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GROUND WATER ANALYSIS NEAR OPEN DUMPS

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MINNESOTA POLLUTION CONTROL AGENCY

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A Report To The
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List of Abbreviations

Inorganic Chemical Parameters

Cond. specific conductivity	TDS = total dissolved solids
l. = lab, f = field	TS = total solids
pH = hydrogen ion concentration	Ca = calcium
Cl = chloride	Mg = magnesium
NH ₃ = ammonia	Fe = iron
NO ₃ = nitrate plus nitrite (NO ₂) ions	K = potassium
T.Alk = total alkalinity	Na = sodium
COD = chemical oxygen demand	SO ₄ = sulfate
As = arsenic	Cation = positively charged ions
Cd = cadmium	Anions = negatively charged ions
Cr = chromium	% Bal. = balance in percent
Pb = lead	
Mn = manganese	
Hg = mercury	
Zn = zinc	
NPDWS - national primary drinking water standard	
NSDWS - national secondary drinking water standard	
EPA - U. S. Environmental Protection Agency	
MPCA - Minnesota Pollution Control Agency	

I. Executive Summary

The goal of this project was to determine to what extent, if any, solid waste open dump sites in Minnesota have contaminated ground water. Fifteen (15) dump sites were selected from a group of 1400 unpermitted dump sites. Each of the sites evaluated in this study was operated as an open dump under criteria established in the Resource Conservation and Recovery Act (RCRA) of 1976. Most of the unpermitted open dumps have been closed for a number of years, however, some sites were selected which have only closed in the past few years and some included in this project were still accepting waste during the course of study. The sites were chosen to be representative of a variety of waste types, management methods, and hydrogeologic settings so that the information gained from the study could be applied to as many situations as possible.

Ground water monitoring wells were installed at designated locations around the margin of each dump by a private contractor. Field measurements were taken and ground water samples were collected on three different occasions during the study by staff from the Minnesota Pollution Control Agency. All water quality samples were analyzed by the Minnesota Department of Health laboratory.

Evaluation of the ground water quality data collected in this study indicate that open dumps have degraded ground water quality regardless of the specific geology at the site or depth to ground water. The results indicate that for each open dump site studied, some portion of the ground water has been degraded by addition of minerals or chemicals to the ground water which can be attributed to solid waste disposal. There were two sites where the

levels of contamination were high enough to require additional investigative work be done to assess the impact that the contaminants may have on the aquifer and the potential health hazards that exist. Those investigations are ongoing under another program and had not been completed at the writing of this report.

Nitrate and cadmium were the only health related inorganic primary drinking water standard parameters which were exceeded in any of the ground water samples. Secondary or aesthetic drinking water standards for ground water quality were frequently exceeded by samples from the monitoring wells indicating that the water near dumps would often be objectionable based on taste and odor. Volatile organic compounds including at least one priority pollutant were detected in ground water at all but two of the dump sites. Ground water at three dump sites had concentrations of volatile organic compounds (VOC) that exceeded the 10^{-5} cancer risk level (10^{-5} level causing an estimated one additional cancer death per 100,000 people over a life time, 70 year consumption).

Mineral and chemical leachate contamination continues to contaminate ground water near open dumps long after the site stops accepting solid waste. Even with improved design and management used in the present generation of permitted landfills, results from monitoring wells indicate that similar ground water contamination is occurring. None of the open dump sites in this study utilized adequate methods needed to decrease leachate generation and subsequent ground water contamination. The need for more advanced methods of solid waste management is supported by more frequent reports of ground water contamination near these disposal sites. One method of dealing

with the problems created by open dumps and poorly designed landfills is to follow-up with good post closure management, ground water monitoring to observe contamination, and implement the remedial measures needed to minimize the adverse impacts on human health and the environment. Unpermitted dumps currently receiving solid waste need to be properly closed as soon as possible or be brought up to standards which assure ground water protection and issued permits.

Proper closure of dumps should include addition of low permeability compacted cover material to increase runoff and reduce infiltration of precipitation. In those cases where ground water contamination has been identified and the potential for a human health hazard exists continued ground water monitoring and site evaluation should be required. Three dump sites were identified which had ground water contamination problems which may require remedial cleanup measures. Two of the three sites mentioned above have been closed more than ten years.

If the group of dump sites chosen for this study are representative of the 1400 dump sites in the State, one could expect to find many more dumps which have caused significant ground water contamination. An effort should be made to identify problem sites and do an investigation when necessary. The need for responsible parties to provide ground water monitoring or initiate remedial cleanup measures should be decided on a site by site basis. Remedial measures should be a higher priority when there is potential for human health impact or significant environmental damage. Overall, this study was highly successful and will assist the Minnesota Pollution Control Agency (MPCA) in making policy related decisions concerning ground water contamination from solid waste facilities.

II. Recommendations

1. Based on the results found in this study, it is likely that only a fraction of the 1400 open dumps in Minnesota will need future detailed evaluation or investigation. The Minnesota Pollution Control Agency (MPCA) should seek funding to screen and identify those open dumps which need remedial action beginning with those which have the greatest potential to impact public health.
2. It is recommended that the following factors be included in the system to screen or identify those open dumps with the greatest potential for causing ground water pollution: Hydrogeology, dump management practices, volume of the dump, and type of waste generators served.
3. In order to preserve ground water quality, the use of active open dumps should be terminated or the facility should be upgraded and permitted.
4. Proper closure of open dumps still accepting waste should be required. In addition, there may also be inactive sites where ground water would still benefit from proper closure. Proper closure may include but is not limited to a sloped low permeability compacted cover to isolate the waste and to increase runoff and reduce infiltration of precipitation.
5. For the three open dumps in this study where ground water contamination has been identified and potential for human health impact exists, continued ground water monitoring and site evaluation should be required.
6. Any decision on the need to initiate remedial cleanup measures at the three contaminated sites found in this study should be reserved until

such time when the potential for impact on human health and the environment have been further evaluated. The balance of the open dumps in this study appear to have a low potential for impacting human health and there does not appear to be justification for further evaluation at this time.

7. Results of sampling for volatile organic chemicals (VOC) at historical dump sites indicate that these and other contaminants can be very persistent, supporting the need for post closure care and monitoring requirements at permitted solid waste disposal facilities.
8. This project was successful in obtaining information necessary to make decisions concerning ground water protection and solid waste disposal site regulation. It is recommended that the MPCA and Legislative Commission on Minnesota Resources (LCMR) continue to pursue similar studies which gather information necessary to protect the resources of Minnesota.

III. Background

A. Program Description

The purpose of this project was to determine to what extent unregulated solid waste dump sites in Minnesota may have contaminated ground water. This goal was accomplished by installing ground water monitoring wells directly adjacent to fifteen selected solid waste dump sites and sampling ground water a minimum of three times over a one year period at each site. Sites were chosen to be representative of a variety of waste types and hydrogeologic settings so that the information gained from the study could be applied to as many situations as possible. There was a lack of data regarding the existence, nature, and extent of ground water contamination at unregulated solid waste dump sites in Minnesota. This information was gathered in order to assist in making decisions regarding the urgency to close active dump sites, the need for continued monitoring by responsible parties, and the potential need to initiate remedial cleanup measures at dumps which may have contaminated ground water. The data gained from the studies will assist the Agency in making reasonable and consistent decisions concerning ground water protection and solid waste disposal site regulation.

B. Site Selection

A list of potential sites was identified through review of the Open Dump Inventory (ODI) and by recommendations of Agency staff or local officials. The ODI was done in 1980 to evaluate existing solid waste disposal facilities in Minnesota. Each of the facilities listed in the ODI was evaluated based on the criteria established under guidance of the Resource Conservation and Recovery Act (RCRA) of 1976 and Section 405(d) of the Clean Water Act. Solid waste facilities were classified as open dumps if they failed to meet any one element of the "Criteria for Classification of Solid Waste Disposal Facilities" (40CFR257). The term "open" refers to the method of operation rather than active vs. inactive. A dump did not have to be "actively" accepting waste in order to be identified as an "open dump". Among the sites inventoried were 120 unpermitted active dumps and approximately 1,200 historical and presumed closed open dump sites. Thus, the ODI report and files provided an excellent source for locating potential sites for ground water monitoring.

Site specific data was gathered for each of the facilities on a list of 50 potential dump sites. The information came from Agency files, site inspections, interviews with local officials, and residents. Table 1 lists 10 major variables which were used to evaluate those sites which could be considered a representative group of open dumps across the State. The goal of site selection was to find 15 sites which had a combination of the variables most common to Minnesota open dump sites. In general, dumps were historically located on land considered of low value or had little potential for development. At the time these dumps were opened, environmental impacts were not thought to be of much concern. Consequently, many dumps are found in abandoned gravel pits and wetlands. The following is a discussion of factors considered in site selection. Table 1 contains a summary of physical variables associated with each site selected for the study. Figure 1 is a state map showing the 15 study sites.

Table 1 - Variables for Consideration in Site Selection for Dump Study

Site Name Location	Geology	Depth To Water Table	Nearby Surface Water	Waste Type	Management	Size Fill/Site (Acres)	History	Cover Material Frequency	Surrounding Land Use
Lave11 Sec. 11, T56N, R19W St. Louis County	glacial outwash sands	8-10 ft.	wetland 3 sides, Two Rivers R. 3/4 mi. E.	MSW	over bank no burn no compac- tion	5/10	open	2 times/ week with sand	forest
Old Duluth City Dump Sec. 8, T50N, R14W St. Louis County	glacial till silty clay & silty sands	less than 10 ft.	in a wet- land, head- waters of E. Chester Creek	MSW Demo. Ind.	area fill no burn no compac- tion	20/30	open 20 yrs. closed 16 yrs.	never until closed	forest -- zoned commercial/ residential
McKinley Sec. 17, T58N, R16W St. Louis County	silty clay till	less than 5 ft.; perched	in wetland, McKinley L. 600' W.	MSW	over bank burned presently no burning	2/10	open	1 month to 1 year	forest
Fifty Lakes Sec. 29, T138, R27W Crow Wing County	silty clay till over sand	20-40 ft.	adj. wet- land, lakes ¼ S. ½ E.	MSW	over bank and trenches	8/15	closed 1 year	1 time/ year	forest
Old Brainerd City Dump Sec. 5, T133N, R28W Crow Wing County	sandy outwash	20-22 ft.	400' to wetland	MSW	area fill burned	30/40	closed 3-10 yrs.	1 time/ week	commercial/ residential
Osage-Carsonville Sec. 20, T140N, R36W Becker County	sand & silt glacial outwash	26-35 ft.	Lake 900'	MSW	trench no burn	4/40	open	1 time/ week	forest
Dilworth Sec. 10, T139N, R48W Clay County	clay & silt glacial lake sed.	3-7 ft.	none	MSW	trench burned	2/2	closed 3-10 years	1 month to 1 year	agri.
Parkers Prairie Sec. 23, T131N, R37W Otter Tail County	sandy outwash	1-19 ft.	Lakes: 400' NE 200' NW 2500' E in wetland	MSW Demo.	over bank past-burn present- trench/burn	5/20	open	1 time/mo. to 1 time per year	agri.

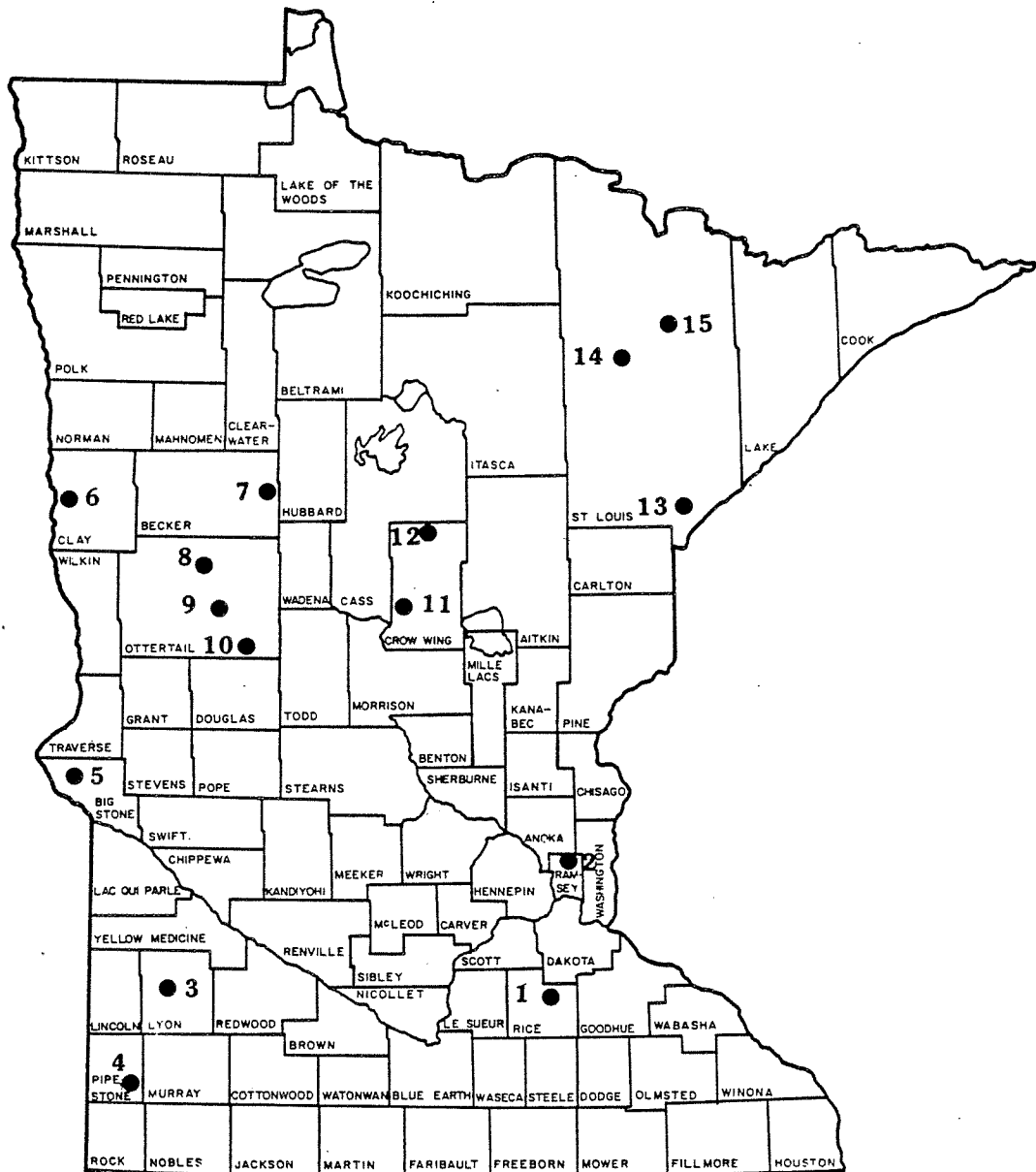
Clinton Sec. 16, T123N, R46W Big Stone County	silty clay till	3-6 ft.	Lakes: 100' SW 1000' E	MSW Demo. Sludge	over bank burn	4/5	closed 1-3 yrs	never until closed	agri.
Perham Sec. 23, T136N, R39W Otter Tail County	outwash sandplain	5-13 ft.	sewage pond 200' N OtterTail R. 3/4 mi.E	MSW	area-fill burned	4/40	closed 3-10 years	1 time/ week to 1 time/mo.	agri.
Henning Sec. 36, T133N, R38W Otter Tail County	silty clay till over sand and gravel	47-72 ft.	none	MSW	trenches burned	5/10	open	1 mo. to 1 time/yr	forest
Marshall Sec. 28, T112N, R41W Lyon County	silty clay till with sand lenses	10-12 ft.	50' to Redwood R.	MSW Ind. Demo.	over bank no burn	8/15	closed 10 yrs	1 week to 1 time/mo	agri. commercial/ industrial
Edgerton Sec. 29, T105N, R45W Pipestone County	sand and gravel outwash	6-8 ft. abandoned municipal wells 400'	600' to Rock R.	MSW Demo.	over bank burned	6/20	closed 1 year	1 time/yr	agri.
Vadnais Heights Sec. Ramsey County	peat over silty clay w/sand and gravel lenses	1-2 ft.	in wetland	Demo. MSW	area-fill	30/40	closed 3-10 years	1 mo. to 1 time/yr	residential
Northfield Sec. 10, T111N, R20W Rice County	silty sand over lime- stone bed- rock less than 10 ft.	5-10 ft.	50' to Cannon R.	Demo. MSW Ind.	area-fill burned	6/10	closed 10 yrs	1 time/wk	recreat./ agri.

