastewater impoundments and the source for the VOC in the groundwater at this site most likely came from the wastewater.

Conclusions

1. The Linton landfill is situated within outwash deposits which are underlain by the Fox Hills Formation.

Table 6. Water quality at the Linton landfill

Well No.	Location	TDS	Cl	SO4	Pb	TOC
Perched Water						
1	Upgradient	528	1	32	1.4	15.8
10	Beneath Landfill	1430	237	169	4.2	51.5
Ground Water						
2	Upgradient	1690	15	938	1.8	16.7
11	Beneath Landfill	1170	141	357	2.4	28.2
4	Downgradient	1060	15.9	332	2.8	28.2
6	Downgradient-adjacent to pond	2770	484	526	3.2	31.4

*all values in mg/l except Pb which is in ug/l

Table 7. Piezometers sampled for VOC's and pesticides at the Linton Landfill.

Well No.	Pesticide	VOC
1	X	X
3	X	X
4		X
5		X
10	X	X
11		X

2. Ten feet of perched groundwater is present approximately 10 feet below the base of buried refuse at this landfill. The water table is present 60 to 70 feet below the base of the buried refuse.

3. There were not sufficient monitoring wells present to determine the direction of groundwater flow beneath the landfill. Shallow groundwater within the Beaver Creek floodplain is flowing to the west-southwest.

4. The information gathered to date indicates that infiltration through the buried refuse is degrading water quality in the perched groundwater zone beneath the landfill, and to a lesser extent groundwater within the Fox Hills Aquifer system and Holocene alluvium. The degradation of the perched water would likewise also degrade any springs along the north side of the landfill.

5. Little or no perceivable increases were detected in the trace metals selected for analysis. The best leachate indicators at this site are the chloride ion and the total organic carbon concentrations. The greatest impact on the groundwater in this area appears to be from the municipal impoundments located north of the landfill.

Recommendations

The Linton landfill was closed during the spring of 1989 and the site has been reclaimed. The soil cap placed over the landfill should help to reduce the quantity of landfill leachate and therefore improve the quality of perched water beneath the site. However, the city will need to maintain this cap, especially along the north portion of the site where erosion from runoff will be greatest.

An additional monitoring well, placed in the southwest corner of the site and screened in the Fox Hills Formation would enable a determination of the direction of groundwater flow beneath the landfill. Any springs found along the side of the valley north of the landfill should be monitored for both water quality and quantity.

WISHEK LANDFILL

Introduction

The Wishek landfill is located approximately one and one-half miles northwest of the City of Wishek (Township 132 North, Range 71 West, nw/nw Section 4) (figure 20). The landfill operated from 1979 until its closure in 1989. A 1952 aerial photograph of the site shows that the landfill is situated within an old gravel pit.

Geology

The Wishek landfill is situated upon the west edge of a southeast-trending meltwater channel now occupied by a small intermittent stream (figures 20 to 22). The channel can be traced over an 18-mile area from north of Burnstad to three miles south of Wishek (Clayton, 1963). The landfill site is underlain by approximately 20 feet of glaciofluvial deposits

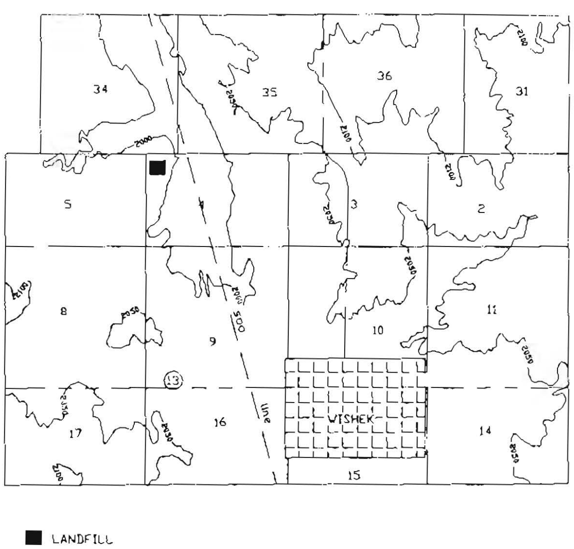

Figure 20. Topographic map of the Wishek landfill area.

(sand and gravel) (figure 23). The outwash deposits are underlain by approximately 10 feet of alternating sandstone, siltstone, and mudstone of the Fox Hills Formation (figure 23). The Fox Hills Formation (upper Cretaceous) was observed in outcrop in a small pit located along the edge of the channel west of wells 6 and 7 (figure 21). The Fox Hills Formation is underlain by dark gray shale of the Pierre Formation. The base of the meltwater channel was cut into the Pierre Formation in this area. Approximately 12 feet of glaciofluvial deposits overly the Pierre Formation in the channel below the Wishek landfill. These deposits consist of approximately 8 feet of sand and gravel overlain by 3 to 4 feet of lacustrine clay (figure 23).

Hydrogeology

The water table is at a depth of between 25 to 30 feet below the surface at the landfill site. Approximately 14 feet of outwash and Fox Hills Formation sedimentary rock occur between the base of the buried refuse and the water table. The water table, in general, exists within the basal portion of the Fox Hills Formation beneath the landfill (figure 23). In profile, the water table mimics the surface topography, i.e., it slopes steeply to the east at the edge of the channel. Within the meltwater channel, the water table exists generally at the base of the lacustrine clay, approximately 3 to 4 feet below the surface (figure 23).

The direction of groundwater flow beneath the landfill appears to be to the north-northeast in the channel below the landfill. The gradient on the water table is 5×10^{-2} to the east beneath the landfill as compared to 2×10^{-3} to the north-northeast within the meltwater channel (figure 24). The hydraulic conductivity of the sand and gravel in the meltwater channel is 2.1×10^{-2} cm/s (table 8). Using these values, and a porosity of 0.25, the average linear velocity of groundwater within the sand and gravel is 175 feet/year.

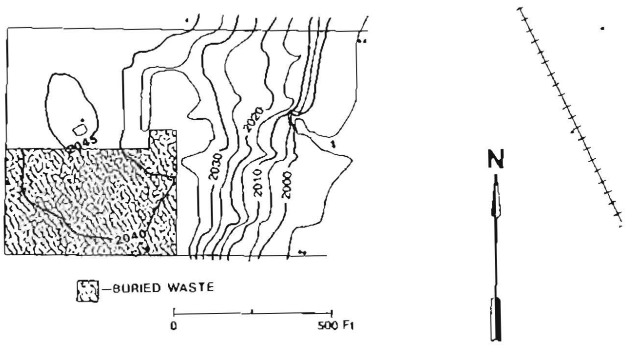

Figure 21. Topographic map of the Wishek landfill.

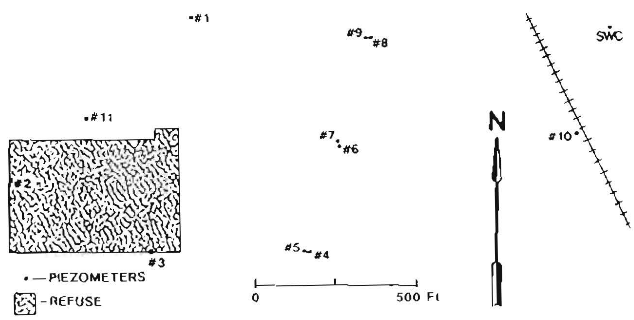

Figure 22. The location of monitoring wells at the Wishek landfill.

Water levels in the monitoring wells at this landfill decreased throughout the first year and one-half of monitoring and then increased during the spring of 1989. Water levels from wells screened in the Pierre Formation declined 4 to 10 feet through the fall of 1987 to the spring of 1989 (figure 25). This decline indicates that little or no groundwater recharge occurred during this 18-month period. The water levels of monitoring wells screened within the outwash in the channel adjacent to the landfill fluctuated 3 to 4 feet during this same period (figure 26). As expected, the shallow wells in the outwash channel showed a much quicker response to seasonal changes than the adjacent Pierre Formation wells (figures 25 and 26).

The Wishek Aquifer system consists of a series of glaciofluvial sand and gravel deposits that range from within 5 feet of the surface down to a depth of 150 feet (Klausing, 1981). Klausing (1983) mapped the Wishek Aquifer over a 21-square-mile area, but did not believe that it included the sand and gravel deposits in the channel below the Wishek landfill. However, Klausing (1983) did map part of an aquifer in the meltwater channel immediately north of the landfill site in Logan County.

The Fox Hills Formation is limited to the northwestern portion of McIntosh County due to erosion (Klausing, 1981). Where present, the Fox Hills Formation may be an important local aquifer. The portion of the Fox Hills Formation that is saturated at this site is generally fine grained i.e., silt and clay (figure 23).

In-situ hydraulic conductivities were determined for sediments adjacent to some of the monitoring well screens (table 8). The hydraulic conductivities that were determined for the various lithologies, (siltstone, claystone, and sand and gravel) generally fell within the normal ranges for these units. The hydraulic conductivity determined for claystone in monitoring well 3 was higher than anticipated and may indicate the presence of fractures or a higher silt content than identified in the field (table 8). An attempt was made to determine the in-situ hydraulic conductivity for shale in monitoring well 11. However, there was not sufficient recovery within the recorded time to plot the slope of the line for the information needed in the Hvorslev equation.

Monitoring Wells

Monitoring wells were generally screened in the Pierre Formation, 5 to 15 feet beneath the water table around the landfill site (figure 23). The monitoring wells placed in the meltwater channel were generally nested in pairs; the deeper one either at the base of the outwash or in the Pierre Formation and the shallower one at the top of the outwash deposit (figure 23).

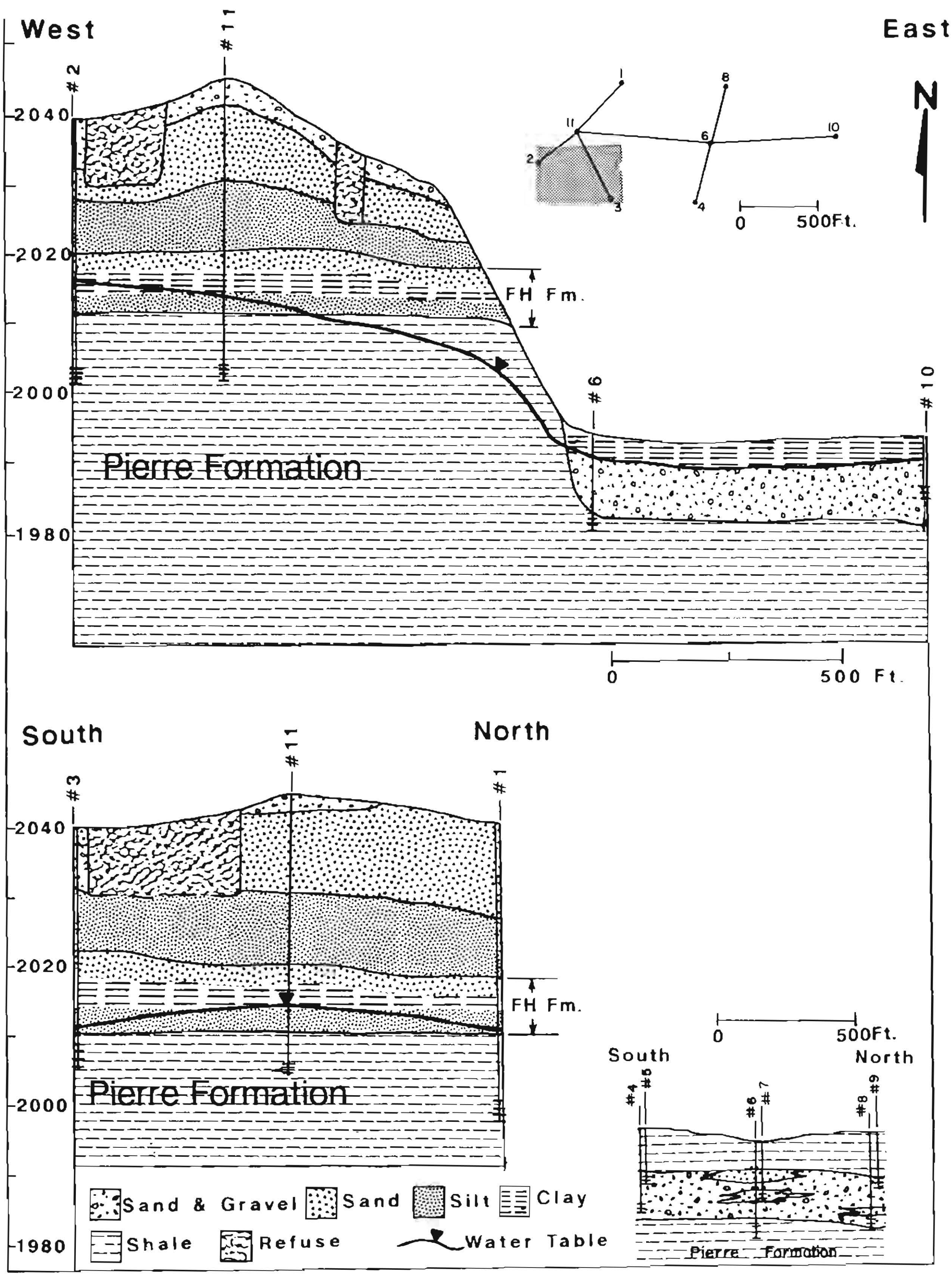

Figure 23. Geologic cross-sections of the Wishek landfill.

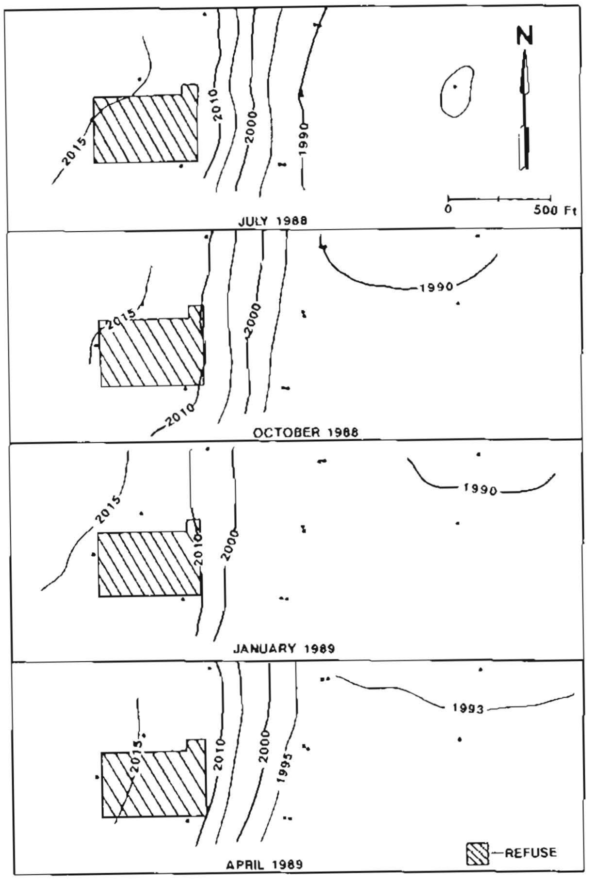

Figure 24. Water table maps of the Wishek landfill.

Groundwater Quality

Concentrations of selected major ions and trace metals in the groundwater at the Wishek landfill appear to be within the normal range for these parameters in shallow groundwater within this area. The isoconcentration maps of these parameters did not reveal a consistent leachate plume, and only a few maps indicated the landfill as the probable source of ion increase (figures 27 to 29). Total dissolved solids and chloride are two parameters that indicate a possible landfill source (figure 27). The level of the chloride ion in natural (nondegraded) shallow groundwater in this area is generally 15 to 30 mg/l. Groundwater beneath the landfill contained up to 300 mg/l of chloride, or 10 times the normal concentrations. Refuse is commonly a source for the chloride ion. However, groundwater within the Pierre Formation generally contains higher than normal levels of the chloride ion. Therefore, in this case the high chloride levels may be natural, a result of buried garbage, or a combination of the two.

The highest concentrations of organic carbon were found in groundwater at wells 10 and 11. The elevated levels at well 11 may be traceable to buried refuse (figure 29). However, the source at well 10 may be related to the adjacent railroad, possibly the creosote from the railroad ties. No pesticides were detected in the four wells sampled at this landfill. Volatile organic compounds were also below detection limits in the seven samples from monitoring wells which were analyzed (table 9).

Conclusions

1. The Wishek landfill is situated within approximately 20 feet of outwash deposits which are underlain by the Fox Hills Formation.

2. The water table occurs approximately 20 feet below the base of the buried refuse. The shallow groundwater flow beneath the landfill is east into the meltwater channel.

3. The water levels (or heads) in the nested piezometers in the meltwater channel indicate that the vertical component of groundwater flow is upward in this area. Groundwater flow appears to be discharging into the outwash from the underlying Pierre Formation. Low-lying areas, such as the base of channels, are generally discharge areas. Monitoring wells were not nested around the landfill because it was assumed, given the locality, that the area underneath the landfill would be a recharge zone.

4. The groundwater information gathered to date at the Wishek landfill indicates that refuse is impacting groundwater quality beneath the site. At this time the impact appears to be small and is difficult to quantify due to the natural variability

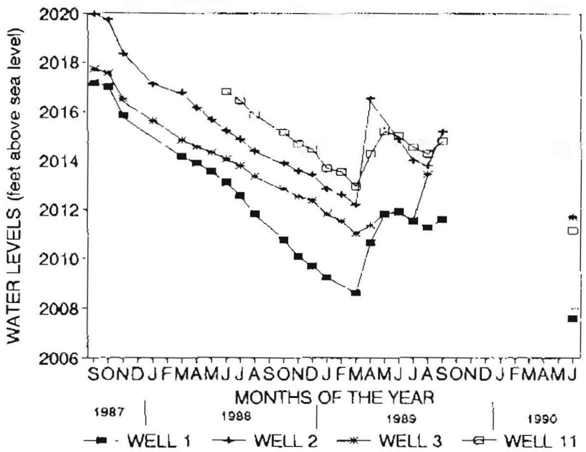

Figure 25. Water-level profiles for wells screened in the Pierre Formation at the Wishek landfill.

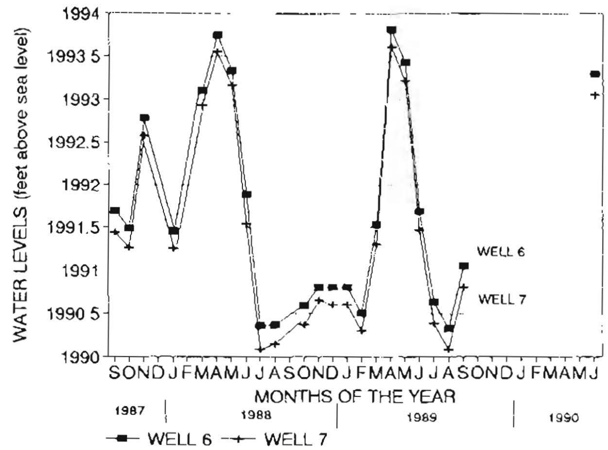

Figure 26. Water-level profiles for wells screened in outwash at the base of the meltwater channel at the Wishek landfill.

Table 8. Hydraulic conductivities of selected sediments at the Wishek landfill.

Well No.	Lithology	Hydraulic Conductivity
1	siltstone	5.0×10^{-4} cm/s
3	claystone	7.4×10^{-4} cm/s
8	sand & gravel	2.1×10^{-2} cm/s

Table 9. Wells which were sampled for VOC's and pesticides at the Wishek landfill.

Well No.	VOC	Pesticide
1	X	X
2	X	
3	X	X
5	X	
8	X	
9	X	X
11	X	X

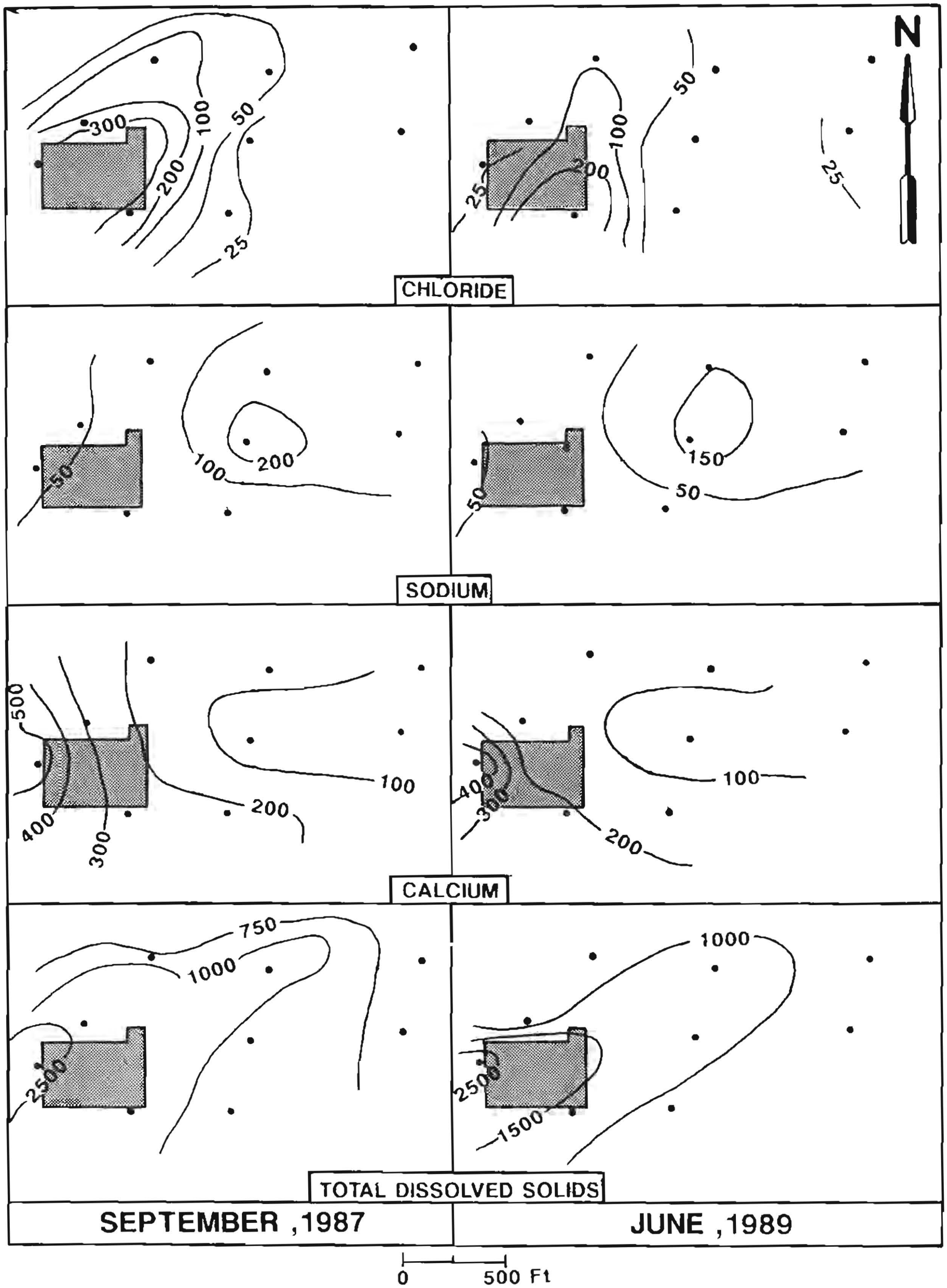

Figure 27. Isoconcentration maps for chloride, sodium, calcium, and TDS at the Wishek landfill.

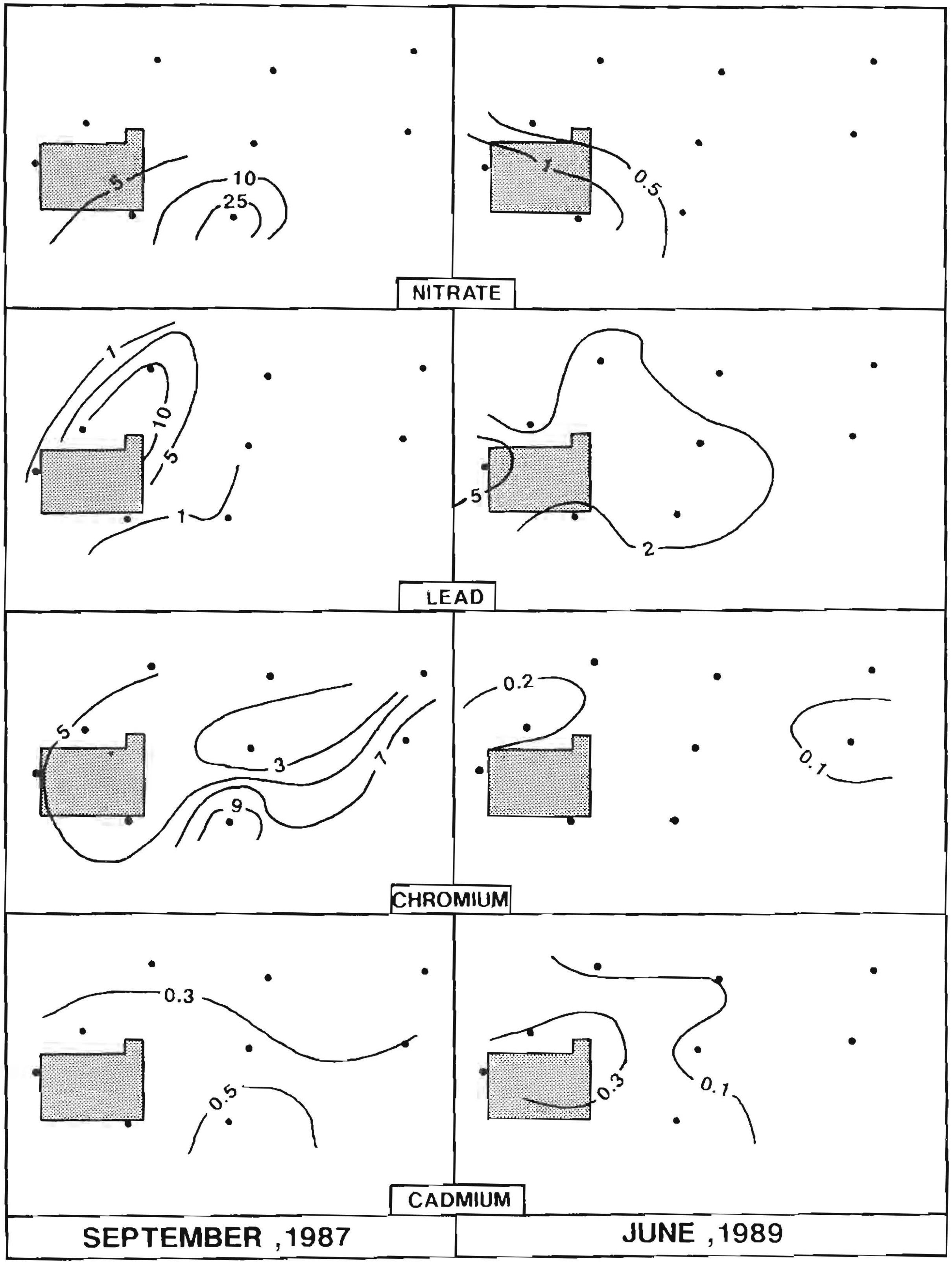

Figure 28. Isoconcentration maps for nitrate, lead, chromium, and cadmium at the Wishek landfill.

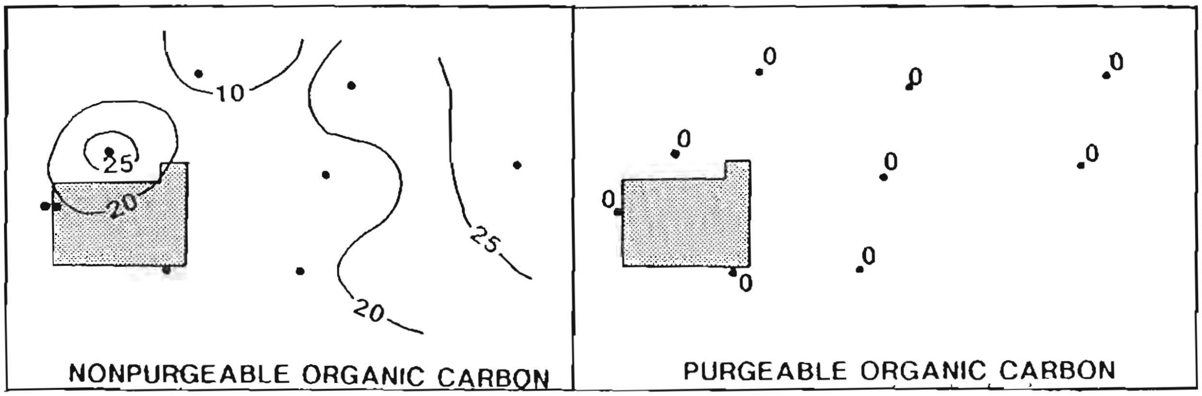

Figure 29. Isoconcentration map for organic carbon at the Wishek landfill.

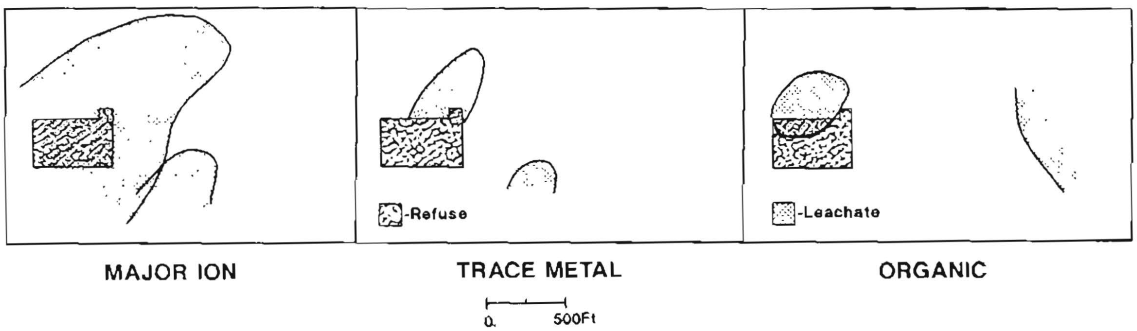

Figure 30. Leachate in groundwater at the Wishek landfill.

of major ion concentrations in groundwater in this area. (figure 30).

Recommendations

The site should be monitored periodically to enable detection of any major groundwater changes. One or two additional monitoring wells should be placed along the east end of the landfill to enable a more accurate determination of the leachate character.

HARVEY LANDFILL

Introduction

The Harvey landfill is located on the edge of the Sheyenne River valley, approximately 1 1/2 miles northeast of the City of Harvey (Township 150 North, Range 72 West, N/2/SW Section 28) (figures 31 and 32). The Harvey landfill is partially located within an abandoned gravel pit and was first operated as an open dump. Local residents believe the site was used for dumping as far back as the 1920s or 1930s. The Harvey landfill was closed in 1988.

The city of Harvey's wastewater impoundments are located just south of the Harvey landfill (figure 33). The wastewater impoundments (lagoons) began operating in the 1970s. In addition, two municipal wells for the City of Harvey are located adjacent to the Sheyenne River only a quarter of a mile east of the landfill and wastewater impoundments.

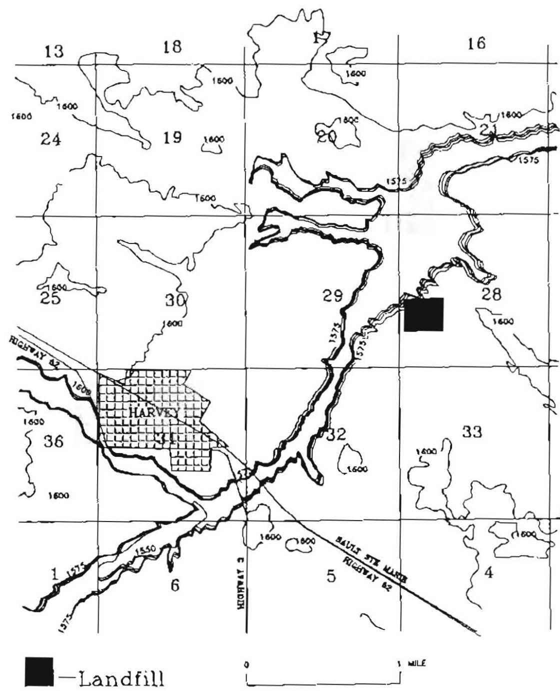

Figure 31. Topographic map of the Harvey landfill area.

Geology

The Harvey landfill is located on the southern edge of a large meltwater trench that contains the Sheyenne River. The landfill is situated within glaciofluvial material (gravel, sand, and silt). These outwash deposits are 15 to 20 feet thick and are underlain by till with a known thickness in excess of 15 feet (figure 34). According to Buturla (1970), the till should be underlain by the Fox Hills Formation and the contact should be close to the 1,550-foot elevation.

Hydrogeology

The wastewater impoundments are having a large impact upon the local groundwater system. A profile of the groundwater table shows the configuration of a groundwater mound in the vicinity of the lagoon (figure 34). The water table varies from a depth of 5 feet beneath the surface along the southern landfill boundary to a depth of 10 to 15 feet along the northern edge of the landfill. Approximately 1/3 to 1/2 of the refuse is buried beneath the groundwater table. This is largely a result of the rise in the water table attributable to the wastewater ponds. A number of springs are located along the hillside beneath the landfill. In addition, a small creek flows through the eastern portion of the site (figure 32).

The groundwater flow direction is generally to the north-northwest (figure 35). The gradient of the water table is approximately 2.8 x 10^{-2} (figure 35). As anticipated, a comparison of the nested monitoring well water levels indicated that the landfill is situated on a groundwater divide (Appendix C). The upland area is a recharge zone and the valley sides and floor are discharge zones.