Abbreviations:

Rivers - R
Creek - Ck
Lake - L
North - N
South - S
East - E
West - W

Mixed Solid Waste - MSW
Demolition material, buildings, roads - Demo
Industrial Waste - Ind
Diseased shade tree and brush waste - tree
Frequency (ex: 2 times per month = 2x/mo.)
Agricultural - Agri.
Recreational - Recreat.

FIGURE 1 GROUND WATER MONITORING NEAR OPEN DUMPS



1. Northfield - Section 2, T11N, R20W; Rice County
2. Vadnais Heights Demolition Landfill - Section 20, T30N, R22W; Ramsey County
3. Marshall - Section 28, T112N, R41W; Lyon County
4. Edgerton - Section 29, T105N, R44W; Pipestone County
5. Clinton - Section 16, T124N, R46W; Big Stone County
6. Dilworth - Section 10, T139N, R48W; Clay County
7. Osage-Carsonville - Section 20, T140N, R36W; Becker County
8. Perham - Section 23, T136N, R39W; Otter Tail County
9. Henning - Section 36, T133N, R38W; Otter Tail County
10. Parkers Prairie - Section 23, T131N, R37W; Otter Tail County
11. Brainerd - Section 5, T133N, R28W; Crow Wing County
12. Fifty Lakes - Section 29, T138N, R27W; Crow Wing County
13. Duluth - Section 8, T50N, R14W; St. Louis County
14. Lavelle - Section 11, T56N, R19W; St. Louis County
15. McKinley - Section 17, T58N, R16W; St. Louis County

Geology -- There were five general geologic categories in which most dump sites were located. Sand and gravel areas found in glacial drift or outwash plains were observed to be the most common location for dumps on the list of potential sites. Abandoned gravel pits provided a convenient dump location because the hole was already excavated, little vegetation made burning safer, vehicles could use existing roads, and cover material was usually available. Unfortunately, these sites generally provided little or no protection for ground water. Some sites are found in glacial till or glacial lake clays with low permeability. The typical local dump site was selected because of low property value and being far enough from town and homes so that animals and smoke from burning would not cause frequent nuisance.

Some dump sites are located in or very near to the bedrock formations. Dumps may be found in rock quarries for the same reasons they were located in gravel pits. If waste material is put in a quarry, there are no protective layers of soil to filter or restrict seepage after precipitation has leached through the waste. The contaminated leachate water then has direct access to the ground water. The worst case situation is where the bedrock has joints, fractures, or cracks allowing leachate to flow into ground water quickly.

Depth to Water Table -- Depth to water table was determined for each site and then grouped into one of three categories: shallow water table (less than 10 feet), water tables 10-30 feet, and depths greater than 30 feet. Sites were selected within each of these groups to determine what influence depth to water table had on ground water. This study looked only at ground water in the first aquifer or water table encountered, which in some cases may represent a perched water table held up by a layer of less permeable soil found below. The first ground water encountered may not be a part of an actual aquifer, but rather a "pocket" of water trapped on top of a very local or small area of "clay" soil. This water is subject to contamination and will in some cases eventually enter the larger ground water system. Near surface ground water may reach or mix with water found in deeper aquifers, but that is dependent on the site specific hydrogeology and is beyond the scope of this study.

Surface Water -- Surface water (lakes, rivers and wetlands, etc.) are interconnected with ground water systems. Ground water commonly discharges to surface water although in some locations and seasons surface water may recharge ground water. Therefore, proximity to surface water may have some influence on ground water quality and a dump's environmental impact. The distance and type of surface water, if any, was considered for each site. Wetlands or low areas with a high water table were the second most common location observed for dumping in the past. Wetlands may be connected to the ground water system and thus convey contamination into the system.

Waste Type -- Most of the material deposited in open dumps consists of mixed solid waste (MSW). However, depending on the location, significant amounts of demolition material, industrial waste, agricultural, commercial, or tree waste may be present. For purposes of this report, mixed or municipal solid waste consists of a mixture of garbage, household goods, paper, metal, plastic goods and yard wastes. Most sites had separate designated areas for brush and tree waste (burnables), tires and appliances.

Management -- The type of management a dump receives is thought to have an influence on its potential for adverse ground water impact. Methods of depositing waste vary from filling in a gravel pit or wetland by dumping over an embankment, to area fill where successive layers are built up forming a mound, or digging a trench. Any one of these methods of deposition may have included burning to reduce volume. Operations varied from using no compaction of waste spread over a wide area to good compaction and leveling at a relatively small working face.

Size -- The area and volume of the dump will most likely change the potential for adverse impact on ground water quality. The larger the dump, the greater volume of material to generate leachate. The surface area to volume ratio of waste may also affect leachate generation and ground water quality. In site selection, an attempt was made to get a good representation of different sized dumps and volumes.

History -- The history of the site was considered during site selection. The number of years the site was open and the number of years the site has been closed are two important variables to evaluate. Dumps were grouped by category: closed 10 or more years, closed 3-10 years, closed 1-3 years, and open-active (refer to Table 1).

Cover Material -- The amount and type of soil material used to cover the refuse was considered in site selection. The frequency at which cover material was put over the refuse was broken down into periods of once every 1-7 days or 7-30 days, 2-3 times a year, once per year, and never covered.

Surrounding Land Use -- The surrounding land use was considered for a number of reasons: public health, outside impacts on ground water, hydrologic influences, and commercial/residential development. The distance to the surrounding wells was recorded; in almost all cases the nearest wells were .25 miles or more from the open dumps. Agricultural and forested areas were the most common land use around the study sites. Access to the margins of the dump was considered because of potential technical problems with the installation and sampling of wells. Those sites with difficult access at key well locations were eliminated.

The interest and cooperation of the local government unit responsible for the open dump was an important consideration in site selection. Among the sites which were considered as potential candidates there were very few negative responses. In all, about 50 open dumps were considered potential sites for the monitoring study; the parties responsible each received a letter introducing the study and asked if they would agree to participate and offer comments. The parties responsible for each site were then contacted by phone and site inspections were arranged to assist in final site selection. The list was narrowed to 15 sites with 3 alternates in case a problem arose causing abandonment of one of the 15. To the extent possible the sites were located in each major geographical region of the State. This was important in order that some climatic differences, population distribution (urban versus rural, recreational and seasonal fluctuation) could be taken into account.

C. Site Descriptions for Dumps Selected for Study

Northfield Dump, Rice County, is located adjacent to the Cannon River 1 mile southwest of town. The six acre dump is located in shallow alluvial soil (fine to coarse sand and gravel) over limestone bedrock. Elevation of the eroded bedrock surface is highly variable along the river. There were no records to indicate if the excavations and the waste were in contact with bedrock. Water table is 10 feet below the surface upslope and 5 feet below ground level next to the river. The dump received mixed solid waste and some industrial wastes. Wastes were dumped in trenches and burned in early years of operation then switched to area-fill with gravel cover material added once a week. The site opened in 1953, garbage was diverted to another location in 1969, and the site was finally closed in 1972. Surrounding land use is agricultural cropland, recreational and flood plain.

Edgerton Dump, Pipestone County, is located about 0.5 miles west of town adjacent to the Rock River. The dump was started in an old gravel pit and covers about four acres. The site, located in alluvial material deposited by an old glacial river, consists of fine to coarse sand with a trace of silt and gravel. The water table is 6 to 8 feet below the natural ground level. The water bearing sands and gravel are underlain by a thick blue clay lens at 8 to 10 feet below grade. Solid waste and demolition material were pushed over the bank into the gravel pit which was excavated down to the top of the water table. The site, which was closed with a final cover in 1983, is surrounded by agricultural land. There are two abandoned municipal wells located about 400 feet down gradient. The wells were recently abandoned after high nitrate levels were discovered (probably not related to the dump).

Parkers Prairie Dump Site, Ottertail County, is located in an agricultural area 0.5 miles east and .25 miles south of town. The geology of the site is glacial outwash material of light brown fine to medium sand with small amounts of coarse sand and gravel. The water table is about 19 feet below the surface in the upland areas and 4 feet in the low areas. The dumping began as over-the-bank into the wetland, and burn system until recent years when burned trenches were used to dispose of garbage while other types of waste (brush, metal, etc.) went into the wetland. The dump covers about five acres. Fill material is covered every six months or when a new trench is dug. The site was open during the study but is scheduled for closure.

Perham Dump, Otter Tail County, is located on a glacial outwash sandplain just south of Highway 10 and the city sewage treatment ponds. The water table ranges from 5-13 feet below ground level. The three acre dump site is mostly above-ground area fill, although some sand was removed prior to dumping. Mixed solid waste placed at this site was burned and then covered with sand once a month for approximately 40 years until it was closed in 1977. The site is surrounded by mostly agricultural land (irrigated) with some homes about 0.5 miles northeast outside the dumps probable zone of influence. Direction of ground water flow is east toward the Otter Tail River, .75 miles away.

Osage-Carsonville Dump, Becker County, accepts mixed waste from a township sized area. The site is located 1.25 miles north of Osage in a rolling area of glacial outwash. Soils are fine to medium sands with some silt layers.

The dump is just east of Straight and Bog Lakes. Water table ranges from 26 to 35 feet below the natural ground elevation. Waste is currently being dumped or pushed into a 20 foot trench and covered with sandy material once a week. The area filled with waste is approximately two acres and is surrounded by woods.

Brainerd Dump, Crow Wing County, is located northwest of the city and west of the Mississippi River. The site is located on a very fine to medium sand with the water table at 22 feet from natural ground level. This dump received mixed waste and some industrial waste. Waste material was dumped over the bank then burned. Cover was applied at least once a week. The fill area grew to nearly 30 acres before it was closed in 1973. The dump and surrounding area is now utilized as an arboretum through a lease agreement with the county. The site is surrounded by commercial property, residential, and a golf course on the south, east, and west sides, respectively. There is a large wetland located northeast of the dump. A previous hydrologic study in the area indicated that ground water flow is east toward the river; that fact was verified by in this study.

Lavell Dump, St. Louis County, is located in a rural area 3.5 miles south of Cherry on County Road 25. The dump is located in an abandoned sand barrow pit. The site geology consists of brown fine to medium glacial outwash sands with traces of silt and gravel. On the north edge, red-brown silty clay and clayey to silty fine sand materials were encountered. There is a large wetland area approximately 0.5 miles away which encompasses the site on the north, west, and south sides. A conifer forest surrounds the site on all sides. West Two Rivers River is located 0.75 miles to the east. Lavell is currently receiving garbage and household refuse (hereafter mixed waste) from rural and small community areas of approximately 240 square miles. Waste or fill area covers about 5 acres. The site is currently operating without a permit. Waste is being pushed over the bank into an excavation within one foot of the water table and it is covered two times a week with sand from further excavation.

Dilworth Dump, Clay County, is located one mile east of Moorhead. This dump is located in a flat terrain with silty clay soil originating from glacial lake sediments. The soil is very dense with low permeability; water table is seasonally high but averages about 7 feet below ground level. Management at the Dilworth dump was unique in that the same small area (150 feet x 450 feet) was reused over and over by digging new trenches in the same area. Parallel trenches were started at one end and moved as needed toward the opposite end and then returned to the beginning point. Less than two acres of land was used to dispose of waste for over 70 years. A good final cover was added after closure. The result of burning the trenches and reusing the land has concentrated waste materials in this area and created a higher than ordinary potential for ground water contamination.

Clinton Dump, Big Stone County, is the second of the two dump sites located in heavier clay soils. The 4 acre dump is located 0.5 miles north of town surrounded entirely by gently rolling crop land. The soils are dark gray-brown silty clay till with a trace of sand and gravel. Soil is dense with very low permeability and a seasonally high water table of 3-6 feet below surface. Mixed solid waste, demolition material, and some sewage sludge has been dumped at this four acre site. Operation consisted of above

grade area fill and burn with little, if any, cover material used. The dump operated from 1950 to 1982 and no final cover material had been added.

Fifty Lakes Dump, Crow Wing County, is located in a resort area with a relatively small year round township population and a larger seasonal influx of vacationers. The dump area covers approximately 8 acres surrounded by forest with an adjacent wetland and two lakes to the south-southeast. Soils are a thin layer of brown silty clay till in the upland areas over fine to medium sand with traces of coarse sand and gravel. The area has rolling topography so the original dump began as over the bank dumping in the wetland downslope and was worked back up slope where long narrow trenches were used for disposal. This site was closed in March 1983, and waste was diverted to the adjacent permitted modified landfill. Surface elevation drops 30 feet across the fill area. The area was covered and seeded after closure. The water table is found at about 40 feet on the upslope edge of the fill and at about 3 feet on the downslope side.

Henning Dump, Otter Tail County, is located 1.5 miles south and .75 miles east of Henninf. The ten acre dump site is surrounded on three sides by forest with agricultural land bordering on the east property line. Gently rolling hills of light brown clayey silt till were found to overlie layers of clayey fine sand and fine to coarse sand and gravel. The depth to water varies from 47-72 feet below the rolling surface. Fine textured layers of drift were found to be moist but not saturated. This site opened in 1973 and remained open through the sampling period accepting mixed solid waste dumped in trenches and burned daily. Cover material is only applied when the trench is full which takes approximately six months to a year depending on season, depth and length of the trench.

Vadnais Heights, Ramsey County. This 30 acre dump site is located in the Twin Cities metropolitan area. The site is located in line with a chain of small lakes and wetlands. The dump began as a mixed waste dump in a wetland using the area-fill method. Waste was diverted to a sanitary landfill after many years of dumping and then the site was used for demolition material until it closed in 1980. The water table is at or near the surface. Surface soil is a peat material which is underlain by silty clay with fine to coarse sand and gravel lenses. The area received a final cover and is now used as a city park and recreation fields. An attempt was made to locate the wells so as to detect mainly the impact of the 14 acre area of demolition material on ground water rather than the older mixed waste portion of the fill. The demolition material consisted of concrete and brick building debris. During the period of operation, cover material was applied intermittently or at least once a year.

Marshall Dump - Lyon County, is a ten acre site located in a lowland till plain about 1.5 miles north of town between North 7th Street and the Redwood River. The now abandoned sewage treatment ponds are located on the opposite side of 7th Street. Sandy and silty clay soil with thin sand lenses was removed from the dump site during construction of the sewage ponds. Waste was dumped in the clay barrow pit excavation. Water table is 10-12 feet below the surface perched on a dense blue clay layer estimated to be 30-40 feet thick based on nearby well logs. The dump was open from 1962-1971. Mixed solid waste, industrial, and demolition material were dumped over a bank with depth of fill reportedly reaching up to 25 feet deep. Cover

material was added a few times a month and a final sloped cover was added after closure. The surrounding land use is a combination of agricultural and commercial industrial.

McKinley Dump, St. Louis County, is located on the south side of the city, with McKinley Lake on the west, and abandoned iron tailings basins on the east. Waste has been dumped over the bank into a wetland since 1969. The site was issued a sanitary landfill permit (SW-3) which expired and was not reissued because of the cities failure to comply with requirements for cover material and open burning. Mixed waste has been covered occasionally in recent years, however, the dumping face is generally open and uncovered. The dump is located on red-brown silty clay till underlain by a layer of gray-brown silty clay with a trace of gravel underlain by gray silty sand. The shallow water table is apparently perched on top of the clayey till at the site. The gray silty sand below was moist but not saturated. This site is relatively small with the fill area being about 1 acre and it did remain in operation during the sampling portion of the study and has since been closed.

Duluth Dump, St. Louis County, is located in the northwest corner of the city limits near the airport. The dump filled in a 20 acre portion of a large wetland which is underlain by red-brown glacial till of silty clay and silty fine sands. Water table is very shallow (less than 10 feet) and apparently perched on top of clayey till in the wetland area. Garbage from the city of Duluth and nearby rural areas was placed in the wetland for about 15 years (1953-1968) by private companies under contract with the city. The wetland is the headwaters for the East Branch Chester Creek. Beaver dams built on the discharge ditch from the wetland caused frequent 2 to 3 foot increases in water level in the dump. This site received mixed waste, demolition material and some industrial waste. Waste received no cover material or compaction other than car and truck traffic. The site did receive a final cover (about 2 feet) after closure and has experienced severe settling in some areas forming potholes where rain water collects and leaches through the waste. The surface is heavily vegetated by a diverse group of grasses, shrubs and small trees. Some vegetation showed signs of stress and the larger trees have died. Demolition material is being added gradually to the surface of the northwest corner of the fill area.

IV. Results

A. Site by Site Analysis

The following discussion is based on ground water quality data obtained from three sample events scheduled approximately eight weeks apart. The study was designed to be a survey of ground water quality near open dump sites and was not intended to represent a complete hydrogeological investigation. The data will be discussed by comparing background water quality, based on an upgradient location or wells apparently not impacted by the dump, to downgradient locations or wells contaminated by leachate (seepage) from waste buried at the site. Concentrations for ambient ground water quality are taken from Analytical Data for 1982 and Principle Aquifer Analysis, MPCA Volume 5, 1982. It is important to note that the concentrations reported here represent only a narrow interval of time and that concentrations may vary significantly around the dump and over time (past and future). The age of the waste and the operation of the dump as a whole varies from site to site and this fact alone may account for some of the variability.

All general references to high or low concentrations mean "relative to" or "compared to" other samples at the same study site or group of sites in the study as implied by the context of the statement. Discussion of sample results relative to drinking water standards and public health impact are stated separately and are compared to published standards for each parameter; these statements are made independent of the former "relative comparisons". The two forms of discussion should be clearly separated and the purpose or intent of each should not be confused.

Seasonal variations in background water quality may have caused some degree of error in data analysis. Being limited to only three sample events and only one sample for certain parameters was also a limiting factor. There may also be some variation due to changes in equipment used for pumping between sample events. It is not recommended that the data presented here be used elsewhere without detailing the study limitations.

Northfield

Four (4) monitoring wells were installed at this site (see Figure 2). Well 1 was 20 feet deep, 12 feet into weathered limestone; it is on the north side of the fill and was presumed to be upgradient (or represent background quality). Water quality analyses indicate that it is the least contaminated with the exception of nitrate, lead and zinc which averaged the highest concentration of the four wells. Wells 2, 3, and 4 range from 11 to 13 feet deep and are located along the Cannon River parallel to the south side of the dump in fine to coarse sand and gravel. Well 4 had the highest levels of contamination at the site; concentrations averaged 3 to 4 times those observed in the other wells. Average specific conductivity increased from 575 umho/cm upgradient to approximately 700 in Wells 2 and 3, and 2200 in Well 4. Average pH measurements show a reciprocal pattern of decreasing from 7.1 at Well 1 to 6.7 at Well 4. These patterns are consistent with what is expected with leachate contamination. Chloride and ammonia concentrations are relatively low in Wells 1, 2 and 3, however, Well 4 is again distinctly higher. Nitrite plus Nitrate (hereafter nitrate) levels were less than 1 mg/l except in Well 1 which averaged 4.1 mg/l. Elevated

nitrate did not come as a surprise since this is an agricultural area of shallow soils over limestone bedrock. Total alkalinity and Chemical Oxygen Demand (COD) show distinct increases in concentration as ground water moves below the respective portions of the dump with Well 4 being 3 to 4 times higher. For metals, arsenic, cadmium, chromium, lead, manganese, and zinc concentrations were generally near or below average concentrations found at sites with similar geology (Edgerton, Parkers Prairie, Perham, Osage, Brainerd, Lavell). Well 4 shows higher metal concentrations than other wells; arsenic and manganese concentrations were above average here and suggest some localized source of contamination within range of Well 4. Total dissolved solids (TDS), calcium, magnesium, iron, potassium, sodium, and sulfate follow a similar trend with concentrations at or below average levels for Wells 1, 2, and 3 compared to other sites and Well 4 being 2 to 4 times higher than other wells at this site. Mercury and copper were not present above their respective detection limits.

While Wells 2 and 3 detected concentrations of most parameters generally higher than background (characterized by Well 1); Well 4 produced ground water with concentrations generally 3 to 4 times higher than other downgradient wells. It is thought that Well 4 was located in a major contamination plume from the dump. Wells 2 and 3 may have been on the fringe of the plume and/or had greater dilution from clean ground water or a stronger influence from the adjacent Cannon River.

Well 4 indicates that ground water quality has been degraded by this dump site, however, only four parameters have concentrations which exceed secondary drinking water standards. Three wells exceed the Minnesota and U.S. Environmental Protection Agency (EPA) Secondary Drinking Water Standards (SDWS) for manganese, 1 well exceeds the level for TDS, 3 wells exceed levels for iron, and 1 well exceeds the standards for sulfate (Table 2). Most of Minnesota's ground water exceed SDWS's for iron and manganese under natural conditions. Two samples for volatile organic compounds (VOC) were taken from Well 4 during the study. Four volatile organic compounds, each a priority pollutant, were detected in each ground water sample; refer to Appendix D for a complete table of VOC's detected and an explanation of the terminology used in the discussion of results. Two of the compounds present in the first sample, vinyl chloride and 1,2 dichloroethane, have a recommended maximum contaminant level (RMCL) set at zero; the 10^{-5} risk levels for these compounds are 10 and 9.4 ug/l, respectively. Vinyl chloride was present but could not be quantified and 1,2-dichloroethane was measured at 0.9 ug/l. Both the first and second sample contained 1,1,2-trichloroethane, reported at 0.4 ug/l and present but below the lower reporting limit (LRL), respectively; this compound has a 10^{-5} risk level of 6 ug/l.

The second sample also contained 1,1,2-trichloroethylene at 0.6 ug/l (RMCL = 0); cis-1,2-dichloroethylene was also present at 0.6 ug/l, but this compound does not have a published RMCL or risk level.

The literature and recent research support the logic that certain organic compounds are present in ground water as byproducts of biodegradation or breakdown of more complex compounds. This pattern was seen in both Northfield samples where related trichloroethylene and dichloroethylene byproduct species are found in the ground water (further information on biodegradation is provided in Appendix D).

In Well 4 at Northfield, the sample from each event and field blanks detected methylene chloride, a priority pollutant with a 10^{-5} risk level of 1.9 ug/l. Since methylene chloride is present in both field blanks at substantial levels and has historically been a common laboratory contaminate at the Minnesota Department of Health (MDH) laboratory, it is reasonable to assume that laboratory contamination is responsible for the reported values.

The amount of each organic compound found in Well 4 is relatively small, however, the presence of chlorinated hydrocarbon contamination is clearly established. Northfield has been closed over 20 years to dumping so it is possible that these results represent a remnant of contamination that was higher at an earlier time. The site is now used as a diseased shade tree burning site and is not sealed off from traffic, so it is also possible that these organics were introduced at some later date. Ground water discharges to the Cannon River directly and does not represent a health hazard. If the water had remained in the aquifer, it could have theory posed some health problems.

TABLE 2 Mean Concentrations For Three Sampling Events

Site/Well	F.Cond umho/cm	L.Cond umho/cm	F.pH log of [H+]	L.pH	Cl mg/l	NH3 mg/l	NO3 mg/l	T.Alk mg/l	COD mg/l	As ug/l	Cd ug/l	Cr ug/l	Pb ug/l	Mn ug/l
Northfld.#1	573	563	7.1	7.4	8.8	0.26	4.1	265	5	1	0.46	0.65	1.35	20
2	645	690	6.8	7.1	1.4	0.27	0.5	360	12.7	1	0.65	0.5	0.4	190
3	726	720	6.9	7.2	10.6	0.26	0.12	343	23	1	1.3	0.9	1.1	190
4	2200	2200	6.7	7	42	9.5	0.1	836	6	6.4	1.3	1.4	0.3	6233
Edgerton #1	687	687	7	7.4	26	0.026	17.3	282	6.1	1	1.2	0.5	0.4	110
2	1016	1233	6.9	7.2	75	0.27	0.44	369	17.7	1	1.4	0.6	0.45	250
3	1168	1067	7.1	7.3	55	0.26	35	306	7.3	1	0.73	0.8	0.35	305
4	2353	2367	6.9	7	183	9.5	0.01	518	26.7	1	1	0.7	0.8	905
P.Prairie #1	504	540	6.8	7.1	27	0.21	0.01	250	16	1	0.6	0.5	0.3	740
2	1068	1100	6.6	6.9	65	0.13	2.8	510	29	1	0.42	0.9	0.4	20
3	1811	1800	6.6	6.8	153	1.3	0.1	730	50	1	0.18	1.1	0.2	3367
4	443	370	6.7	6.9	20	0.39	0.1	158	41	1.4	1.2	1.1	0.5	1287
Osage #1	895	900	6.7	6.9	3.1	0.03	0.64	280	8.9	1	1.3	1.1	0.3	250
2	487	520	6.8	7.4	5.5	0.05	0.72	280	7.5	1	4.7	0.8	0.5	20
3	722	713	6.8	7.1	33	0.03	1.76	365	7.5	1	10.2	0.87	1.1	33
4	670	653	6.8	7.2	5.3	0.05	3.8	260	5.6	1	1.9	0.8	0.6	20
Perham #1	812	704	6.9	7.5	36	0.02	39	130	6.3	1	0.52	0.7	0.2	20
2	338	403	7.3	7.7	58	0.023	3.1	170	5	1	0.48	1.2	0.5	20
3	1556	1537	6.8	7.3	123	0.05	38.7	240	12.8	1	0.25	1	0.25	210
4	1144	1167	7.1	7.2	41	0.05	35	310	11	1	0.8	0.5	0.67	1367
Brainerd #1	300	330	7.5	7.8	4.8	0.04	0.86	160	6.8	1	4.2	0.9	2.1	40
2	1351	1900	6.9	7.3	30	0.05	0.71	460	22	2.3	3.1	1.7	1.4	780
3	2390	2767	6.5	6.8	293	70	0.01	1110	203	24	0.95	5.6	0.9	1403
4	1733	1867	6.5	6.6	87	35	0.39	840	113	30	4.5	2.7	4	1653
Arb.Well	221	220	7.75	7.7	0.98	0.08	0.01	100	5	5.2	0.09	0.5	0.4	170
Lavell #1	168	170	6.3	6.6	0.61	0.02	0.03	140	28	1	0.24	0.95	0.4	27
2	108	117	6.9	6.9	1.8	0.02	0.94	60	8	1	0.53	0.5	0.6	20
3	50	50	6.4	6.6	2.4	0.02	0.14	21	5	1	0.56	0.73	0.73	20
4	91	100	6.6	7.1	3.5	0.02	0.013	37	7.7	1	1.1	2.8	0.37	20
Henning #1	1005	1023	6.7	6.9	29	0.03	1.5	485	7.7	1	0.83	0.73	0.3	80
2	597	640	7.1	7.3	3.5	0.023	0.88	330	5.1	1	1.4	1.3	0.3	37
4	905	877	7	7.1	20	0.16	0.01	435	11.8	1	0.48	0.53	0.2	233
Schultz well	435	470	7.4	7.6	0.65	0.02	2.2	230	5	1	0.89	0.6	0.3	20
Fifty L.#1	336	373	7.3	7.5	1.1	0.31	0.09	200	6.6	1	1.7	3	1.2	20
2	813	813	6.3	6.3	40	3.4	0.01	386	72	1.03	1	0.63	0.47	67
3	563	563	6	6.2	29	0.03	3.4	123	30	1.5	0.92	5.1	0.63	46500
4	270	270	5.8	6.1	19	0.03	0.29	100	12	2	0.5	0.5	0.25	20
Clinton #1	3512	3534	6.7	7.1	143	0.21	1.5	543	50	2	1.5	1.3	1.2	240
2	2945	3533	6.5	7.1	76	0.1	1.5	480	14	1	1	1	0.57	277
3	3854	4100	6.7	7.2	223	0.22	25	403	26	2	1.2	1.4	0.57	147
4	3116	3400	6.8	7.3	40	0.13	6.4	363	33	2	0.91	1.9	0.53	123