Water levels in most monitoring wells fluctuated with the seasons during the two year

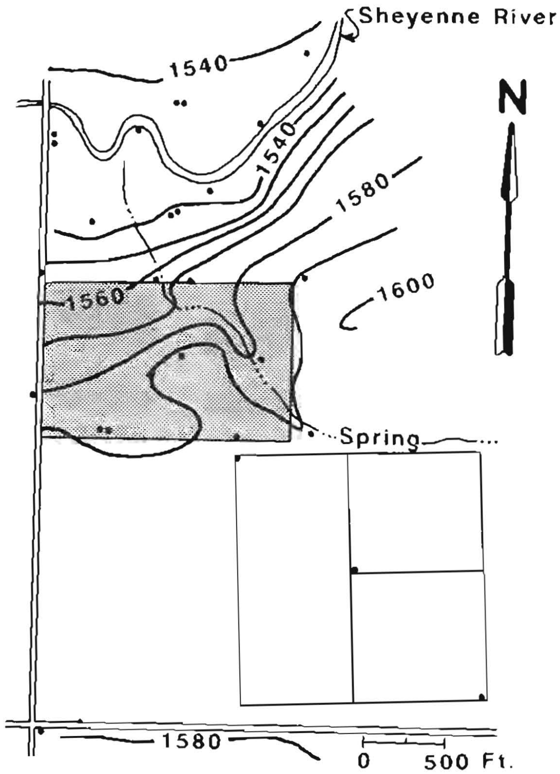

Figure 32. Topographic map of the Harvey landfill.

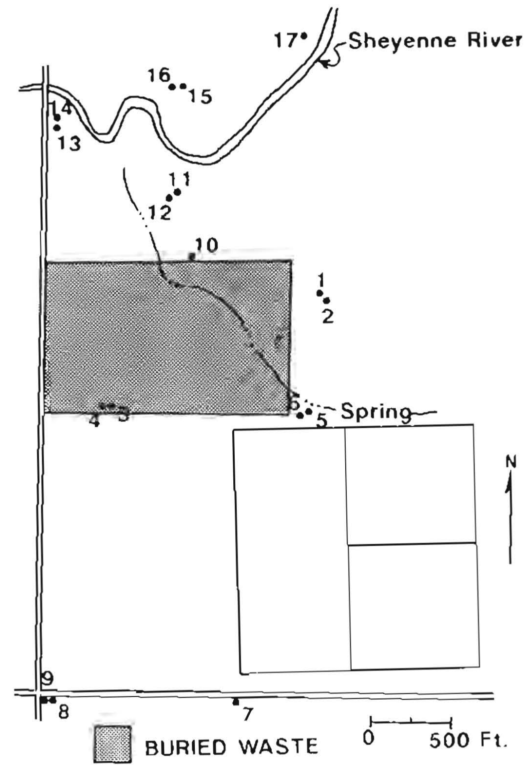

Figure 33. Location of monitoring wells at the Harvey landfill.

monitoring period, i.e., the water levels increased in the winter and spring and decreased in the summer and fall (figure 36) (appendix C). Monitoring wells 1 and 2 generally declined throughout the monitoring period with a slight recovery in the spring of 1989 (figure 37). The rates and times of water-level fluctuation coincide with monitoring wells both upgradient and downgradient from the wastewater impoundments (appendix C).

In-situ hydraulic conductivity tests were performed on several monitoring wells screened in sand and silt at this site (table 10). The hydraulic conductivity of the glacial outwash was found to vary from 6×10^{-2} cm/sec to 1.3×10^{-5} cm/sec. These values fall within the normal range for units of sand and silt (Freeze and Cherry, 1979). An unsuccessful slug test was attempted in well 6, which was screened in till. The average linear velocity of groundwater within the glacial outwash is extremely variable and ranges from 1.5 feet/year to 6952 feet/year (using a porosity of 0.25).

Monitoring Wells

Monitoring wells were generally nested in pairs at the Harvey landfill site. Wells were placed in and around the landfill as well as along the Sheyenne River floodplain below the site. In addition, wells 7, 8, and 9 were placed south of the landfill to provide information on groundwater upgradient of the wastewater impoundments (figure 33). The deeper of the paired monitoring wells was generally screened in till or at the base

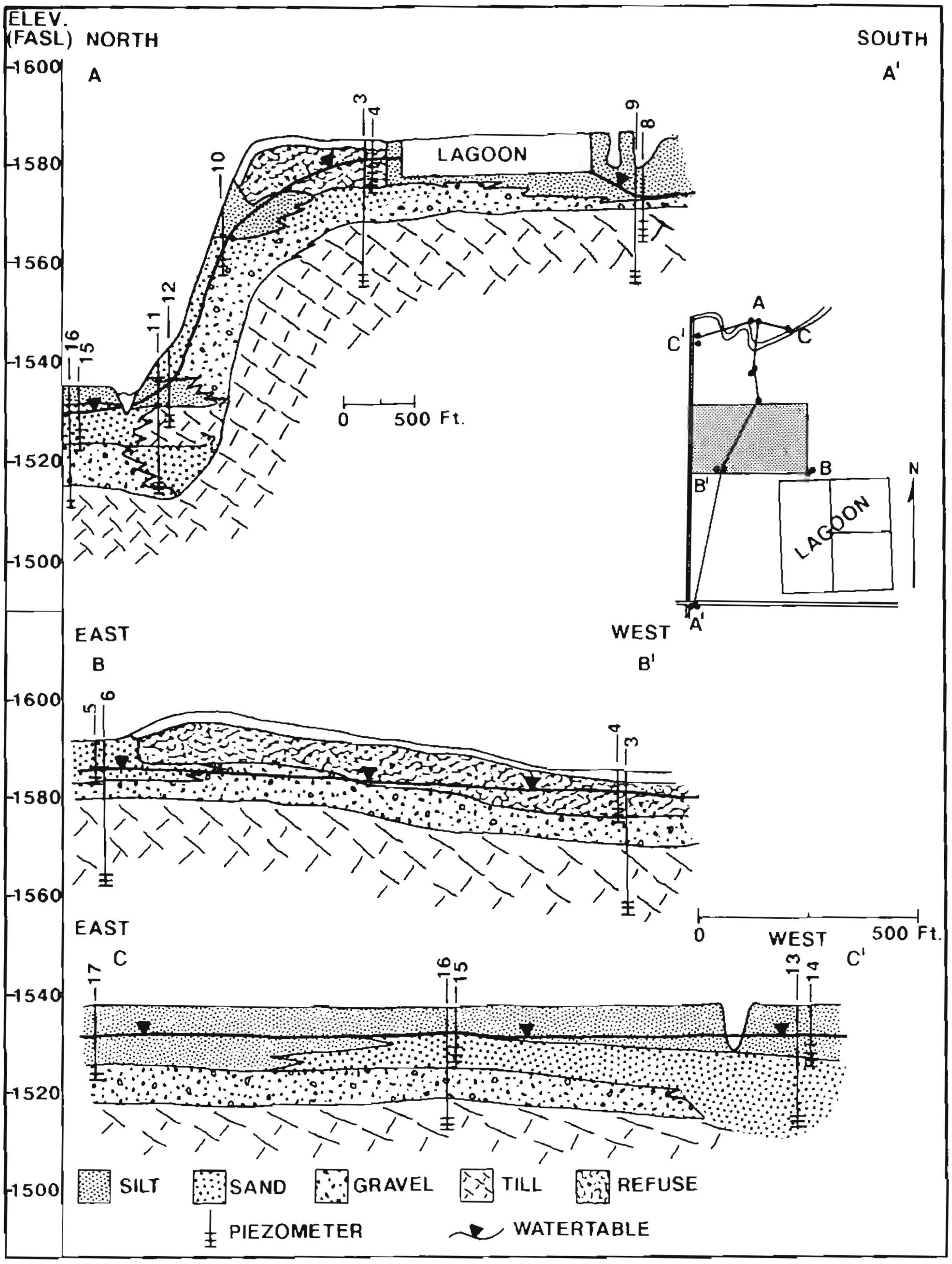

Figure 34. Geologic cross-sections of the Harvey landfill.

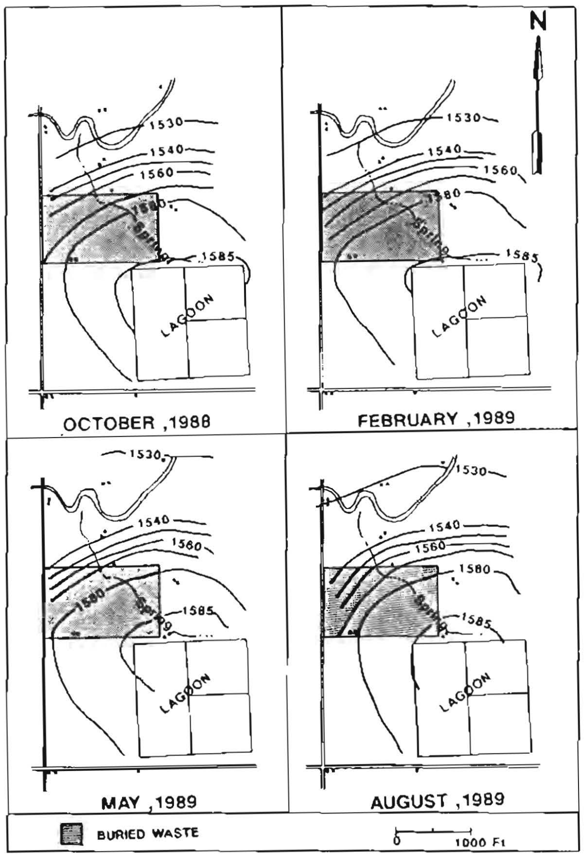

Figure 35. Water table maps for the Harvey landfill.

of the outwash. The shallow monitoring well was generally screened close to the water table (figure 34).

Groundwater Quality

Isoconcentration maps were constructed from selected parameters analyzed from groundwater samples taken in October, 1987, June, 1989, and June, 1990. These maps used data from monitoring wells screened only in outwash sediments. A general pattern of increased chemical concentration is discernible both in and around the wastewater impoundments and the landfill (figures 38 to 41). This increase is even more apparent when comparing background wells to wells located within or adjacent to the landfill (table 11).

A very high value of 83 ug/l of chromium was reported in the June 1989 sample from monitoring well 2 (0 ug/l in 1987) (figure 40). This well is located in an area outside of the buried refuse boundary. However, isolated pockets of buried refuse occur beyond the boundary and a large volume of scrap metal was present near this well. The source of chromium may be from either surface of subsurface refuse. Another potential source could be a Cretaceous shale boulder within the outwash. These shales tend to have abnormally high concentrations of some trace metals (although chromium is generally not one of them). The high arsenic levels in monitoring well 15 may also be attributable to a Cretaceous shale source.

In addition to the groundwater monitoring, water samples were taken from the Sheyenne River, from surface water within the landfill, from springs below the landfill, and from the wastewater impoundments. This data is summarized in table 12 and the location of the samples is shown in figure 42.

Three parameters (F, Pb, and TOC) were found to be high in the wastewater within the impoundments (table 12). The high fluoride ion concentration is a result of fluoridation of the city water supply and the lead may be coming from residential lead pipes or lead solder. The sample labeled "Co" was taken in stagnant water (cattail slough) in the road ditch south of the impoundments (figure 42). This area is likely being impacted by wastewater seeping out of the impoundments. The chemical concentrations of the surface water at this site are also increased as a result of evaporation. Samples C_1, C_2, and C_3 were obtained from the small creek flowing through the landfill (figure 42). Ion concentrations are generally high and do not appreciably decrease from C_1 to C_3 (table 12). The C_3 sample was taken at the farthest point from the landfill from which a bucket sample could be obtained. Beyond this point, the surface water spread out over a large area and it was not possible to obtain a large (one gallon) clean sample. However, the surface water could be

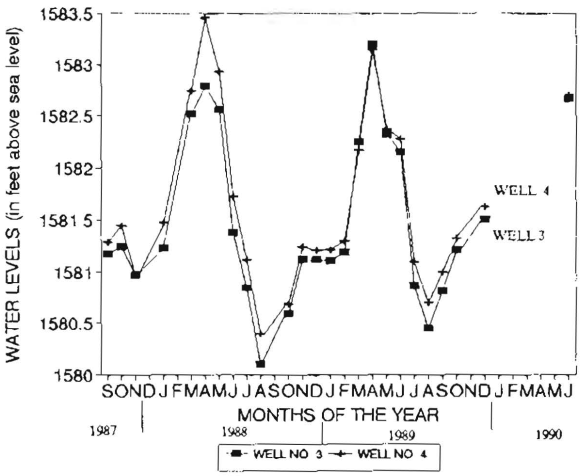

Figure 36. Water-level profiles for monitoring wells 3 and 4 at the Harvey landfill.

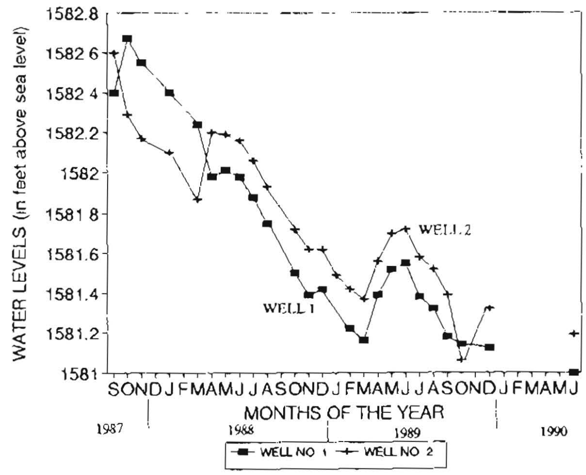

Figure 37. Water-level profiles for monitoring wells 1 and 2 at the Harvey landfill.

Table 10. Hydraulic conductivities of sediment adjacent to selected monitoring well screens at the Harvey landfill.

Well no.	Lithology	Hydraulic Conductivity
1	sand	8 x 10^{-5} cm/sec.
7	sand	6 x 10^{-2} cm/sec.
10	sand & silt	1.3 x 10^{-5} cm/sec.
11	sand	1.4 x 10^{-4} cm/sec.
14	silt	1.3 x 10^{-3} cm/sec.
15	sand	4 x 10^{-4} cm/sec.

Table 11. A comparison of groundwater chemistry at the Harvey landfill (June, 1989).

WELL NO.	LOCATION	TDS	Cl	SO_4	Cr	TOC
8	(upgradient)	871	5	378	0	4.8
4	(landfill)	1600	180	206	1.02	20.6
17	(downgradient)	480	12	65	0.3	8.4

NOTE: Cr and TOC values in ug/l all others in mg/l.

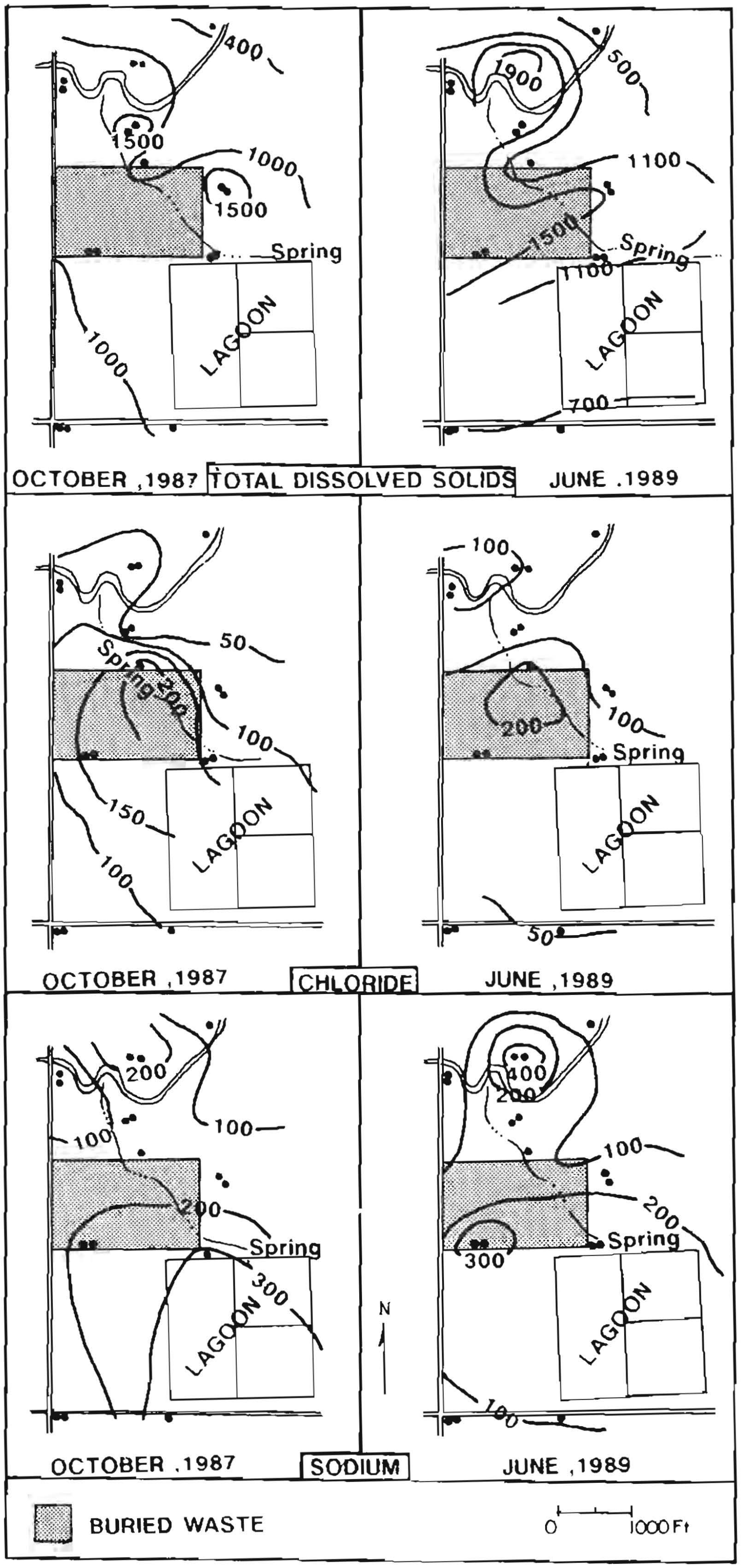

Figure 38. Isoconcentration maps for TDS, chloride, and sodium at the Harvey landfill.

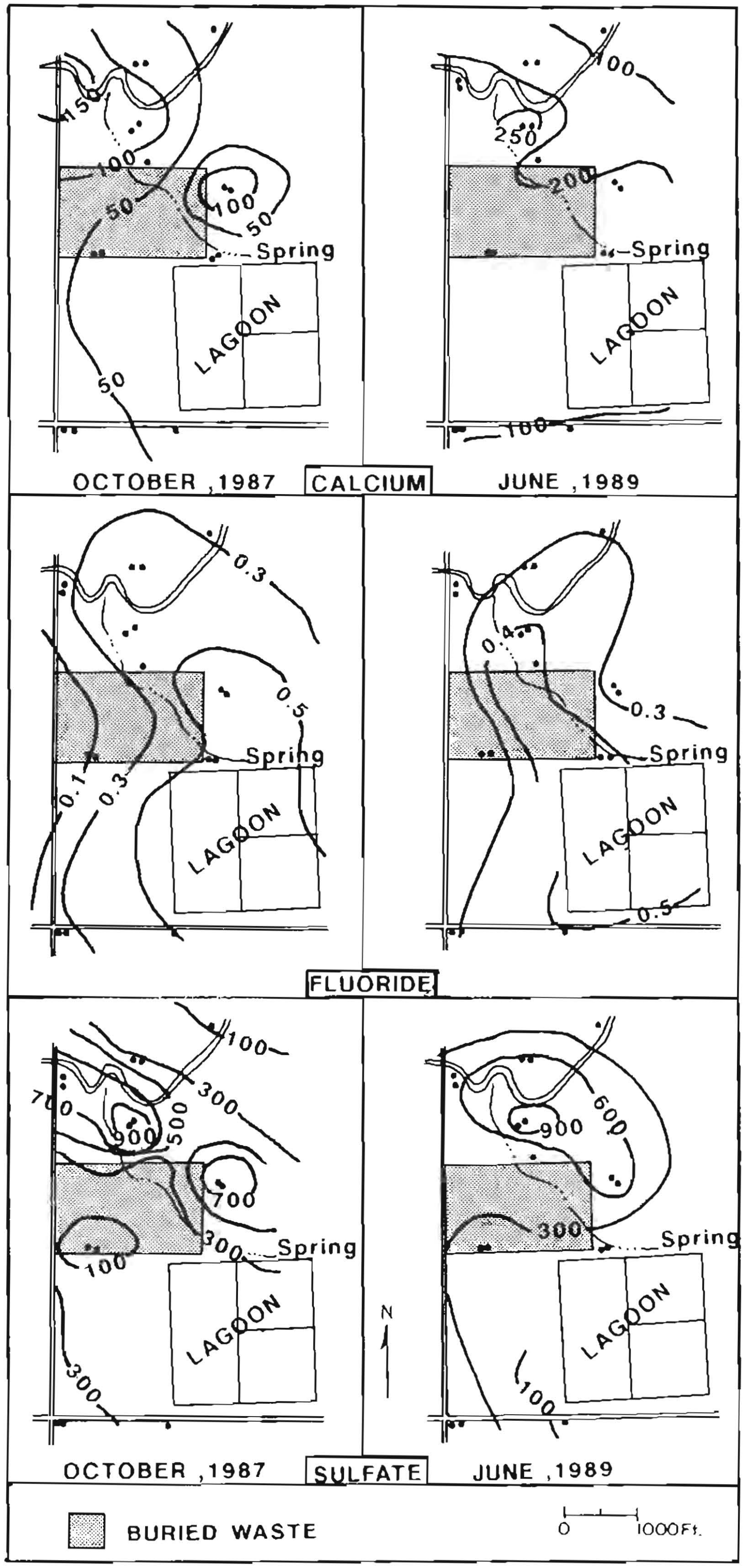

Figure 39. Isoconcentration maps for calcium, fluoride, and sulfate at the Harvey landfill.

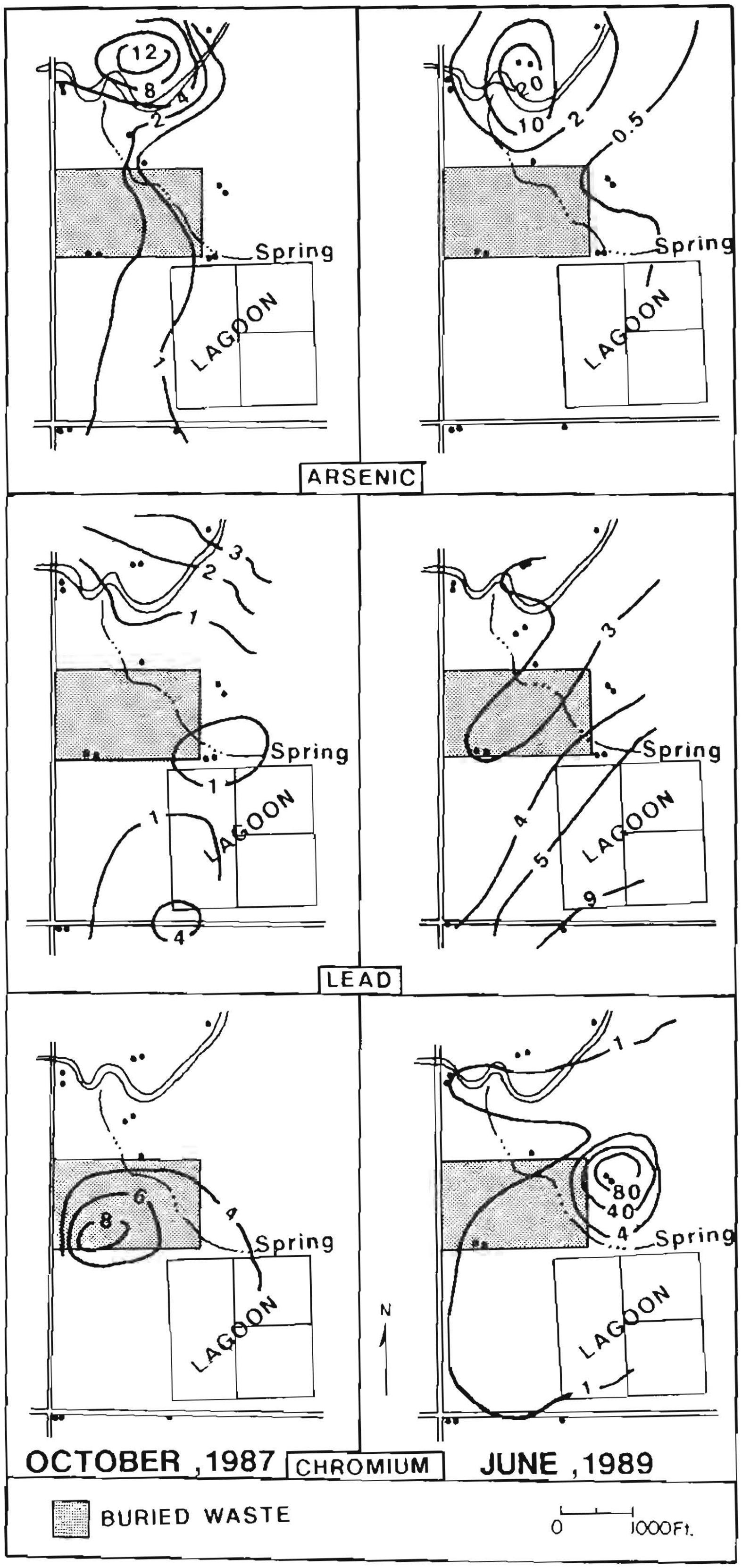

Figure 40. Isoconcentration maps for arsenic, lead, and chromium at the Harvey landfill.

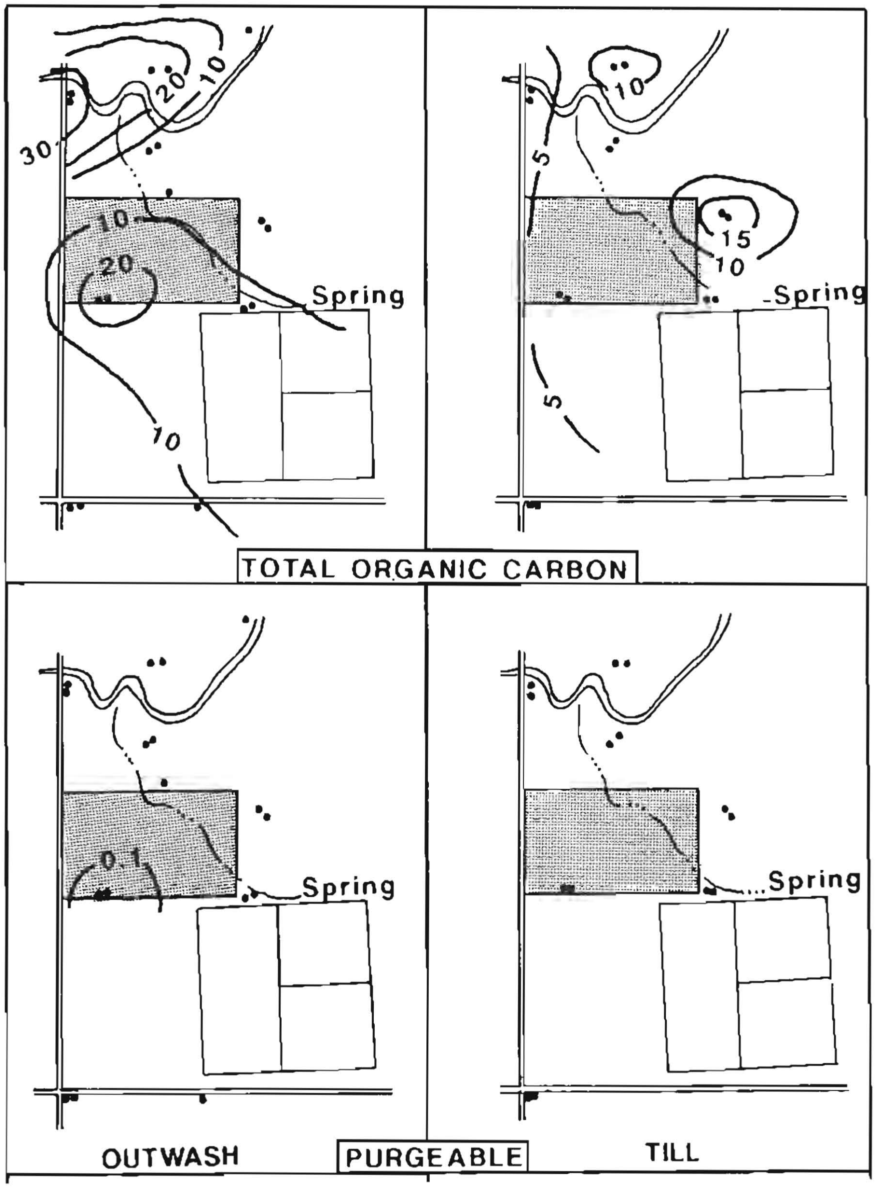

Figure 41. Isoconcentration maps for organic carbon at the Harvey landfill.

traced beyond this point to its contact with the Sheyenne River.

A comparison of water chemistry from the Sheyenne River, both upstream and downstream from the Harvey landfill and wastewater impoundments (Su and Sd, - table 12), did not demonstrate an appreciable impact on the water quality of the river during our study (Appendix D). Although the chloride level nearly doubled from Su (18 mg/l) to Sd (34 mg/l), it is still within the normal range for surface water.

Nine wells were tested for VOC's and three were analyzed for pesticides at the Harvey landfill (table 13). In addition, water from a spring at the southern edge of the landfill was analyzed for both VOC's and pesticides. Neither

Table 12. A comparison of surface water chemistry at the Harvey landfill

SOURCE	TDS	Cl	F	Pb	TOC
La (impoundment)	754	84	2.55	22	38.3
Co (creek)	2100	211	0.43	1.8	48.9
C1 (creek)	1610	176	0.63	1.5	25.5
C2 (creek)	1710	162	0.52	1.6	22
C3 (creek)	1720	165	0.52	1.0	22
Su (Sheyenne R., up)	833	19	0.32	1.8	22.6
Sd (Sheyenne R., down)	991	34	0.37	0.37	25.2

NOTE: Pb in ug/l, all others in mg/l.

the groundwater nor the surface water tested at this site contained detectable amounts of the 17 pesticides that we tested for. Two groundwater samples from wells 4 and 10, taken in 1987, contained high concentrations of the following volatile organic compounds: toluene 4-7 ug/l, diiodomethane 6 ug/l, ethyl benzene 34 ug/l, p & m xylene 92 ug/l, ethylmethylbenzene 221 ug/l, 1,2, 4 - trimethylbenzene 264 ug/l, 1, 3, 5 - trimethylbenzene 262 ug/l, methylpropylbenzene 77 ug/l, and ethyldimethylbenzene 105 ug/l. Only monitoring well 4, which was partially screened in waste, contained detectable amounts of VOC's in 1990 (5.6 ug/l of cis-1, 2-dichloroethylene, 6.5 ug/l of ethyl benzene, and 38.1 ug/l of 1,2,4-trimethylbenzene). A strong odor, black coloration, and an oily sheen were noted in water samples taken from this monitoring well. The primary sources for these organic chemicals are coal tar, petroleum products, rubber solvents, metal degreasers, anesthetics and refrigerants (appendix G).

Conclusions

1. The surface of the Harvey landfill is underlain by 15 to 20 feet of outwash sand and gravel which is underlain by till.

2. The water table occurs at depths ranging from 5 to 15 feet beneath the surface of the landfill site. Approximately 1/3 to 1/2 of the refuse at the landfill is buried beneath the water table.

3. Seepage from the City of Harvey wastewater impoundments have raised the water table at the landfill site.

4. Groundwater flow is generally to the north into the Sheyenne River Valley.

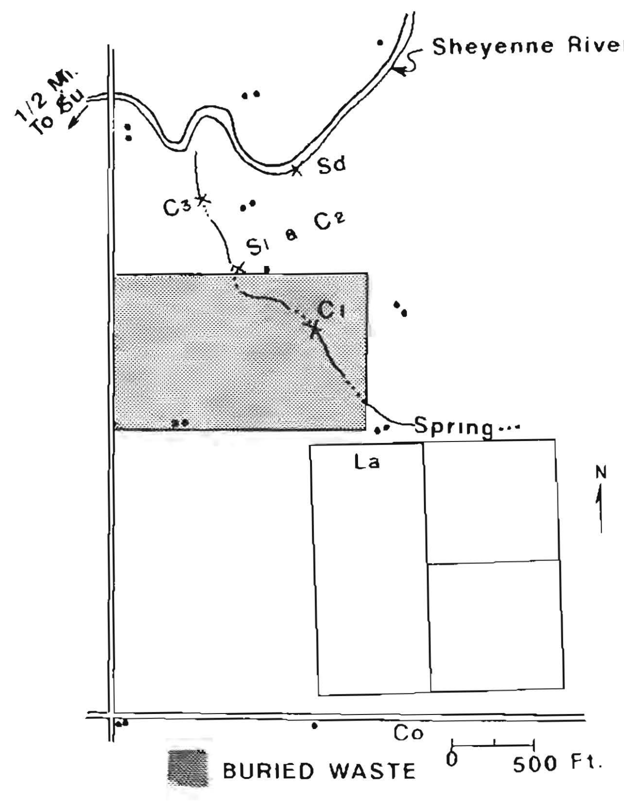

Figure 42. The location of surface water samples at the Harvey landfill.

Table 13. Monitoring wells selected for VOC and pesticide analysis at the Harvey landfill.

Well no.	VOC's	Pesticides
1	X	
2	X	
3	X	
4	X	X
5	X	
10	X	X
11		X
12	X	
13	X	
14	X	
Spring	X	X

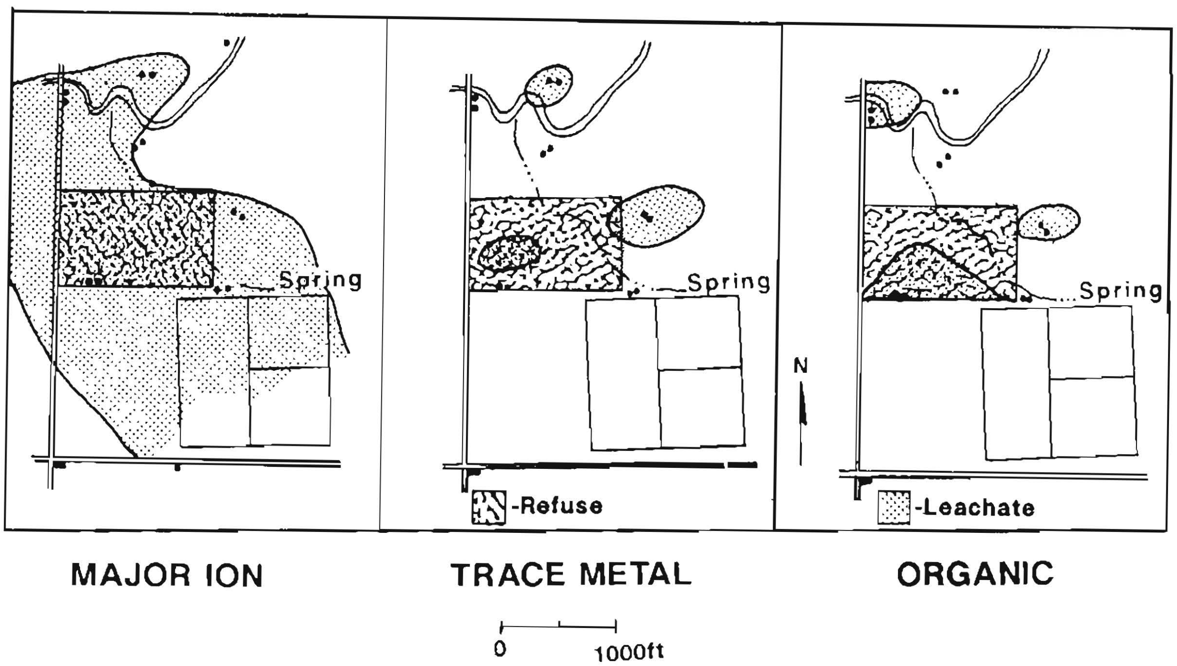

Figure 43. Leachate in groundwater at the Harvey landfill.

5. A general increase in ionic concentrations within groundwater is evident both within and downgradient from the Harvey landfill. This increase is generally moderate and may not extend downgradient beyond 1,000 feet from the landfill (figure 43).

6. Surface water, which has been degraded by either or both the landfill and the wastewater impoundments, is reaching the Sheyenne River. The impact appears, at this time, to be only slightly due to the leachate chemistry and the low ratio of leachate volume to the Sheyenne River.

7. The placement of wastewater impoundments in close proximity to the Harvey landfill has increased the impact of the landfill by

raising the groundwater table and saturating a much higher percentage of buried garbage than would normally have occurred. The close proximity of the landfill and impoundments have made it difficult to identify the specific impact that each of the facilities is having on the surrounding area.

Recommendations

More frequent VOC analysis is needed of the groundwater and surface water at this site to determine the range of organic concentrations in the leachate.

If, in the future, the landfill is found to be impacting the water quality of the Sheyenne River and the underlying aquifer to an unacceptable degree, the City of Harvey should consider relocating the wastewater impoundments, thereby lowering the water table in the landfill.

DEVILS LAKE LANDFILL

Introduction

The Devils Lake landfill is located approximately six miles north of the City of Devils Lake (Township 154 North, Range 64 West, ne section 5) (figure 44). The landfill is located in rolling hills, with moderate to high relief. Surface drainage is moderate to poor and there are no streams in the vicinity. The site is surrounded by farmland and there are two large potholes (one to the north, the other west) in close proximity to the landfill (figure 45). The Devils Lake landfill opened in 1977 and is still in operation.

Geology

The Devils Lake landfill is located within collapsed glacial sediments with an undulating surface containing local slopes of 0 to 20 degrees (Hobbs and Bluemle, 1987). The site is underlain primarily by till that is more than 45 feet thick (figure 46). An interbedded sand layer is present throughout the landfill site. The top of this sand layer is at a depth of approximately 20 feet. The sand layer increases in thickness from 3 feet at the northern portion of the landfill to 15 feet at the southeast corner of the landfill.

The total thickness of the glacial sediments at this site is unknown. A dark gray shale was encountered at a depth of 35 feet in monitoring well 6 (appendix A). Graney (in progress) interpreted the 5 feet of shale to be an isolated block within the till. Till is extremely variable in thickness in this area, but generally ranges from 50 to 100 feet (Hutchinson and Klausing, 1980).

Hydrogeology

The Devils Lake landfill is situated within

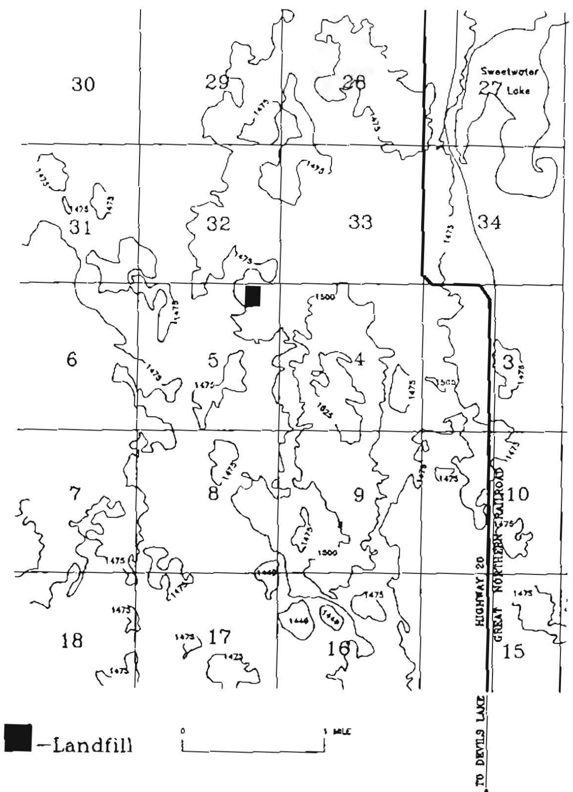

Figure 44. Topographic map of the Devils Lake area.

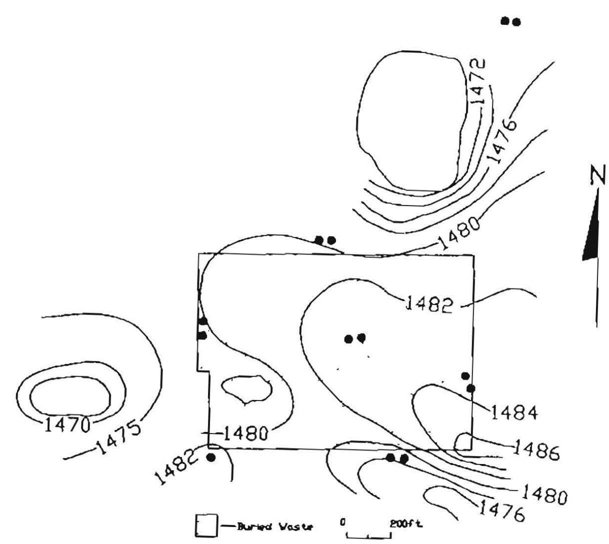

Figure 45. Topographic map of the Devils Lake landfill.

a groundwater recharge area. The water table occurs at a depth of 12 to 18 feet below the surface of the landfill. The water table appears to be mounded within a portion of the landfill and has components of groundwater flow to the southwest, west, and northwest (figures 47 and 48). The gradient on the water table is approximately 1 x 10^{-2} to the west-southwest. Water levels generally declined throughout the study except for a brief recovery during the spring, 1989 (figure 49).

In-situ hydraulic conductivity tests were performed on many of the wells. However, many of the screen intervals contain both till and sand and were not reported (table 14). The average linear velocity of groundwater in the till is 14.5 feet/year (using a porosity of 0.30). The average velocity of groundwater in the sand ranges from 3.5 to 121.7 feet/year (using a porosity of 0.25).

Monitoring Wells

Monitoring wells were generally nested in pairs at the Devils Lake landfill (figure 46). The shallow monitoring well was generally placed at or near the water table and the deep monitoring well was screened 10 to 20 feet deeper. The locations of the monitoring wells were limited to the area within the boundaries of the landfill because we did not have the funds to pay land damages to drill in the surrounding farmland. Two upgradient monitoring wells were placed in the road ditch north of the landfill site (figure 46).

Groundwater Quality

High concentrations of several major ions and trace metals were found in the groundwater adjacent to the Devils Lake landfill. A comparison of the isoconcentration maps for the selected parameters reveals no consistent shape or pattern to the leachate plume (figures 50 to 52). This inconsistency is believed to be a result of the heterogeneity of the buried waste and the irregular flow patterns in the fractured till. Monitoring

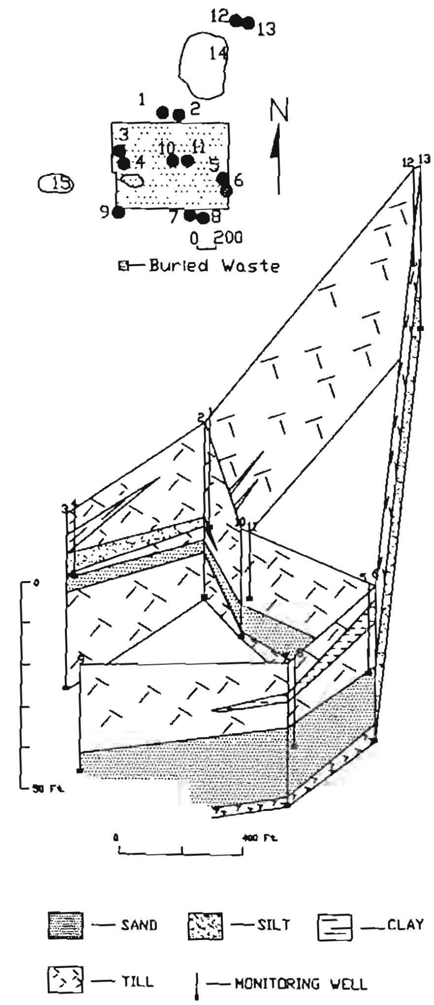

Figure 46. Geologic fence diagram of the Devils Lake landfill.

wells 12 (formerly A) and 13 (formerly B) were constructed as background wells (figure 45). However, the groundwater in these wells is highly mineralized, especially with regards to Na (2010 mg/l) and SO_4 (8840 mg/l) (appendix D). The source of this mineralization may be sodium sulfate salts which accumulated over time in the adjacent potholes.

In addition to the 13 water samples obtained from the monitoring wells, surface water was sampled from two potholes adjacent to the landfill (#14 and #15) and from a small pond inside the landfill (#16) (table 15).

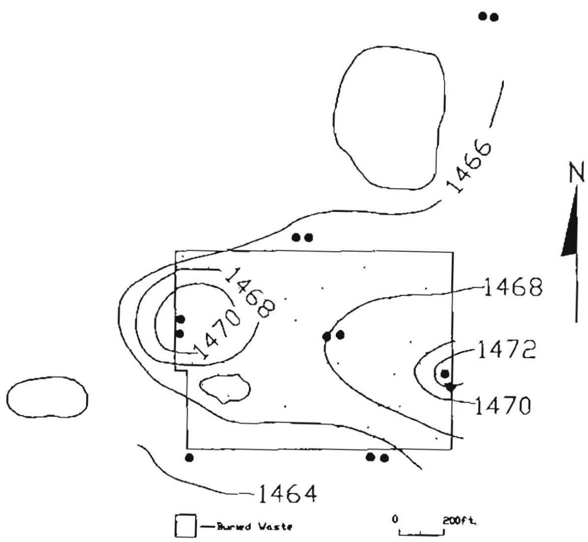

Figure 47. Water table map of the Devils Lake landfill.

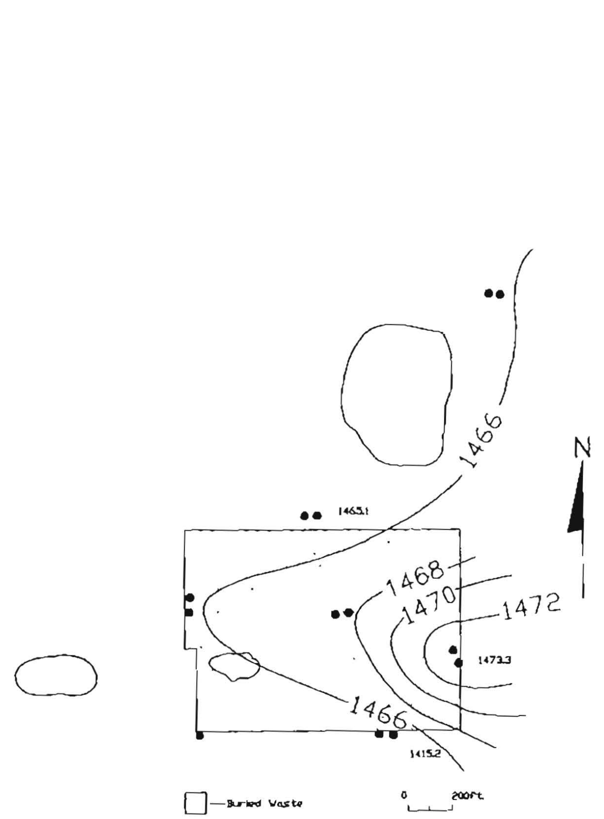

Figure 48. Potentiometric map of the base of the sand lense.

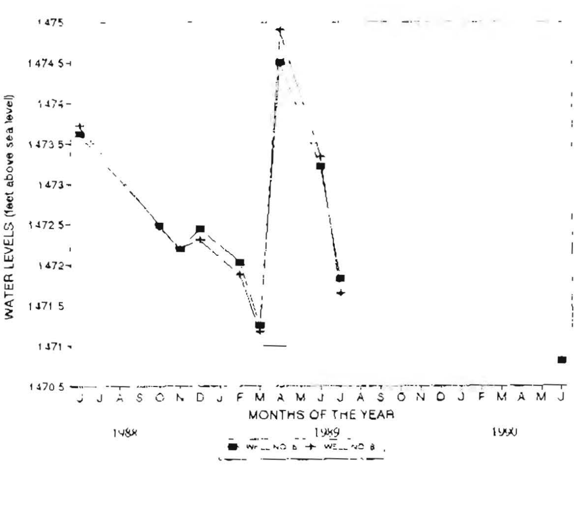

Figure 49. Water-level profiles at the Devils Lake landfill.

A comparison of the surface water quality demonstrates that the pond inside the landfill has been slightly degraded by the surrounding refuse (table 15). The best evidence appears to be the elevated chloride (35.8 mg/l) and iron (.32mg/l) concentrations. It is not possible, given the available data, to determine what, if any, impact the landfill is having on the adjacent potholes.

A water sample was also obtained from the landfill shop well (#17, appendix D). The depth of the well is unknown, but it is believed to be screened within fractured shale of the Pierre Formation. The Pierre Formation generally contains medium to high concentrations of the chloride ion (404 mg/l in sample #17). All, or part, of the chloride ion concentration found in groundwater beneath the landfill may be attributable to upward leakage from the Pierre Formation. Hydraulic head values were not available for the shop well. Therefore, a determination of

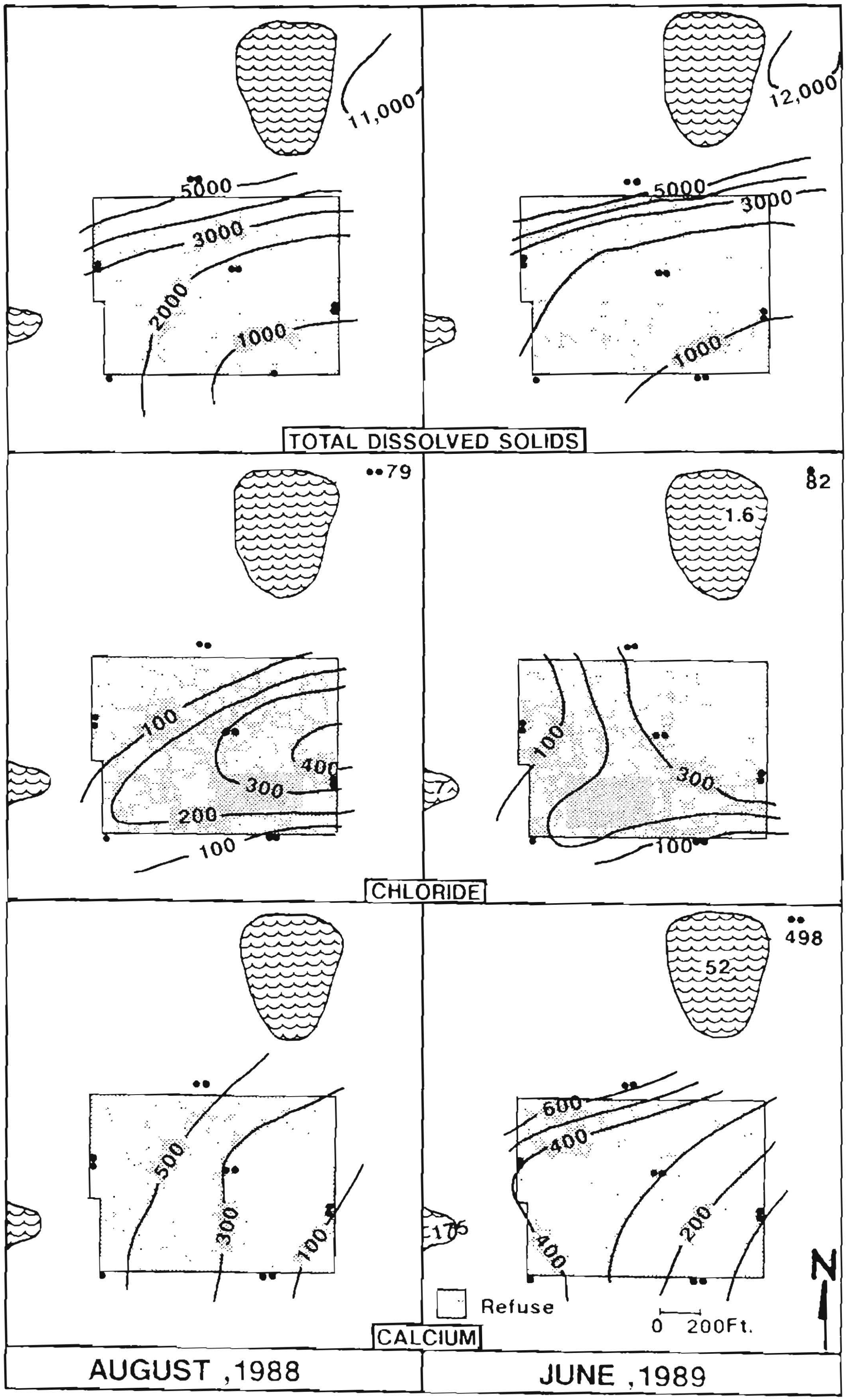

Figure 50. Isoconcentration maps for TDS, chloride, and calcium at the Devils Lake landfill.

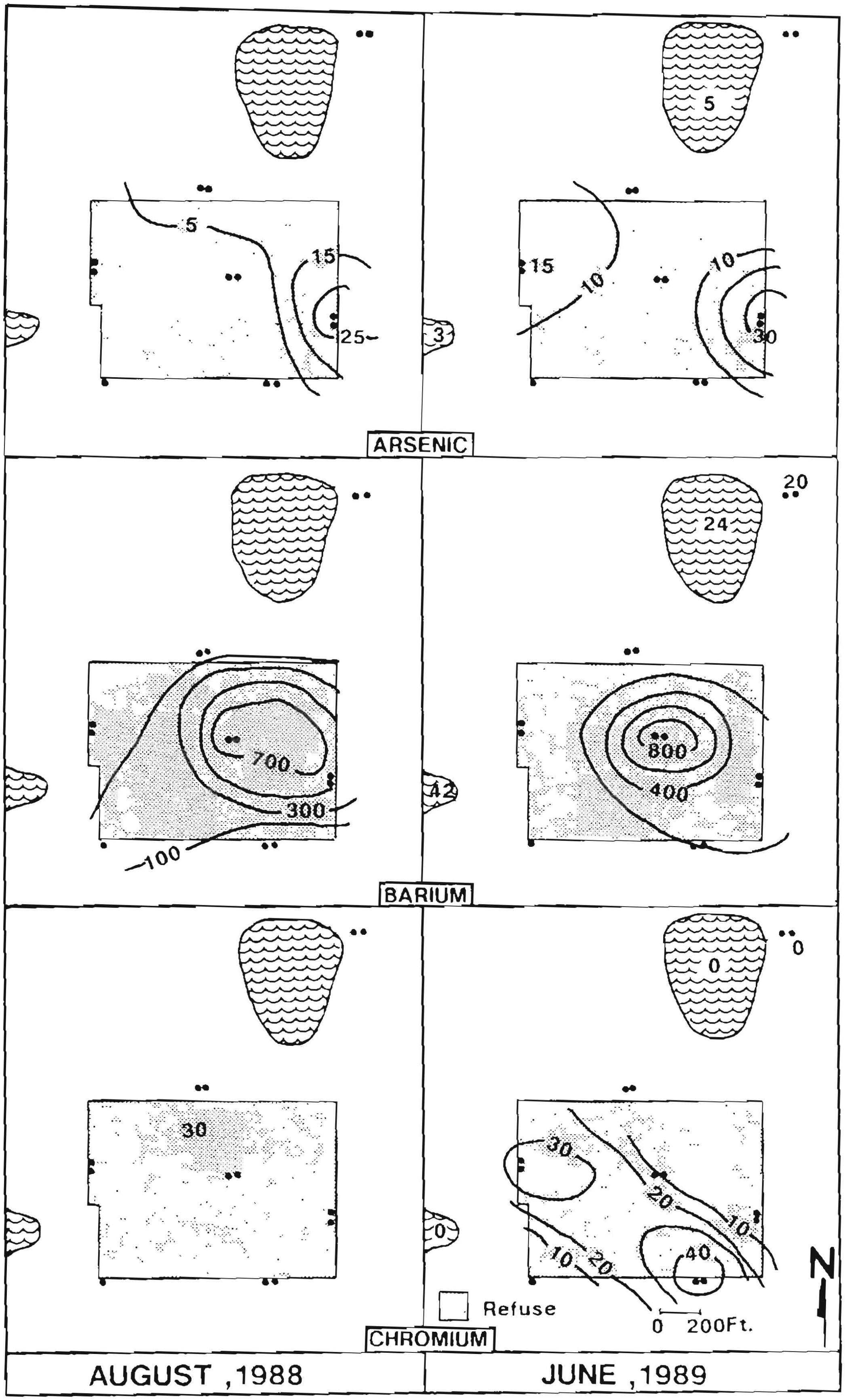

Figure 51. Isoconcentration maps for arsenic, barium, and chromium at the Devils Lake landfill.

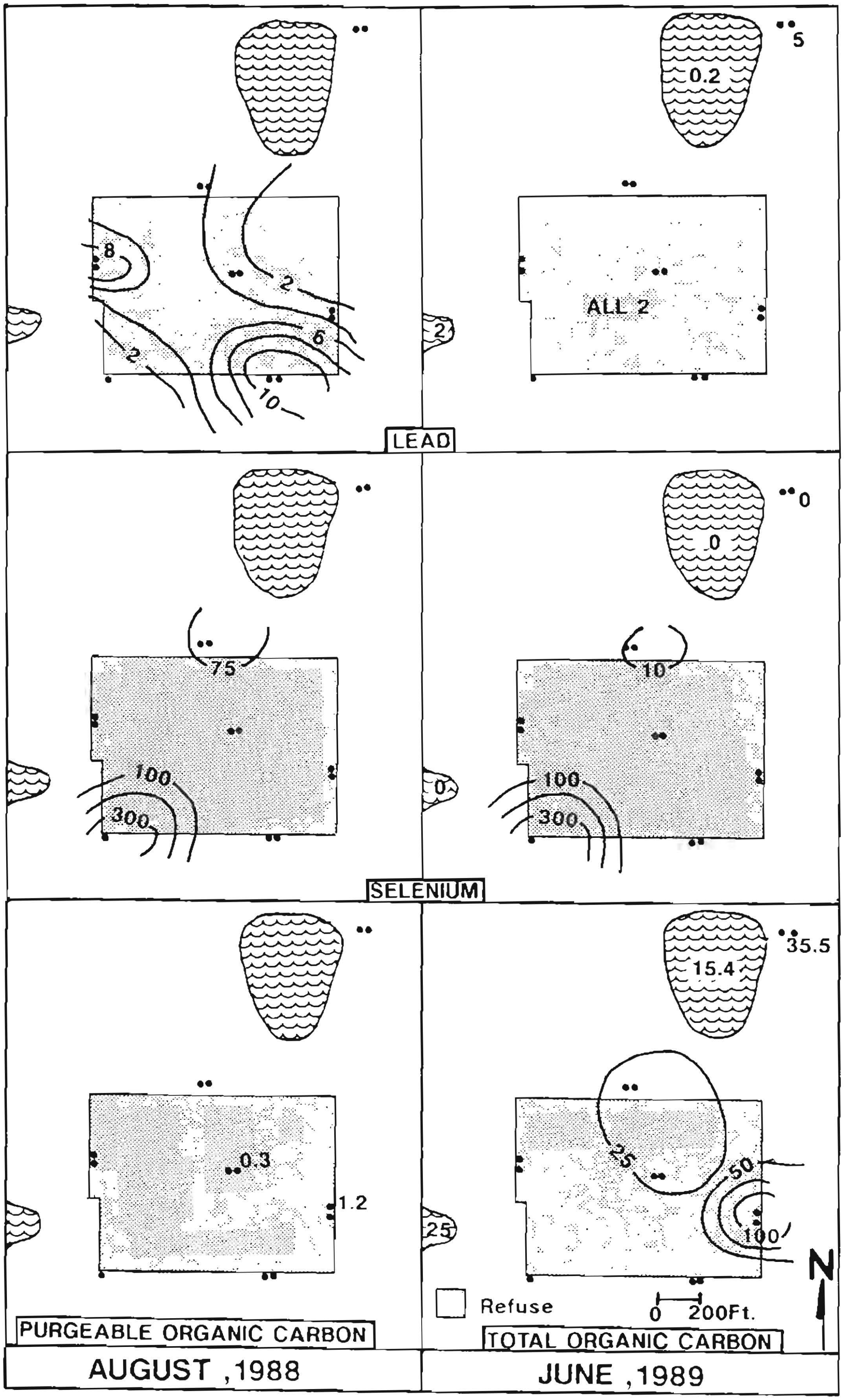

Figure 52. Isoconcentration maps for lead, selenium, and organic carbon at the Devils Lake landfill.

Table 14. Hydraulic conductivities of sediment adjacent to selected monitoring well screens at the Devils Lake landfill.

Well No.	Lithology	Hydraulic conductivity
2	till	3.76×10^{-4} cm/s
3	till	3.33×10^{-4} cm/s
4	sand and silt	1.44×10^{-3} cm/s
6	sand	3.09×10^{-4} cm/s
8	sand	2.94×10^{-3} cm/s
12	sand	8.37×10^{-5} cm/s

(from Graney, in progress)

Table 15. Surface water quality at the Devils Lake landfill.

Sample #	Distance from Landfill	TDS	Cl	SO_4	Fe	Pb	TOC
14	300 Feet North	215	1.6	1	0.17	0.2	15.5
15	150 Feet West	1280	7.	850	0.14	2.0	25.
16	Inside Landfill	963	35.8	566	0.32	2.2	10.5

Pb in ug/l all others in mg/l

the vertical flow direction within the Pierre Formation could not be made.

High levels of organic carbon were found in monitoring wells 1 (46 mg/l TOC) and 5 (113 mg/l TOC) (figure 52). The top of the screen in monitoring well 5 is approximately 2 to 3 feet below the base of the buried refuse. The water samples from this well had a deep green coloration and a very strong odor. The high concentrations of organic carbon in the east, central and northern portion of the landfill generally correspond to the high concentration levels of the major ion and trace metals. At present, there is no explanation for the high organic carbon levels in groundwater at wells 12 and 13 (appendix F).

Water samples from seven monitoring wells were analyzed for VOC's and three of these samples were also analyzed for pesticides (table 16). None of the three wells tested contained detectable concentrations of the 17 targeted pesticides. However, four of the wells (5, 6, 10, and 11) contained detectable concentrations of VOC's (table 17). Monitoring wells 5 and 11 each contained a number of detectable volatile organic compounds. Monitoring well 6 contained the highest concentrations of VOC's with 121 ug/l of chloroethane. The source of many of these organic compounds are solvents, degreasers, refrigerants, etc. (appendix F). The source of the polyvinyl chloride in the water samples may be the result of chemical breakdown of the PVC (polyvinyl chloride) casing caused by the chemically reactive leachate (table 17).

Conclusions

1. A sand lense is present within the till beneath the landfill site. This sand lense thickens to the south and southeast, but its extent beyond the landfill boundaries is unknown.

2. The base of the buried refuse was within 5 feet of the water table during this study.

3. The shallow groundwater beneath and adjacent to the Devils Lake landfill is highly

Table 16. Monitoring wells at the Devils Lake landfill which were analyzed for TOC's and pesticides.

Well no.	VOC	Pesticides
1	X	
4	X	X
9	X	
8	X	
5	X	X
10	X	
11	X	X

Table 17. Volatile organic compounds detected in groundwater at the Devils Lake landfill.

Well no.	VOC	Concentrations in ug/l
5	Benzene	5.4
	Vinyl chloride	1.4
	Ethyl benzene	8.0
	Chloroethane	14.5
6	Chloroethane	121
10	Vinyl chloride	1.8
11	Vinyl chloride	5.2
	Trichloroethylene	4.1
	trans1, 2-Dichloroethylene	5.6
	cis-1,2-Dichloroethylene	21.3
	1,1-Dichloroethane	8.6
	1,2-Dichloropropane	18.8
	Dichlorodifluoromethane	28.6

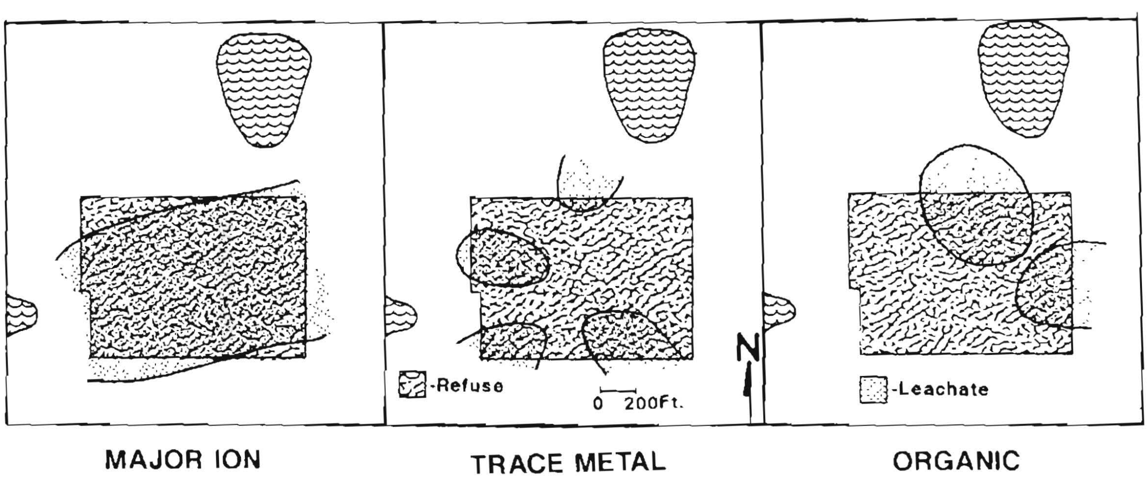

Figure 53. Leachate migration at the Devils Lake landfill.

mineralized. High concentrations of the chloride ion, arsenic, barium, chromium, lead, selenium, organic carbon, and volatile organic compounds were detected in the groundwater.

4. No well-defined plume boundary is discernible from the isoconcentration maps. This is believed to be a result of the placement of the monitoring wells, the heterogeneity of the waste, and flow through a fractured media (figure 53).

5. Due to the placement of the monitoring wells, it could not be determined how far beyond the landfill boundary groundwater is being degraded.

6. A portion of the increase in major ion and trace metal concentrations in the groundwater at the Devils Lake landfill may be attributable to upward leakage from the Pierre Formation. However, this leakage would not be the source of the volatile organic compounds.

7. The impact of the Devils Lake landfill upon the water quality of the adjacent potholes was not determined.

Recommendations

The Devils Lake landfill is underlain by more permeable sediments than was previously believed. The high TOC and VOC concentrations in the groundwater indicate that refuse leachate has reached and is migrating within the groundwater system. Additional monitoring wells should be installed 400 to 500 feet beyond the landfill boundaries to determine the extent of groundwater contamination. The Devils Lake landfill is nearing capacity. Expansion of the present landfill boundaries should not occur until an expanded study has determined the full impact of the present site on the surrounding environment.

HILLSBORO LANDFILL

Introduction

The Hillsboro landfill is located in central Traill County, approximately 3 miles northwest of the City of Hillsboro (Township 146 North, Range 51 West, ne/sw section 24) (figure 54). The landfill began operation in 1976 and closed in 1987. The landfill is situated within a flat area and is surrounded by farmland (figure 55).