Hg ug/l	Zn ug/l	TDS mg/l	T.S. mg/l	Ca mg/l	Mg mg/l	Fe mg/l	K mg/l	Na mg/l	SO4 mg/l	Cation	Anion	*BAL
0.1	17.5	315	400	160	100	50	0.7	5.2	22	5450	5990	-9.1
0.1	14	390	410	220	120	430	2.8	6.5	23	7160	7700	-7
0.1	12	400	580	230	140	730	1.9	5.5	50	7690	8510	-9.6
0.1	12	1400	1800	570	450	19000	130	4.8	490	25890	27460	-5.7
0.1	10.5	430	460	190	110	50	1.6	14	29	6660	740	-10.1
0.1	38	777	880	350	200	50	4.8	20	150	12000	12170	-1.4
0.1	10	703	920	370	220	50	3.6	18	120	12690	13740	-7.7
0.1	11.5	1734	1700	690	470	50	6.2	58	550	25910	22400	13.6
0.1	10	320	410	180	82	640	1.6	6.1	5	5500	5870	-5.4
0.1	10	545	750	360	180	50	6.1	37	15	12590	13120	-4.1
0.1	10	1300	1400	470	270	14000	97	120	150	22000	22680	-3
0.1	10	265	200	40	17	1800	20	9.8	16	2290	2290	-8.9
0.1	10	1100	1100	470	120	50	1	4	14	12000	10960	8.7
0.1	10	310	390	380	100	50	0.6	2.9	10	9740	5930	39.2
0.1	10	490	2300	290	110	50	1.3	22	35	9000	9090	-1
0.1	10	1800	2200	200	96	50	1	4.1	44	6130	6400	-4.3
0.1	10	535	610	230	110	50	1.2	3.3	46	6980	7260	-4
0.1	10	240	260	84	42	50	2	39	5	4290	8410	-49
0.1	10	1200	1200	300	180	50	100	120	250	17480	17730	-1.4
0.1	10	795	730	260	140	50	43	33	86	10570	10850	-2.6
0.1	10	210	2700	110	52	50	1	4.2	9.1	3450	3600	-4.2
0.1	40	1200	1300	350	310	50	130	62	430	19310	19420	-0.6
0.12	20	1400	1400	350	160	33000	72	180	11	19990	25740	-22.3
0.4	35	1015	1300	470	170	47000	76	68	85	17770	20040	-11.4
0.1	54	140	150	80	26	530	0.5	3	5.1	2260	2130	6
0.1	10	107	420	33	19	50	1.2	2.8	6.1	1190	3740	-68.1
0.1	10	78	600	20	13	50	1.5	3	15	830	1550	-46.5
0.12	10	42	100	10	10	50	0.7	1.9	7.6	300	570	-46.5
0.11	10	90	230	18	11	50	0.7	3.8	12	770	880	-12.6
0.1	10	625	610	330	170	50	2.1	5	41	1027	1085	-5.3
0.1	11.3	365	390	230	120	50	2.1	2.4	20	7160	7360	-2.8
0.1	10.3	505	450	220	150	5000	3	5.8	30	7730	8250	-6.2
0.15	10	260	270	140	86	50	1.4	2.4	10	4660	4980	-6.3
0.1	10	250	4300	250	41	50	0.7	3	11	5970	4270	28.5
0.1	10	410	560	220	58	48000	15	38	14	13060	13990	-6.6
0.1	10.6	490	930	400	150	50	1.1	8.9	170	5980	6820	-12.3
0.1	10	150	160	64	25	50	1.5	8.5	9.6	2190	2440	-10.1
0.5	33	3433	5600	1000		50	9.8	8.4	1800	44600	47750	-6.6
0.1	16	3500	3900	1200	1100	50	9.3	41	1900	48040	49310	-2.6
0.23	14	4067	4700	1500	1200	50	9	66	2200	57140	59650	-4.2
0.1	13	3533	3800	1100	1100	50	5	49	2100	46290	50630	-8.6

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TABLE 2 'Mean Concentrations For Three Sampling Events

Site/Well	F.Cond umho/cm	L.Cond umho/cm	F.pH log of [H+]	L.pH [H+]	Cl mg/l	NH3 mg/l	NO3 mg/l	T.Alk mg/l	COD mg/l	As ug/l	Cd ug/l	Cr ug/l	Pb ug/l	Mn ug/l
Dilworth #1	5514	5333	6.7	6.9	1600	0.3	0.01	605	65	1	0.92	1.5	0.77	2800
2	2401	2433	6.9	7.2	287	7.2	1	775	48	1.5	1.7	0.73	0.9	1377
3	2870	2900	6.7	6.9	530	0.43	0.11	705	56	15.8	1	0.67	0.93	3233
4	2836	2800	7.2	7.3	537	0.14	0.02	420	21	1	0.61	0.77	0.47	583
Vadnais H#1	1145	1133	6.9	7	32	5.7	0.19	520	26	2	0.06	0.5	0.2	1400
2	1545	1633	6.7	6.8	58	18	0.02	877	96	1.1	0.33	0.7	0.3	1567
3	1624	1633	6.7	6.7	103	22	0.09	777	65	1.6	0.61	0.6	0.4	1467
4	1366	1367	6.6	6.9	20	13	0.013	480	61	1	0.11	0.5	0.2	3000
Marshall #1	4750	5033	6.7	7	7.4	0.04	0.59	423	15	2	1.8	1.4	1.1	843
2	2116	2300	7.3	7.2	46	0.15	0.23	240	25	1	0.2	0.6	1	20
3	2179	1500	6.7	7.3	106	0.65	1.1	360	12	2	0.55	0.95	0.6	70
4	4484	4667	6.5	6.9	400	0.19	13	517	24	2	0.96	1	0.83	117
McKinley #1	359	375	6.4	6.7	3.5	0.07	0.11	80	7	1	1.5	0.8	1.4	30
2	190	180	6.2	6.2	12	0.11	0.6	32	14	1	0.53	0.5	0.7	20
3	418	430	6.4	6.5	12	0.63	0.01	203	87	1	3.2	2.9	2.5	1167
4	994	960	6.6	7	24	0.33	0.01	480	51	1	6.6	1.5	2	1310
Duluth #1	595	587	6.7	7.7	14	0.05	0.04	160	30	1	0.47	2.8	0.6	20
2	328	353	7	7.3	7.3	0.2	0.01	210	7	1	0.13	0.5	0.4	1100
3	1571	593	6.2	6.3	8.3	33	0.01	530	78	1	0.34	2.2	0.56	830
4	2917	2500	6.7	6.7	340	6.7	0.01	960	80	1	0.17	1.7	0.26	1600
Lepac house	478	530	7.5	7.6	36	0.1	0.03	120	20	1	0.04	0.5	0.3	360
Average	1375.2	1391.8	6.8	7.0	100.1	3.9	4.0	378.1	30.1	2.4	1.3	1.2	0.7	1457.7
Minimum	50	50	5.8	6.1	0.61	0.02	0.01	21	5	1	0.04	0.5	0.2	20
Maximum	5514	5333	7.75	7.8	1600	70	39	1110	203	30	10.2	5.6	4	46500
Std.Dev.	1231.5	1272.4	0.4	0.4	226.1	11.1	9.6	244.6	34.0	5.0	1.7	1.0	0.6	5869.6
NPDWS/NSDWS	NA	NA	6.50	to 8.5	250	NA	10	NA	NA	50	10	50	50	50

Hg ug/l	Zn ug/l	TDS mg/l	T.S. mg/l	Ca mg/l	Mg mg/l	Fe mg/l	K mg/l	Na mg/l	SO4 mg/l	Cation	Anion	xBAL
0.01	12	4000	15000	820	1300	410	11	430	750	61600	71600	-14
0.18	12	1500	8100	270	530	50	70	220	240	27500	28620	-3.9
0.15	12	1800	2100	340	470	1200	8.4	340	240	31380	33020	-5
0.12	10	1950	2300	390	650	50	10	220	440	30740	32920	-6.6
0.1	10	560	1200	430	140	14000	5.8	16	93	12250	13180	-7
0.6	10	900	1100	580	200	130000	5.7	27	2.7	16940	19620	=13
0.7	10	677	1400	540	220	23000	6.6	16	12	16080	19320	-16.8
0.1	10	540	560	330	130	2000	6.8	28	11	10610	10100	4.8
0.12	20	5067	6200	1100	2100	50	21	220	3400	74230	7300	1.7
0.1	10	1500	1300	490	280	50	2.1	11	600	15940	17040	-6.5
0.24	10	1850	1500	680	200	50	9.9	7.8	730	18200	18300	-0.5
0.17	19	3967	4500	1300	1000	50	28	330	2000	61250	63900	-4.2
0.1	10	220	240	100	47	50	1.7	5.1	78	3210	3300	-2.8
0.1	10	79	91	22	14	50	1.8	4	11	940	1150	-18.1
0.12	34	403	1900	95	34	500	1.6	38	28	4290	4270	0.6
0.55	39	545	1600	280	140	50	4.1	36	68	10090	13940	-27.6
0.1	10	410	490	140	78	50	2.4	49	140	6580	6660	-1.2
0.1	10	240	540	120	66	210	1.3	6.5	9.1	4040	4610	-12.3
0.12	10.3	280	660	280	64	130000	13	13	2.1	6910	12350	-44
0.1	16	1200	940	240	140	140	13	100	13	12340	14460	-14.7
0.1	10	310	330	130	100	100	1.9	12	8.2	5180	3460	33.1
0.1	14.5	1047.0	1687.4	368.0	264.4	7640.2	16.1	52.1	320.5	15516.7	15364.9	-7.5
0.01	10	42	91	10	10	50	0.5	1.9	2.1	300	570	-68.1
0.7	54	5067	15000	1500	2100	130000	130	430	3400	74230	71600	39.2
0.1	9.4	1161.0	2347.4	327.1	383.6	24462	30.6	89.2	672.1	16641.4	16058.2	16.9
2	5000	500	NA	NA	NA	300	NA	NA	250			

Edgerton

Figure 3 indicates the location of four monitoring wells at the Edgerton dump. Well 1, located on the north side near the entrance, is the upgradient well and in general had the lowest concentration for each parameter with the exception of nitrate. The average nitrate concentration (17.3) is above drinking water standard and may be a result of agricultural sources. A pair of municipal wells .25 miles downgradient were closed recently due to high nitrate levels. Average specific conductivity ranges from 700 umho/cm in Well 1 and 1000-1200 in Wells 2 and 3 up to 2300 umhos/cm in Well 4. A trend of increasing contamination paralleling conductivity occurs in the average concentrations for chloride, total alkalinity, ammonia, and COD. Well 4 has the highest concentrations while Wells 2 and 3 have elevated levels but are moderate compared to Well 4.

Metals arsenic, mercury, copper, and iron in all wells were determined to be below the detection limits. Chromium and cadmium were each found to be present in similar quantities in all wells. Lead levels ranged from 0.35 to 0.45 ug/l in Wells 1, 2, and 3 and increased to 0.80 in Well 4. Manganese, magnesium, TDS, potassium, sodium, and sulfate all showed similar trends of increasing concentration noted above for conductivity and the general chemistry parameters.

Well 4 appears to indicate the level of ground water contamination resulting from this dump site. Well 1 exceeds the standard for nitrate but is not likely a result of the dump. Four wells exceed the Mn standard, three exceed the TDS standard, and one exceeds the sulfate standard. Wells at this site indicate concentrations of 12 parameters are above the mean for ambient surficial sand aquifers (MPCA, 1982) but these concentrations over the drinking water standards are common for shallow aquifers in Southwestern Minnesota. Wells 2 and 4 were sampled for organic compounds and none were reported other than methylene chloride, which was also present in the field blank and was assumed to be laboratory contamination. Evaluation of individual well data clearly shows that ground water is degraded by this dump and Well 4 can be used to quantify the extent of contamination. The amount of contamination detected, however, does not appear to represent a threat to public health at this time, although when both the municipal wells and the dump were operational a more serious threat did exist.

Parkers Prairie

Four monitoring wells were installed at this dump site (Figure 4). Well 1 is the upgradient well and represents background water quality. Wells 2, 3 and 4 are located to intercept ground water flow from different sections of the dump. Well 2 is closest to the trenches used in recent years for garbage resulting in higher specific conductivity, lower pH, and elevated chloride, nitrate, total alkalinity, and COD. Well 3 is downgradient from both the newer trenches and the older portion of area fill which is currently used for yard waste and burnable material. Well 3 had the highest mean conductivity, chloride, ammonia, total alkalinity, COD, and the lower pH. Well 4 is 200 feet east and 50 feet north of Well 3 on the opposite side of a wetland. Ground water quality measured at Well 4 was similar to Wells 2 and 3 with the added influence of the wetland and additional dilution. Mean concentrations of conductivity, chloride and total

alkalinity, at Well 4 are lower than any other well at the site. Ammonia and COD are elevated which may be related to the wetland. Arsenic is below the detection limit on Wells 1, 2 and 3. Well 4 shows higher levels of arsenic, cadmium, and lead than the other wells on site. Similar amounts of chromium were found in Wells 2, 3 and 4. Manganese was high in Well 3 (3367 ug/l) more than 2.5 times the mean concentration in Well 4 (1287 ug/l) along with Well 1 (740 ug/l); all three exceed the drinking water standard (50 ug/l). Mercury, zinc, and copper concentrations were all below detection limits at this site. TDS, calcium, and magnesium are elevated in Wells 2 and 3 with Well 3 again showing highest concentrations. Wells 3 and 4 have very high iron levels, exceeding drinking water standards and the ambient aquifer mean by 7-8 times. Potassium, sodium, and sulfate concentrations are up to ten times higher in Well 3 compared to other wells on site.

Two samples for volatile organic chemicals were taken at this site (see table in Appendix D). Well 3 contained five organic compounds four of which are priority pollutants. Three were determined present but could not be quantified; each had 10^{-5} risk level of 1.9 ug/l. A fourth compound 1,1,2-Trichloroethylene was present at a concentration below the lower reporting limit (LRL), however, it has an RMCL of zero and 10^{-5} level of 27 ug/l. The fifth compound, also a priority pollutant, was found at levels just above the LRL.

Well 3 was sampled again in September 1984 and produced a list of 16 organic compounds in ground water, nine of which are priority pollutants. Three compounds present have RMCL's of zero and one at .00075 ug/l. Seven compounds present have 10^{-5} risk levels of 1.9 ug/l, five of which could not be quantified, and one (trichlorofluoromethane) that exceeded the 10^{-5} risk level.

Among the four wells at this site, Well 3 clearly represents the greatest ground water impact from both the old waste fill area and the active trench area at this dump. Well 4 had higher levels of arsenic and cadmium. The ground water quality has been significantly degraded by this operation. Significant increases in most parameters measured were observed in ground water as it leaves the dump area. Concentrations for 13 parameters were found to exceed ambient mean values for similar aquifers, however, only three - manganese, TDS, and iron - exceeded the secondary drinking water standards for inorganic compounds.

Considering the organic compounds measured, ground water quality at the property line could not be characterized as safe drinking water, however, considering the remote location it is unlikely that this site would pose a public health hazard based on the information collected. Sites such as this which are located near residential developments may represent a threat to public health depending upon ground water gradients and usage.

Perham

Ground water quality at the Perham site is influenced by at least two major sources other than the dump itself. The dump is bordered on two sides by agricultural crop land with a center pivot irrigation system in the field on the western edge (upgradient); on the north side of the dump is the city wastewater treatment system discharge to a "holding pond" which looks and

performs more like an infiltration basin and wetland (Figure 5). The influence of the irrigation system can be noted in the high nitrate levels (35 to 39 mg/l) in Wells 1, 3, and 4 (see Table 2). The wastewater treatment system appears to have a diluting effect on most parameters in Well 2 compared to Well 1 except for levels of chloride, sodium, cadmium, chromium, and lead. Specific conductivity, total alkalinity and COD in Wells 3 and 4 were two to three times higher than in Wells 1 and 2. The following elements were reported to be below their respective detection limits in all wells; arsenic, mercury, zinc, copper, and iron. Concentrations of other metals analyzed fall within a relatively close range and do not show any strong trends with the exception of manganese which was very high in Well 4. Wells 3 and 4 had elevated levels of potassium, sodium, and sulfate with Well 3 being 2 to 3 times higher than Well 4 concentrations. Well 3 generally had the highest concentrations measured when compared to the other wells on site.

The nitrate drinking water standard is exceeded in three wells most likely due to agricultural irrigation and cropping. Manganese and sulfate each exceed standards in different wells while TDS is over the limit in three wells.

Two samples for organic chemicals were taken, one each from Wells 3 and 4 and no organic compounds were detected in either sample.

This dump site was closed in 1977 and is relatively old compared to other sites, yet by comparing upgradient and downgradient wells, degradation of ground water quality is apparent. When all parameters are compared to ambient mean values for similar aquifers there are 12 parameters which exceed the mean. Drinking water standards are exceeded for one primary standard nitrate and three secondary standards. This site may have caused contamination at one time but cannot be said to be a hazard to ground water quality at this time.