Geology

The Hillsboro landfill is situated within the Glacial Lake Agassiz Plain (Bluemle, 1967). The landfill is underlain primarily by silt, sandy loam, and silty clay loam (figure 56). A thick sand layer is present at a depth of 10 to 15 feet below the surface along the west and southwest edge of the landfill. A sand body was also encountered at a depth of 30 to 82 feet in hole #9 (appendix A). The silt and loam deposits are lacustrine in origin and were deposited within a preglacial lake system (Maletzke, 1988). The sand body or bodies encountered at the site were deposited by rivers flowing into these preglacial lakes and may represent the eastern edge of a compaction ridge (Clayton, 1980).

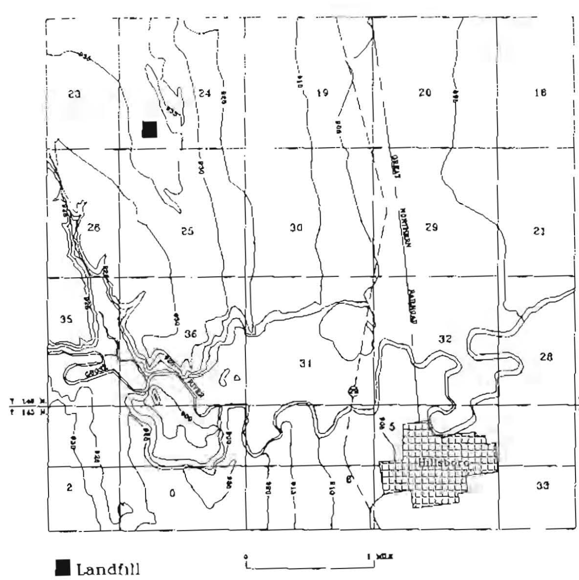

Figure 54. Topographic map of the Hillsboro area.

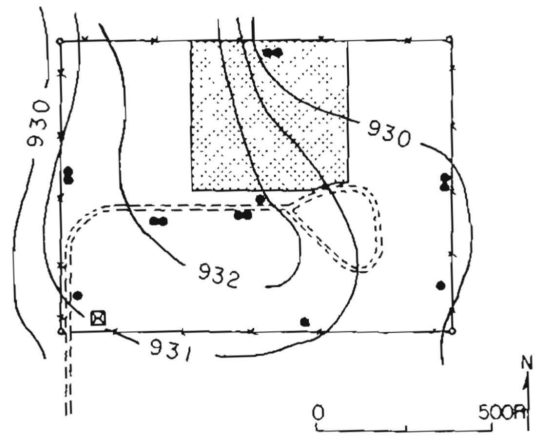

Figure 55. Topographic map of the Hillsboro landfill (from Maletzke, 1988).

Hydrogeology

The Hillsboro landfill is situated, in part, over the Hillsboro Aquifer. The Hillsboro Aquifer extends over an area of 35 square miles within Traill County. The sand body encountered in hole #9 is part of this aquifer system. The water table lies at a depth of 5 to 13 feet below the surface at the landfill site. Maletzke (1988) found that the water table at this site declined an average of 4 feet, during the period from May through August, 1988, due to the drought of 1988 (figure 57).

Groundwater below the study site is flowing to the south-southeast (figure 58). The gradient on the water table averages 4.78 x 10^{-3} within this area (Maletzke, 1988). Hydraulic conductivities for sediment at the landfill ranged from 1.65 x 10^{-4} cm/s (clayey silt) to 1.01 x 10^{-2} cm/s (sand) (Maletzke, 1988). A comparison of the hydraulic head values of nested piezometers indicated that the landfill is within a recharge

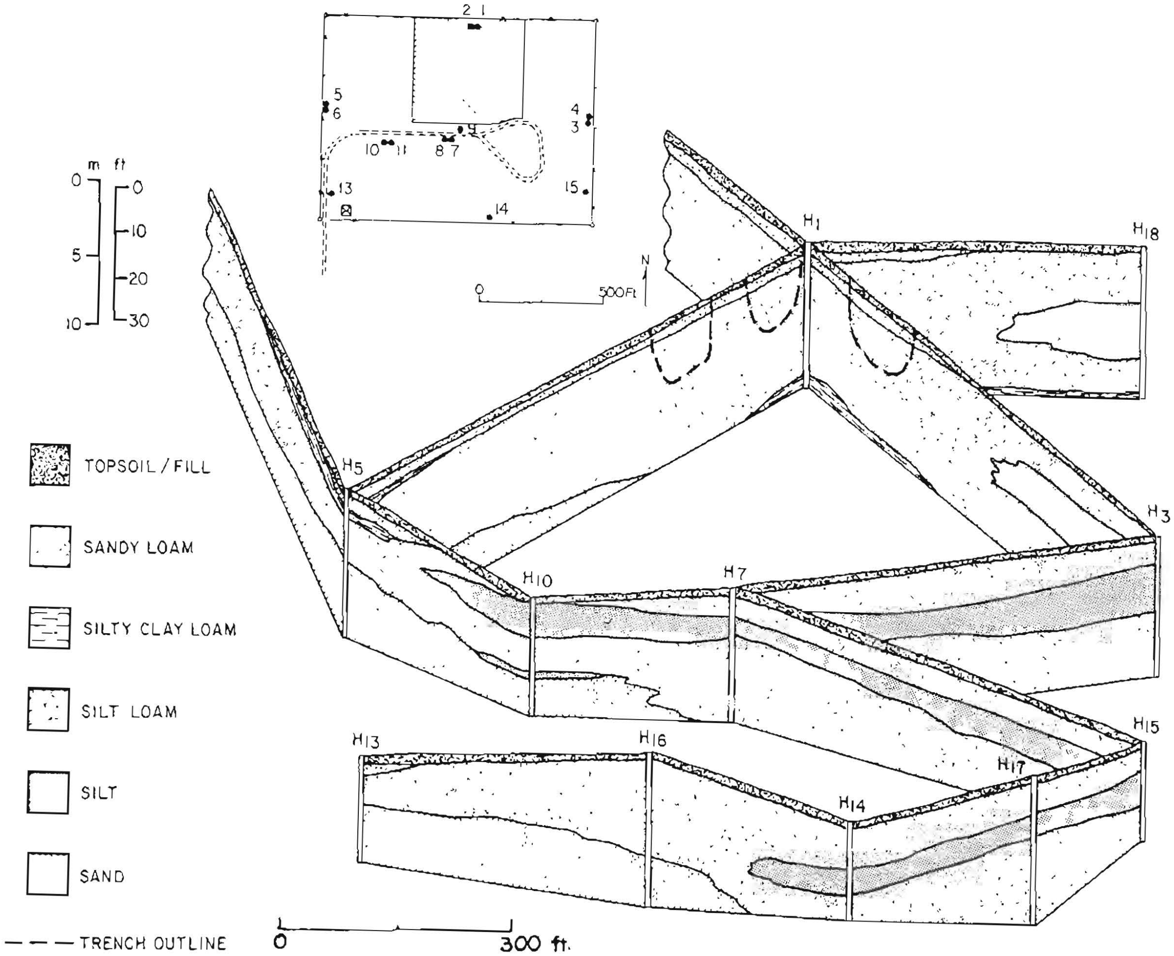

Figure 56. Geologic fence diagram of the Hillsboro landfill (from Maletzke, 1988).

area. The average vertical gradient is 1.36 x 10^{-1} (Maletzke, 1988). Given this information, Maletzke (1988) estimated the average linear velocity of groundwater beneath the landfill to be 27.1 ft/yr.

Monitoring Wells

The monitoring wells at this site were generally nested in pairs at depths of 32 and 12 feet (figure 55). An attempt was made to place a monitoring well at 82 feet, but due to well completion problems, the well was screened at a depth of 58 feet.

Groundwater Quality

A plume of degraded groundwater centered beneath the Hillsboro landfill is evident in many of the isoconcentration maps (figures 59 to 61). Maletzke (1988) felt that the inconsistencies demonstrated between the various plume shapes reflected the heterogeneity of the buried refuse. An increase in the concentration of most trace metals is occurring beneath and downgradient from the buried refuse. These increases are generally slight and no levels were found that exceeded the maximum permissible concentration limits (drinking water standards). High concen-

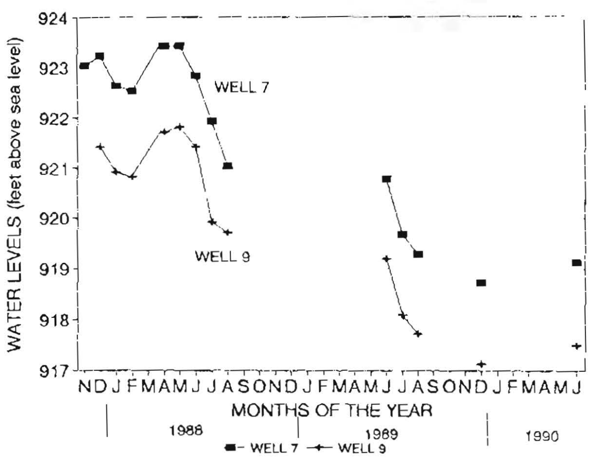

Figure 57. Profile of water levels from selected wells at the Hillsboro landfill.

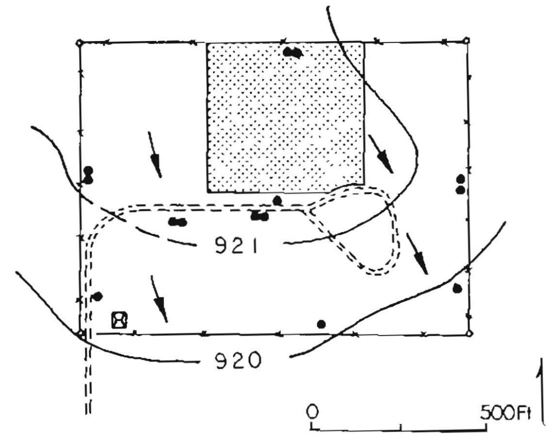

Figure 58. Water table map of the Hillsboro landfill (from Maletzke, 1988).

trations of the chloride ion were found in groundwater southwest of the landfill (well 11) (figure 59) (appendix D). The chloride levels detected are 10 to 100 times higher than background concentrations in this area. The plume of increased chloride ion concentrations appears to be confined to an area approximately 200 to 300 feet in diameter.

The TOC analysis of groundwater samples obtained in June, 1989 indicated high concentrations of organic carbon in groundwater around the Hillsboro landfill. The background level was 3 to 4 mg/l compared to 20 and 21 mg/l found in wells 7 and 4, respectively (figure 60). The plume of high TOC values was not found to extend beyond 350 feet from the boundary of buried refuse.

Seven wells were tested at the Hillsboro landfill for VOC's and three for pesticides (table 18). None of the 17 pesticides tested for were found above detectable limits. Only well 11 contained detectable concentrations of VOC's (24.9 ug/l Dichloromethane, 21.3 ug/l cis-1,2-Dichloroethylene, 8.3 ug/l Tetrachloroethylene) (figure 56). The logical source for these VOCs are solvents, dry cleaning solvents, metal degreasers, etc. (appendix F).

Conclusions

1. The Hillsboro landfill is situated within silt, sandy loam, and silty clay loam.

2. The Hillsboro landfill is located over the Hillsboro aquifer.

3. The water table occurs at a depth of 5 to 13 feet below the surface at the landfill. Refuse trenches were excavated to a depth of 15 feet. Therefore, a significant portion (10 to 30%) of refuse may be buried beneath the water table.

4. Groundwater was degraded in an area approximately 200 to 300 feet downgradient from the landfill boundary (figure 62). The major ion and trace metal concentrations within this plume are generally only slightly elevated above the background levels and have not been found in excess of drinking water standards (with the exception of chloride). The organic carbon levels were found to be high within a 300-foot diameter plume downgradient of the buried refuse.

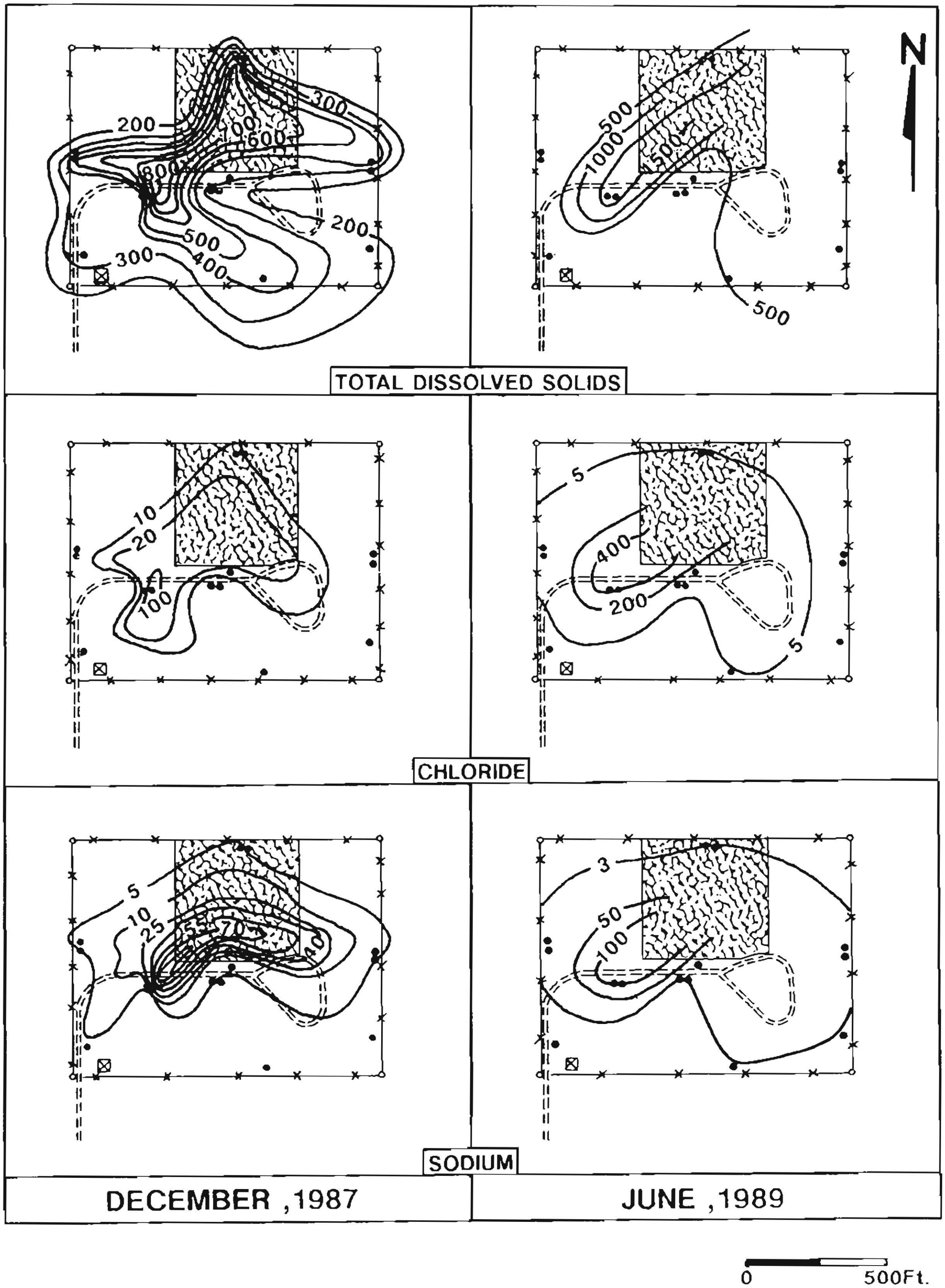

Figure 59. Isoconcentration maps for TDS, chloride, and sodium at the Hillsboro landfill (1987 map from Maletzke, 1988).

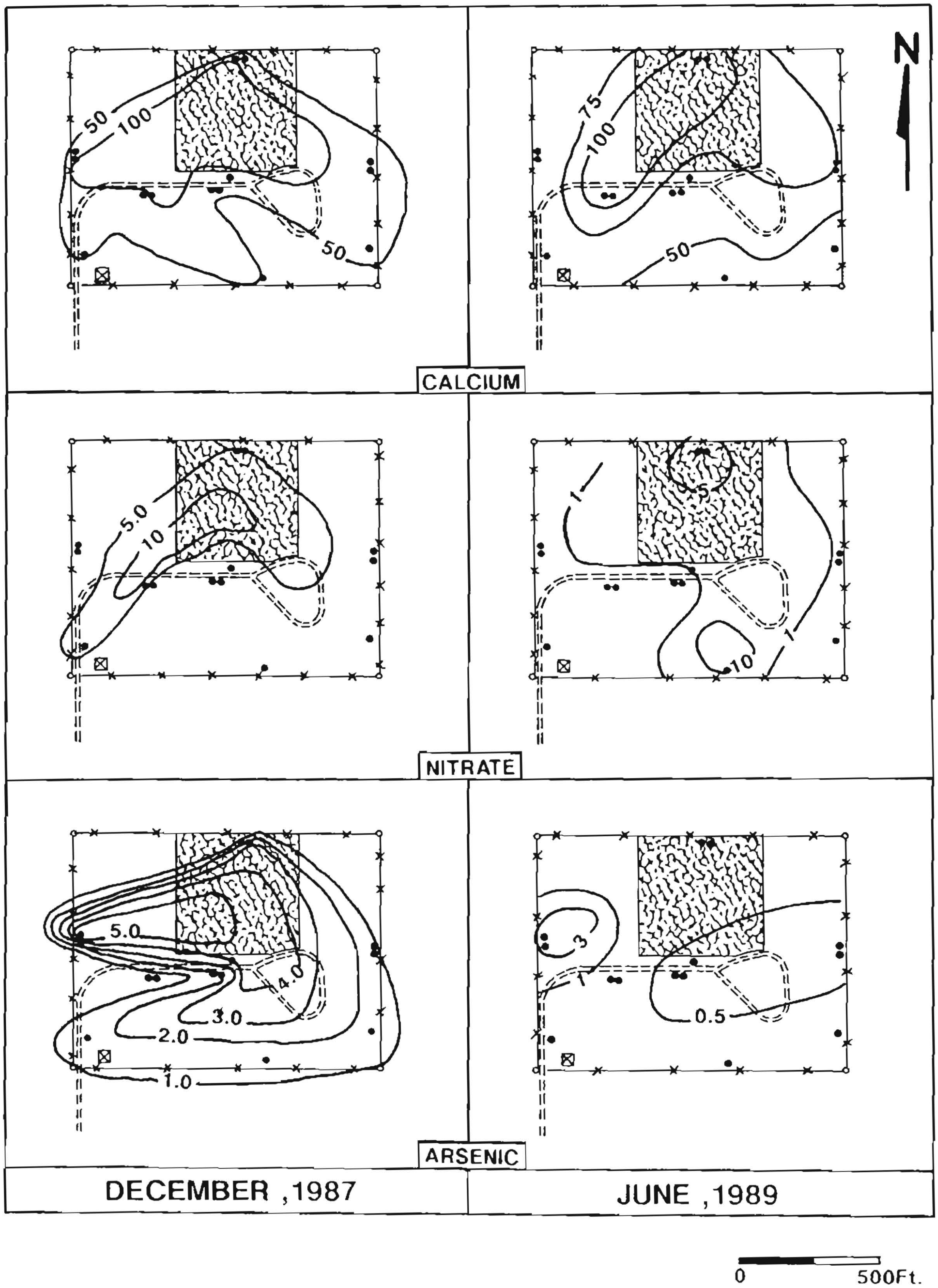

Figure 60. Isoconcentration maps for calcium, nitrate, and arsenic at the Hillsboro landfill.

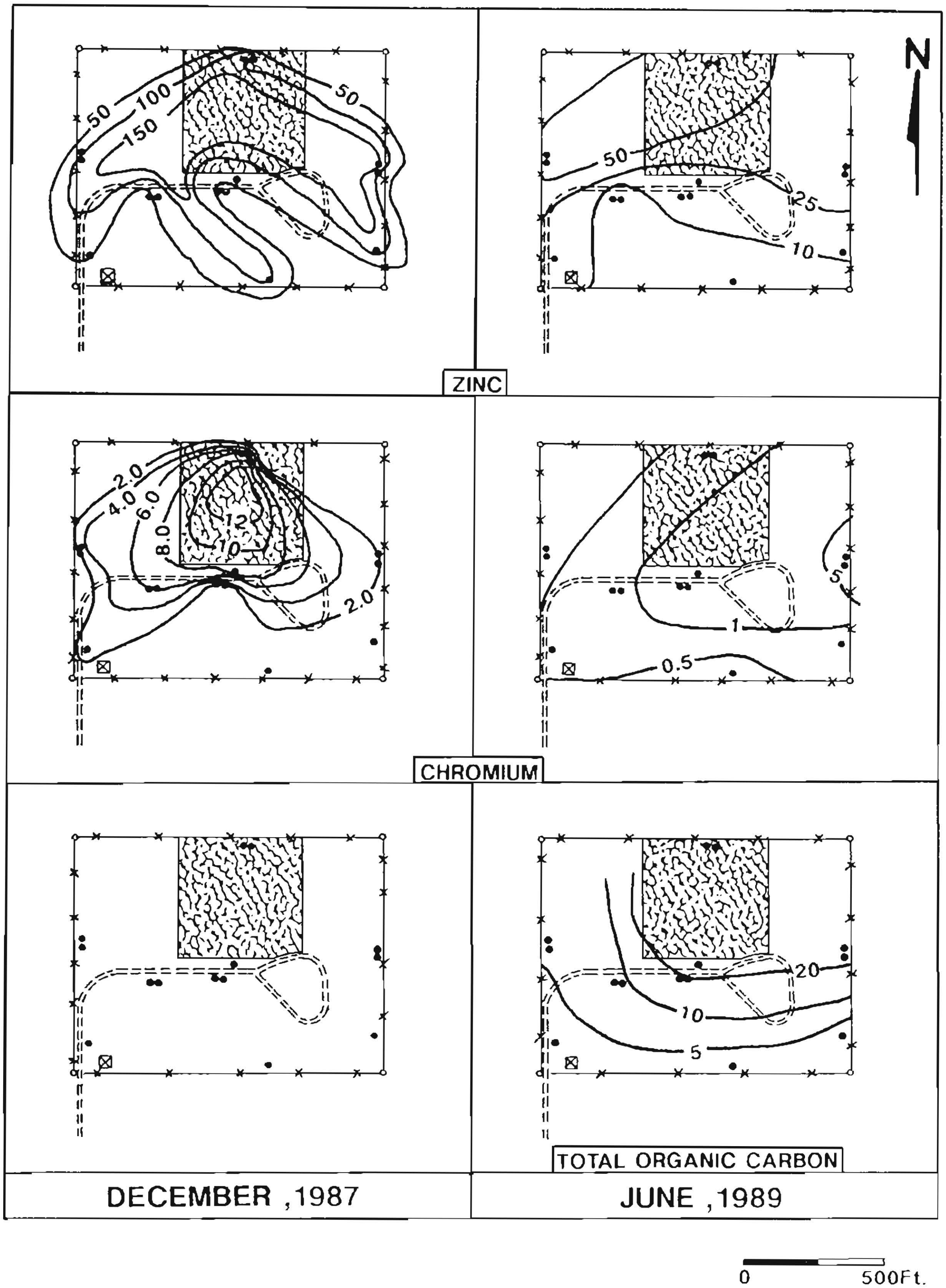

Figure 61. Isoconcentration maps for zinc, chromium, and organic carbon at the Hillsboro landfill.

Table 18. Monitoring wells sampled for VOC and pesticide analysis at the Hillsboro landfill.

Well no.	VOC	Pesticide
2	X	
3	X	
5	X	
7	X	X
9	X	X
10	X	X
11	X	

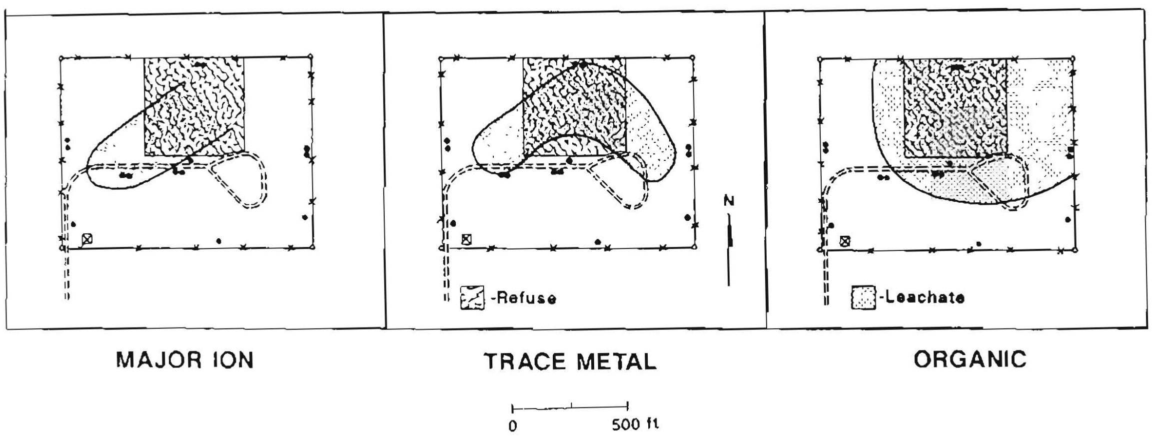

Figure 62. Leachate migration at the Hillsboro landfill.

Recommendations

Additional monitoring wells should be placed downgradient of the landfill to determine the impact of this site on the Hillsboro Aquifer. At least two wells should be screened at the base of the Hillsboro aquifer to detect any leachate which may migrate along this horizon.

PROJECT CONCLUSIONS

1. Leachate from buried refuse was detected in groundwater at each of the six landfill study sites.

2. The size of the leachate plume varied from landfill to landfill (table 19).

3. The landfill leachate was generally characterized by low to moderate increases in the major ion concentrations, little to no increase in the trace metal concentrations (for the metals that were tested), and moderate to high concentrations of organic carbon.

4. Purgeable organic carbon was only found in 5% of the groundwater samples.

5. Two of the landfill study sites were situated within abandoned gravel pits (Wishek and Harvey) and two other sites were located within ravines (Williston and Linton).

6. This study was conducted during an extended period of drought, which resulted in water levels in the monitoring wells declining as much as three to five feet (figure 63). The resulting decrease in precipitation created less landfill leachate and therefore less leachate recharged the shallow groundwater systems beneath these sites. The drought even impacted those sites where portions of the refuse is buried below the water table, such as Harvey and Hillsboro, by reducing the percentage of the waste found below the water table. Therefore, the results of this study may well represent the minimum concentrations of leachate that might be expected to be generated in these types of settings.

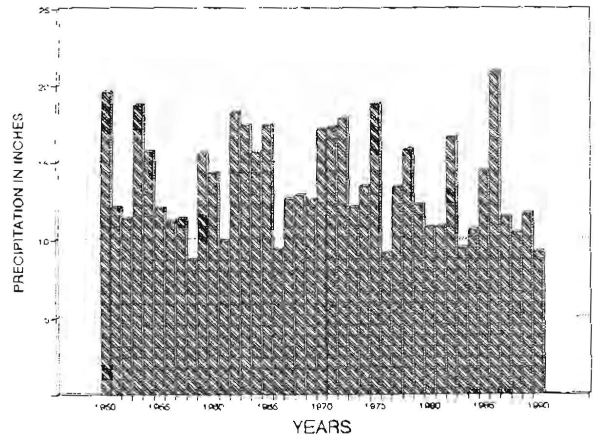

Figure 63. Annual precipitation at Williston from 1950-1990.

7. The earth resistivity surveys were generally not a useful tool in delineating landfill leachate. This is because the TDS of the leachate was not sufficiently high to mask the variations in resistivity due to the heterogeneity of the geologic units. Maletzke (1988) did find earth resistivity

Table 19. The distance leachate has been identified beyond the selected landfill boundaries.

Site	Extent Beyond Refuse Boundary
Williston	>350 Feet
Linton	>150 Feet
Wishek	100 Feet
Harvey	1,000 Feet
Devils Lake	Could not be determined due to placement of wells.
Hillsboro	300 Feet

to be useful at the Hillsboro landfill where the near-surface geology was more homogeneous.

8. It should be noted that only a select number of ions and trace metals were tested for during this project. The analysis of these water samples for additional parameters may demonstrate a much higher impact of the landfill on the surrounding area.

SUMMARY

Study Sites

Five of the six landfills studied have been closed; only the Devils Lake landfill is still in operation. The five closed sites have all been capped with sediment and the surface recontoured to minimize moisture infiltration. This action should reduce the amount of leachate produced at the landfills. The landfill caps will have to be maintained indefinitely to assure they do not erode. The Williston, Linton, Wishek, and Harvey landfills are all particularly susceptible to erosion because they are located in old ravines or on the edges of channels where erosion from runoff is often intensified.

Refuse is in direct contact with groundwater at the Harvey and Hillsboro landfills. Groundwater quality around the Harvey landfill will not improve as long as the municipal wastewater impoundments operate at their present location. Relocation of the wastewater ponds would lower the water table in the landfill and reduce its impact on groundwater quality. The City of Harvey has regraded the area around the stream that flows through the landfill in an effort to improve the surface water quality. While this may be of some benefit, a better solution would be to construct a north-south trench 500 feet east of the landfill boundary. This trench would divert surface water away from the landfill and improve the quality of water by preventing it from coming into contact with refuse.

Similar measures would also be needed at the Hillsboro landfill to prevent or at least minimize the amount of refuse that is in direct contact with groundwater. The water table could be lowered by continuously pumping a series of wells, although the sediment may be too fine grained for this to work effectively. Alternatively, the refuse could be dug up and transported to a more suitable waste disposal site. The Hillsboro landfill is a good example of how difficult and costly it is to minimize the impact of a landfill which is located in a geologically poorly suited area. Measures such as removing the waste or lowering the water table are very expensive and do not entirely solve the problem.

This project demonstrated that refuse leachate is being generated at landfills in the subhumid to semi-arid climate of North Dakota. The results of this study reinforce the importance of siting a sanitary landfill within a geological setting well suited for solid waste disposal. Proper design and operation of landfills also helps to minimize the impact of refuse leachate on the surrounding environment. These landfills, as with all open or closed landfills, should continue to be monitored for a long period of time. Three years is not a sufficient length of time to determine the long-term chemical variation of landfill leachate.

There are over 100 closed dumps or landfills in North Dakota. Many of these were closed because they were located in sites that were not well suited geologically for waste disposal. The groundwater around many of these sites has never been monitored. These old sites should be investigated and the groundwater should be monitored for the foreseeable future to determine their long-term impact on the surrounding environment.

History and Future of Solid Waste Disposal

The environmental impacts of the generation and disposal of solid waste has received much national attention during the last few years. The primary focus has been on the urbanized areas of the East Coast, but concern has also been expressed in the more rural areas of the Midwest. The plight of the "garbage" (garbage barge) from New York City in the late 1980s did much to raise the consciousness of people to the problems associated with waste disposal. Additional concern has risen over the transportation of wastes from the urbanized states along the East Coast to landfills in the rural eastern and midwestern states. This was more recently demonstrated by the refusal of a number of midwest states to accept a train loaded with New York City waste. The importation of wastes and the federal laws governing interstate commerce have been, and will likely continue to be, a litigated issue as states attempt to limit the amount of wastes crossing their borders.

New EPA rules are anticipated to drastically change solid-waste disposal in the United States. In North Dakota, a number of landfills are expected to close; a few new regional landfills will be sited in their place by the time the new rules come out in 1993. The results of this study should be used to emphasize the importance of placing these landfills in the best possible geologic settings.

A number of the dumps and landfills that have operated, or are still operating, in the state are situated within areas where the geology is not well suited for waste disposal, i.e., the potential for contamination of local groundwater and/or surface water is increased because of the geologic conditions at the site. This has occurred because geology was rarely considered when these sites were chosen. The overriding factor in the siting process was not concern for the long-term environmental impacts that might occur, but for the immediate economic factors associated with it, such as the purchase price of the land and the proximity to town. In an agricultural state like North Dakota, the price of land is generally determined by its ability to sustain a crop. Therefore, nonfarmable land such as abandoned gravel pits and abandoned lignite mines often became favored locations for dumps and later landfills. Gravel pits generally are in direct connection with unconfined aquifers and lignite mines in connection with confined aquifers. These aquifers are often of regional extent and importance. The placement of solid waste in these types of environments may result in the widespread contamination of the aquifers.

Approximately one third of the State of North Dakota can be identified as being poorly suited for waste disposal, given our present knowledge of the geology of the State (figure 64). The primary areas of avoidance in the glaciated portion of North Dakota are glaciofluvial sand and gravel deposits and the edges of meltwater trenches. The Fox Hills Formation (Cretaceous) and the Cannonball Formation (Paleocene) are the primary bedrock units to avoid when siting landfills because of the laterally extensive sandstones found in these units. River and creek valleys and the badlands in western North Dakota are also poor areas for landfills because of flooding and erosion along the butte and valley slopes. Much of the remaining two-thirds of the State would be determined to be unsuitable (due to more local conditions) following detailed site investigations. Therefore, it is understandable why a number of the old landfills are situated in unsuitable areas given the small percentage of geologically suitable land in the State. The careful siting of a landfill will save money in the long run. The additional costs of properly siting and designing a landfill will be recouped in the future by reducing the likelihood of having to pay for expensive remedial actions.

When I began this study in 1987, landfill permit applications often consisted of a document of only a few pages, with little or no subsurface geologic or hydrogeologic information. One of the most common comments made in Geological Survey reviews during the 1980s was that there was not sufficient geologic information available on the application to make a determination on the geologic suitability of the site. The permitting process has changed dramatically over the past few years. Landfill permit applications are now routinely tens to hundreds of pages long and contain detailed geologic and hydrogeologic information that was gathered specifically for the

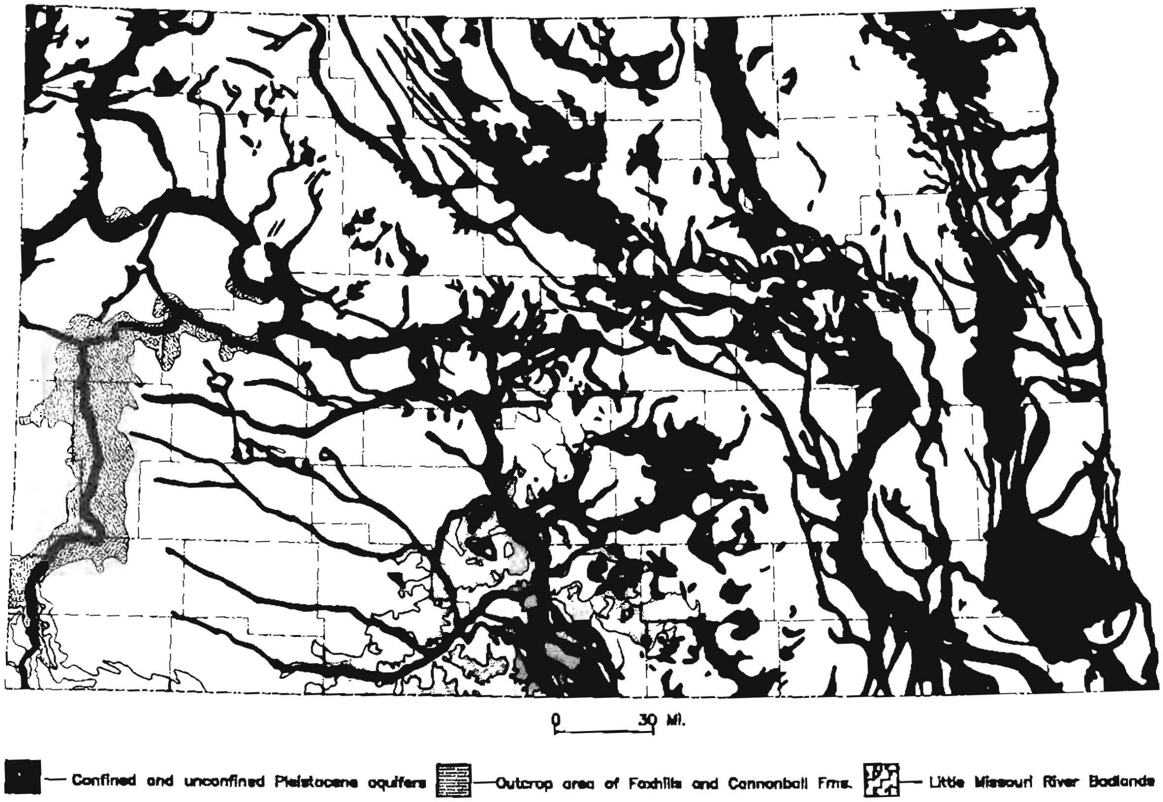

Figure 64. Waste disposal suitability map for North Dakota. (Map was compiled from information in the ND Geological Survey County Bulletins, Parts 1-3).

permit. In the past, city officials or the landfill owner generally prepared the application permit with whatever information was already available (such as data from county bulletins). Geotechnical consultants now routinely perform this task. In the past we were lucky to have one or two boreholes at the site. Today it is commonplace for a geotechnical company to drill 10 to 30 test holes and install numerous monitoring wells around the sites. This additional information has greatly improved the process of evaluating landfill applications.

The heightened public concern for the proper disposal of solid waste will continue to pressure both the private sector and government to seek and permit only those disposal sites that are situated in areas where the geology will minimize the adverse impacts of the landfill leachate. We must recognize these environmental concerns go on long after the landfill has closed. Geologic processes, such as erosion, may be controlled during the time that the landfill is in operation due to engineered designs. However, over the next 100 or 1,000 years these processes will overcome engineering designs unless they are carefully maintained. Since we cannot guarantee that this will happen, we must avoid these types of settings.

Waste reduction, including the reuse and recycling of materials and the proper siting of waste disposal facilities are two important components of the solution for our waste disposal problems. It is our obligation to correctly address our solid waste problems now, rather than choosing the cheapest alternatives and risk burdening future generations with our mistakes.

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APPENDICES

APPENDIX A

LITHOLOGIC DESCRIPTIONS OF DRILL HOLES

WILLISTON LANDFILL

154-101-ne/sw/nw16
#1 and #2

Depth drilled (ft): 38 — Surface elev. (ft): 1937.5
Screen interval (ft): 1 = 20-22.5, 2 = 31.5-36.5

Lithologic Log

Unit	Description	Depth
SOIL		0-1
LOAM	dark to medium brown.	1-3
CLAY	dark to medium brown, silty, clinker and lignite fragments, organic rich.	3-15
SAND & GRAVEL	gravel up to 2 inch diameter.	15-20
SAND	green/gray, clayey, fine to coarse.	20-23
Sentinel Butte Formation		
CLAY	gray/blue, silty.	23-38

154-101-sw/se/nw16
#3, #4, and #10

Depth drilled (ft): 49 — Surface elev. (ft): 1916.3
Screen interval (ft): 3 = 31-36, 4 = 19-24, 10 = 3.5-6.5*

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SAND & GRAVEL	dark brown, organic, up to 2 inch.	1-7
Sentinel Butte Formation		
CLAY	gray/blue to gray/green, silty, FeO stained, FeO concretions.	7-9
SILT	gray to medium gray, very fine grained, contains concretions.	9-17
SILT	medium to dark gray, contains clay and sand lenses.	17-49

154-101-se/nw/nw
#5 and #6

Depth drilled (ft): 25 — Surface elev. (ft): 1928.05
Screen interval (ft): 5 = 11-16* , 6 = 18-23

*** solid pipe is below screen**

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SAND & GRAVEL	dark brown, organic, up to 2 inch.	1-4
SAND & GRAVEL	medium brown to tan, very coarse sand.	4-16
Sentinel Butte Formation		
CLAY	gray/blue, silty, with silt lenses.	16-24

154-101-sw/nw/nw16
#7 and #8

Depth drilled (ft): 34 Surface elev. (ft): 1929.15
Screen interval (ft): 7 = 9.5-14.5*, 8 = 29-34

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SAND & GRAVEL	medium brown, gravel up to 3 inch diameter.	1-9
SAND	medium brown, very coarse grained.	9-16
Sentinel Butte Formation		
CLAY	dark green to blue, silty.	16-18
SILT	gray/green, clayey, micaceous, contains lignite stringers.	18-34

154-101-ne/se/nw16
#9

Depth drilled (ft): 19 Surface elev. (ft): 1918.65
Screen interval (ft): 8.5-13.5*

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SAND	medium brown, contains pebbles.	1-3
GRAVEL	up to 4 inches in diameter.	3-4
SAND	light brown, coarse grained, dirty.	4-6
SAND	medium brown to tan, coarse, clean.	6-12
Sentinel Butte Formation		
CLAY	gray/blue, silty.	12-19

154-101-sw/se/ne16
#11

Depth drilled (ft): 4 | Surface elev. (ft): 1907.7
Screen interval (ft): 1-4

Lithologic Log

Unit	Description	Depth
SOIL		0-.5
GRAVEL		.5-2
Sentinel Butte Formation		
SILT	light gray/blue, clayey.	2-4

154-101-ne/sw/nw16
#12

Depth drilled (ft): 23 | Surface elev. (ft): 1937.2
Screen interval (ft): 9-19*

Lithologic Log

Unit	Description	Depth
SAND	gray/brown, coarse grained.	0-4
CLAY	medium to dark brown, silty, pebbly.	4-12
SAND	light to medium brown, silty, contains lignite fragments.	12-15
GRAVEL		15-17
SAND & GRAVEL	medium brown, moist.	17-21.5
Sentinel Butte Formation		
SILT	light gray/blue, clayey.	21.5-23

154-101-se/se/sw9
#13

Depth drilled (ft): 78 | Surface elev. (ft): 2008.2
Screen interval (ft): 68-78

Lithologic Log

Unit	Description	Depth
FILL	slopewash.	0-4
SAND	light brown, medium sand, some gravel.	4-8
SAND	yellow/brown to red/brown, medium grained, quartz and rock fragments.	8-14
SAND & GRAVEL	up to 3 inches in diameter.	14-19

SAND & GRAVEL	dark brown.	19-32
SAND & GRAVEL	dark brown, dirty, lignite fragments.	32-34
LIGNITE	slag, poor quality, reworked.	34-39
Sentinel Butte Formation		
LIGNITE	better quality.	39-40
CLAY	gray/blue, silty.	40-41
CLAY	dark brown, carbonaceous.	41-43
CLAY	gray blue, silty.	43-48
CLAY	gray/brown, silty.	48-63
CLAY	gray to green/blue, contains thin lignite stringers.	63-78

154-101-sw/nw/nw16
#14

Depth drilled (ft): 8 Surface elev. (ft): 1934
Screen interval (ft): 2-7

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SAND & GRAVEL	brown, dry.	1-2
SAND & GRAVEL	dark brown to black, organic, saturated.	2-6
Sentinel Butte Formation		
CLAY	gray, silty.	6-8

154-101-ne/ne/nw16
#15

Depth drilled (ft): 83 Surface elev. (ft): 2000.9
Screen interval (ft): 73-83

Lithologic Log

Unit	Description	Depth
SOIL		0-1
LOAM	light tan.	1-3
TILL	medium to light brown.	3-14
TILL	dark gray/brown, some lignite pebbles.	14-35
SILT	gray/brown, clayey, clinker and lignite fragments, contains lenses of gravel.	35-73
SAND	medium brown, fine to medium grained, contains pebbles.	73-82
Sentinel Butte Formation		
CLAY	gray/blue, silty.	82-83

154-101-ne/ne/nw16
#16

Depth drilled (ft): 68
Screen interval (ft): 58-68

Surface elev. (ft): 1994.2

Lithologic Log

Unit	Description	Depth
SOIL		0-1
COLLUVIUM	light brown to tan, clayey, pebbles.	1-4
TILL	gray to light gray, clayey, pebbly FeO stains, lignite pebbles.	4-33
GRAVEL	1 to 3 inch diameter.	33-38
SAND & GRAVEL	medium brown, fine to coarse grained, up to 1 inch diameter.	38-48
Sentinel Butte Formation		
CLAY	gray/ blue, silty.	48-62
LIGNITE		62-64
CLAY	gray/blue, silty.	64-67
LIGNITE		67-68

154-101-nw/se/nw16
#17

Depth drilled (ft): 43
Screen interval (ft): not instrumented.

Surface elev. (ft): 1966.1

Lithologic Log

Unit	Description	Depth
FILL		0-9
GARBAGE		9-11
Bedrock		
CLAY	gray to brown, silty, lignite stringers, gypsum crystals.	11-18
SILT	medium brown, clayey, lignite stringers, iron oxide stained, gypsum crystals.	18-23
CLAY	gray to blue, clean.	23-30
LIGNITE		30-30.5
CLAY	dark to medium brown, carbonaceous.	30.5-31.5
CLAY	green to blue, silty.	31.5-35
LIGNITE		35-38
CLAY	medium to dark brown, carbonaceous.	38-40
SILT	green to blue, moist.	40-43

154-101-sw/nw/nw16
#18

Depth drilled (ft): 11 Surface elev. (ft): 1966.1
Screen interval (ft): not instrumented.

Lithologic Log

Unit	Description	Depth
FILL		0-5
GARBAGE		5-11
	Hit obstruction at 11 feet	

154-101-sw/nw/nw16
#19

Depth drilled (ft): 45 Surface elev. (ft): 1966.1
Screened interval (ft): 29-36.5

Lithologic Log

Unit	Description	Depth
FILL		0-4
GARBAGE		4-30
SAND	medium to dark gray, pebbly, moist.	30-33
	Bedrock	
CLAY	gray to blue, silty, moist to saturated.	33-45

154-101-nw/nw/ne16
#20

Depth drilled (ft): 47.5 Surface elev. (ft): 2036.4
Screen interval (ft): not instrumented.

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
TILL	yellow-brown.	1-8
TILL	medium brown.	8-15
SAND AND GRAVEL	medium brown, fine to coarse, grained sand, contains lenses of coarse gravel up to 2 inch diameter, well rounded.	15-47.5

154-101-se/ne/nw16
#21

Depth drilled (ft): 78 Surface elev. (ft): 2023.4
Screened interval (ft): 78-75

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
TILL	light to medium brown, pebbly.	1-19
SAND AND GRAVEL	light brown, medium grained, with gravel lenses.	19-54
Bedrock		
SAND	dark brown to black, organic, lignite slack.	54-59
LIGNITE		59-63.5
CLAY	green micaceous, rootlets.	63.5-78

LINTON LANDFILL

132-77-sw/sw/se12
#1

Depth drilled (ft): 38 feet
Screen interval: 25-28 feet*

Surface elev. (ft): 1759.7

Lithologic Log

Unit	Description	Depth
SOIL		0-1
LOAM	medium to dark brown.	1-3
SAND	gray/brown, very fine to fine grained, subrounded quartz.	3-15
GRAVEL		15-15.3
SAND	medium to dark brown, medium to coarse grained, subrounded quartz and rock fragments, some pebbles.	15.3-26
SAND & GRAVEL		26-27
CLAY	gray/blue, clean.	27-29
SAND	gray/brown, fine to medium grained, silty.	29-38

132-77-se/nw/se12
#2

Depth drilled (ft): 78
Screen interval (ft): 73-78

Surface elev. (ft): 1756.5

Lithologic Log

Unit	Description	Depth
SOIL		0-1
LOESS	light brown outwash.	1-3
SAND	gray/brown, silty, very fine to fine grained.	3-6
SAND	brown, medium to fine grained, some gravel.	6-8
SAND & GRAVEL	medium brown, gravel up to 1 inch in diameter, sand is medium to coarse grained, subrounded.	8-12
CLAY	yellow/brown, silty, micaceous, contains very fine grained sand lenses, iron oxide stained.	12-29
CLAY	medium to dark gray, clean.	29-36
Fox Hills Formation		
SAND	gray/brown, very fine grained sand, moist.	36-43
SAND	medium to light brown, fine to coarse	43-67

	grained, subrounded to rounded, quartz and rock fragments.	
CLAY	gray, silty.	67-78

132-77-nw/se/se12
#3 and #4

Depth drilled (ft): 39 Surface elev. (ft): 1722.2
Screen interval (ft): 3 = 36-39, 4 = 19.5-24.5

Lithologic Log

Unit	Description	Depth
SOIL		0-1
LOESS	medium to dark brown, clayey.	1-3
SAND	gray/brown to brown, fine grained, clinker fragments.	3-6.5
GRAVEL	up to 1 inch in diameter.	6.5-7
SAND & GRAVEL	medium brown, coarse grained, subrounded to subangular, quartz and rock fragments, gravel up to 1 inch.	7-13
Fox Hills Formation		
SILT	gray/brown, contains sand and clay lenses.	13-21
SAND	medium brown, contains fine grained lenses.	21-35
Pierre Formation		
CLAY	dark gray to blue, clean.	35-39

132-77-sw/ne/se12
#5 and #6

Depth drilled (ft): 21.5 Surface elev. (ft): 1688
Screen interval (ft): 5 = 18.5-21.5, 6 = 8.5-12.5

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SILT	dark brown to black, clayey, organic, moist.	1-6
SILT	gray, clayey.	6-10
SAND & GRAVEL	gray/brown, gray/brown, fine to medium grained.	10-21.5

132-77-sw/ne/se12
#7

Depth drilled (ft): 12.75 Surface elev. (ft): 1692

Screen interval (ft): 8.75-12.75

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SILT	dark brown to black, clayey, organic.	1-3
SILT	medium gray, clayey, moist.	3-7
SAND & GRAVEL	medium brown, less than 1 inch in diameter.	7-13

132-77-ne/nw/se12
#8 and #9

Depth drilled (ft): 25   Surface elev. (ft): 1688
Screen interval (ft): 8 = 22-25,   9 = 6-10

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SILT	dark gray/black to medium gray, organic, clayey.	1-4
SAND	medium to light brown, fine to medium grained, some silt.	4-22
Pierre Formation		
CLAY	gray, clean.	22-25

132-77-nw/nw/se12
#10 and #11

Depth drilled (ft): 72   Surface elev. (ft): 1753.75
Screen interval (ft): 10 = 20-25*,   11 = 67-72

Lithologic Log

Unit	Description	Depth
FILL		0-2
GARBAGE	diapers, newspapers, plastic bags, fish heads.	2-13
SAND	light brown, fine to very fine grained.	13-20
SAND	light to medium gray/green, fine to very fine gr.	20-28
CLAY	blue, clean.	28-32
Fox Hills Formation		
CLAY	blue to gray/brown, laminated.	32-33
SAND	gray to light brown, medium to fine grained, some pebble lenses.	33-62
CLAY	light yellow/brown, interbedded with sand and silt, FeO stained, laminated, micaceous.	62-65

SAND	brown, FeO stained.	65-66
CLAY	gray/blue, thin sand lenses.	66-70
SAND	medium brown, fined grained, well sorted.	70-72

132-77-ne/ne/se12
#12

Depth drilled (ft): 20
Screen interval (ft): 12-17

Surface elev. (ft): 1698

Lithologic Log

Unit	Description	Depth
SOIL		0-2
CLAY	dark to medium brown, silty, laminated.	2-10
SAND & GRAVEL	medium to light brown, coarse grained.	10-20

WISHEK LANDFILL

132-71-nw/nw/nw4
#1

Depth drilled (ft): 43 Surface elev. (ft): 2042.5
Screen interval (ft): 40-43 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SILT	gray/brown to medium brown.	1-3
SAND	gray/brown, very fine grained.	3-5
SAND	medium brown, contains gravel up to 1 inch diameter, FeO concretions.	5-7
SAND	yellow/brown, medium-fine grained, subrounded, quartz.	7-14
SILT	light gray/brown, sandy.	14-19
SILT/CLAY	gray/brown, interbedded, clayey, fractured, FeO stained fractures, micaceous.	19-23
SILT	light gray/brown to tan, clayey, very micaceous.	23-28
CLAY	light to medium gray, silty, cuttings contain pebbles.	28-43

132-71-nw/nw/nw4
#2

Depth drilled (ft): 38 Surface elev. (ft): 2039.6
Screen interval: 35.5-38.5 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
GRAVEL	5 mm to 30 cm diameter pebbles.	1-6
SAND	gray/brown, coarse grained.	6-7
SILT	gray, sandy.	7-11
CONC.		11-12.5
SILT	light gray/brown to tan, clayey, micaceous, moist, FeO concretions.	12.5-21
CONC.		21-21.5
CLAY	tan/brown, silty to clean, micaceous FeO stained.	21.5-23
SILT	brown/tan, clayey, pebbly.	23-28

CLAY	gray/blue to medium blue, FeO stained contains gastropod shells.	28-38

132-71-sw/nw/nw4
#3

Depth drilled (ft): 35 Surface elev. (ft): 2039.2
Screen interval (ft): 32-35 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
SILT	medium to dark brown, clayey, contains very fine sand lenses.	1-3
SAND/GRAVEL	medium brown, medium to coarse grained sand and pea size gravel.	3-9
SILT	gray/brown, clayey, FeO stains, moist contains pebbles.	9-18
SAND	gray/brown, silty, micaceous, FeO.	18-23
CLAY	gray/ brown, silty, micaceous.	23-28
SILT	gray/brown, clayey.	28-30
CLAY	gray/blue to dark gray, FeO stains, contains gastropod shells, saturated.	30-35

132-71-se/nw/nw4
#4 and #5

Depth drilled (ft): 18 Surface elev. (ft): 1995.7
Screen interval (ft): 4 = 10-12 feet, 5 = 6-8 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-.5
CLAY	light to medium gray to gray/brown, clean at top, silty at base.	.5-6
SAND & GRAVEL	olive green, medium to coarse grained sand, gravel generally less than 1 inch in diameter.	6-13
CLAY	medium gray, clean.	13-18

132-71-se/nw/nw4
#6 and #7

Depth drilled (ft): 14 Surface elev. (ft): 1994.3
Screen interval (ft): 6 = 12-14 feet, 7 = 6-8 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
CLAY	medium gray to gray/brown, contains organic lenses.	1-4
SILT	blue/gray to green/gray, clayey, moist.	4-6
SAND & GRAVEL		6-7
SILT	brown, clayey, pebbly.	7-9
GRAVEL	coarse.	9-11
CLAY	gray to gray/green.	11-14

132-71-ne/nw/nw4
#8 and #9

Depth drilled (ft): 14.5 Surface elev. (ft): 1994.8
Screen interval (ft): 8 = 12-14 feet, 9 = 6-8 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
CLAY	medium to dark gray, contains organic lenses.	1-6.5
GRAVEL		6.5-11
CLAY	medium gray, silty.	11-12
SAND & GRAVEL		12-13.5
CLAY	medium gray, clean.	13.5-14.5

132-71-sw/ne/nw4
#10

Depth drilled (ft): 10 Surface elev. (ft): 1990.8
Screen interval (ft): 6-8 feet

Lithologic Log

Unit	Description	Depth
SOIL		0-1
CLAY	gray to gray/brown, clean at top, silty	1-3

	at base.	
SAND & GRAVEL	gray/brown, coarse grained, gravel up 2 inches in diameter.	3-10

132-71-nw/nw/nw4
#11

Depth drilled (ft): 41 Surface elev. (ft): 2045.1
Screen interval (ft): 37 to 42 feet

Lithologic Log

Unit	Description	Depth
LAG	contains gravel and boulders.	0-3.5
SAND	red/brown, silty, contains clay lenses.	3.5-14
SILT	gray, clayey, some very fine grained clinker fragments, clay inc. with depth.	14-25
SAND	light brown, very fine grained.	25-28
CLAY	light brown, silty, FeO stained.	28-30
SILT	light gray/brown, clayey.	30-34
CLAY	gray, contains very fine grained sand lenses.	34-41

HARVEY LANDFILL

150-72-ne/sw28
#1 and #2

Depth drilled (ft): 31 Surface Elev. (ft): 1597.87
Screen interval (ft): 1 = 24-26, 2 = 13-18

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
TILL	light brown to gray brown, pebbly, clinker fragments, clayey, and silty.	1-7
SAND	gray/brown to yellow/brown, very fine grained, iron oxide stained.	7-13
SAND	medium to dark brown, very fine grained, saturated.	13-18
GRAVEL		18-21
SAND	medium gray, medium to fine grained.	21-28
TILL	medium to dark gray, pebbly.	28-31

150-72-se/nw/sw28
#3 and #4

Depth drilled (ft): 30 Surface elev. (ft): 1585.45
Screen interval (ft): 3 = 27.5-29.5, 4 = 5-10

Lithologic Log

Unit	Description	Depth
SAND	yellow/brown, very fine grained, fill.	0-2
GARBAGE		2-9
ALLUVIUM	dark brown to gray, pebbly, alternating fine grain to coarse sand and gravel.	9-15
TILL	gray/brown, pebbly.	15-30

150-72-sw/ne/sw28
#5 and #6

Depth drilled (ft): 30 Surface elev. (ft): 1590.87
Screen interval (ft): 5 = 4-9, 6 = 27.5-30

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
SAND	orange/yellow, medium grained, clayey.	1-4
SAND	yellow/brown, contains silty clay lenses, iron oxide stained.	4-9
GRAVEL		9-12
TILL	dark gray, clayey, pebbly, iron oxide stained fractures.	12-30

150-72-ne/ne/nw33
#7

Depth drilled (ft): 10 Surface elev. (ft): 1579.72
Screen interval (ft): 5-9

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
SAND	yellow/brown, very fine to fine grained, some pebble zones and clinker fragments.	1-8
SAND	gray/blue, fine grained.	8-10

150-72-nw/nw/nw33
#8 and #9

Depth drilled (ft): 23 Surface elev. (ft): 1584
Screen interval (ft): 8 = 8.5-13.5, 9 = 21-23

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
SILT	yellow/brown, alternating with gray sand layers, very fine grained, iron oxide pebbles, occasional pebbles.	1-6
SAND	gray/brown, very fine to fine grained.	6-8
TILL	gray/blue, pebbles.	8-23

150-72-ne/nw/sw28
#10

Depth drilled (ft): 12 Surface elev. (ft): 1571.72
Screen interval (ft): 9.5-12.5

Lithologic Log

Unit	Description	Depth
ALLUVIUM	variable lithology, gray/blue to yellow/brown, silty at base, contains clay zones, fine to coarse sand layers, boulders.	0-5
SAND	gray/blue, ranges from very fine to coarse, some small pebbles.	5-9
SILT	gray, clayey, some very fine to fine sand.	9-11
GRAVEL	very coarse.	11-12

150-72-se/sw/nw28
#11 and #12

Depth drilled (ft): 28 Surface elev. (ft): 1540.72
Screen interval (ft): 11 = 26-28, 12 = 11.5-15

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
SAND	light to medium brown, fine to medium grained, some coarse grains, subrounded quartz and rock fragments.	1-5
TILL	gray to yellow/brown, some sand zones.	5-9
TILL	gray/blue, clayey, pebbly.	9-18
SAND	gray/green, fine to very fine grained quartz and rock fragments, some small pebbles.	18-28

150-72-sw/sw/nw28
#13 and #14

Depth drilled (ft): 25 Surface elev. (ft): 1537.62
Screen interval (ft): 13 = 23-25, 14 = 8.5-12.5

Lithologic Log

Unit	Description	Depth
ALLUVIUM	soil.	0-1
SAND	gray to purple/gray, clayey to silty.	1-11
SAND	gray, fine to coarse grained, subrounded quartz and rock fragments, some gravel.	11-25

150-72-se/sw/nw28
#15 and #16

Depth drilled (ft): 25 Surface elev. (ft): 1535.77

Screen interval (ft): 15 = 8-12, 16 = 23-25

Lithologic Log

Unit	Description	Depth
ALLUVIUM	soil.	0-1
SILT	gray to gray/brown, clayey, some sand lenses.	1-5
SAND	gray, very fine grained.	5-12
GRAVEL	very coarse.	12-14
GRAVEL AND SAND	alternating layers.	14-18
TILL	dark gray, clayey, pebbly.	18-25

150-72-nw/se/nw28
#17

Depth drilled (ft): 15
Surface elev. (ft): 1535.77
Screen interval (ft): 13-15

Lithologic Log

Unit	Description	Depth
ALLUVIUM	soil.	0-1
SILT	light to medium brown/gray, very fine sand, clayey.	1-12
GRAVEL	coarse.	12-15

DEVILS LAKE LANDFILL

154-64-nw/ne/ne5
#1 & #2

Depth drilled (ft): 46 Surface elev. (ft): 1480
Screen interval (ft): 1 = 22-28, 2 = 40-45

Lithologic Log

Unit	Description	Depth
TOPSOIL	loess, brownish-black.	0-1
TILL	grayish-brown, clasts up to 5cm.	1-3
TILL	brown, iron stained, clasts 3 to 5cm.	3-8
TILL	light brown, clasts up to 7mm.	8-13
TILL	light brown, clasts up to 7mm gypsum crystal and iron staining concentrated along fracture in core.	13-23
TILL	dark grey, clasts 2mm to 5cm.	23-25
SAND	grayish-black, medium to very coarse grain, cross bedded, poorly sorted.	25-27
TILL	dark grey, clasts 2mm to 3cm.	27-30
SILT TO SAND	grey, sand is very fine grain, well sorted.	30-33
TILL	dark grey, clasts up to 1cm.	33-40
TILL	dark grey, silty, very few clasts, clasts up to 1cm.	40-43
TILL	dark grey, shaley, clasts up to 5cm.	43-46

154-64-nw/ne/ne5
#3 and #4

Depth drilled (ft): 45 Surface elev. (ft): 1479.5
Screen interval (ft): 3 = 38-43, 4 = 13-18

Lithologic Log

Unit	Description	Depth
FILL	reworked material.	0-3
TILL	grayish-brown to medium brown, clasts 3 to 8mm.	3-5
CLAY	grey to black, organic rich, laminated, tree bark and roots common.	5-8
CLAY	grey, no longer organic.	8-10
SILT	light brownish-grey, well sorted.	10-13
SILT	light brown to grey, clayey.	13-15
SAND	light brown, fine grain, well sorted.	15-19
TILL	greenish-grey, clasts 4mm to 2cm.	19-28
TILL	dark grey, shaley, clasts up to 5cm.	28-45

154-64-se/ne/ne5
#5 and #6

Depth drilled (ft): 20 Surface elev. (ft): 1483
Screen interval (ft): 5 = 18-23, 6 = 29-34

Lithologic Log

Unit	Description	Depth
FILL	and reworked material.	0-3
CLAY	black, organic rich.	3-5
SILT AND CLAY	grey to yellowish-brown, interbedded.	5-8
TILL	grayish-brown, clasts 2mm to 8mm, hematite staining common.	8-11
TILL	brown, clasts 2mm to 8mm, hematite staining common.	11-20
SAND	gray/blue, medium grained.	20-33
SAND AND CLAY	interbedded, gray medium grained sand, dark gray clay.	33-35
Pierre Formation(?)		
CLAY	dark gray, shaley.	35-40

154-64-se/ne/ne5
#7 and #8

Depth drilled (ft): 36 Surface elev. (ft): 1481.4
Screen interval (ft): 7 = 31-36, 8 = 17-22

Lithologic Log

Unit	Description	Depth
TOPSOIL	loess, reworked.	0-1
TILL	brownish-grey, clasts 1mm to 5mm, hematite staining.	1-7.5
CLAY	brownish-grey, very hard and compact, fissile, hematite staining.	7.5-9
TILL	bluish-grey, shaley, hard and compact, clasts 3mm to 8mm.	9-16
SAND	brownish-grey, fine to very fine grain, well sorted.	16-22
SAND	grey, fine to very fine, well sorted.	22-32
SILT	grey, well sorted.	32-34
TILL	brownish grey, clasts 3mm to 8mm.	34-36

154-64-sw/ne/ne5
#9

Depth drilled (ft): 28 Surface elev. (ft): 1482.9
Screen interval (ft): 23-28

Lithologic Log

Unit	Description	Depth
TOPSOIL	loess, reworked.	0-1
TILL	brown, clasts 2mm to 8mm.	1-8
TILL	brown, clasts 2mm to 8mm.	8-18
TILL	brown, clasts 2mm to 8mm.	18-20
TILL	brown, silty, clasts 2mm to 8mm.	20-23
SAND AND SILT	brown, sand varies from medium grain to very fine grain, well sorted.	23-25
SAND	brown, varies from very fine to fine, well sorted.	25-28

154-64-ne/ne/ne5
#10 and #11

Depth drilled (ft): 28 Surface elev. (ft): 1480
Screen interval (ft): 10 = 21-26, 11 = 13-18

Lithologic Log

Unit	Description	Depth
FILL	and reworked material.	0-5
REFUSE		5-9
TILL	grayish-green, clasts 2mm to 10mm, large shale clasts, strong odor.	9-13
TILL	brown to grey, clasts 2mm to 10mm.	13-18
SAND AND TILL	grayish brown, sand varies from very coarse to very fine, well sorted.	18-25
TILL	dark blue, shaley, hematite staining along possible fractures.	25-28

155-64-nw/sw/sw33
#12 and #13

Depth drilled (ft): 43 Surface elev. (ft): 1476.2
Screen interval (ft): 12 = 38-43, 13 = 20-25

Lithologic Log

Unit	Description	Depth
TOPSOIL	loess, reworked.	0-1
CLAY	light brownish-grey.	1-3
TILL	light brown, clasts 5mm to cm.	3-5
TILL	dark brown, clasts 5mm to 2cm.	5-16
TILL	dark grey, clasts 5mm to 2cm.	16-18
TILL	blackish-grey, clasts 5mm to 2cm.	18-19

TILL	bluish-black, clasts up to 1cm.	19-21
SAND	bluish-grey, very fine grain, well sorted.	21-28
SAND	bluish-grey, very fine grain to medium grain, well sorted.	28-43

HILLSBORO LANDFILL

146-51-nw/se/sw24
#1 and #2

Depth drilled (ft): 32 Surface elev. (ft): 930
Screen interval (ft): 1 = 30-32, 2 = 7-12

Lithologic Log

Unit	Description	Depth
FILL		0-2
SAND	dark grayish brown, color wet-very dark grayish brown, fine-medium grained, moderately sorted, subangular-subrounded.	2-4
SAND AND SILT	light yellowish brown, color wet-brown, fine-medium grained, subangular-subrounded, some angular grains, sphericity, FeO stain on sand grains.	4-17
SAND AND SILT	very pale brown, color wet-dark yellowish brown, fine-grained, subrounded, well sorted.	17-22
SAND AND SILT	light yellowish brown, color wet-brown, fine grained, well-sorted, angular-subrounded, sphericity.	22-27
SAND AND SILT	light brownish gray, color wet-grayish brown, fine-medium grained, well sorted, subangular-subrounded.	27-30
SAND	silt, and some clay, gray, color wet-dark gray, very fine to fine grained, well sorted.	30-32

146-51-ne/se/sw24
#3 and #4

Depth drilled (ft): 32 Surface elev. (ft): 931
Screen interval (ft): 3 = 29.5-31.5, 4 = 7.5-12.5

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-2
SAND AND SILT	medium brown, fine to medium grained.	2-5
SAND AND SILT	light yellow brown, fine-medium grained.	5-7
SAND AND SILT	alternating red and gray layers, very fine-grained, well sorted, subrounded.	7-9
SAND AND SILT	light yellowish brown, color wet-dark yellowish brown, very fine to fine grained, well sorted, subrounded.	9-22
SAND AND SILT	pale brown, color wet-dark grayish brown, similar to above.	22-32

146-51-nw/se/sw24
#5 and #6

Depth drilled (ft): 32 — Surface elev. (ft): 932

Screen interval (ft): 5 = 28-30, 6 = 7-12

Lithologic Log

Unit	Description	Depth
TOPSOIL		0-1
SAND	brown, color wet-dark brown, fine to medium grained, moderately sorted, subangular.	1-3
SAND AND SILT	very pale brown, color wet-dark yellowish brown, very fine to fine grained, well sorted, subrounded, FeO stained.	3-6
CLAY AND SILT	very pale brown, and yellowish red, color wet-yellowish brown and dark yellowish brown, FeO stained.	6-7.5
SAND AND SILT	light yellowish brown, color wet-dark yellowish brown, very fine grained, moderately sorted, subangular.	7.5-12
SAND	some silt, pale brown, color wet-dark brown, medium-coarse grained, well sorted, subangular to subrounded.	12-22
SAND	pale brown, color wet-dark brown, fine to medium grained, very well sorted, subrounded to rounded.	22-32