Osage - Carsonville

Four ground water monitoring wells were installed and sampled at the Osage site (Figure 6). Average specific conductivity in the four wells ranges from 650 to 900 umhos/cm with the highest conductivities found at Wells 1 and 3. Field pH measurements averaged 6.8 for Wells 2, 3, and 4 and 6.7 for Well 1. Well 3 was the only place where chloride was elevated. Ammonia, nitrate, total alkalinity, and COD concentrations were relatively low and similar between wells indicating no trends. The elements of arsenic, mercury, zinc, copper, and iron were at or below detection limits at all the wells on site. Cadmium was high in Wells 2 and 3 compared to other on site wells and other similar sites. Chromium, lead, and manganese concentrations were similar between wells, except for increased manganese in Well 1. TDS concentrations were notably higher in Wells 1 and 4. Magnesium and potassium levels were similar in all wells. Well 3 had higher sodium levels and sulfate levels were elevated in both Wells 3 and 4.

Comparing the concentration between wells did not indicate a distinct pattern of contamination as it had on other sites. Maximum concentrations for the various parameters were more or less evenly distributed between Wells 1, 3, and 4. Ground water elevations were not very helpful, because

elevations for Wells 2, 3, and 4 did not differ enough to differentiate a gradient from survey error. Water elevations in Well 1 eliminate it as a potential downgradient well. Well 3 was assumed to be the downgradient location based on topography, and parameter concentrations.

*The average cadmium concentration (10.2 ug/l) in Well 3 exceeds the drinking water standard of 10 ug/l; however the cadmium concentrations were inconsistent over the sampling events 29.0, 1.5, 0.2 ug/l respectively for sample events 1, 2, and 3 which decreases the credibility of the high value. Well 1 exceeds the drinking water standard for manganese and both Wells 1 and 2 exceed standards on TDS.

Wells 3 and 4 were sampled for organic chemicals. Three organic compounds were present in Well 3, 1,1,2-trichloroethylene a priority pollutant with an RMCL of zero was found at 0.3 ug/l. Two other compounds with a 10^{-5} risk level of 1.9 ug/l were present, one of which could not be quantified, and the other was present at a concentration less than the reporting limit (see Appendix D). Well 4 had two priority pollutant compounds present, 1,1,1-trichloroethane - RMCL of .00075 ug/l was observed at 0.2 ug/l and trichlorofluoromethane was observed to be 0.6 ug/l compared to the 1.9 ug/l 10^{-5} risk level.

Overall this site has had only minor ground water degradation. Cadmium in Well 3 is the only primary drinking water standard exceeded and even that is somewhat doubtful. Manganese and TDS secondary standards were also exceeded. The presence of the organic compounds is probably of the greatest concern. Ground water is assumed to discharge to the adjacent Bog Lake and therefore potential for any impact on public health is negligible at the concentrations observed.

Brainerd

The ground water quality at the Brainerd City Dump was evaluated based on results from four monitoring wells and a production well at the arboretum maintenance building (see Figure 7). The arboretum well is a four inch steel cased well approximately 55 feet deep. Analysis of this well revealed slightly elevated levels of arsenic (5.2 ug/l), manganese (170 ug/l), zinc (54 ug/l), and iron (530 ug/l) over the background quality in Well 1. Levels of zinc and iron may originate in part from the well construction and plumbing system. Based on our samples, quality of water in the arboretum well has not been adversely affected by the dump.

Mean specific conductivity ranges from 300 umho/cm in Well 1 to 2400 in Well 3. Field pH measurements averaged 7.5, 6.9, 6.5 and 6.5 respectively for Well 1, 2, 3, and 4. Concentrations for chloride, ammonia, total alkalinity, and COD all showed a similar increase to the south along the downgradient side of the fill (from Well 2 to 4 to 3). Well 3 had very high concentrations for chloride, ammonia, total alkalinity, and COD (2 to 3 times higher than Well 4, ten times higher than Well 2 for chloride and COD). Average arsenic concentrations were high in Wells 3 (24 ug/l) and 4 (30 ug/l); these levels were the highest observed at any any of the 15 sites. Mean chromium levels were higher in Well 3 (5.6 ug/l) than Well 4 (2.7 ug/l). Cadmium levels reached as high as 8.8 ug/l with a mean of 4.5 ug/l in Well 4 which was only slightly higher than Well 1 (mean 4.2 ug/l)

and Well 2 (mean 3.1 ug/l). Since Well 1 is upgradient, the natural levels of cadmium may be that high. Lead levels reached 10 ug/l in Well 4 (mean 4 ug/l). Mercury was below detection in the majority of the wells sampled for this project, however, Well 4 at Brainerd mercury averaged 0.40 ug/l while Well 3 was just above the reporting limit at 0.12 ug/l. Compared with other sites, Wells 3 and 4 have consistently high concentrations of heavy metals while other sites may have had one or more metals at a high concentrations. Wells 2, 3, and 4 had similar mean concentrations of TDS, calcium, magnesium, and zinc. Iron was extremely high in Wells 3 and 4 (33,000 and 47,000 ug/l respectively). Well 2 had the highest mean concentration for zinc, magnesium, potassium, and sulfate out of all three of the downgradient wells.

Wells 3 and 4 were sampled for volatile organic chemicals. The samples were analyzed with both the Gas Chromatograph (GC) and Gas Chromatograph Mass Spectrometer (GCMS). Well 3 produced a list of 36 organic compounds, 15 of these are on the list of priority pollutants (see Appendix D). Five compounds present in the ground water exceed the RMCL of zero or 0.00075. Three compounds have a 10^{-5} risk level of 1.9 ug/l, two of were reported to be present but could not be quantified, the third - methylene chloride (a common laboratory contaminant) - was reported present at 1.7 ug/l. Methylene chloride was not present in the field blank and considering the variety of other compounds present, it is possible that it is actually present in the ground water.

Well 4 produced a list of 28 different organic compounds, 14 of which are on the priority pollutant list. There were 18 compounds present near or exceeding the 10^{-5} risk level and the RMCL. Seven of the eighteen were also found in Well 3 three months earlier.

Ground water at the Brainerd dump site has higher than normal concentrations of numerous parameters measured during this study. Mean concentrations for 16 of the 22 parameters exceeded the mean ambient concentrations. Drinking water standards are exceeded for five inorganic parameters (chloride, manganese, TDS, iron, and sulfate) and eight organic compounds.

Together, the inorganic and organic results indicate that ground water has been contaminated at this site. Heavy metals are present at levels higher than those found at similar sites. The variety and high concentrations of some organic compounds may represent a public health problem in drinking water. The direction of ground water flow is known to be east-southeast toward the Mississippi River. It is not known if there are any wells in use for human consumption between the dump and the discharge point at the river. An ongoing investigation (separate from this study) was initiated to determine the need for protective or corrective measures needed at this site.

Lavell

There were three existing wells at this site prior to installation of the four wells in this study (Figure 8). The existing wells were 4 inch steel casing 20 feet deep with no screen, only an open end at the bottom. The existing wells were not sampled because of problems with the metal casing and unanswered questions about construction methods, they were however used to help establish ground water elevations.

Results for all four wells show very low concentrations for all parameters by comparison to other study sites. Measured concentrations for inorganics are lower across the board than at any other site studied. Well 1 is located in a pocket of red-brown silty fine sand, which was not found elsewhere on the site. Overall there was little variation in concentrations between wells. Mean concentrations in Well 4 were only slightly higher than Wells 2 and 3.

There were only four parameters which had concentrations over the mean ambient levels for surficial sand aquifers. Average field pH for Wells 1, 2, and 3 were below the acceptable drinking water pH range (SDWS) during the third sampling round. This was the only measured parameter which exceeded the drinking water standard.

Two samples for volatile organic chemicals were taken at Lavell. The first from Well 3 found no organic compounds above the lower reporting limit. The second sample from Well 4 contained two compounds 1,1,2-trichloroethylene observed at 0.3 ug/l with an RMCL = 0 and 10^{-5} risk level = 27 ug/l; Methylene chloride observed at 2.2 ug/l with a 10^{-5} risk level of 1.9 ug/l. Methylene chloride was not observed in the field blank so it is possible that it was actually there rather than laboratory contamination.

Direction of ground water flow could not be accurately predicted. Water elevations did not show a consistent flow direction or established horizontal gradients; there could be a significant downward component to the flow. More deep wells and piezometer installations would be necessary to decipher the flow pattern at this site. A leachate contaminant plume was not detected with the wells installed. However, based on the amount of waste buried and coarse sands, it is probable that a plume of contamination exists elsewhere or deeper in the aquifer. No degradation was detected in the shallow ground water which was sampled.

Dilworth

This site is similar to Clinton with heavy clay soils of low permeability (Figure 9). Specific conductivity was twice as high, and chloride was three times higher in Well 1 when compared to the other wells on site. Wells 1 and 3 had the lowest mean pH values. Well 2 had the highest mean values for nitrogen (ammonia and nitrate), potassium and total alkalinity. Because the nitrogen and potassium levels were much higher here than other wells, the levels may be a response to agricultural fertilizer spilled or overapplied in the field located only five feet away. Well 3 had the highest levels of arsenic ranging from 7.2-27 ug/l. Mean values for other heavy metals were similar between wells and did not show a clear pattern of contamination in one particular well. Well 1 had the highest mean concentrations for TDS, total solids (TS), calcium, magnesium, sodium, and sulfate. The soil at this site was a heavy clay originating from lake sediments; the background effects on ground water chemistry are similar to those discussed under Clinton. Compared to the surficial sand sites total anions and cations were 4 to 8 times higher in the clay sites in all wells not just limited to contaminated wells. Direction of ground water movement could not be determined. Wells had to be compared on a site by site basis relative to each other and their respective background conditions.

Two samples for volatile organic compounds were collected at this site; Well 4 produced no reportable compounds. Well 1 produced a list of seven

compounds (five priority pollutants). Three of the observed compounds have a 10^{-5} risk level of 1.9 ug/l, however, actual amounts present could not be quantified. Ethyl ether was present at comparatively high levels (20.0 ug/l) at this old dump site. 1,1,2-Trichloroethylene was observed at 0.2 ug/l and this compound has an RMCL of 0 ug/l.

Drinking water standards were exceeded in seven different parameters at this site. Most were secondary standards (i.e., aesthetic), however, particular attention should be drawn to the abnormally high chloride levels (1400-1800 mg/l) in Well 1. Arsenic levels exceeded the Minnesota drinking water standard in Well 1 (7.5-27 ug/l). Manganese levels in contaminated Wells 1 and 3 were three times higher than the average for all study sites and the background level. If the wells are ranked in order of decreasing contamination they would be Well 1, 2, 3, 4.

The soils are deep heavy clay and have an extremely low permeability. A more extensive investigation would have to be done to find the extent of pollutant migration. There was no apparent danger to human health. There were several municipal supply wells within a mile radius, however, they are 250-300 feet deep and separated vertically from the water observed by a minimum of 100 feet of heavy clay.

Clinton

Four monitoring wells were located in this heavy clay till soil (Figure 10). Well screens and sand packs were extended to 15 feet in length to collect an adequate sample volume. Recharge rates were very slow under these low permeability conditions. Soil conditions alone caused a characteristic change in background water quality. Specific conductivity and dissolved solids increased by 3 to 5 times as did several other parameters measured (see Table 2). Chloride concentrations were 2 to 5 times higher in Wells 1 and 3. Nitrate was the highest in Well 3 (mean 25 mg/l) followed by Well 4 (mean 6.4 mg/l). An unknown portion of the nitrate may be attributed to the surrounding agricultural cropland. Well 3 is likely influenced by seepage from a large low area in the adjacent field which collects surface runoff. Total alkalinity and COD concentrations fall within a relatively narrow range of values with Well 1 having the highest levels.

Arsenic, copper, and iron were not found above detection limits at this site. Mean cadmium and chromium levels were similar in all wells ranging from .91-1.5 ug/l and 1.0-1.9 ug/l respectively. Well 1 had a noticeably higher mean concentration for lead, mercury, and zinc but none were above drinking water standards. Average manganese levels were 2 to 3 times higher in Wells 1 and 2; all four wells exceeded the manganese drinking water standard (50 ug/l) but the background level may be as high as 80 ug/l so only Wells 1 and 2 were recognized as higher than normal. TDS, calcium, magnesium, sodium, and sulfate concentrations were higher in all wells here compared to other sites in the study and Well 3 had the highest mean concentration.

Volatile organic chemical samples were collected from Wells 1 and 3 (see Appendix D). Well 1 produced only one compound, 1,1,2-Trichloroethylene, a priority pollutant, with an RMCL of 0.0 ug/l. It was observed at 0.3 ug/l. Well 3 produced two related compounds, Cis-1,2-Dichloroethylene at 0.2 ug/l

and 1,1,2-Trichloroethylene at 0.2 ug/l with an RMCL of 0 ug/l. Methylene chloride was also reported present in the sample but was discounted because the same amount was present in the field blank.

Ground water quality at the Clinton site did not meet drinking water standards for pH (in 4 wells), chloride in well 3, nitrate in well 3, Manganese (4 wells), TDS (4 wells), and sulfate (4 wells). High concentrations in some of the aesthetic parameters may be attributed to the geology of the site. Wells 1 and 3 detected the highest levels of contamination and can be used to determine the adverse impact on ground water when compared to Well 4, the least contaminated well. The levels of health related parameters are relatively low and the soils have a low permeability. The ground water evaluated is not of an aquifer that can be practically extracted for domestic use and the static water levels in the nearest wells are 40 feet or more below the ground water analyzed. The conclusion then is that this site has degraded ground water quality but due to its small size and the fact that it is closed, no additional action is recommended to protect ground water or public health.

Fifty Lakes

Wells 1, 2, and 3 were installed for this study and Well 4 was an existing two inch pastic well (Figure 11). Well 1 is located upslope and upgradient from the dump. Sample results for Well 1 indicate that physical and chemical parameters measured are generally below the ambient mean levels for similar aquifers. Well 4 is a slightly deeper downgradient well located midway between Wells 2 and 3. Well 4 shows the lowest pH values of the four wells. Wells 2, 3, and 4 show signs of moderate leachate contamination; pH is lower, conductivity, chloride, total alkalinity, and COD are highest in Well 2. Mercury and copper were below detection limits in all wells at this site. Other metals in Wells 2 and 3 were present at low levels. Chromium concentrations ranged from 0.5 to 6.7 ug/l in Wells 2 and 3. (Cadmium background levels were apparently higher than the ambient aquifer mean level.) Manganese concentrations were also high in Wells 2 and 3.

Two samples were collected for volatile organic chemicals. Well 2 was sampled in June and two organic compounds were detected. Both compounds have a 10^{-5} risk level of 1.9 ug/l, however, the amount present could not be quantified for either compound. Because the risk levels for these compounds are relatively low, they could represent a potential health hazard if drinking water wells were nearby. At the time of this study the laboratory did not have the capability needed to quantify these compounds. Well 3 was sampled in September 1985 and no volatile organic compounds were reported. This site is remote with no ground water development downgradient between the site and Meyer Lake.

Overall 60 samples and 13 different parameters exceeded the mean ambient concentrations. Ground water quality was degraded by the dump but the concentrations did not exceed drinking water standards except for: 1) pH which was below the desirable range in three wells; 2) manganese in two wells exceeded standards, mean values 6,200 and 1,283 ug/l respectively; and 3) Well 2 exceeded standards for TDS and iron.