146-51-sw/se/sw24
#7 and #8

Depth drilled (ft): 32 — Surface elev. (ft): 935

Screen interval (ft): 7 = 28-30, 8 = 7-12

Lithologic Log

Unit	Description	Depth
FILL		0-2
SAND	light yellowish brown, color wet-dark yellowish brown, very fine grained, well sorted, subrounded, FeO stained, micaceous.	2-6
SILT AND CLAY	very pale brown and yellowish red, color wet-dark brown, FeO stained.	6-12
SAND AND SILT	light yellowish brown, color wet-dark brown, very fine grained, well sorted, subrounded, FeO stained, some mica.	12-17
SAND	some silt, light yellowish brown, color wet-dark brown, very fine grained, well sorted, subrounded, FeO stained, micaceous.	17-32

146-51-sw/se/sw24
#9

Depth drilled (ft): 82.5 Surface elev. (ft): 932
Screen interval (ft): 53.5-58.5

Lithologic Log

Unit	Description	Depth
FILL		0-2
SAND AND SILT	very pale brown, color wet-yellowish brown, fine grained, well sorted, subangular to subrounded, some FeO staining.	2-5
SAND	pale brown, thinly laminated, color wet-dark yellowish brown, fine-grained, well sorted, subangular to subrounded.	5-7.5
SAND AND SILT	light gray and light yellowish brown, color wet-grayish brown and yellowish brown, very fine grained, well sorted, subrounded, FeO stained, thinly laminated in lower 5 feet.	7.5-15
SAND AND SILT	pale brown, color wet-dark brown, very fine to fine grained, well sorted, subrounded.	15-24
CLAY AND SILT	gray.	24-25
SAND AND SILT	pale brown, color wet-dark grayish brown, very fine grained, micaceous.	25-30
SAND	light brownish gray, color wet-grayish brown, medium grained, subangular to subrounded, sphericity, moderately sorted.	30-40
SAND	gray, color wet-gray, salt and pepper, medium to coarse grained, moderately sorted, subangular to rounded, some FeO stain, sand coarsens downward.	40-82.5

146-51-sw/se/sw24
#10 and #11

Depth drilled (ft): 25 Surface elev. (ft): 932
Screen interval (ft): 10 = 23-25, 11 = 11.5-17

Lithologic Log

Unit	Description	Depth
FILL/TOPSOIL		0-2
CLAY	light gray, color wet-brown.	2-2.5
SAND	light yellowish brown, color wet-yellowish brown, very fine grained, well sorted, subangular, FeO stained, some mica flakes.	2.5-5
SAND	pale brown, color wet-yellowish brown, fine	5-12.5

	grained, moderately sorted, subangular-subrounded, thinly laminated, FeO stained lamina prominent, micaceous.	
SAND	pale brown, color wet-dark brown, laminae absent, fine-medium grained, subrounded-well rounded, moderately sorted.	12.5-17
CLAY AND SILT	very pale brown, color wet-yellowish brown.	17-17.5
SAND AND SILT	pale brown, color wet-dark brown, medium grained, moderately sorted, subrounded to rounded.	17.5-25

APPENDIX B

Monitoring Well Information

Table 7. The Screened Intervals for Monitoring Wells at the Williston Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)	Pipe Below Screen
1	1937.5 (1.17)	1937.5	20 - 22.5	
		1938.67 (Pre 10/88)		
2	1937.5 (.33)	1937.83	31 - 36.5	
3	1916.3 (.42)	1916.72	31 - 36	
4	1916.3 (.58)	1916.88	19 - 24	
5*	1928.05 (.21)	1928.26	14 - 19	3
6	1928.05 (.13)	1928.18	18 - 23	
7*	1929.15 (.42)	1929.57	9.5 - 14.5	5
8	1929.15 (.33)	1929.48	29 - 34	
9*	1918.65 (+.38)	1919.03	8.5 - 13.5	5
10*	1916.3 (.33)	1916.63	3.5 - 6.5	5
11	1907.7 (.25)	1907.95	1 - 4	
12*	1937.2 (1.17)	1938.37	9 - 19	3
		1937.2 (Pre 10/88)		
13	2008.2 (.25) +3	2011.2	68 - 78	
		2008.45 (Pre 10/88)		
14	1934 ≈	1934	2 - 7	
15	2000.9 (.92)	2001.82	73 - 83	
16	1994.2 (.5)	1994.7	58 - 68	
17			5.2 - 7.5	
19*	1966.1 (2.92)	1969.02	29 - 36.5	9
21	2023.4 (2)	2025.4	75 - 78	

*** Perched Water Well**

Table 8. The Screened Intervals for Monitoring Wells at the Linton Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)	Pipe Below Screen
1*	1759.7	1761.37	25 - 28	10
2	1756.5	1756.71	73 - 78	
3	1722.2	1722.33	36 - 39	
4	1722.2	1722.03	19.5 - 24.5	
5	1688	1688.33	18 - 21.5	
6	1688	1688.33	8 - 12.5	
7	1692	1692.33	8 - 12.75	
8	1688	1688.25	22 - 25	
9	1688	1688.21	6 - 10	
10*	1753.75	1756	20 - 25	10
11	1753.75	1755.83	67 - 72	
12	1698	1701	12 - 17	
TCT	1753.5	1756.5		

*** Perched Water Well**

Table 9. The Screened Intervals for Monitoring Wells at the Wishek Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)
1	2042.5	2042.17	40 - 43
2	2039.6	2039.85	35.5 - 38.5
3	2039.2	2039.43	32 - 35
4	1995.7	1996.37	10 - 12
5	1995.7	1996.03	6 - 8
6	1994.3	1996.05	12.8 - 14.8
7	1994.3	1996.05	6 - 8
8	1994.8	1996	12 - 14
9	1994.8	1991.75	6 - 8
10	1990.8	1992.88	6 - 8
11	2045.1	2046.33	37 - 42

Table 10. The Screened Intervals for Monitoring Wells at the Harvey Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)
1	1597.87	1598.12	24 - 26
2	1597.87	1598.04	13 - 18
3	1585.45	1585.87	27.5 - 29.5
4	1585.45	1585.78	5 - 10
5	1590.87	1593.54	4 - 9
6	1590.87	1593.29	27.5 - 30
7	1579.72	1581.39	5 - 9
8	1584	1585.67	8.5 - 13.5
9	1584	1584.42	21 - 23
10	1571.72	1572.03	9.5 - 12.5
11	1540.72	1541.97	26 - 28
12	1540.72	1541.47	11.5 - 15
13	1537.62	1537.95	23 - 25
14	1537.62	1538.04	8.5 - 12.5
15	1535.77	1536.27	8 - 12
16	1535.77	1536.02	23 - 25
17	1535.77	1536.01	13 - 15

Table 11. The Screened Intervals for Monitoring Wells at the Devils Lake Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)
1	1480	1483.08	23 - 28
2	1480	1480.03	40 - 45
3	1479.5	1481.42	38 - 43
4	1479.5	1480.92	13 - 18
5	1483	1485.25	18 - 23
6	1483	1485.05	29 - 34
7	1481.4	1483.04	31 - 36
8	1481.4	1484.98	17 - 22
9	1482.9	1484.98	23 - 28
10	1480	1482.67	21 - 25
11	1480	1482.58	13 - 18
12	1476.2	1479.87	20 - 25
13	1476.2	1478.07	38 - 43

Table 12. The Screened Intervals for Monitoring Wells at the Hillsboro Landfill

Well #	L. S. Elevation	Reading Elevation	Screened Interval (feet below the surface)
1	930		30 - 32
2	930		7 - 12
3	931		29.5 - 31.5
4	931		7.5 - 12.5
5	932		28 - 30
6	932		7 - 12
7	935		28 - 30
8	935		7 - 12
9	932		53.5 - 58.5
10	932		23 - 25
11	932		11.5 - 17
12	933		14.5 - 24.5
13	932		11.9 - 21.9
14	931		8 - 18
15	930		7.5 - 17.5

APPENDIX C

Water Levels in Monitoring Wells

WILLISTON LANDFILL

Well No.	1	2	3	4	5	6	7	8	9	10	12	13	15	16	19	21
SEPT.,87	1918.71	1918.29	1906.68	1906.68	1917.45	1917.46	1912.29	1915.6	1908.34	1911.86		1942.81	1931.62	1942.76		
OCT.,87	1918.64	1918.29	1906.63	1906.63	1917.48	1917.4	1915.18	1915.64	1907.69	1911.65	1918.72	1942.77	1931.52	1942.96		
NOV.,87	1919.4	1917.44	1906.7	1906.7	1917.55	1917	1916	1915.67	1907.75	1911.36	1918.69	1942.84	1931.56	1942.77		
DEC.,87																
JAN.,88	1919.34	1917.39	1906.8	1906.88	1917.45	1916.97	1915.56	1915.31	1907.3	1911.3	1918.56	1942.75	1931.55	1942.72		
FEB.,88																
MAR.,88	1919.2	1917.24	1906.75	1906.75	1917.28	1916.86	1915.95	1915.7	1907.21	1911.26	1918.43	1942.63	1931.4	1942.57		
APR.,88																
MAY,88	1919.29	1917.24	1906.7	1906.75	1917.25	1916.82	1915.96	1915.66	1907.75	1911.25	1918.41	1942.65	1931.4	1942.72		
JUNE,88	1919.1	1916.88	1906.27	1906.13	1917.1	1916.67	1915.44	1915.19	1908.07	1911.16	1918.3	1942.63	1931.28	1942.65		
JULY,88	1919.03	1916.82	1906.17	1906.2	1917.05	1916.56	1915.31	1914.94	1907.56	1911.08	1918.23		1931.18	1942.62		
AUG.,88	1919.09	1916.67	1905.9	1905.9	1916.87	1916.37	1914.56	1914.06	1907.15	1911.1	1918.21	1942.8	1931.15	1942.77		1960.64
SEPT.,88																
OCT.,88	1918.66	1916.7	1906.44	1906.44	1916.53	1916.05	1915.15	1915.01	1906.25	1910.74	1918.12	1942.58	1930.97	1942.68	1919.1	1960.45
NOV.,88	1918.64	1916.82	1906.4	1906.4	1916.35	1915.87	1915.26	1915.06	1906.63	1910.4	1918.09	1942.48	1930.75	1942.58	1919.19	1960.39
DEC.,88	1918.62	1916.67	1906.4	1906.43	1916.24	1915.76	1915.24	1915.04	1906.7	1910.2	1918.07	1942.48	1930.65	1942.62	1919.25	1960.34
JAN.,89	1918.59	1916.51	1906.25	1906.28	1916.13	1915.62	1915.14	1914.91	1906.69	1909.95	1918.01	1942.5	1930.52	1942.52	1919.27	1960.31
FEB.,89	1918.54	1916.41	1906.43	1906.45			1914.96	1914.78	1906.69	1909.28	1917.98	1942.51	1930.43	1942.54	1919.42	1960.17
MAR.,89	1918.54	1916.59	1906.79	1906.8			1915.58	1915.44	1906.78	1909.1	1917.99		1930.45	1942.6	1919.45	1960.17
APR.,89	1918.58	1916.61	1906.73	1906.75	1916.35	1915.9	1916.06	1915.69	1907.78	1908.89	1918.05		1930.31	1942.5	1919.47	1960.13
MAY,89	1918.62	1916.61	1906.65	1906.65	1916.32	1915.86	1915.91	1915.52	1908.78	1908.76	1918.08		1930.3	1942.57	1919.54	1960.29
JUNE,89	1917.33	1916.47	1906.53	1906.53	1916.18	1915.86	1915.46	1915.37	1909.85	1906.95	1917.99	1942.31	1930.28	1942.89	1919.09	1960.54
JULY,89																
AUG.,89	1918.44	1916.18	1906.07	1906.09	1915.85	1915.4	1914.64	1914.46	1909.11	1906.89	1917.91	1942.45		1943.76		1960.93
SEPT.,89																
OCT.,89	1917.26	1916.14	1906.2	1906.2	1915.65	1915.27	1914.91	1914.79	1908.03	1906.8	1917.87	1942.34	1930.6	1943.77	1919.14	1960.94
NOV.,89																
DEC.,89	1917.44	1916.29	1906.17	1906.2	1915.5	1914.96	1915.06	1914.88	1907.65	1907.03	1917.99	1942.5	1930.73	1943.77	1919.25	1960.96
JAN.,90	1917.57	1916.34	1906.42	1906.42	1915.4	1914.82	1915.16	1915.16	1907.3	1907.5	1918.05	1942.52	1930.9	1943.85	1919.37	1960.92
FEB.,90																
MAR.,90	1917.54	1916.45	1906.73	1906.73	1915.38	1914.82	1915.31	1915.26	1910.05	1907.81	1918.04	1942.58	1930.97	1943.86	1919.49	1960.79
APR.,90																
MAY,90																
JUNE,90	1917.39	1916.39	1906.51	1906.53	1915.35	1914.77	1915.29	1915.04	1910.85	1907.89	1917.95	1942.66	1930.93	1943.88	1919.72	1960.55
JULY,90	1917.29	1916.19	1906.15	1906.75	1915.25	1914.67	1914.86	1914.56	1910.33		1917.91	1942.61	1930.7	1943.67	1919.17	1960.39

LINTON LANDFILL

Well No.	1	2	3	4	5	6	7	8	9	10	11	12
SEPT.,87	1741.26	1685.38	1703.1	1702.87	1682.26	1682.26	1682.29	1681.95	1681.68			
OCT.,87	1741.16	1685.35	1703.04	1702.8	1682.16	1682.1	1682.22	1681.85	1681.58			
NOV.,87	1740.82	1684.96	1702.88	1702.66		1681.98	1682.23		1681.51			
DEC.,87												
JAN.,88	1740.62	1685.11	1702.78	1702.53	1681.98	1681.88	1682.03	1681.45	1681.61			
FEB.,88												
MAR.,88	1740.26	1686.14	1704.15	1703.87	1684.95	1684.75	1684.19	1684.61	1684.31			
APR.,88												
MAY,88	1740.17	1687.11	1705.08	1704.88	1684.68	1684.53	1684.58	1684.05	1683.81			
JUNE,88	1739.95	1685.81	1703.48	1703.25	1682.77	1684.38	1682.82	1682.34	1682.08	1733.4	1688.82	1684.27
JULY,88	1739.86	1685.15	1702.78	1702.54	1681.93	1681.9	1681.86	1681.49	1681.25	1733.35	1688.46	1683.94
AUG.,88	1739.59	1684.24	1701.96	1701.72	1681.16	1681.14	1681.11	1680.84	1680.57	1733.25	1688.03	1683.63
SEPT.,88												
OCT.,88	1739.32	1683.68	1701.5	1701.26	1680.72	1680.69	1680.68	1680.44	1680.19	1733.17	1687.79	1683.89
NOV.,88	1739.27	1683.71	1701.58	1701.48	1680.81	1680.83	1681	1680.55	1680.31	1733.25	1687.88	1684.02
DEC.,88	1739.32	1684.15	1701.76	1701.5	1680.98	1680.85	1681.05	1680.71	1680.47	1733.3	1688.03	1684.05
JAN.,89	1738.99	1683.74	1701.68					1680.68	1680.44	1733.18	1687.83	1684.05
FEB.,89	1739.28	1684.03	1701.75		1680.98	1680.83	1681.01	1680.7	1680.46	1733.2	1687.95	
MAR.,89	1738.82	1683.85	1701.75	1701.51	1681.01	1680.87		1680.79	1680.55	1733.1	1687.83	1684.85
APR.,89	1738.85	1687.26	1705.49	1705.24	1686.48	1686.27	1685.51	1686.8	1686.53	1733.08	1688.77	1685.8
MAY,89	1738.77	1687.23	1705.17	1704.94	1684.76	1684.61	1684.6	1684.43	1684.2	1733.03	1688.89	1685.3
JUNE,89	1738.67	1686.01	1703.9	1703.66	1683.18	1683.03	1683.09	1682.83	1682.59	1732.97	1688.61	1684.48
JULY,89	1738.51	1684.85	1702.61	1702.41	1681.84	1681.71	1681.78	1681.54	1681.3	1732.85	1687.98	1683.88
AUG.,89	1738.47		1702.18	1701.98	1681.38	1681.26	1681.33	1681.07	1680.83	1732.8	1687.84	1683.7
SEPT.,89	1738.89		1703.55	1703.33	1683.57	1683.33	1683.1	1683.38	1683.05	1732.75	1688.16	1684.94
OCT.,89												
NOV.,89												
DEC.,89												
JAN.,90												
FEB.,90												
MAR.,90												
APR.,90												
MAY,90												
JUNE,90	1738.26	1685.46	1703.38	1703.07	1682.49	1682.41	1678.44	1682.15	1681.93	1732.48	1688.2	1684.69

WISHEK LANDFILL

Well No.	1	2	3	4	5	6	7	8	9	10	11	NDSWC
SEPT.,87	2017.17	2019.97	2017.73	1992.86	1992.52	1991.69	1991.44	1991.33	1991.22	1987.14		1990.28
OCT.,87	2017.04	2019.74	2017.58	1992.76	1992.45	1991.49	1991.26	1991.23	1991.12	1987.01		
NOV.,87	2015.87	2018.35	2016.53	1993.4	1993.06	1992.78	1992.58	1991.78	1991.68	1987.43		
DEC.,87												
JAN.,88		2017.15	2015.63	1992.37	1992.58	1991.45	1991.25	1991.03	1990.98	1986.73		1989.9
FEB.,88												
MAR.,88	2014.18	2016.79	2014.87	1993.32	1993.04	1993.1	1992.93		1992.43	1987.99		1991.06
APR.,88	2013.92	2016.15	2014.58	1994.05	1993.98	1993.75	1993.55	1992.93	1992.88	1988.53		1991.65
MAY,88	2013.56	2015.67	2014.33	1993.68	1993.57	1993.33	1993.16	1992.59	1992.53	1988.19		1991.26
JUNE,88	2013.12	2015.24	2014.07	1992.55	1992.52	1991.89	1991.54	1991.28	1991.18	1986.97	2016.81	1990.1
JULY,88	2012.58	2014.88	2013.79	1991.24	1991.19	1990.36	1990.08	1990.24	1990.17	1986.11	2016.45	1989.29
AUG.,88	2011.81	2014.39	2013.36	1990.89	1990.81	1990.37	1990.14	1990	1989.9	1985.86	2015.86	1988.96
SEPT.,88												
OCT.,88	2010.77	2013.9	2012.86	1991.12	1991.04	1990.59	1990.37	1990.08	1990	1985.86	2015.15	1988.93
NOV.,88	2010.07	2013.57	2012.55	1991.45	1991.11	1990.8	1990.65	1990.28	1990.23	1986.01	2014.7	
DEC.,88	2009.69	2013.45	2012.39	1991.47	1991.38	1990.8	1990.6	1990.3	1990.25	1986.05	2014.47	
JAN.,89	2009.25	2012.85	2011.81	1991.47	1991.43	1990.8	1990.6	1990.28	1990.22	1986.02	2013.7	1989.11
FEB.,89		2012.63	2011.55	1991.17	1991.13	1990.5	1990.3	1990.13	1990.05	1985.83	2013.55	
MAR.,89	2008.62	2012.23	2011.03	1991.69	1991.61	1991.53	1991.3	1991.1	1991.01		2012.97	
APR.,89	2010.64	2016.55	2011.35	1993.53	1993.58	1993.81	1993.61	1993.13	1993.05	1988.74	2014.29	1991.73
MAY,89	2011.83		2011.83	1993.52	1993.45	1993.43	1993.21	1992.75	1992.67	1988.16	2015.22	1991.25
JUNE,89	2011.96	2014.88	2011.88	1992.43	1992.34	1991.69	1991.47	1991.35	1991.28	1987	2015.02	
JULY,89	2011.51	2014.02	2011.58	1991.09	1991.03	1990.63	1990.38	1990.36	1990.28	1986.16	2014.55	1989.35
AUG.,89	2011.27	2013.81	2013.46	1990.76	1990.72	1990.32	1990.07	1990.04	1989.95	1985.9	2014.3	1989.07
SEPT.,89	2011.59	2015.18		1991.42	1991.38	1991.05	1990.8	1990.58	1990.48	1986.28	2014.81	1989.44
OCT.,89												
NOV.,89												
DEC.,89												
JAN.,90												
FEB.,90												
MAR.,90												
APR.,90												
MAY,90												
JUNE,90	2007.58	2011.7	2011.7	1992.92	1992.88	1993.29	1993.05	1992.13	1992.03	1987.57	2011.15	

HARVEY LANDFILL

Well No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEPT.,87	1582.4	1582.6	1581.18	1581.29	1586.52	1586.88	1577.12	1579.5	1579.38	1567.44	1537.97	1533.48	1530.98	1531.02
OCT.,87	1582.67	1582.29	1581.24	1581.45	1586.34	1585.1	1577	1579.38	1579.27	1567.32	1537.9	1533.63	1530.73	1531.22
NOV.,87	1582.55	1582.17	1580.97	1580.98	1586.04	1586.24	1576.84	1579.27	1579.22	1567.6	1537.97	1534.07	1531.18	1531.09
DEC.,87														
JAN.,88	1582.4	1582.1	1581.23	1581.48	1585.27	1585.48	1575.76	1578.81	1578.84	1567.64		1533.84	1530.81	
FEB.,88														
MAR.,88	1582.24	1581.87	1582.52	1582.75	1587.13	1586.88	1577.09	1580.6	1580.32	1568.1		1534.15	1531.18	1531.25
APR.,88	1581.98	1582.2	1582.79	1583.45	1588.54	1588.93	1577.24	1579.53	1579.43	1569.15	1538.36	1535.04	1531.26	1531.18
MAY,88	1582.01	1582.19	1582.56	1582.93	1587.7	1588.2	1577.17	1579.6	1579.53	1568.69	1538.38	1534.84	1531.19	1531.12
JUNE,88	1581.98	1582.16	1581.38	1581.73	1586.89	1587.16	1576.12	1579.24	1579.17	1567.56	1538.21	1534.5	1530.98	1530.97
JULY,88	1581.88	1582.06	1580.85	1581.12	1586.39	1586.36	1575.47	1578.81	1578.73	1567.41	1538.15	1534.38	1530.63	1530.49
AUG.,88	1581.75	1581.93	1580.1	1580.4	1585.63	1585.74	1574.88	1578.27	1578.22	1566.59	1537.44	1532.96	1529.47	1529.36
SEPT.,88														
OCT.,88	1581.5	1581.72	1580.59	1580.69	1585.37	1585.45	1575.21	1578.06	1577.99	1566.23	1536.92	1532.09	1528.58	1528.48
NOV.,88	1581.39	1581.62	1581.12	1581.24	1585.26	1585.5	1575.45	1577.99	1577.92	1566.98	1537.28	1533.07	1529.25	1529.2
DEC.,88	1581.42	1581.62	1581.12	1581.21	1584.99	1585.16	1575.11	1577.97	1578.02	1566.78	1537.34	1532.81	1529.2	1529.14
JAN.,89		1581.49	1581.11	1581.22	1585.21	1585.09	1574.94			1566.03		1532.41		
FEB.,89	1581.22	1581.42	1581.19	1581.3	1585.42	1585.52	1575.01	1577.75	1577.72	1565.83		1532.42	1528.63	1528.5
MAR.,89	1581.16	1581.37	1582.26	1582.17	1585.39	1585.28	1575.68	1579.57	1579.17	1566.33		1532.6	1528.63	1528.71
APR.,89	1581.39	1581.56	1583.2	1583.15	1588.3	1587.55	1576.99	1579.3	1578.82			1535.11	1530.5	1530.39
MAY,89	1581.52	1581.7	1582.33	1582.38	1587.74	1588.07	1576.47	1578.82	1578.77	1569.15	1538.86	1535.3	1530.55	1530.54
JUNE,89	1581.55	1581.72	1582.16	1582.28	1587.16	1587.49	1576.51	1578.74	1578.72	1569.3	1538.83	1538.23	1530.64	1530.63
JULY,89	1581.38	1581.58	1580.87	1581.1	1586.52	1586.54	1575.47	1578.33	1578.26	1566.85	1538.02	1533.52	1530.01	1529.89
AUG.,89	1581.32	1581.52	1580.45	1580.7	1586.04	1586.49	1575.2	1578.05	1577.98	1566.07	1537.62	1532.95	1530.22	1530.12
SEPT.,89	1581.18	1581.39	1580.82	1581	1586.16	1586.31	1576.8	1577.92	1577.83	1566.55	1537.38	1533.02	1530.43	1530.44
OCT.,89	1581.14	1581.06	1581.22	1581.33			1575.77	1577.74	1577.7	1566.55	1536.27	1533.09	1530.1	1530.04
NOV.,89														
DEC.,89	1581.12	1581.32	1581.51	1581.63	1586.07	1586.14	1575.77	1577.72	1577.67	1567	1537.67	1533.77	1530.5	1530.46
JAN.,90														
FEB.,90														
MAR.,90														
APR.,90														
MAY,90														
JUNE,90	1581	1581.19	1582.67	1582.71	1587.69	1587.89	1576.79	1578.47	1578.42	1569.12	1538.47	1535.07	1531.87	1531.86

DEVILS LAKE LANDFILL

well no	1	2	3	4	5	6	7	8	9	10	11	12	13
L.S. elev.	1480	1480	1479.5	1479.5	1483	1483	1481.4	1481.4	1482.9	1480	1480	1476.2	1476.2
reading e.	1483.08	1480.3	1481.42	1480.92	1485.25	1485.5	1483.4	1484.98	1484.98	1482.67	1482.58	1479.87	1478.7
JUNE,88	1468.02	1466.55	1466.95	1469.4	1473.62	1473.72	1466.34	1466.33	1465.9	1470.58	1470.91	1468.24	1468.46
JULY,88													
AUG.,88													
SEPT.,88													
OCT.,88	1466.15	1465.13	1465.14	1467.67	1472.49	1472.46	1464.75	1464.67	1464.31	1469.27	1470.28	1466.16	1466.36
NOV.,88	1465.56	1464.72	1464.84	1467.5	1472.19	1472.2	1470.07	1464.33	1464.33	1468.87	1469.92	1465.7	1465.97
DEC.,88	1465.49	1464.49	1464.59	1467.37	1472.45	1472.31	1464.27	1464.11	1463.92	1468.76	1469.62	1465.6	1465.81
JAN.,89													
FEB.,89	1464.91	1463.99	1464.2	1467.27	1472.03	1471.88	1463.71	1463.62	1463.29	1468.2	1469.13	1465.47	1465.71
MAR.,89	1464.35	1463.64	1463.7	1467.17	1471.25	1471.17	1463.35	1463.23	1462.91	1467.67	1469.14	1464.55	1465.77
APR.,89	1466.23	1464.67	1465.25	1471.83	1474.51	1474.9	1465.44	1466.07	1464.7	1467.55	1468.37	1465.43	1465.64
MAY,89													
JUNE,89	1466.8	1465.12	1465.77	1470.46	1473.22	1473.34	1465.23	1465.25	1464.72	1467.64	1468.39	1466.07	1466.3
JULY,89	1465.94	1464.54	1465.2	1469.24	1471.83	1471.65	1464.42	1464.38	1463.95	1467.52	1468.21	1465.65	1465.88
AUG.,89													
SEPT.,89	1464.74	1463.78	1464.07	1468.17								1464.9	1465.14
OCT.,89													
NOV.,89													
DEC.,89													
JAN.,90													
FEB.,90													
MAR.,90													
APR.,90													
MAY,90													
JUNE,90	1463.26	1462.38	1463.24	1471.07	1470.81	1470.82	1462.5	1462.33	1462.08	1465.82	1466.88	1463.21	1463.4

HILLSBORO LANDFILL

WELL NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NOV.,87	922.52	922.47	921.58	921.45	921.93	921.89	923.03	DRY					10.4	11.1	10.2
DEC.,87	922.62	922.27	920.38	921.25	921.43	920.89	923.23		921.42	922.2	921.95		10.5	11.2	11
JAN.,88	922.12	922.27	922.08	921.35	921.63	921.49	922.63		920.92	921.9	921.45		11	11.7	10.6
FEB.,88	921.72	922.27	921.08	918.85	921.53	919.69	922.53		920.82	921.6	921.25		11.2	11.6	10.7
MAR.,88															
APR.,88	921.02	925.17	922.98	918.65	922.33	919.29	923.43		921.72	922.4	922.05		10.2	11	9
MAY,88	922.92	924.67	923.08	919.05	922.43	919.69	923.43		921.82	922.6	922.25		10.1	10.6	8.9
JUNE,88	922.42	922.87	921.18	921.05	922.23	921.59	922.83		921.42	922.1	921.85		10.4	11.1	10.6
JULY,88	920.92	920.47	919.58	918.55	920.83	920.49	921.93		919.92	920.9	920.65		11.6	12.3	12.7
AUG.,88	920.32	919.57	917.38	918.65	916.43	920.09	921.03		919.72	920.6	920.05		12.1	12.9	13.3
SEPT.,88															
OCT.,88															
NOV.,88															
DEC.,88															
JAN.,89															
FEB.,89															
MAR.,89															
APR.,89															
MAY,89															
JUNE,89	920.82	920.61	919.77	920.07	920.28	920.36	920.78		919.2	919.62	919.48	14.27	14.32	14.94	13
JULY,89	919.53	918.92	918.31	918.45	919.23	919.64	919.69		918.09	918.59	918.51		15.35		
AUG.,89	919.2	918.12	917.93	918.45	918.86	919.64	919.29		917.72	918.2	918.12	15.78	15.74	16.44	16.17
SEPT.,89															
OCT.,89															
NOV.,89															
DEC.,89	918.64	918.12			918.25	919.64	918.73		917.12	917.6	917.5		16.35		
JAN.,90															
FEB.,90															
MAR.,90															
APR.,90															
MAY,90															
JUNE,90	919.2	918.67	918.18	918.4	918.63	919.64	919.13		917.5	917.95	917.8		16.02		14.85

APPENDIX D

Groundwater and Surface Water Chemistry

Sta.	Piezometer or sample number
Date	Sampling date
Cond.	Specific conductance in micromhos/cm.
TDS	Total dissolved solids in milligrams/litre
Fe	Iron in milligrams/litre
Mn	Manganese in milligrams/litre
Ca	Calcium in milligrams/litre
Mg	Magnesium in milligrams/litre
Total H.	Total hardness in milligrams/litre
K	Potassium in milligrams/litre
Na	Sodium in milligrams/litre
Cl	Chloride in milligrams/litre
$S0_4$	Sulfate in milligrams/litre
Total A.	Total alkalinity ($CaC0_3$) in milligrams/litre
$HC0_3$	Bicarbonate in milligrams/litre
$C0_3$	Carbonate in milligrams/litre
F	Fluoride in milligrams/litre
%Na	Percent sodium
As	Arsenic in micrograms/litre
Ba	Barium in micrograms/litre
Cd	Cadmium in micrograms/litre
Cr	Chromium in micrograms/litre
Cu	Copper in micrograms/litre
Pb	Lead in micrograms/litre
F. pH	Field pH
Se	Selenium in micrograms/litre
F. Temp.	Field Temperature in degrees Celsius
F. Cond.	Field Conductivity in micromhas/cm.
Turb.	Turbidity
Zn	Zinc in micrograms/litre
SAR	Sodium absorption ratio
N	Nitrate reported as N in milligrams/litre

WILLISTON LANDFILL

Sta.	WO-1	WO-2	WO-3	WO-4	WO-5	WO-6	WO-7
Date	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87
Total A	627.	491.	714.	355.	477.	422.	437.
As	3.9	0.4	1.0	1.3	1.5	1.7	4.8
HCO_3	766.	599.	872.	433.	583.	515.	533.
Cd	0.12	0.46	0.28	0.05	0.35	0.45	0.10
CO_3	0.	0.	0.	0.	0.	0.	0.
Cl	593.	61.0	8.5	1.6	293.	139.	5.5
F	0.0	0.2	0.3	0.2	0.1	0.1	0.2
Total H	2290.	697.	463.	312.	987.	744.	523.
Pb	0.0	0.9	0.8	0.5	0.5	0.6	1.0
N	0.0	0.0	0.0	0.0	0.0	0.0	0.1
pH	7.5	7.6	7.6	7.9	7.6	7.5	7.5
F.pH	6.72	7.03	7.10	7.56	7.07	7.04	7.10
Temp.	14.	10.	10.	11.	12.	12.	12.
Se	0.	0.	0.	0.	0.	0.	1.
%Na	11.8	18.1	54.3	32.5	14.8	7.0	18.1
SO_4	827.	178.	209.	133.	194.	164.	167.
TDS	2700.	839.	1030.	521.	1190.	842.	664.
Turb.	2.00	<1.	<1.	<1.	<1.	<1.	<1.
SAR	1.29	1.17	4.99	1.71	1.10	0.41	1.02
Cond.	3976.	1288.	1576.	862.0	2019.	1383.	1054.
F. Cond.	2760.	850.0	1070.	580.0	1370.	950.0	734.0
Ba	249.	91.2	40.0	62.	363.	307.	133.
Ca	504.	148.	83.0	59.5	233.	185.	106.
Cu	0.0	9.0	52.0	38.0	28.0	19.0	39.0
Fe	0.680	0.094	0.017	0.020	0.034	0.026	0.899
Mg	251.	79.2	55.5	39.7	98.3	68.4	62.6
Mn	7.43	0.899	0.167	0.163	2.95	2.27	0.823
K	6.00	6.60	8.80	4.00	8.60	5.90	6.60
Na	142.	71.1	240.	69.5	79.2	25.8	53.4
Cr	0.00	0.00	0.00	2.50	0.00	0.00	1.60
Zn	219.	103.	52.	2.	133.	161.	123.

Sta.	WO-1	WO-2	WO-3	WO-4	WO-5	WO-6	WO-7
Date	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89
Cu	82.9	63.6	12.4	34.1	141.	61.	11.0
Zn	1.	2.	2.	12.	6.	9.	51.
Ba	165.	66.0	75.0	60.0	445.	237.	211.
Na	150.	61.2	76.4	209.	82.7	15.7	47.9
Mg	206.	54.0	42.9	59.8	93.7	70.7	61.9
K	6.00	5.80	4.60	5.70	5.30	3.80	<10
Ca	410.	103.	63.2	98.6	199.	235.	104.
Mn	5.40	0.536	0.168	0.180	2.77	1.54	0.122
Fe	22.6	0.373	0.119	0.014	0.450	0.216	0.008
Cr	4.23	0.00	0.26	0.44	2.40	0.00	0.00
As	4.8	0.6	0.4	0.7	0.8	0.3	1.1
Se	<4.	0.	0.	0.	<4.	<8.	0.
Cd	<1.	0.03	0.15	0.00	0.50	0.24	0.18
Pb	3.4	2.0	1.2	3.2	2.6	1.3	0.5
Cl	791.	25.1	5.8	14.6	272.	166.	4.5
F	0.03	0.29	0.22	0.23	0.10	0.08	0.37
F. Cond.	-	0.97	0.69	1.22	1.49	1.20	0.94
F. ph	-	7.14	7.20	7.10	7.19	7.10	6.85
F. Temp.	-	11.	8.	8.	9.	8.	-
pH	8.40	7.40	7.80	7.50	7.50	7.40	7.70
CO_3	4.	0.	0.	0.	0.	0.	0
HCO_3	221.	555.	428.	862.	586.	570.	504.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	188.	455.	351.	706.	480.	467.	413.
Cond.	3070.	1146.	916.0	1666	2020.	1592.	1045.
SO_4	564.	121.	124.	211.	143.	153.	156.
N	0.09	0.02	0.16	0.02	0.06	0.03	0.23
Total H	1870.	480.	335.	493.	883.	878.	515.
Turb.	-	2.00	2.00	<1	2.00	3.00	2.00
TDS	2240.	644.	528.	1020.	1080.	925.	630.
NPOC	23.1		8.8	9.0	9.4	10.1	9.1
POC	0.		0.	0.	0.	0.	0.
TOC	23.1		8.8	9.0	9.4	10.1	9.1

Sta.	WO-8	WO-9	WO-10	WO-11	WO-12	WO-13	WO-14
Date	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87
Total A	507.	473.	287.	842.	667.	300.	1220.
As	0.9	6.1	2.3	3.4	1.8	1.9	1.8
HCO_3	619.	577.	351.	1030.	815.	336.	1490.
Cd	0.22	0.46	0.22	0.19	0.03	0.37	0.00
CO_3	0.	0.	0.	0.	0.	15.	0.
Cl	3.4	4.6	70.1	12.5	184.	51.1	14.2
F	0.3	0.4	0.2	0.5	0.1	0.9	1.1
Total H	378.	138.	1010.	286.	1190.	92.	170.
Pb	1.2	2.6	0.4	0.8	0.0	0.0	0.9
N	0.5	2.1	0.7	0.0	0.0	0.1	0.4
pH	7.6	8.2	7.8	8.0	7.1	8.6	8.1
F.pH	7.20	7.95	7.40	7.50	6.60	7.80	7.57
Temp.	11.	12.	15.	14.	11.	9.	14.
Se	0.	2.	0.	0.	1.	0.	1.
%Na	40.6	88.1	15.2	85.0	3.3	75.9	89.3
SO_4	130.	642.	823.	1170.	357.	29.	257.
TDS	686.	1460.	1490.	2530.	1370.	429.	1720.
Turb.	<1.	<1.	<1.	<1.	10.0	<1.	2.00
SAR	2.67	17.4	1.14	19.2	0.24	6.06	21.8
Cond.	1099.	2050.	1924.	3512.	2132.	968.0	2472.
F. Cond.	740.0	1428.	1445.	987.0	1400.	463.0	1810.
Ba	168.	80.5	71.0	87.0	176.	265.	338.
Ca	73.4	26.8	198.	52.4	293.	19.1	31.5
Cu	0.0	0.0	22.0	8.0	0.0	0.0	25.0
Fe	0.035	0.024	0.008	0.100	4.45	0.013	0.458
Mg	47.3	17.3	126.	37.6	112.	10.8	22.1
Mn	0.045	0.044	0.023	0.992	1.97	0.110	0.122
K	5.40	8.50	10.6	7.90	3.20	4.50	6.20
Na	120.	470.	83.4	745.	18.8	134.	653.
Cr	0.00	0.00	0.00	3.20	0.00	4.70	2.70
Zn	57.	38.	73.	50.	121.	131.	139.

Sta.	WO-8	WO-9	WO-10	WO-11	WO-12	WO-13	WO-14
Date	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89
Cu	4.0	4.0		34.0	0.0	2.0	9.0
Zn	79.	32.		87.	35.	16.	78.
Ba	139.	88.0		211.	197.	122.	102.
Na	133.	500.		962.	9.3	94.8	485.
Mg	44.4	28.1		8.5	107.	8.9	20.3
K	5.80	7.90		1.00	4.90	3.10	3.50
Ca	71.8	39.7		8.20	323.	18.7	27.3
Mn	0.133	0.040		0.109	0.853	0.110	0.194
Fe	0.190	0.119		0.037	0.622	0.051	0.724
Cr	0.00	0.00		0.00	0.00	0.00	0.00
As	0.3	1.5		2.6	2.5	1.4	1.0
Se	0.	<4.		<5.	<5.	0.	0.
Cd	0.15	0.00		<1.	<0.5	0.08	<1.
Pb	3.2	2.9		4.2	2.8	9.6	2.3
Cl	3.2	5.4		17.7	194.	1.3	5.8
F	0.37	0.39		0.41	0.14	0.85	0.70
F. Cond.	0.88	1.66		3.01	1.93	8.20	1.65
F. ph	7.20	7.70		7.37	6.90	1.	7.40
F. Temp.	9.	8.		13.	16.	376.	10.
pH	7.60	8.00		7.80	7.70	0.	8.00
CO_3	0.	0.		0.	0.	310.	0.
HCO_3	616.	829.		963.	789.	600.0	1180.
OH	0.	0.		0.	0.	15.	0.
Total A	505.	679.		789.	646.	0.07	966.
Cond.	1138.	2280.		3970.	2200.	16.3	2120.
SO_4	128.	508.		1220.	331.	0.0	220.
N	0.24	6.90		0.07	0.53	16.3	0.18
Total H	362.	215.		55.	1250	83.	152.
Turb.	<1.	<1.		2.00	3.00	2.00	2.00
TDS	691.	1530.		2690.	1360.	328.	1340.
NPOC	6.9	8.7	9.8		42.3	13.8	22.2
POC	0.	0.	0.		1.0	0.1	0.
TOC	6.9	8.7	9.8		43.3	13.9	22.2

Sta.	WO-15	WO-16	WO-17	WO-19	WO-21	WO-Cu	WO-Cd
Date	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87	09/23/87
Total A	604.	400.	1200.			902.	935.
As	1.1	0.8	6.5			2.2	3.0
HCO_3	737.	488.	1440.			1050.	1010.
Cd	0.29	0.18	0.00			0.00	0.42
CO_3	0.	0.	12.			24.	63.
Cl	41.0	20.3	27.4			16.9	16.4
F	0.2	0.2	0.5			0.5	0.5
Total H	946.	471.	435.			248.	210.
Pb	0.5	0.0	0.3			0.5	2.0
N	0.0	0.0	0.6			0.0	0.0
pH	7.0	7.6	8.1			8.5	8.6
F.pH	6.59	7.23	7.60			8.35	8.47
Temp.	10.	9.	14.			14.	15.
Se	1.	0.	0.			1.	0.
%Na	18.2	15.1	82.9			89.0	89.7
SO_4	384.	109.	1280.			1290.	1310.
TDS	1210.	572.	3150.			2860.	2810.
Turb.	<1.	<1.	<1.			<1.	<1.
SAR	1.37	0.78	20.4			25.6	25.4
Cond.	1638.	874.0	4305.			3893.	3976.
F. Cond.	1090.	580.0	3050.			2850.	3000.
Ba	65.0	87.0	66.6			13.0	26.0
Ca	240.	115.	68.0			42.4	33.4
Cu	17.0	0.0	9.0			17.0	13.0
Fe	0.870	0.022	0.256			0.021	0.064
Mg	84.2	44.7	64.3			34.4	30.8
Mn	1.67	0.440	0.883			0.000	0.009
K	5.00	3.80	11.7			5.30	8.90
Na	97.2	38.7	976.			926.	848.
Cr	4.60	0.40	0.00			1.40	7.70
Zn	161.	3.	45.			117.	0.

Sta.	WO-15	WO-16	WO-17	WO-19	WO-21	WO-22	WO-23
Date	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89	05/16/89
Cu	1.0	1.0		0.0	29.0	2.0	3.0
Zn	103.	38.		107.	44.	41.	14.
Ba	255.	128.		896.	160.	77.	67.0
Na	50.7	36.4		145.	44.4	850.	809.
Mg	87.1	40.5		172.	69.4	45.8	45.3
K	5.40	3.80		13.7	6.10	29.6	9.10
Ca	247.	108.		314.	151.	52.8	54.5
Mn	1.87	0.463		2.76	1.41	0.040	0.043
Fe	3.29	0.202		3.42	0.410	0.763	0.0485
Cr	0.00	0.00		2.76	0.04	0.50	0.80
As	1.1	0.7		2.6	1.3	3.8	4.2
Se	<4.	<6.		1.	<10.	<4.	<4.
Cd	<0.5	0.00		<0.5	0.00	<1.	<4.
Pb	0.7	0.9		0.9	8.0	5.2	2.6
Cl	43.2	32.1		500.	30.6	16.0	15.7
F	0.22	0.24		0.14	0.21	0.42	0.42
F. Cond.	1.44	0.78		2.78	1.10	3.95	3.83
F. ph	6.47	6.92		6.74	6.44	8.18	8.16
F. Temp.	11.	10.		16.	11.	21.	20.
pH	7.20	7.60		8.50	7.30	8.60	8.50
CO_3	0.	0.		17.	0.	30.	18.
HCO_3	70.4	465.		671.	579.	967.	985.
OH	0.	0.		0.	0.	0.	0.
Total A	577.	381.		578.	474.	841.	837.
Cond.	1808.	949.		2160.	1350.	3990.	3990.
SO_4	432.	81.		56.	249.	1280.	1290.
N	0.07	0.07		0.15	0.34	0.04	0.04
Total H	976.	437.		-	663.	320.	323.
Turb.	31.0	2.00		1490.	<1.	<1.	<1.
TDS	1210.	531.		1550.	837.	2780.	2730.
NPOC	6.7	13.5		19.4	10.3	34.2	28.2
POC	0.	0.		0.	0.	0.	0.
TOC	6.7	13.5		19.4	10.3	34.2	28.2

LINTON LANDFILL

Sta.	L-1	L-2	L-3	L-4	L-5	L-6	L-7
Date	09/27/87	09/27/87	09/27/87	09/27/87	09/27/87	09/27/87	09/27/87
Total A	331.	310.	447.	402.	608.	552.	626.
As	1.3	1.4	1.8	1.1	2.2	1.4	2.4
HCO_3	404.	379.	546.	491.	742.	674.	764.
Cd	0.72	0.33	0.46	0.38	0.22	0.95	0.24
CO_3	0.	0.	0.	0.	0.	0.	0.
Cl	2.9	161.	37.9	19.9	462.	467.	462.
F	0.2	0.2	0.2	0.3	0.5	0.3	0.2
Total H	350.	1240.	219.	545.	551.	712.	668.
Pb	1.3	0.2	0.3	1.7	0.4	0.4	0.1
N	2.8	0.0	0.0	0.0	0.0	1.8	2.4
pH	7.8	7.3	7.8	7.7	7.6	7.5	7.6
F.pH	7.49	6.92	7.68	7.48	7.09	7.26	7.16
Temp.	10.	10.	9.	10.	9.	11.	12.
Se	1.	0.	0.	0.	0.	0.	0.
%Na	7.1	26.0	69.7	29.0	64.9	57.1	59.3
SO_4	25.	1040.	212.	311.	347.	390.	379.
TDS	378.	2050.	835.	866.	1860.	1900.	1930.
Turb.	<1.	<1.	<1.	<1.	2.00	<1.	<1.
SAR	0.29	2.49	6.84	1.92	8.73	7.12	7.56
Cond.	659.0	2606.	1328.	1294.	3080.	2997.	2966.
F. Cond.	444.0	1646.	836.0	972.	1851.	1927.	1958.
Ba	60.0	38.2	42.0	84.0	95.0	226.	173.
Ca	97.7	367.	58.5	128.	141.	188.	186.
Cu	10.0	3.0	34.0	22.0	11.0	44.0	0.0
Fe	0.018	0.037	0.022	0.009	0.319	0.008	0.008
Mg	25.8	79.3	17.7	54.8	48.2	58.9	49.0
Mn	0.039	6.07	0.699	0.075	2.73	1.58	1.59
K	3.10	14.7	7.20	7.30	20.2	15.1	20.2
Na	120.3	202.	233.	103.	471.	437.	450.
Cr	1.10	0.70	5.10	0.90	0.00	2.90	0.00
Zn	0.	93.	0.	0.	0.	123.	81.

Sta.	L-1	L-2	L-3	L-4	L-5	L-6	l-7
Date	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89
Cu	0.0	6.0	13.0	0.0	1.0	3.0	0.0
Zn	38.	36.	27.	30.	38.	37.	42.
Ba	71.0	29.0	37.0	104.	57.0	124.	110.
Na	9.2	108.	233.	75.6	497.	493.	506.
Mg	25.1	72.0	11.6	75.8	62.1	64.1	39.5
Ca	86.9	260.	36.4	129.	172.	194.	232.
Mn	0.047	5.21	0.490	0.189	2.14	1.69	0.027
Fe	0.145	0.370	0.058	0.253	0.219	0.068	0.033
K	4.78	15.4	13.4	8.93	27.0	21.4	28.6
Cr	0.40	0.02	0.46	0.16	6.76	0.00	0.26
As	0.7	0.0	1.4	1.3	0.4	0.8	0.4
Se	1.	0.	0.	0.	0.	0.	0.
Cd	0.20	0.10	0.04	0.14	0.00	0.08	0.00
Pb	1.4	1.8	1.8	2.8	5.0	3.2	10.4
Cl	1.0	15.0	32.0	15.9	474.	484.	575.
F	0.23	0.19	0.33	0.27	0.53	0.32	0.22
F. Cond.	850.0	2060.	1280.	1290.	3280.	3380.	3580.
F. ph	8.11	7.60	8.33	8.07	7.65	7.93	7.54
F. Temp.	9.	10.	9.	8.	7.	8.	8.
pH	7.60	7.20	7.80	7.60	7.20	7.50	7.20
CO_3	0.	0.	0.	0.	0.	0.	0.
HCO_3	404.	393.	582.	479.	706.	739.	764.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	331.	322.	477.	392.	578.	605.	626.
Cond.	660.0	2110.	1318.	1328.	3370.	3460.	3640.
SO_4	32.	938.	198.	332.	526.	534.	479.
N	2.33	0.01	0.04	0.82	0.01	11.6	7.20
NPOC	15.8	16.7	16.7	28.2	39.4	31.4	33.8
POC	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOC	15.8	16.7	16.7	28.2	39.4	31.4	33.8
Total H	321.	946.	139.	634.	686.	749.	743.
Turb.	2.00	2.00	2.00	2.00	3.00	2.00	2.00
TDS	528.	1690.	1050.	1060.	2700.	2770.	2910.

Sta.	L-8	L-9	L-CW
Date	09/27/87	09/27/87	09/27/87
Total A	532.	603.	352.
As	8.2	4.7	1.1
HCO_3	649.	736.	430.
Cd	0.00	0.34	0.35
CO_3	0.	0.	0.
Cl	386.	389.	18.5
F	0.3	0.3	0.2
Total H	555.	622.	605.
Pb	1.1	2.6	2.2
N	0.0	0.8	3.7
pH	7.7	7.8	7.5
F.pH	7.29	7.21	7.20
Temp.	12.	13.	14.
Se	0.	2.	24.
%Na	63.6	58.5	25.3
SO_4	380.	303.	392.
TDS	1740.	1690.	957.
Turb.	8.00	2.00	<1.
SAR	8.25	7.06	1.67
Cond.	2771.	2678.	1370.
F. Cond.	1868.	1843.	991.0
Ba	66.7	223.	40.7
Ca	146.	157.	169.
Cu	0.0	7.1	27.5
Fe	2.11	0.329	0.002
Mg	46.0	55.6	44.6
Mn	1.62	3.65	0.019
K	12.5	13.8	10.0
Na	447.	405.	94.6
Cr	0.00	2.70	2.30
Zn	57.	79.	203.

Sta.	L-8	L-9	L-10	L-11	L-12
Date	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89
Cu	2.0	4.0	0.0	21.0	4.0
Zn	33.	24.	41.	61.	37.
Ba	74.0	145.	169.	49.0	238.
Na	527.	467.	154.	17.9	431.
Mg	58.3	64.5	80.7	55.7	50.5
K	16.6	14.3	17.0	10.3	12.6
Ca	190.	200.	258.	300.	214.
Mn	1.29	0.423	6.77	2.56	6.04
Fe	4.35	0.041	0.756	0.072	0.373
Cr	0.00	0.96	0.92	0.60	1.06
As	5.8	1.6	1.8	0.4	1.7
Se	0.	1.	1.	1.	1.
Cd	0.00	0.06	0.00	0.26	0.00
Pb	3.4	4.2	4.2	2.4	2.0
Cl	456.	424.	237.	141.	507.
F	0.40	0.30	0.17	0.24	0.22
F. Cond.	3100.	-	2310.	1750.	3160.
F. ph	7.88	-	7.34	7.51	7.71
F. Temp.	8.	-	15.	12.	9.
pH	7.40	7.40	7.00	7.10	7.30
CO_3	0.	0.	0.	0.	0.
HCO_3	809.	745.	1030.	573.	924.
OH	0.	0.	0.	0.	0.
Total A	663.	610.	844.	469.	757.
Cond.	3110.	2920.	2350.	1788.	3250.
SO_4	390.	346.	169.	357.	275.
N	0.05	3.10	0.65	1.25	0.18
NPOC	24.8	40.9	51.4	28.2	46.2
POC	0.1	0.0	0.1	0.0	0.0
TOC	24.9	40.9	51.5	28.2	46.2
Total H	715.	765.	977.	979.	743.
Turb.	25.0	2.00	6.00	2.00	5.00
TDS	2040.	1900.	1430.	1170	1950.

WISHEK LANDFILL

Sta.	W-1	W-2	W-3	W-4	W-5	W-6	W-7
Date	09/26/87	09/26/87	09/26/87	09/26/87	09/26/87	09/26/87	09/26/87
Total A	310.	440.	366.	459.	542.	576.	654.
As	1.3	0.3	0.7	0.3	1.8	1.3	8.3
HCO_3	379.	537.	447.	561.	662.	703.	798.
Cd	0.34	0.21	0.26	0.63	1.13	0.32	0.00
CO_3	0.	0.	0.	0.	0.	0.	0.
Cl	113.	23.9	305.	27.8	23.0	13.1	15.8
F	0.1	0.1	0.2	0.1	0.1	0.1	0.2
Total H	657.	2320.	1130.	796.	692.	276.	203.
Pb	10.3	1.0	0.8	0.4	1.0	0.6	0.7
N	0.0	2.4	6.5	27.1	4.5	0.0	0.0
pH	7.5	7.2	7.8	7.5	7.6	7.8	7.9
F.pH	7.07	6.87	6.97	7.21	7.22	7.34	7.40
Temp.	9.	9.	9.	11.	13.	12.	14.
Se	0.	6.	1.	4.	0.	1.	0.
%Na	12.9	4.8	6.6	9.4	17.9	63.7	73.9
SO_4	170.	1650.	220.	187.	139.	178.	109.
TDS	751.	2810.	1200.	931.	818.	862.	860.
Turb.	<1.	<1.	<1.	<1.	<1.	<1.	<1.
SAR	0.76	0.48	0.47	0.59	1.15	5.86	8.12
Cond.	1164.	3245.	2081.	1452.	1267.	1360.	1370.
F. Cond.	733.0	1940.	1313.	964.0	879.0	938.0	975.0
Ba	63.0	22.0	63.0	122.	142.	39.6	80.9
Ca	175.	564.	263.	208.	163.	62.0	40.6
Cu	125.	58.0	47.0	0.0	71.0	0.0	0.0
Fe	0.052	0.030	0.020	0.014	0.052	0.131	0.087
Mg	53.4	222.	116.	67.2	69.1	29.3	24.7
Mn	0.536	0.545	0.071	0.785	1.63	0.523	0.949
K	8.30	18.6	10.3	5.60	7.70	9.30	10.7
Na	45.0	53.7	36.7	38.2	69.5	224.	266.
Cr	4.20	5.30	0.60	9.20	4.50	1.60	1.50
Zn	18.	0.	1.	66.	0.	47.	26.

Sta.	W-1	W-2	W-3	W-4	W-5	W-6	W-7
Date	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89	06/22/89
Cu	0.0	0.0	2.0	0.0	0.0	4.0	1.0
Zn	15.	37.	11.	73.	3.	10.	51.
Ba	53.0	16.0	27.0	77.0	166.	41.0	84.0
Na	30.4	57.6	25.5	31.1	76.8	165.	217.
Mg	40.3	183.	76.8	42.8	36.2	23.1	17.9
Ca	139.	475.	204.	148.	131.	51.8	37.9
Mn	0.458	0.372	0.045	0.340	1.43	0.386	0.772
Fe	0.117	0.055	0.178	0.041	0.015	0.028	0.530
K	9.94	22.5	11.4	4.50	6.02	9.87	9.81
Cr	0.10	0.06	0.00	0.00	0.14	0.00	0.00
As	0.3	0.0	0.0	0.2	1.9	0.1	5.0
Se	0.	0.	0.	4.	2.	2.	1.
Cd	0.08	0.00	0.00	0.28	0.00	0.00	0.00
Pb	2.2	6.2	1.8	2.4	2.2	2.4	1.6
Cl	96.7	25.7	231.	11.9	16.7	11.4	13.8
F	0.15	0.15	0.28	0.14	0.18	0.17	0.17
F. Cond.	1130.	3110.	1780.	1110.	1180.	1310.	1350.
F. ph	7.00	7.36	7.49	7.10	7.38	7.45	7.38
F. Temp.	10.	10.	10.	6.	7.	8.	8.
pH	7.20	6.90	7.10	7.30	7.60	7.80	7.60
CO_3	0.	0.	0.	0.	0.	0.	0.
HCO_3	398.	505.	547.	583.	632.	692.	774.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	326.	414.	448.	477.	518.	567.	634.
Cond.	1174.	3240.	1845.	1111.	1177.	1294.	1335.
SO_4	168.	1560.	209.	170.	167.	169.	130.
N	0.03	1.45	1.38	0.44	0.01	0.11	0.03
NPOC	9.5	17.0	18.5	18.5	18.5	15.2	20.0
POC	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOC	9.5	17.0	18.5	18.5	18.5	15.2	20.0
Total H	513.	1940.	826.	546.	476.	225.	168.
Turb.	2.00	2.00	2.00	2.00	2.00	2.00	3.00
TDS	939.	2590.	1480.	889.	942.	1040.	1070.

Sta.	W-8	W-9	W-10
Date	09/26/87	09/26/87	09/26/87
Total A	454.	521.	455.
As	1.3	4.5	1.1
HCO_3	554.	624.	556.
Cd	0.15	0.07	0.30
CO_3	0.	6.	0.
Cl	51.8	60.1	27.8
F	0.2	0.3	0.3
Total H	589.	683.	373.
Pb	0.2	0.0	0.0
N	0.0	0.0	0.0
pH	7.7	8.0	7.8
F.pH	7.43	7.42	7.46
Temp.	13.	14.	12.
Se	0.	1.	0.
%Na	39.0	55.7	45.5
SO_4	442.	890.	123.
TDS	1140.	1860.	692.
Turb.	3.00	<1.	<1.
SAR	3.12	6.59	3.24
Cond.	1669.	2503.	1082.
F. Cond.	1161.	1780.	766.
Ba	35.0	35.0	20.0
Ca	113.	62.7	57.5
Cu	0.8	0.5	31.0
Fe	1.40	0.014	0.248
Mg	74.4	128.	55.6
Mn	1.17.	0.886	1.18
K	9.30	9.50	10.3
Na	174.	396.	144.
Cr	3.50	1.30	7.80
Zn	36.	88.	15.

Sta.	W-8	W-9	W-10	W-11
Date	09/26/87	09/26/87	09/26/87	09/26/87
Cu	0.0	0.0	8.0	0.0
Zn	21.	19.	32.	22.
Ba	30.0	23.0	21.0	50.0
Na	151.	201.	65.1	27.8
Mg	65.8	80.7	30.4	57.2
Ca	106.	62.5	36.9	132.
Mn	0.802	0.774	0.562	0.282
Fe	1.18	1.37	0.015	0.063
K	10.1	8.22	9.34	10.9
Cr	0.02	0.00	0.18	0.38
As	0.4	0.6	0.5	0.1
Se	1.	0.	0.	0.
Cd	0.10	0.00	0.04	0.32
Pb	0.8	2.6	1.2	1.6
Cl	41.1	43.8	27.4	13.2
F	0.21	0.23	0.31	0.13
F. Cond.	1560.	1630.	710.0	1120.
F. ph	7.40	7.27	7.83	7.19
F. Temp.	6.	7.	10.	9.
pH	7.60	7.40	7.80	7.00
CO_3	0.	0.	0.	0.
HCO_3	587.	627.	294.	682.
OH	0.	0.	0.	0.
Total A	481.	514.	241.	559.
Cond.	1543.	1607.	735.0	1184.
SO_4	386.	430.	103.	115.
N	0.07	0.01	0.04	0.03
NPOC	23.0	23.3	27.5	25.1
POC	0.0	0.0	0.0	0.0
TOC	23.0	23.3	27.5	25.1
Total H	536.	488.	217.	565.
Turb.	4.00	11.0	2.00	2.00
TDS	1230.	1290.	588.	947.

HARVEY LANDFILL

Sta.	H-1	H-2	H-3	H-4	H-5	H-6	H-7
Date	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87
Total A	354.	361.	281.	1110.	627.	226.	822.
As	1.1	0.0	10.3	2.3	0.8	2.1	1.2
HCO_3	432.	441.	324.	1360.	650.	267.	1000.
Cd	0.29	0.19	0.12	0.05	0.38	0.21	0.73
CO_3	0.	0.	10.	0.	57.	4.	0.
Cl	59.0	71.4	40.1	0.0	136.	42.2	101.
F	0.3	0.7	0.3	0.1	0.5	0.4	0.5
Total H	797.	916.	259.	551.	318.	234.	223.
Pb	1.9	0.4	0.9	0.7	1.3	0.2	4.0
N	0.0	0.3	0.0	0.0	0.4	0.0	0.0
pH	7.7	7.8	8.5	7.1	8.9	8.4	7.7
F.pH	7.27	7.29	7.35	6.93	7.43	7.71	7.73
Temp.	8.	9.	8.	12.	11.	8.	12.
Se	0.	0.	0.	0.	0.	0.	2.
%Na	27.3	23.1	50.5	52.2	67.6	51.0	77.9
SO_4	799.	869.	166.	9.	213.	198.	138.
TDS	1460.	1570.	581.	1130.	1130.	566.	1160.
Turb.	<1.	<1.	<1.	-	<1.	<1.	<1.
SAR	2.13	1.82	3.29	5.16	7.46	3.19	10.6
Cond.	2112.	2235.	1318.	2390.	2307.	1236.	2042.
F. Cond.	1775.	1851.	1136.	2460.	2160.	1000.	5110.
Ba	47.0	31.4	89.3	438.	228.	140.	90.9
Ca	134.	127.	28.6	37.7	10.4	34.4	13.2
Cu	4.4	5.1	0.6	1.4	23.2	5.7	3.0
Fe	0.003	0.001	0.000	14.6	0.005	0.000	0.000
Mg	112.	145.	45.5	111.	70.9	35.9	46.2
Mn	0.008	0.000	0.000	0.242	0.000	0.000	0.002
K	9.20	6.70	9.80	19.3	11.9	7.10	7.80
Na	138.	127.	122.	279.	306.	112.	363.
Cr	1.00	0.00	6.50	8.70	5.40	2.00	0.00
Zn	47.	55.	33.	44.	41.	39.	56.

Sta.	Ha-1	Ha-2	Ha-3	Ha-4	Ha-5	Ha-6	Ha-7
Date	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89
Cu	4.0	6.0	0.0	0.0	18.0	8.0	7.0
Zn	16.	13.	13.	28.	20.	17.	22.
Ba	31.0	21.0	79.0	429.	209.	90.0	73.0
Na	138.	143.	110.	342.	243.	69.1	163.
Mg	173.	99.8	34.8	119.	66.2	36.3	33.2
K	7.20	9.40	8.70	15.2	9.30	5.70	7.30
Ca	237.	227.	78.6	114.	106.	93.3	40.2
Mn	0.000	2.10	0.800	1.61	0.279	0.751	0.393
Fe	0.041	0.058	0.020	3.49	0.876	0.076	0.098
Cr	1.30	82.8	4.54	1.02	3.66	0.54	0.22
As	0.4	0.4	4.2	0.6	0.8	1.0	0.7
Se	0.	0.	0.	0.	1.	0.	2.
Cd	0.20	0.18	0.03	0.01	0.37	0.14	0.68
Pb	3.6	3.6	3.2	3.4	4.4	4.4	9.0
Cl	82.4	39.6	31.4	180.	145.	16.4	68.5
F	0.24	0.25	0.32	0.13	0.38	0.44	0.48
F. Cond.	2130.	1890.	9500.	2480.	1990.	960.0	1180.
F. ph	7.65	7.55	7.26	6.97	7.46	7.73	7.65
F. Temp.	8.	8.	6.	12.	8.	8.	12.
pH	7.80	7.50	7.60	7.20	7.60	7.80	7.70
CO_3	0.	0.	0.	0.	0.	0.	0.
HCO_3	458.	431.	524.	1250.	833.	367.	657.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	375.	353.	429.	1020.	682.	301.	538.
Cond.	2290.	2000.	1053.	2500.	2140.	953.0	1300.
SO_4	931.	772.	110.	206.	261.	192.	86.
N	0.62	0.03	0.00	0.00	11.2	0.98	0.16
NPOC	15.5	5.2	8.2	20.6	10.7	7.1	8.9
POC	0.0	0.0	0.0	0.1	0.0	0.0	0.0
TOC	15.5	5.2	8.2	20.7	10.7	7.1	8.9
Total H	1300.	978.	340.	775.	537.	383.	237.
Turb.	<1.	<1.	<1.	19.0	<1.	2.00	2.00
TDS	1800.	1500.	632.	1590.	1290.	598.	723.

Sta.	H-8	H-9	H-10	H-11	H-12	H-13	H-14
Date	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87	10/06/87
Total A	360.	283.	294.	441.	178.	171.	209.
As	2.6	0.7	0.2	72.7	2.4	3.4	3.6
HCO_3	439.	346.	336.	538.	217.	196.	255.
Cd	0.39	0.63	0.17	0.28	0.37	0.48	0.54
CO_3	0.	0.	11.	0.	0.	6.	0.
Cl	5.4	1.9	218.	26.7	35.7	23.1	91.0
F	0.3	0.3	0.4	0.7	0.4	0.4	0.3
Total H	394.	233.	424.	844.	791.	229.	853.
Pb	0.7	2.2	0.5	2.6	1.0	0.4	0.7
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pH	7.7	7.8	8.5	7.4	7.6	8.4	7.8
F.pH	7.75	7.25	6.99	6.85	7.05	7.21	7.28
Temp.	8.	10.	10.	8.	10.	8.	10.
Se	0.	0.	0.	0.	0.	0.	0.
%Na	35.9	25.3	36.0	30.2	31.3	46.4	16.5
SO_4	383.	101.	120.	974.	947.	183.	695.
TDS	841.	385.	748.	1740.	1520.	477.	1270.
Turb.	<1.	<1.	<1.	4.00	<1.	<1	<1.
SAR	2.23	1.04	2.33	2.52	2.57	2.63	1.16
Cond.	1399.	704.0	1823.	2421.	2359.	1099.	1681.
F. Cond.	1126.	616.0	1653.	2300.	2140.	876.0	1587.
Ba	105.	152.	197.	24.6	61.3	46.6	98.0
Ca	72.6	34.4	31.7	202.	149.	33.0	168.
Cu	0.0	10.8	5.1	6.4	9.1	0.0	1.4
Fe	0.000	0.000	0.000	0.216	0.000	0.000	0.000
Mg	51.7	35.7	83.7	82.5	102.	35.6	105.
Mn	0.000	0.001	0.000	0.033	0.000	0.003	2.38
K	10.3	5.10	8.60	18.8	13.7	8.30	9.40
Na	102.	36.4	110	169.	166.	91.7	77.8
Cr	0.00	0.00	0.00	0.60	0.00	0.00	0.00
Zn	52.	105.	35.	48.	29.	29.	59.