Henning

By comparison with other sites in the study, ground water contamination was low to moderate at this site. This site has four monitoring wells (Figure 12), Wells 1 and 2 are deep two inch PVC wells. No samples were collected from Well 3. Well 4 was an existing four inch steel cased well and is distinct from all other monitoring wells sampled in that it draws aquifer water from approximately 30 feet below the top of the water table; this has affected the potential for detection of contaminants and the interpretation of the data. An additional well on the adjacent Swartz farm was sampled for background data; this four inch steel cased well is approximately 60 feet deep and located about 500 feet east at an abandoned building site.

Average values for pH were low and conductivity, chloride, nitrate, and total alkalinity are highest in Well 1. Concentrations in Well 4 were similar to Well 1 although somewhat lower. The mean ammonia concentration, although small in magnitude, was five times higher in Well 4 than Wells 1 and 2; COD values were also higher in Well 4. Arsenic, copper, and mercury were below detection limits for all wells at this site. Chromium and cadmium concentrations were slightly higher in Well 2 followed by 1 then 4.

The Swartz well results indicate that ground water in that location is of relatively high quality; concentrations are generally lower than the mean ambient levels of similar aquifers. The monitoring well results show that concentrations of 11 parameters exceeded the mean ambient levels. Two wells exceeded drinking water standards for TDS and one well exceeded the iron standard.

Two samples for volatile organic compounds were taken at Henning (see Appendix D). Well 1 produced a list of five organic compounds present in the ground water (4 out of 5 are priority pollutants). The compound 1,1 Dichloroethylene (reported at 0.6 ug/l) exceeded the 10^{-5} risk level of 0.33 ug/l. Three compounds are present at levels which exceed the RMCL. Two other compounds present have a 10^{-5} risk level of 1.9 ug/l; the observed concentration of Trichlorofluoromethane (0.4 ug/l) was below the risk level and the quantity of Dichlorodifluoromethane could not be determined. Well 4 produced a list of eight organic compounds (six are priority pollutants). Three compounds have a 10^{-5} risk level of 1.9 ug/l, concentrations could not be determined on two of those and the third was below reporting limits. Two compounds present exceeded the listed RMCL.

The levels of organic compounds in the ground water would be of greater health concern here than the inorganic parameters which were measured. Sample results indicated that the ground water has been degraded both in the inorganic and the organic areas. The concentrations are relatively low, however, RMCL's for the organics present were exceeded. This dump is still active. There is potential for adverse health impacts because of nearby domestic wells (approximately .25 miles) therefore, additional sampling and more work needs to be done to establish the direction of flow, gradient, and potential impact. There is no way of knowing what the concentrations may have been or may become without further sampling.

Vadnais Heights

Four monitoring wells were installed on the perimeter of the demolition landfill (DLF) portion of the fill area (Figure 13). The direction of ground water flow, approximated by water elevations, would indicate that some part of the ground water flow passes under and through the older adjacent garbage dump influencing data recorded from the downgradient monitoring wells. The result being that some well data reported are influenced by both the old garbage dump and the DLF.

Specific conductivity was highest and pH values were lowest in Wells 2 and 3, which are presumed to be the "downgradient" contaminated wells. The mean chloride concentration in Well 3 (103 mg/l) was nearly two times the concentration in Well 2 (58 mg/l). Ammonia was elevated in all of the monitoring wells ranging from 5.2 to 25.6 mg/l; this is attributed to the fact that all of the fill was placed over the top of a wetland with up to 12 feet of peat. Total alkalinity in Wells 2 and 3 were two times the overall average concentration for all sites. COD concentrations were high in all wells due in part to the peat at this site. The heavy metals (arsenic, cadmium, chromium, and lead) were present in Wells 2 and 3 at levels only slightly above the detection limit. Manganese concentrations were relatively high, 1400-1567 mg/l, in Wells 1, 2, and 3 and 3000 mg/l in Well 4. Copper and zinc were below detection limits in all wells. Average iron concentrations were highest in Well 3 (23,000 mg/l), Wells 1 and 2 had 13,000-14,000 ug/l and Well 4 had 2,000 ug/l iron. Potassium levels were similar in all wells averaging from 5.7 to 6.8 mg/l. Wells 2 and 3 were sampled for VOCs. Well 3 had trichloroethylene present at the lower reporting limit (0.2 ug/l) while Well 2 reported none.

Wells 2 and 3 had the highest concentrations for the majority of the parameters analyzed and therefore represent the maximum impact on ground water with proper consideration being given to background levels. One sample from Well 3 was below the drinking water standard for pH. All four wells exceeded the secondary (aesthetic) drinking water standards for manganese, total dissolved solids, and iron. The leachate indicator parameters show some degradation of ground water quality. The impact attributed to the demolition landfill could not be separated from the old garbage dump because of the direction of ground water flow. With the exception of those parameters influenced significantly by the peat soils, most concentrations were comparable to those observed at other dump sites.

Marshall

Regional ground water flows to the northeast in the watershed and local ground water flow systems are often toward the Redwood River. Ground water flow at this site is to the northeast toward Well 4 (Figure 14). Water movement is slow through layers of clayey, silty fine to coarse sands and low permeability lenses of silt and clay underlain by a dense layer of low permeability clay. Wells 1 and 4 had the highest mean concentrations of the four wells. Well 1 had higher concentrations of heavy metals and specific conductivity while Well 4 had low pH, high chlorides, ammonia, nitrate, alkalinity, calcium, potassium and sodium which are common indicators of leachate contamination. Ground water elevations indicate that leachate contaminated flow would be toward Well 4 and this is confirmed by the parameters. The heavy metal levels in Well 1 could be from one or more sources;

1. the now abandoned sewage treatment lagoons are less than 50 feet away (across the road) and would have been upgradient; and,

2. ground water mounding may have induced contaminant flow toward Well 1 from the dump.

Conductivity and dissolved solids concentrations are 2 to 2.5 times higher in Wells 1 and 4 compared to Wells 2 and 3. Sulfate levels were high in all wells (ranging from 600-3400 mg/l) but particularly high in Wells 1 and 4; high sulfate in Well 1 (3400 mg/l) would tend to support the ground water mounding theory of contamination above. High sulfate concentrations are likely a result of an agricultural sulfur processing and storage facility which operated on top of the fill for a number of years after closure. Arsenic, iron and copper were below detection limits in all samples. While heavy metal concentrations were distinctly higher in Wells 1 and 4, the levels were average compared to other similar sites.

Drinking water standards were exceeded for six measured parameters; nitrate was the only primary standard exceeded (two samples from Well 4); secondary standards were exceeded for pH, chloride, manganese, dissolved solids, and sulfate.

The monitoring wells were ranked in order of frequency of highest mean concentrations (for all 25 parameters) in descending order Wells 4, 1, 3, 2 with Well 4 showing the greatest amount of leachate contamination and Well 2 showing the least impact.

Two samples for volatile organic compound analysis were taken; Well 1 test results found only methylene chloride which was also reported in the corresponding field blank at a similar concentration discounting its significance. The sample from Well 4 produced three compounds, each a priority pollutant, with a relatively low acceptable level. Chloroform has a 10^{-5} risk level of 1.9 ug/l was reported present but at a concentration below reporting limits. Trichlorofluoromethane has a 10^{-5} level of 1.9 ug/l and was measured at 0.4 ug/l in the ground water. 1,1,2-Trichloroethylene has an RMCL of 0 ug/l and was reported present at 0.2 ug/l in ground water.

This dump site has been closed for more than ten years and the leachate generated was expected to be less concentrated, however, chloride levels in Well 4 averaged 400 mg/l (four times the overall average). Sodium and total dissolved solids (Wells 1 and 4) were some of the highest levels observed at any of the sites. Results indicate that this site has and is still degrading water quality.

The volatile organics measured were few in number and of relatively low concentration; the significance may be in the persistence of the chemicals being present more than ten years after closure. The parameters measured at high levels are indicator parameters and do not pose a public health threat. In addition, the surficial ground water monitored at this site discharges to the Redwood River a short distance from the boundary.

McKinley

The four monitoring wells placed at this dump site (Figure 15) are intercepting a perched water table (water which has been trapped or infiltration has been slowed by the underlying clay till layer with a low permeability). The wetland which borders the site on the west and south is

assumed to be underlain by this same till layer. The preliminary soil boring indicated that the till layer was underlain by a coarse sand with a trace of silt and gravel, moist but not saturated. In order to detect the impact of this relatively small waste fill area (approximately 1 acre), wells were placed very shallow.

Wells 3 and 4 generally had the highest concentrations of indicator parameters and heavy metals. Ground water elevations indicate that Wells 1 and 2 are upgradient and Wells 3 and 4 are downgradient from the dump. Leachate usually lowers the pH of water downgradient, however, at this site the condition was reversed with the lowest mean pH occurring in Well 2. Cadmium, chromium and lead were elevated to above average levels in Wells 3 and 4 compared to other similar sites. Mercury was elevated in Well 4 to as high as 0.99 mg/l in the second sample event but was below the reporting limit in the first event.

All four wells at this site were sampled for volatile organic compounds. In the first sample round, methylene chloride was present in three of four samples and also in the field blank at a higher concentration, therefore, its significance has been discounted. 1,1,2-Trichloroethylene was present in Well 1 at 0.4 ug/l and the RMCL for that compound is 0.0 ug/l. Well 3 had 1,1,2,2-Tetrachloroethylene present in the sample but at a level below the reporting limit (2.0 ug/l), the RMCL is 0 ug/l for this compound and the reporting limit is higher than other compounds with similar RMCL's; its presence in ground water may be of concern. Well 4 was sampled for volatile organic compounds on two different occasions. The first sample reported only methylene chloride and was discussed above, the second sample had Cis-1,2-Dichloroethylene present in the water but the amount was below the reporting limit of 0.2 ug/l.

The ranking of the monitoring wells (most frequently having a high concentration to lowest) was Wells 4, 3, 1, 2. Secondary drinking water standards were exceeded for four parameters (pH - both field and laboratory, manganese; total dissolved solids, and iron). No primary standards were exceeded. This is a small dump site which can generate only a small amount of leachate, however, its impact on ground water can be seen in the data from indicator parameters, the organic parameters, and particularly in the heavy metals parameters. Ground water quality has been degraded but there does not appear to be a threat to public health because of the site's geologic setting and location.

Duluth

Waste was deposited in a wetland at this dump site. The water table in the dump and surrounding area is very shallow. Three monitoring wells are at the dump-wetland interface and Well 1 is located south of the fill on higher ground in red-brown silty and clayey fine sand till (Figure 16). Ground water elevations indicate that flow is north and east toward Chester Creek. Well 4 had the highest mean concentration most frequently, followed by Wells 3, 1, 2 and the Lepac house well in decreasing order. Leachate indicator parameters (conductivity, pH, chloride, ammonia, alkalinity, and COD, etc.) indicate that Wells 3 and 4 are contaminated by leachate. Well 1, although it has the highest localized head (water elevation), also appears to be adversely impacted by the dump; this may be due to some localized ground

water mounding effect from poor compaction and surface drainage on the fill. Well 1 also had the highest mean concentrations for cadmium and chromium followed by Wells 3 then 4. These levels are still relatively low and may be caused by higher natural levels in the soil. Manganese levels were high in Wells 2, 3, and 4. Lead was significantly higher in Well 3 than other wells on the site and had the highest mean concentration found in the study.

Two samples for volatile organic compounds were taken from Well 4. The first sample produced five compounds, three of which were priority pollutants (see Appendix D). Three compounds present had a 10^{-5} risk level of 1.9 ug/l but were not quantified. 1,1,2-Trichloroethylene was present at 0.2 ug/l and has an RMCL of 0 ug/l. Ethyl ether was also present at 1.3 ug/l. The second sample from Well 4 also had ethyl ether present at 3.0 ug/l plus four other compounds which are priority pollutants. Two of the compounds, with 10^{-5} risk levels of 1.9 ug/l, were also present in the first sample. There were two new compounds detected; toluene was present but at a level below the lower reporting limit and vinyl chloride (RMCL 0 ug/l) was present but could not be quantified.

The well which supplies drinking water for the Lepac home was sampled for volatile organic compounds from an outside faucet. The one compound detected was 1,2-Dichloroethane, a priority pollutant, with an RMCL of 0.0 ug/l; the amount observed in the sample was below the reporting limit.

By comparison of well concentrations for numerous parameters at this site, it is evident that ground water quality has been degraded by this dump. Secondary drinking water standards were exceeded for five parameters (occurring in Wells 3 and 4). It is not known what portion of the contaminated ground water discharges to the wetland and Chester Creek and what portion remains in the aquifer. Leachate indicator and metal parameter concentrations were relatively low in the Lepac home well sample. The detection of a relatively high risk volatile organic compound in the Lepac well is cause for some concern and the owners were notified of the results and the well was resampled. (Results are not available at the time of this report).

Mean concentrations for inorganic parameters in the contaminated monitoring wells were some of the highest found at similar sites during the study. Excluding the clay sites, the levels here were second only to the Brainerd dump in mean concentration. Evaluation of this dump site is expected to continue beyond the scope and time frame of this study. The potential impact will be made after results of the additional sampling are completed.