Sta.	Ha-8	Ha-9	Ha-10	Ha-11	Ha-12	Ha-13	Ha-14
Date	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89
Cu	3.0	4.0	3.0	1.0	0.0	4.0	6.0
Zn	23.	14.	14.	23.	16.	21.	50.
Ba	61.0	117.	132.	13.0	36.0	28.0	56.0
Na	99.8	12.6	101.	146.	138.	75.9	58.5
Mg	46.2	23.0	77.8	83.8	87.8	30.7	115.
K	8.10	2.80	5.30	16.8	15.9	6.30	9.50
Ca	121.	48.1	117.	264.	272.	85.5	244.
Mn	0.777	0.176	0.709	0.894	1.71	0.270	7.49
Fe	0.065	0.042	0.023	1.50	0.007	0.015	0.033
Cr	0.90	1.04	0.50	1.76	0.92	0.78	0.74
As	1.1	0.6	0.6	48.5	12.8	2.3	1.6
Se	0.	0.	0.	0.	3.	6.	5.
Cd	0.25	0.16	0.33	0.16	0.26	0.33	0.49
Pb	3.8	3.8	3.4	3.4	3.6	3.8	3.6
Cl	4.9	1.1	218.	25.5	21.4	18.1	95.6
F	0.27	0.22	0.40	0.42	0.44	0.41	0.21
F. Cond.	1280.	500.0	1610.	2320.	2250.	920.0	1630.
F. ph	7.55	7.88	7.41	7.30	7.40	7.74	7.39
F. Temp.	9.	9.	8.	10.	9.	8.	8.
pH	7.70	7.90	7.50	7.30	7.40	7.80	7.50
CO_3	0.	0.	0.	0.	0.	0.	0.
HCO_3	432.	275.	606.	541.	515.	416.	478.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	354.	225.	496.	443.	422.	341.	391.
Cond.	1316.	517.0	1664.	2300.	2260.	964.0	1895.
SO_4	378.	59.	74.	983.	904.	159.	582.
N	0.03	0.02	0.01	0.00	0.16	0.20	0.08
NPOC	4.8	3.0	7.1	5.9	5.8	4.6	31.0
POC	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOC	4.8	3.0	7.1	5.9	5.8	4.6	31.0
Total H	493.	215.	613.	1000.	1040.	340.	1080.
Turb.	2.00	<1.	2.00	3.00	2.00	2.00	2.00
TDS	871.	282.	892.	1790.	1690.	581.	1340.

Sta. Date	H-15 10/06/87	H-16 10/06/87	H-17 10/06/87	H-18 10/06/87	H-C1 10/06/87	H-C2 10/06/87	H-Su 10/06/87
Total A	592.		236.	1110.	670.	671.	382.
As	12.0		0.0	2.4	4.0	0.0	4.2
HCO_3	723.		274.	1360.	818.	819.	432.
Cd	1.57		0.31	0.00	0.06	0.03	0.26
CO_3	0.		7.	0.	0.	0.	17.
Cl	53.6		13.7	160.	36.2	37.0	12.6
F	0.4		0.3	0.1	0.4	0.3	0.2
Total H	380.		162.	562.	333.	405.	256.
Pb	1.7		3.4	0.0	1.3	1.2	2.2
N	0.0		0.7	0.0	0.0	0.4	0.1
pH	7.8		8.5	7.1	7.9	7.9	8.7
F.pH	7.36		7.18	7.00	7.40	7.30	8.73
Temp.	9.		10.	12.	10.	10.	12.
Se	0.		0.	1.	0.	0.	0.
%Na	62.3		55.8	53.1	65.7	62.2	57.7
SO_4	307.		101.	9.	321.	334.	182.
TDS	1140.		404.	1300.	1170.	1230.	673.
Turb.	<1.		<1.	90.0	<1.	<1.	<1.
SAR	6.46		3.22	5.39	7.04	6.66	4.38
Cond.	1795.		655.0	2266.	1944.	1959.	1092.
F. Cond.	1493.		756.0	2230.	1616.	1666.	1050.
Ba	90.6		77.6	496.	50.3	70.7	87.0
Ca	89.6		21.7	33.7	58.3	83.5	37.1
Cu	3.4		3.0	1.6	0.0	0.5	4.7
Fe	0.000		0.001	17.6	0.024	0.025	0.001
Mg	37.9		26.2	116.	45.6	47.7	39.6
Mn	1.07		0.002	0.271	0.034	0.0180	0.001
K	5.00		2.40	19.7	12.0	12.0	10.7
Na	290.		94.4	294.	296.	308.	161.
Cr	0.00		0.00	10.5	0.00	0.00	0.00
Zn	86.		53.	31.	56.	38.	50.

Sta. Date	Ha-15 06/17/89	Ha-16 06/17/89	Ha-17 06/17/89	Ha-18 06/17/89	Ha-19 06/17/89	Ha-20 06/17/89	Ha-Su 06/17/89
Cu	3.0	3.0	11.0				2.0
Zn	6.	10.	50.				3.
Ba	100.	26.0	79.0				39.0
Na	423.	484.	80.5				230.
Mg	66.0	65.7	23.5				31.0
K	7.50	11.9	2.40				7.80
Ca	159.	159.	69.9				30.7
Mn	1.42	0.629	0.362				0.033
Fe	0.118	0.026	0.002				0.056
Cr	0.62	0.64	0.30				0.60
As	22.8	2.7	2.7				5.1
Se	0.	0.	0.				0.
Cd	0.24	0.04	0.21				0.00
Pb	3.2	3.0	2.3				1.8
Cl	104.	20.5	12.2				18.9
F	0.30	0.35	0.25				0.32
F. Cond.	2790.	3020.	790.0				1290.
F. ph	7.55	7.99	7.77				9.43
F. Temp.	9.	14.	12.				16.
pH	7.80	8.10	7.80				9.30
CO_3	0.	10.	0.				87.
HCO_3	1090.	597.	460.				389.
OH	0.	0.	0.				0.
Total A	893.	506.	377.				464.
Cond.	2830.	2800.	841.0				1306.
SO_4	632.	1020.	65				236.
N	0.13	0.12	0.41				0.01
NPOC	23.9	13.7	8.4				22.6
POC	0.0	0.0	0.0				0.0
TOC	23.9	13.7	8.4				22.6
Total H	669.	668.	271.				204.
Turb.	2.00	3.00	2.00				2.00
TDS	1930.	2070.	482.				833.

Sta.	H-Sd	H-S1
Date	10/06/87	10/06/87
Total A	390.	659.
As	3.7	4.3
HCO_3	462.	698.
Cd	0.00	0.04
CO_3	7.	52.
Cl	14.4	166.
F	0.3	0.4
Total H	240.	686.
Pb	0.0	0.8
N	0.1	0.1
pH	8.4	8.8
F.pH	8.07	7.19
Temp.	10.	10.
Se	0.	0.
%Na	57.9	54.9
SO_4	180.	725.
TDS	665.	1880.
Turb.	<1.	15.0
SAR	4.29	6.42
Cond.	1123.	3265.
F. Cond.	967.	2890.
Ba	85.	92.4
Ca	34.7	31.0
Cu	6.2	0.9
Fe	0.001	3.01
Mg	37.3	148.
Mn	0.005	0.017
K	10.4	23.2
Na	153.	387.
Cr	0.00	4.50
Zn	27.	46.

Sta.	Ha-Sd	Ha-Co	Ha-C1	Ha-C2	Ha-C3	Ha-La
Date	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89	06/17/89
Cu	2.0	2.0	0.0	1.0	2.0	8.0
Zn	9.	13.	5.	15.	7.	31.
Ba	48.0	38.0	28.0	42.0	47.0	46.0
Na	266.	552.	365.	370.	368.	212.
Mg	42.2	100.	107.	114.	111.	23.2
K	9.10	26.0	14.4	16.6	17.3	17.4
Ca	38.4	47.1	61.3	76.0	75.6	30.6
Mn	0.038	0.221	0.035	0.123	0.035	0.040
Fe	0.055	0.290	0.093	0.160	0.108	0.434
Cr	0.60	1.20	1.06	0.68	0.48	1.38
As	5.8	11.2	7.0	3.0	3.3	5.0
Se	0.	0.	0.	0.	0.	1.
Cd	0.08	0.04	0.10	0.04	0.02	0.23
Pb	17.0	1.8	1.5	1.6	1.0	22.0
Cl	34.4	211.	176.	162.	165.	84.3
F	0.37	0.43	0.63	0.52	0.52	2.55
F. Cond.	1520.	3000.	2370.	2600.	2580.	1340.
F. ph	9.20	8.58	8.18	8.04	8.40	8.09
F. Temp.	20.	23.	14.	16.	24.	19.
pH	9.10	8.60	8.20	8.20	8.40	8.20
CO_3	69.	49.	10.	2.	30.	4.
HCO_3	473.	873.	703.	852.	802.	507.
OH	0.	0.	0.	0.	0.	0.
Total A	502.	797.	592.	701.	707.	422.
Cond.	1514.	3150.	2460.	2640.	2680.	1328.
SO_4	299.	686.	528.	552.	556.	132.
N	0.02	0.02	0.02	0.40	0.23	0.06
NPOC	25.2	48.9	25.5	22.0	22.0	38.3
POC	0.0	0.0	0.0	0.0	0.0	0.0
TOC	25.2	48.9	25.5	22.0	22.0	38.3
Total H	270.	529.	594.	659.	646.	172.
Turb.	2.00	5.00	2.00	2.00	2.00	7.00
TDS	991.	2100.	1610.	1710.	1720.	754.

DEVILS LAKE LANDFILL

Sta.	D-1	D-2	D-3	D-4	D-5	D-6	D-7
Date	08/25/88	08/25/88	08/25/88	08/25/88	08/25/88	08/25/88	08/25/88
Total A	560.	434.	395.	522.	437.	734.	319.
As	7.4	3.3	3.4	0.6	18.4	28.9	1.2
HCO_3	684.	530.	482.	637.	533.	896.	390.
Cd	4.80	3.56	2.80	4.90	6.80	2.30	15.1
CO_3	0.	0.	0.	0.	0.	0.	0.
Cl	31.0	20.6	3.8	5.9	405.	108.	42.7
F	0.2	0.1	0.2	0.1	0.3	0.3	0.1
Total H	3060.	1600.	461.	2520.	545.	509.	488.
Pb	3.5	1.0	8.0	3.5	0.4	2.2	0.9
N	0.8	0.1	0.1	0.1	0.1	0.1	0.0
pH	7.4	7.5	7.6	7.0	7.8	7.7	7.7
F.pH	6.95	7.20	7.35	6.87	7.46	7.50	7.38
Temp.	11.	12.	12.	10.	11.	11.	11.
Se	76.	1.	0.	0.	1.	0.	0.
%Na	32.0	22.1	15.6	2.5	47.0	44.9	1.9
SO_4	3520.	1480.	148.	1950.	106.	36.	126.
TDS	5550.	2540.	597.	3180.	1180.	950.	535.
Turb.	3.00	2.00	2.00	2.00	3.00	3.00	2.00
SAR	5.24	2.28	0.80	0.26	4.15	3.69	0.08
Cond.	6570.	3520.	1010.	3470.	2050.	1637.	927.0
F. Cond.	750.0	499.0	191.0	556.0	358.0	303.0	174.0
Ba	157.	101.	157.	74.9	388.	681.	166.
Ca	569.	408.	128.	659.	98.5	108.	124.
Cu	3.6	4.5	4.4	4.4	2.5	2.9	2.4
Fe	1.09	0.111	0.059	0.050	0.167	0.142	0.078
Mg	398.	142.	34.4	212.	72.7	58.3	43.3
Mn	1.65	2.88	0.876	0.088	2.83	1.12	1.18
K	25.4	14.6	5.90	4.40	7.00	6.60	2.70
Na	666.	210.	39.4	29.6	223.	192.	4.3
Cr	<30.	<30.	<30.	<30.	<30.	<30.	<30.
Zn	190.	163.	96.	48.	70.	65.	54.

Sta.	D-1	D-2	D-3	D-4	D-5	D-6	D-7
Date	06/19/89	06/19/89	06/19/89	06/19/89	06/19/89	06/19/89	06/19/89
Cu	3.0	0.0	0.0	12.0	0.0	0.0	0.0
Zn	41.	32.	5.	16.	15.	11.	57.
Ba	26.0	18.0	65.0	29.0	310.	382.	146.
Na	686.	202.	30.3	16.8	233.	164.	2.8
Mg	418.	123.	27.3	138.	82.4	58.0	43.1
K	24.9	12.2	4.10	1.80	4.70	5.50	1.60
Ca	626.	485.	99.9	400.	88.5	104.	126.
Mn	1.81	3.71	0.751	0.067	1.84	0.725	1.75
Fe	0.019	3.64	0.167	0.064	4.08	11.6	0.100
Cr	1.08	0.72	0.38	33.5	3.42	.078	0.00
As	2.4	8.7	15.1	0.1	5.3	36.9	1.0
Se	14.	0.	1.	0.	1.	0.	0.
Cd	0.00	0.00	0.80	0.06	0.00	0.00	0.10
Pb	1.5	1.3	1.8	2.0	2.3	1.9	1.5
Cl	304.	265.	2.0	3.9	332.	131.	46.8
F	0.18	0.15	0.19	0.11	0.30	0.28	0.97
F. Cond.	6380.	3840.	880.0	2640.	2240.	1610.	940.0
F. ph	6.95	6.98	7.30	6.83	7.46	7.47	7.33
F. Temp.	7.	7.	7.	7.	9.	9.	9.
pH	7.00	6.90	7.30	6.80	7.40	7.40	7.40
CO_3	0.	0.	0.	0.	0.	0.	0.
HCO_3	683.	543.	493.	634.	578.	863.	385.
OH	0.	0.	0.	0.	0.	0.	0.
Total A	559.	445.	404.	519.	473.	707.	315.
Cond.	6350.	3820.	894.0	2600.	2250.	1629.	959.0
SO_4	3350.	1600.	94.	1160.	237.	81.	143.
N	0.28	0.01	0.01	1.55	0.00	0.01	0.01
NPOC	46.6	16.4	6.5	9.9	111.8	35.5	8.3
POC	0.0	0.0	0.0	0.0	1.2	1.2	0.0
TOC	46.6	16.4	6.5	9.9	113.0	36.7	8.3
Total H	3290.	1720.	362.	1570.	560.	499.	492.
Turb.	2.00	2.00	2.00	2.00	25.0	3.00	2.00
TDS	5750.	2950.	501.	2040.	1260.	969.	553.

Sta.	D-8	D-9	D-10	D-11	D-A	D-B
Date	08/25/88	08/25/88	08/25/88	08/25/88	08/25/88	08/25/88
Total A	301.	314.	459.	710.	663.	680.
As	1.6	1.1	1.2	3.4	0.0	0.0
HCO_3	367.	383.	560.	867.	809.	830.
Cd	8.60	3.74	1.26	2.98	0.90	1.10
CO_3	0.	0.	0.	0.	0.	0.
Cl	3.7	176.	308.	302.	79.2	57.4
F	0.1	0.3	0.2	0.1	0.2	0.2
Total H	344.	1680.	1050.	1260.	1750.	4580.
Pb	9.5	2.1	2.2	0.0	0.0	2.7
N	1.0	6.0	0.0	0.1	0.0	0.2
pH	7.7	7.6	7.8	7.0	7.6	7.6
F.pH	7.40	7.21	7.45	6.87	7.50	7.28
Temp.	10.	10.	14.	12.	10.	9.
Se	1.	315.	1.	3.	64.	1.
%Na	3.9	5.1	4.5	6.9	74.1	47.4
SO_4	51.	1100.	43.	75.	5670.	8070.
TDS	364.	2150.	1010.	1280.	9070.	11800.
Turb.	2.00	2.00	4.00	5.00	3.00	3.00
SAR	0.15	0.44	0.31	0.52	24.0	12.2
Cond.	643.0	2740.	2220.	2420.	10160.	11750.
F. Cond.	131.0	430.0	-	345.0	1025.	1033.
Ba	126.	93.5	364	827.	95.7	75.3
Ca	81.5	503.	217.	292.	390.	518.
Cu	2.7	3.0	0.0	3.0	0.0	2.5
Fe	0.097	0.042	0.071	0.818	0.273	0.112
Mg	34.1	102.	124.	129.	188.	799.
Mn	0.023	0.035	1.16	9.33	1.42	1.32
K	2.20	8.90	15.7	10.2	34.6	32.0
Na	6.5	41.3	23.0	42.8	2310.	1900.
Cr	<30.	<30.	<30.	<30.	<30.	<30.
Zn	64.	71.	12.	8.	62.	94.

Sta.	D-8	D-9	D-10	D-11	D-12	D-13
Date	06/19/89	06/19/89	06/19/89	06/19/89	06/19/89	06/19/89
Cu	2.0	1.0	2.0	1.0	3.0	0.0
Zn	46.	22.	24.	61.	20.	45.
Ba	203.	24.0	440.	873.	12.0	20.0
Na	3.1	29.0	13.3	25.4	2380.	2010.
Mg	33.5	86.8	170.	107.	167.	1040.
K	1.00	6.50	10.6	6.70	36.0	30.8
Ca	83.4	421.	293.	266.	349.	498.
Mn	0.020	0.021	0.633	6.45	1.43	3.54
Fe	0.037	0.122	0.080	3.50	3.13	0.010
Cr	46.9	3 04	9.62	1.42	0.00	0.00
As	0.7	0.1	0.6	3.8	4.9	3.8
Se	0.	308.	1.	0.	6.	5.
Cd	0.06	0.04	0.27	0.16	0.00	0.00
Pb	1.8	1.9	1.5	1.6	1.6	4.8
Cl	2.9	192.	383.	301.	82.3	55.6
F	0.10	0.32	0.36	0.17	0.14	0.20
F. Cond.	640.0	2850.	2990.	2250.	10260.	12290.
F. ph	7.37	7.16	7.14	6.89	7.04	7.06
F. Temp.	-	8.	8.	10.	6.	7.
pH	7.50	7.20	7.20	7.00	7.30	7.10
CO_3	0.	0.	0.	0.	0.	0.
HCO_3	402.	390.	1230.	916.	845.	827.
OH	0.	0.	0.	0.	0.	0.
Total A	329.	319.	1010.	750.	692.	677.
Cond.	688.0	2840.	3020.	2220.	10380.	12450.
SO_4	42.	1010.	52.	24.	5760.	8840.
N	4.50	6.40	0.00	0.05	0.06	0.04
NPOC	5.4	9.8	23.1	29.0	24.5	35.5
POC	0.0	0.0	0.0	0.3	0.0	0.0
TOC	5.4	9.8	23.1	29.3	24.5	35.5
Total H	346.	1410.	1430.	1110.	1560.	5520.
Turb.	2.00	2.00	2.00	5.00	5.00	2.00
TDS	384.	1970.	1530.	1180.	9190.	12900.

Sta. Date	D-14 06/19/89	D-15 06/19/89	D-16 06/19/89	D-17 06/19/89
Cu	18.0	1.0	2.0	0.0
Zn	12.	25.	20.	19.
Ba	24.0	42.0	58.	8.0
Na	14.2	47.7	42.4	677.
Mg	19.9	122.	74.2	10.4
K	9.10	28.9	8.50	7.80
Ca	51.5	175.	151.	31.4
Mn	0.055	0.040	0.101	0.088
Fe	0.171	0.141	0.319	0.450
Cr	0.00	0.00	0.00	4.60
As	5.3	3.4	0.8	0.0
Se	0.	0.	0.	1.
Cd	0.03	0.01	0.00	0.00
Pb	0.2	2.0	2.2	2.4
Cl	1.6	7.0	35.8	404.
F	0.18	0.13	0.19	0.50
F. Cond.	340.0	1700.	1340.	3830.
F. ph	8.98	8.67	8.03	8.13
F. Temp.	19.	18.	24.	8.
pH	9.00	8.20	8.00	8.00
CO_3	20.	0.	0.	0.
HCO_3	198.	97.	172.	830.
OH	0.	0.	0.	0.
Total A	195.	79.	141.	680.
Cond.	374.	1646.	1317.	3720.
SO_4	1.	850.	566.	737.
N	0.04	0.08	0.04	0.21
NPOC	15.4	25.0	10.5	8.5
POC	0.0	0.0	0.0	-
TOC	15.4	25.0	10.5	-
Total H	211.	940.	683.	121.
Turb.	3.00	2.00	2.00	2.00
TDS	215.	1280.	963.	2280.

HILLSBORO LANDFILL

Sta.	HL-1	HL-2	HL-3	HL-4	HL-5	HL-6	HL-7
Date	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88
Total A	191.	414.	305.		274.	-	287.
As	2.5	0.7	2.1		3.3	0.8	0.8
HCO_3	233.	505.	373.		335.	-	351.
Cd	2.70	1.72	3.56		6.36	4.02	13.1
CO_3	0.	0.	0.		0.	-	0.
Cl	2.1	6.7	3.1		4.4	-	3.2
F	0.2	0.1	0.2		0.3	-	0.3
Total H	221.	495.	350.		291.	514.	290.
Pb	3.9	1.3	0.7		0.9	2.7	2.6
N	0.1	3.7	0.0		0.2	-	0.1
pH	8.0	8.1	8.0		7.9	-	7.9
F.pH	7.20	6.95	7.40		7.40	7.19	7.47
Temp.	25.	31.	10.		14.	24.	16.
Se	1.	1.	0.		1.	1.	0.
%Na	0.9	1.3	0.0		4.3	3.5	5.8
SO_4	19.	25.	32.		12.	-	12.
TDS	215.	467	338.		286.	-	292.
Turb.	2.00	<1.	1.00		2.00	-	2.00
SAR	0.03	0.06	0.00		0.16	0.16	0.21
Cond.	400.0	820.0	591.0		520.0	-	545.0
F. Cond.	494.0	861.0	853.		556.0	905.0	562.0
Ba	264.	151.	221.		292.	369.	316.
Ca	56.6	113.	77.5		61.3	125.	56.3
Cu	9.4	7.5	5.5		5.2	9.7	5.7
Fe	0.329	0.387	0.286		0.044	0.064	0.073
Mg	19.2	51.4	38.0		33.5	48.9	36.2
Mn	0.518	0.050	0.562		0.882	0.057	0.431
K	2.50	2.30	3.30		2.80	2.90	2.80
Na	0.9	3.1	0.0		6.1	8.6	8.2
Cr	<30.	<30.	<30.		<30.	<30.	<30.
Zn	70.	65.	62.		60.	97.	74.

Sta.	H-1	H-2	H-3	H-4	H-5	H-6	H-7
Date	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89
Cu	1.0	3.0	0.0	3.0	2.0		2.0
Zn	24.	55.	16.	33.	20.		12.
Ba	350.	251.	218.	206.	224.		270.
Na	0.8	2.9	0.0	4.8	4.8		1.9
Mg	17.7	47.1	29.6	79.9	33.2		38.1
Ca	60.1	120.	60.5	75.7	60.3		59.6
Mn	0.493	0.022	0.444	0.023	0.671		0.716
Fe	0.276	0.099	0.035	0.608	0.033		0.013
K	0.900	1.00	2.26	1.46	6.97		3.29
Cr	0.42	0.64	0.36	6.14	1.82		1.48
As	0.9	0.0	0.7	0.8	3.6		0.0
Se	0.	0.	0.	0.	0.		0.
Cd	0.16	0.27	0.13	0.03	0.00		0.00
Pb	1.4	1.2	0 6	2.0	1.2		1.4
Cl	1.5	5.4	1.6	1.8	8.3		2.3
F	0.22	0.18	0.23	0.30	0.30		0.31
F. Cond.	380.0	804.0	520.0	650.0	530.0		500.0
F. ph	7.50	7.13	7.40	7.28	7.29		7.47
F. Temp.	9.	11.	7.	8.	8.		10.
pH	7.60	7.40	7.50	7.60	7.60		7.70
CO_3	0.	0.	0.	0.	0.		0.
HCO_3	232.	559.	362.	521.	344.		370.
OH	0.	0.	0.	0.	0.		0.
Total A	190.	458.	296.	427.	282.		303.
Cond.	384.0	836.0	538.0	834.0	540.0		528.0
SO_4	21.	13.	12.	78.	8.		4.
N	0.04	4.84	0.04	1.09	0.02		0.07
NPOC	-	-	8.8	21.3	6.4		20.0
POC	-	-	0.0	0.0	0.0		0.0
TOC	-	-	8.8	21.3	6.4		20.0
Total H	223.	494.	273.	518.	287.		306.
Turb.	3.00	2.00	2.00	2.00	2.00		2.00
TDS	216.	486.	430.	667.	432.		422.

Sta.	HL-8	HL-9	HL-10	HL-11	HL-12	HL-13	HL-14
Date	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88	08/24/88
Total A		282.	249.	412.	349.	269.	466.
As		2.2	0.6	0.5	0.7	0.6	1.0
HCO_3		344.	304.	503.	426.	328.	546.
Cd		9.40	4.70	7.60	3.26	4.30	1.94
CO_3		0.	0.	0.	0.	0.	11.
Cl		13.1	4.8	314.	31.3	4.3	2.3
F		0.2	0.2	0.2	0.3	0.3	0.5
Total H		329.	329.	625.	613.	344.	460.
Pb		1.7	1.5	4.9	0.8	8.1	1.5
N		0.1	9.2	0.1	26.5	10.5	0.0
pH		7.8	7.8	7.8	7.7	7.8	8.1
F.pH		7.36	7.54	7.18	7.25	7.51	7.48
Temp.		12.	21.	22.	11.	12.	12.
Se		0.	3.	1.	2.	1.	1.
%Na		5.1	0.1	29.7	2.7	2.5	1.7
SO_4		35.	37.	67.	96.	26.	11.
TDS		339.	341.	953.	661.	348.	424.
Turb.		2.00	3.00	2.00	2.00	2.00	3.00
SAR		0.19	0.00	2.12	0.14	0.10	0.08
Cond.		611.0	607.0	1798.	1085.	627.0	818.0
F. Cond.		646.0	615.0	1274.	875.	610.0	767.0
Ba		271.	296.	495.	290.	161.	104.
Ca		77.6	68.8	110.	119.	50.0	35.0
Cu		1.9	1.6	2.0	1.1	1.0	2.3
Fe		0.059	0 035	0.096	0.027	0.057	0.538
Mg		32.8	38.1	85.4	76.6	53.3	90.5
Mn		0.621	0.018	0.012	0.058	0 006	0.034
K		2.80	1.70	6.90	2.50	2.00	1.60
Na		8.1	0.1	122.	7.8	4.1	3.7
Cr		<30.	<30.	<30.	<30.	<30.	<30.
Zn		87.	43.	88.	40.	78.	70.

Sta.	H-8	H-9	H-10	H-11	H-12	H-13	H-14
Date	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89	06/20/89
Cu		1.0	0.0	0.0	2.0	0.0	0.0
Zn		13.	8.	4.	34.	15.	4.
Ba		211.	294.	443.	237.	105.	120.
Na		6.0	0.5	107.	3.0	0.0	2.6
Mg		31.6	37.3	74.3	50.1	32.8	46.7
Ca		77.0	71.9	113.	83.3	53.4	48.2
Mn		0.543	0.014	0.008	0.042	0.005	0.011
Fe		0.926	0.001	0.045	0.185	0.079	0 010
K		2.67	2.07	10.8	2.77	1 05	2.72
Cr		1.08	1.10	0.90	0.00	0.64	0.24
As		2.8	0.0	0.0	1.6	0.0	0.2
Se		0.	2.	0.	2.	2.	1.
Cd		0.00	0.04	0.02	0.18	0.28	0.20
Pb		1.2	1.6	1.0	6.2	1.0	1.2
Cl		10.9	3.6	414.	19.7	0.7	4.9
F		0.24	0.21	0.18	0.35	0.26	0.35
F. Cond.		560.0	550.0	1840.	10.00	500.	620.0
F. ph		7.28	7.33	7.11	7.10	7.38	7.47
F. Temp.		10.	8.	9.	14.	9.	8.
pH		7.60	7.60	7.50	7.70	7.60	7.60
CO_3		0.	0.	0.	0.	0.	0.
HCO_3		358.	301.	447.	390.	357.	352.
OH		0.	0.	0.	0.	0.	0.
Total A		293.	247.	366.	319.	292.	288.
Cond.		583.	584.0	1960.	855.0	522.0	626.0
SO_4		28.	32.	63.	75.	9.	30.
N		0.04	9.50	0.06	17.4	0.68	9.60
NPOC		4.3	2.6	8.4	4.8	3.0	3.3
POC		0.0	0.0	0.0	0.0	0.1	0.0
TOC		4.3	2.6	8.40	4.8	3.1	3.3
Total H		323.	333.	588.	414.	268.	313.
Turb.		8.00	2.00	3.00	2.00	2.00	2.00
TDS		466.	467.	1570.	684.	418.	501.

Sta.	HL-15
Date	08/24/88
Total A	264.
As	1.0
HCO_3	322.
Cd	2.04
CO_3	0.
Cl	2.0
F	0.3
Total H	289.
Pb	2.0
N	1.8
pH	7.9
F.pH	7.37
Temp.	12.
Se	3.
%Na	4.8
SO_4	25.
TDS	293.
Turb.	2.00
SAR	0.17
Cond.	535.0
F. Cond.	605.0
Ba	83.4
Ca	53.0
Cu	1.2
Fe	0.425
Mg	38.1
Mn	0.027
K	2.00
Na	6.7
Cr	<30.
Zn	68.

Sta.	H-15
Date	06/20/89
Cu	1.0
Zn	12.
Ba	150.
Na	3.2
Mg	86.2
Ca	30.4
Mn	0.017
Fe	0.093
K	1.39
Cr	0.70
As	0.1
Se	2.
Cd	0.02
Pb	2.6
Cl	1.6
F	0.58
F. Cond.	790.0
F. ph	7.41
F. Temp.	10.
pH	7.70
CO_3	0.
HCO_3	633.
OH	0.
Total A	518.
Cond.	844.0
SO_4	5.
N	0.02
NPOC	3.6
POC	0.0
TOC	3.6
Total H	431.
Turb.	2.00
TDS	675.

WILLISTON LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	1	25.7	0	25.7	23.1
2	2	6.4	0	6.4	
3	3	4.3	0	4.3	8.8
4	4	9.0	0	9.0	9
5	5	7.9	0	7.9	9.4
6	6	5.5	0	5.5	10.1
7	7	5.0	0	5.0	9.1
8	8	4.9	0	4.9	6.9
9	9	6.7	0	6.7	8.7
10	10	6.7	0	6.7	9.8
11	11	25.3	0	25.3	
12	12	15.6	0	15.6	43.3
13	13	6.9	0	6.9	13.9
14	14	30.3	0	30.3	22.2
15	15	10.4	0	10.4	6.7
16	16	7.2	0	7.2	13.5
UPSTREAM	17	45.6	0	45.6	
DOWNSTREAM	18	51.0	0	51.0	
19	19	48.2	0.1	48.3	19.4
21	21	14.2	0	14.2	10.3

* in mg/l

LINTON LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	22	3.8	0	3.8	15.8
2	24	3.5	0	3.5	16.7
3	27	4.0	0	4.0	16.7
4	26	3.6	0	3.6	28.2
5	29	9.2	0	9.2	39.4
6	28	6.7	0	6.7	31.4
7	30	5.7	0	5.7	33.8
8	32	8.2	0	8.2	24.9
9	33	7.6	0	7.6	40.9
10	23	8.8	0	8.8	51.5
11	25	3.4	0	3.4	28.2
12	31	6.1	0	6.1	46.2
LAGOON	34	17.8	0	17.8	

* in mg/l

WISHEK LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	41	3.8	0	3.8	9.5
2	45	6.6	0	6.6	17
3	38	5.0	0	5.0	18.5
4	39	2.2	0	2.2	18.5
5	40	2.8	0	2.8	18.5
6	44	3.9	0	3.9	15.2
7	43	2.3	0	2.3	20
8	36	6.7	0	6.7	23
9	37	10.0	0	10.0	23.3
10	35	4.3	0	4.3	27.5
11	42	4.5	0	4.5	25.1

* in mg/l

DEVILS LAKE LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	48	35.5	0	35.5	46.6
2	49	10.2	0	10.2	16.4
3	50	4.7	0	4.7	6.5
4	51	7.2	0	7.2	9.9
5	55	100.4	0.6	101.0	113
6	56	28.6	0.2	28.8	35.5
7	53	6.0	0	6.0	8.3
8	54	5.7	0	5.7	5.4
9	52	10.9	0	10.9	9.8
10	57	21.3	0	21.3	23.1
11	58	15.1	0	15.1	29.3
12	47	22.9	0	22.9	24.5
13	46	30.8	0	30.8	35.5

* in mg/l

HARVEY LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	67	8.4	0	8.4	15.5
2	68	6.3	0	6.3	5.2
3	76	9.1	0	9.1	8.2
4	77	20.9	0.3	21.2	20.7
5	74	11.7	0	11.7	10.7
6	75	5.4	0	5.4	7.1
7	59	13.8	0	13.8	8.9
8	60	7.0	0	7.0	4.8
9	61	3.8	0	3.8	3.0
10	69	8.4	0.1	8.5	7.1
11	71	7.5	0	7.5	5.9
12	72	7.3	0	7.3	5.8
13	62	6.7	0	6.7	4.6
14	63	7.0	0	7.0	31
15	66				23.9
16	65				13.7
SHEYENNE R	64	18.8	0	18.8	
SHEYENNE R	73	19.8	0	19.8	
SPRING	70	23.0	0	23.0	
SPRING	78				
STREAM	79				

* in mg/l

HILLSBORO LANDFILL					
		1990			1989
WELL NO.	SAMPLE NO.	NPOC	POC	TOC	TOC
1	80	2.2	0	2.2	
2	81	4.2	0	4.2	
3	82	3.4	0	3.4	8.8
5	91	2.9	0	2.9	6.4
6	92				
7	88	2.9	0	2.9	20.0
8	87				
9	86	3.2	0	3.2	4.3
10	89	2.9	0	2.9	2.6
11	90	9.0	0	9.0	8.4
13	93	3.2	0	3.2	3.0
14	85				3.3
15	83	3.6	0	3.6	3.6
	84				

* in mg/l