FIGURE 2 - NORTHFIELD CITY DUMP
T111N R20W SECTION 27
RICE COUNTY

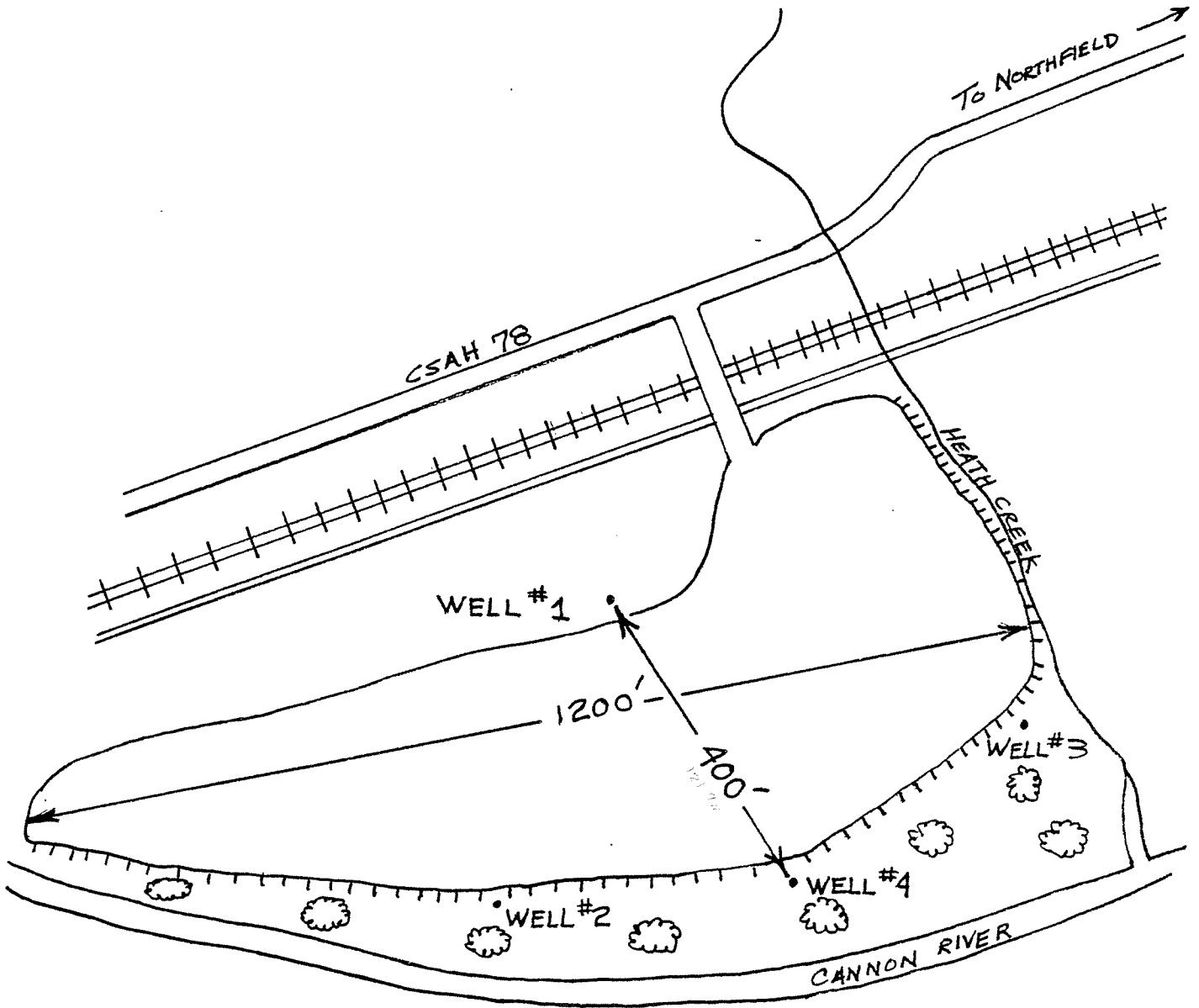


FIGURE 3 - EDGERTON CITY DUMP
T105N R44W SECTION 29
PIPESTONE COUNTY

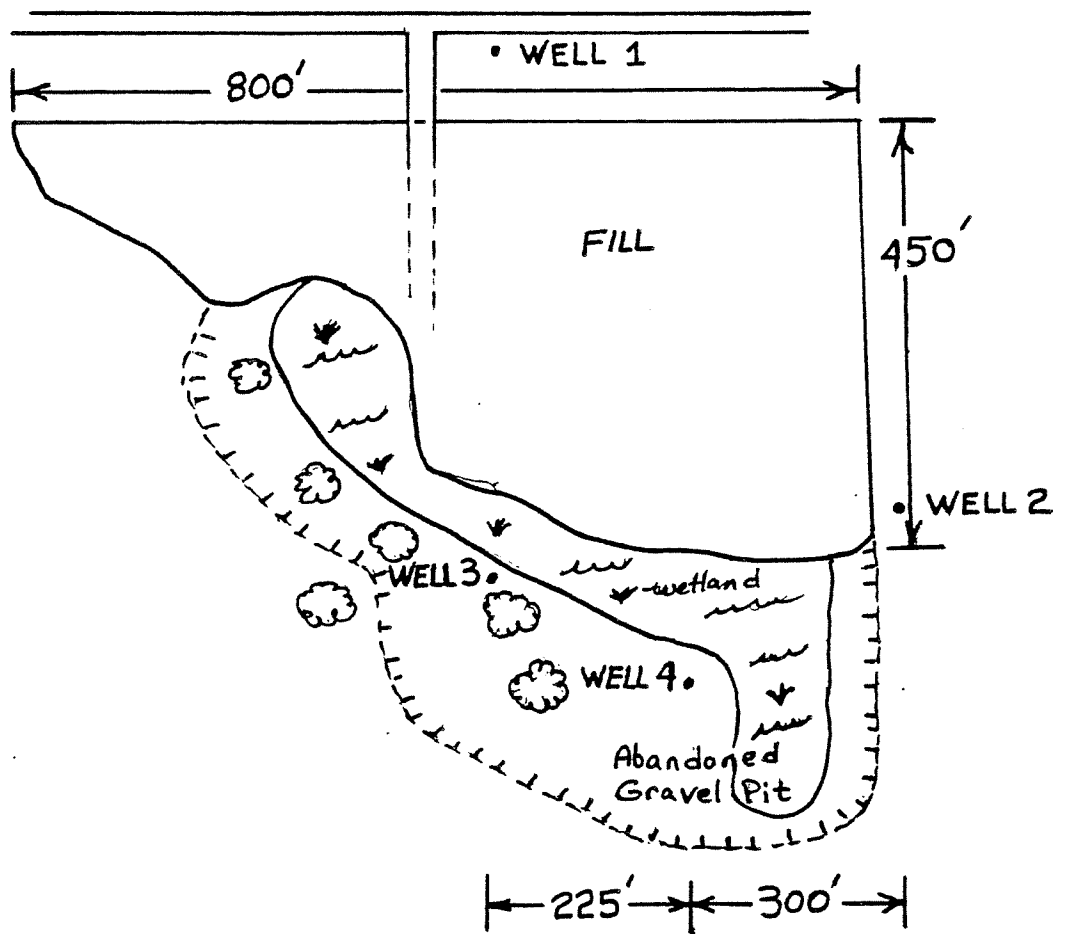


FIGURE 5 - PERHAM CITY DUMP
T13EN R39W SECTION 23
OTTER TAIL COUNTY

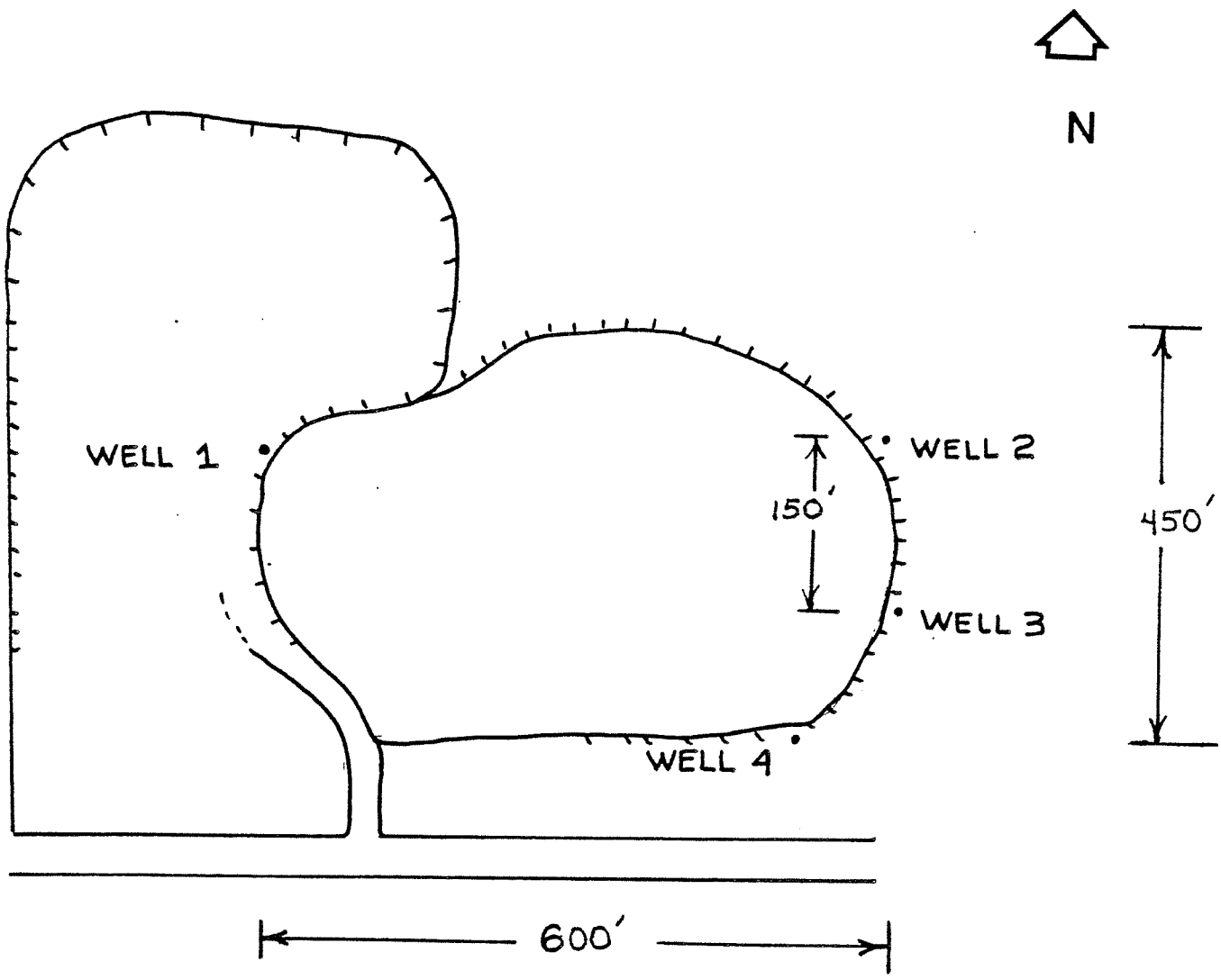


FIGURE 6 -- OSAGE-CARSONVILLE DUMP
T140N R36W SECTION 20
BECKER COUNTY

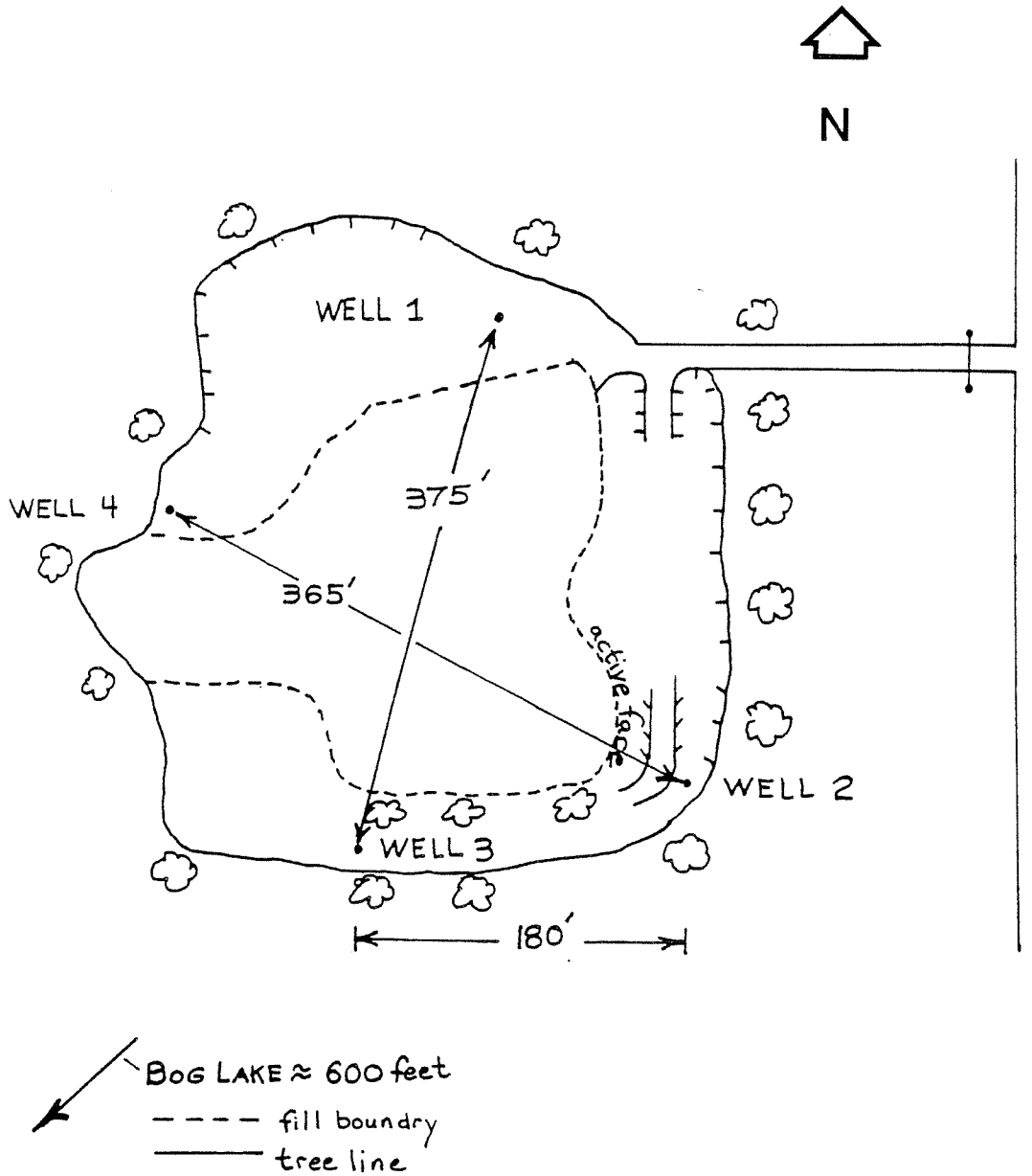


FIGURE 8 - LAVELL AREA DUMP
T56N R18W SECTION 11
ST. LOUIS COUNTY

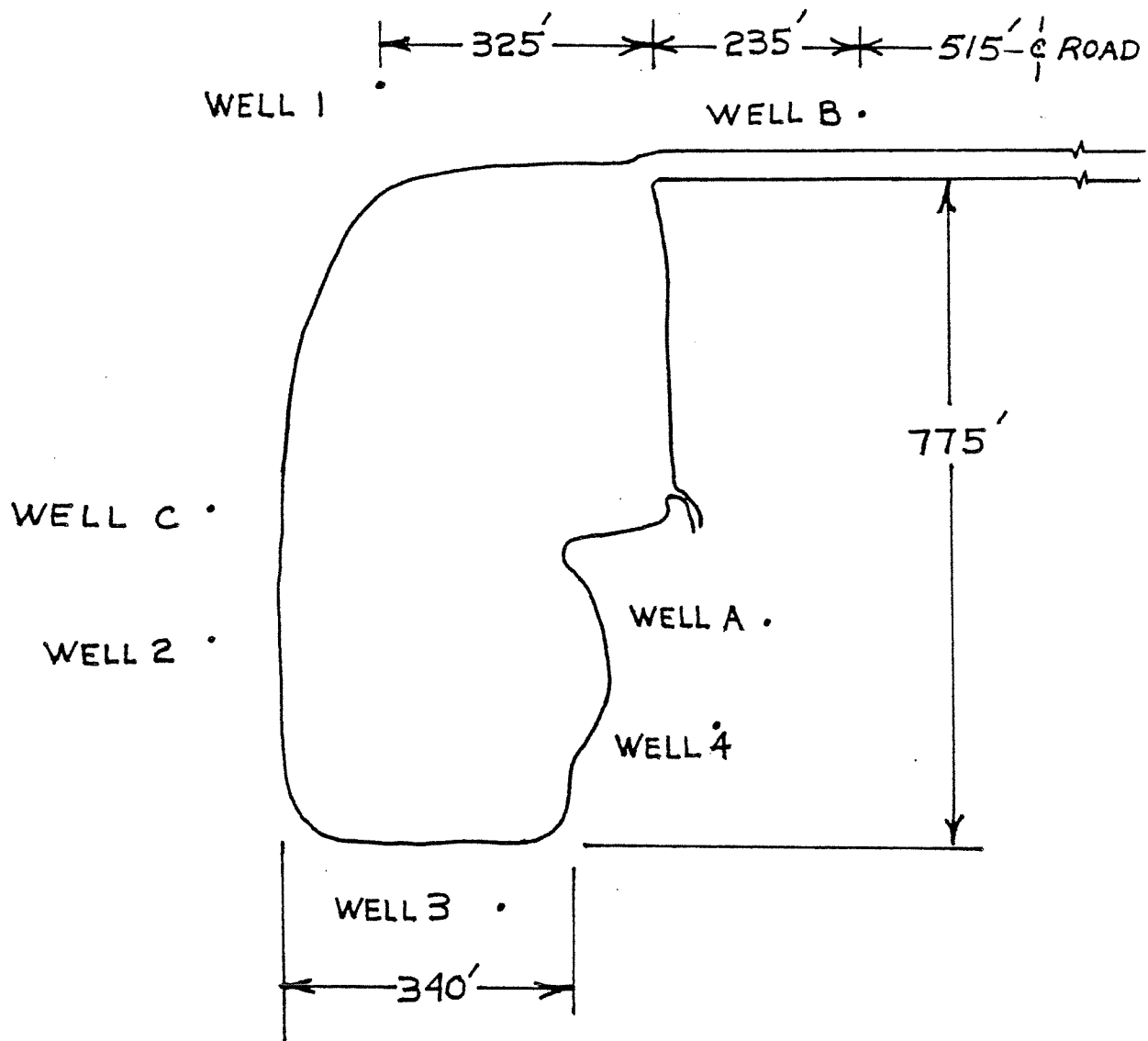


FIGURE 9 - DILWORTH CITY DUMP
T139N R48W SECTION 10
CLAY COUNTY

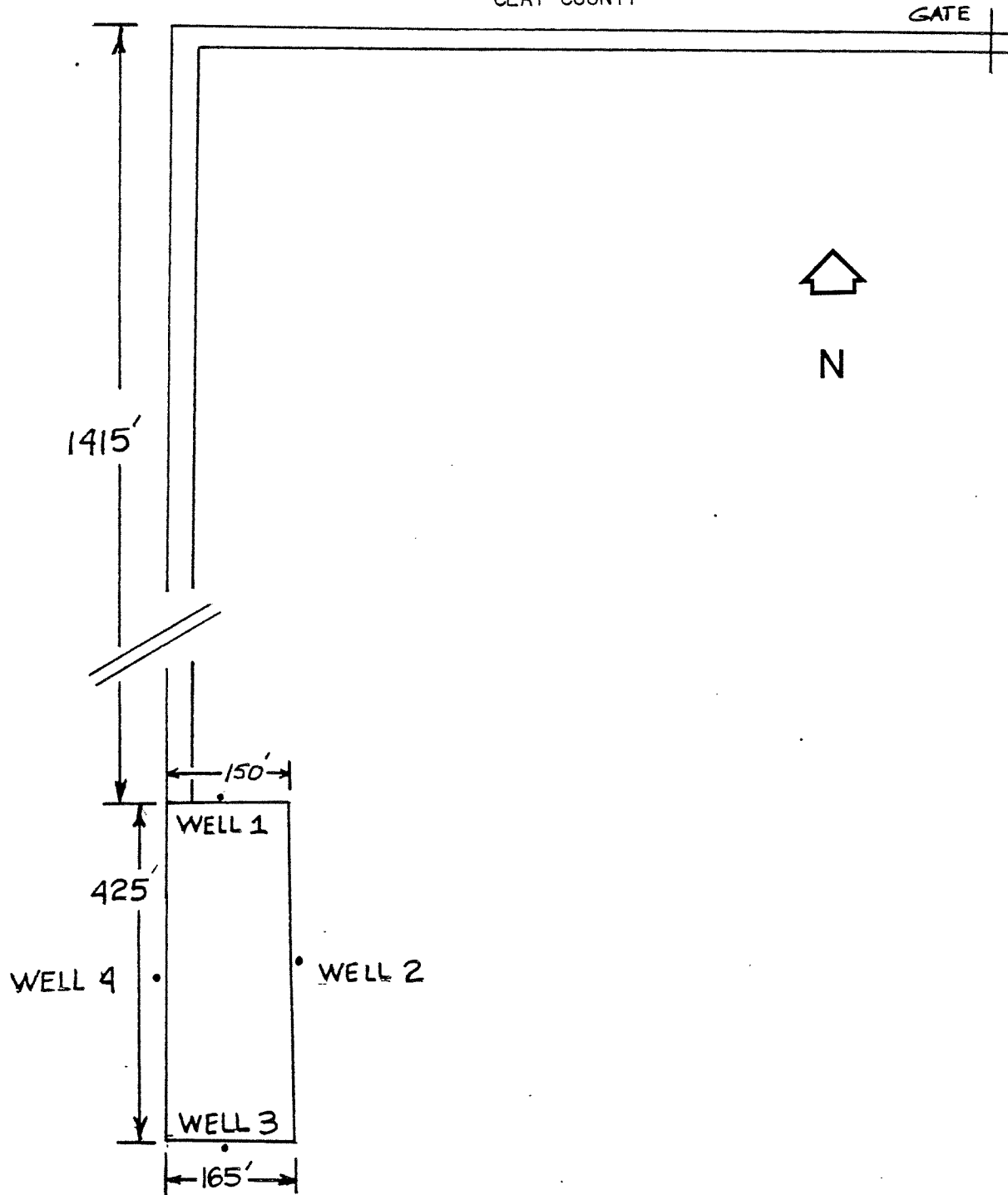


FIGURE 10 - CLINTON CITY DUMP
T124 R45 SECTION 1E
BIG STONE COUNTY

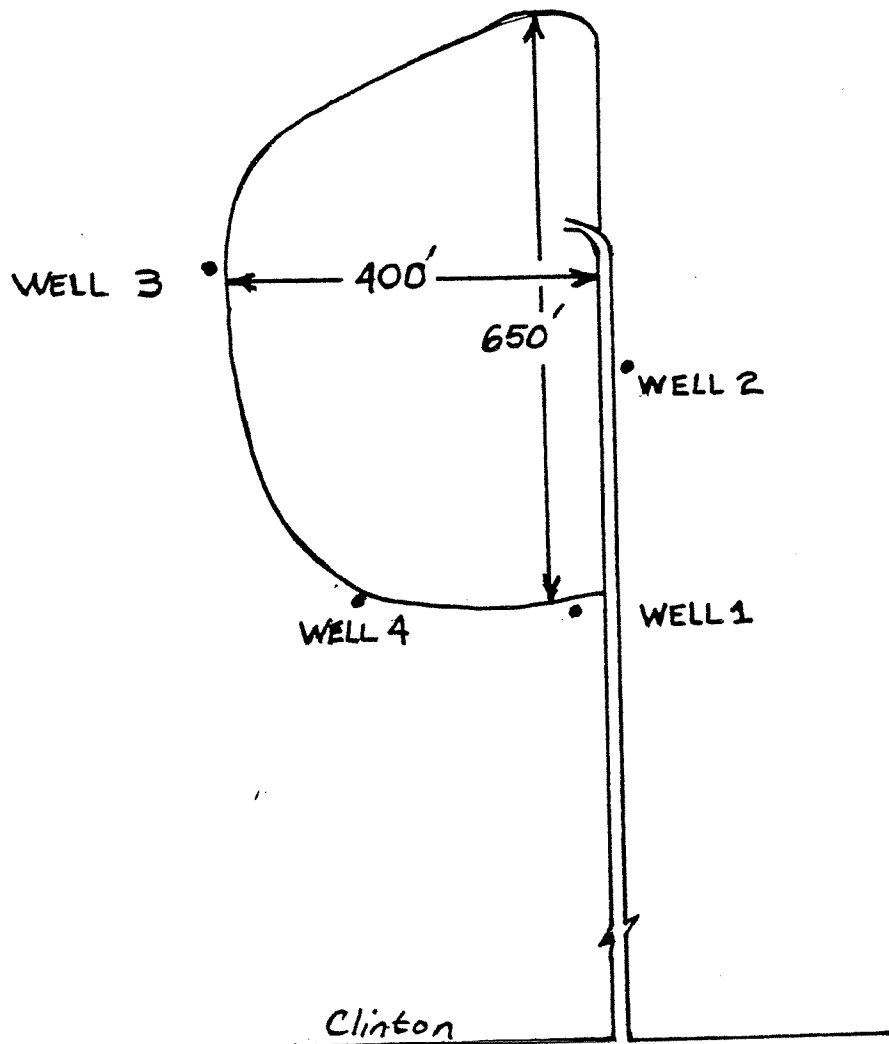


FIGURE 11 - FIFTY LAKES TOWNSHIP DUMP
T138N R27W SECTION 29
CROW WING COUNTY

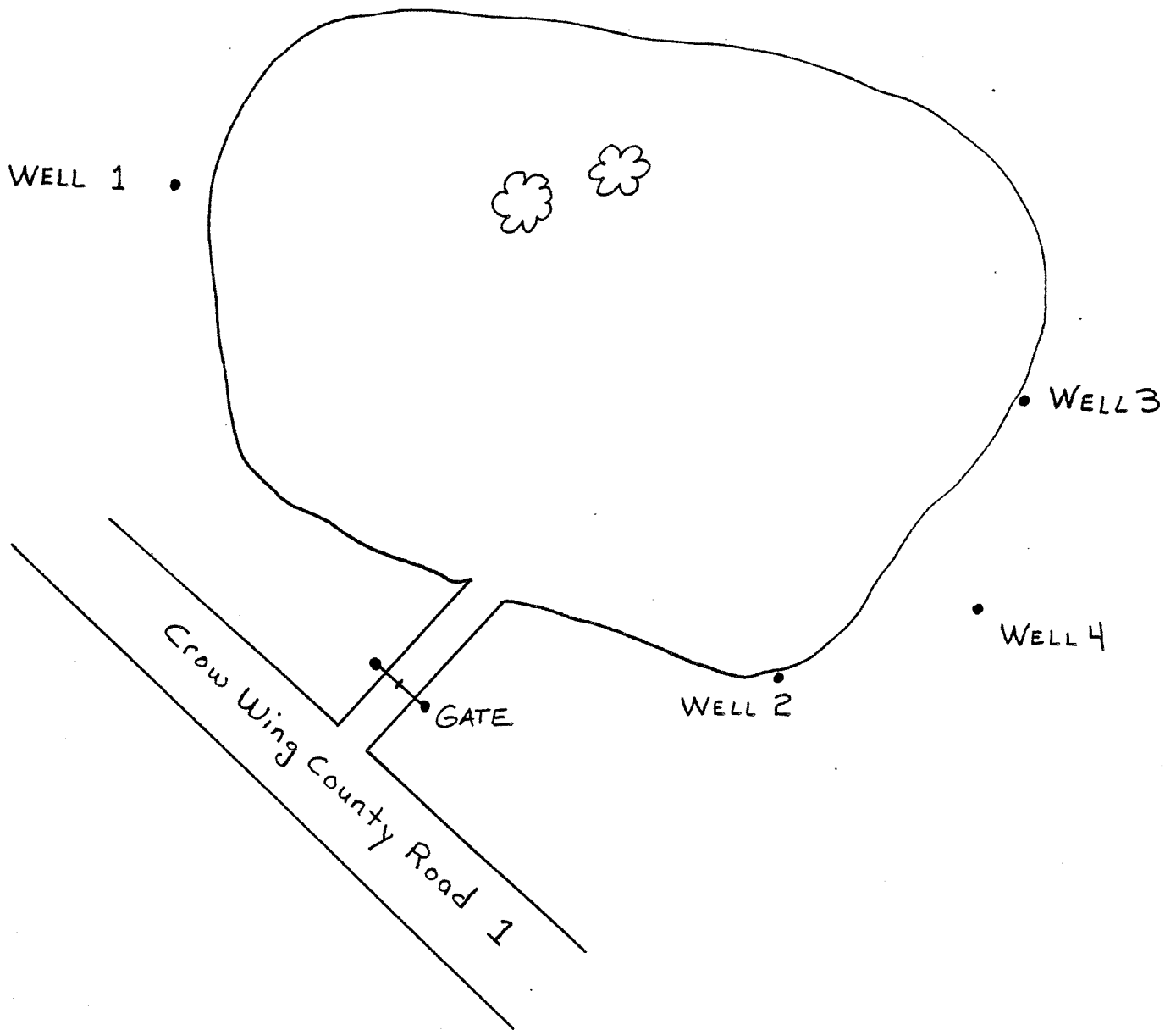
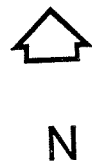


FIGURE 12 - HENNING CITY DUMP
T133N R38W SECTION 36
OTTER TAIL COUNTY

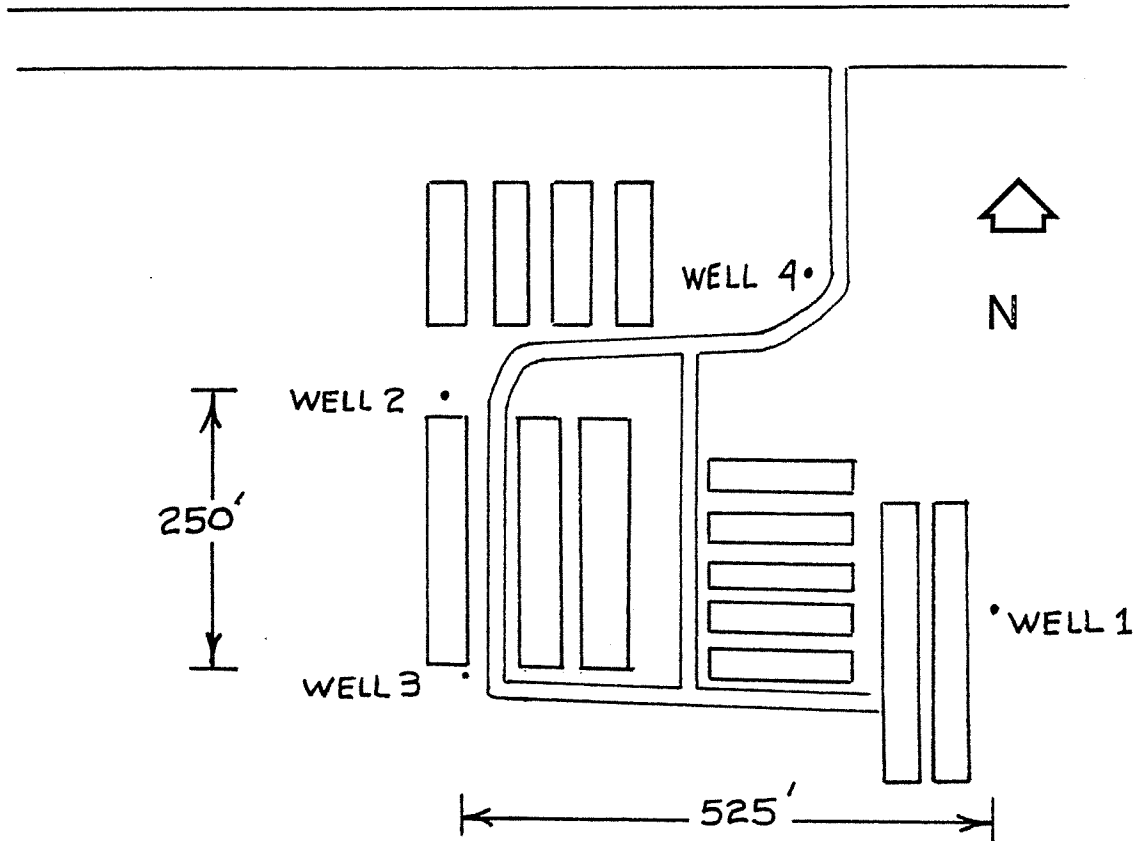


FIGURE 13 - VADNAIS HEIGHTS DEMOLITION LANDFILL
T30N F22W SECTION 20
RAMSEY COUNTY

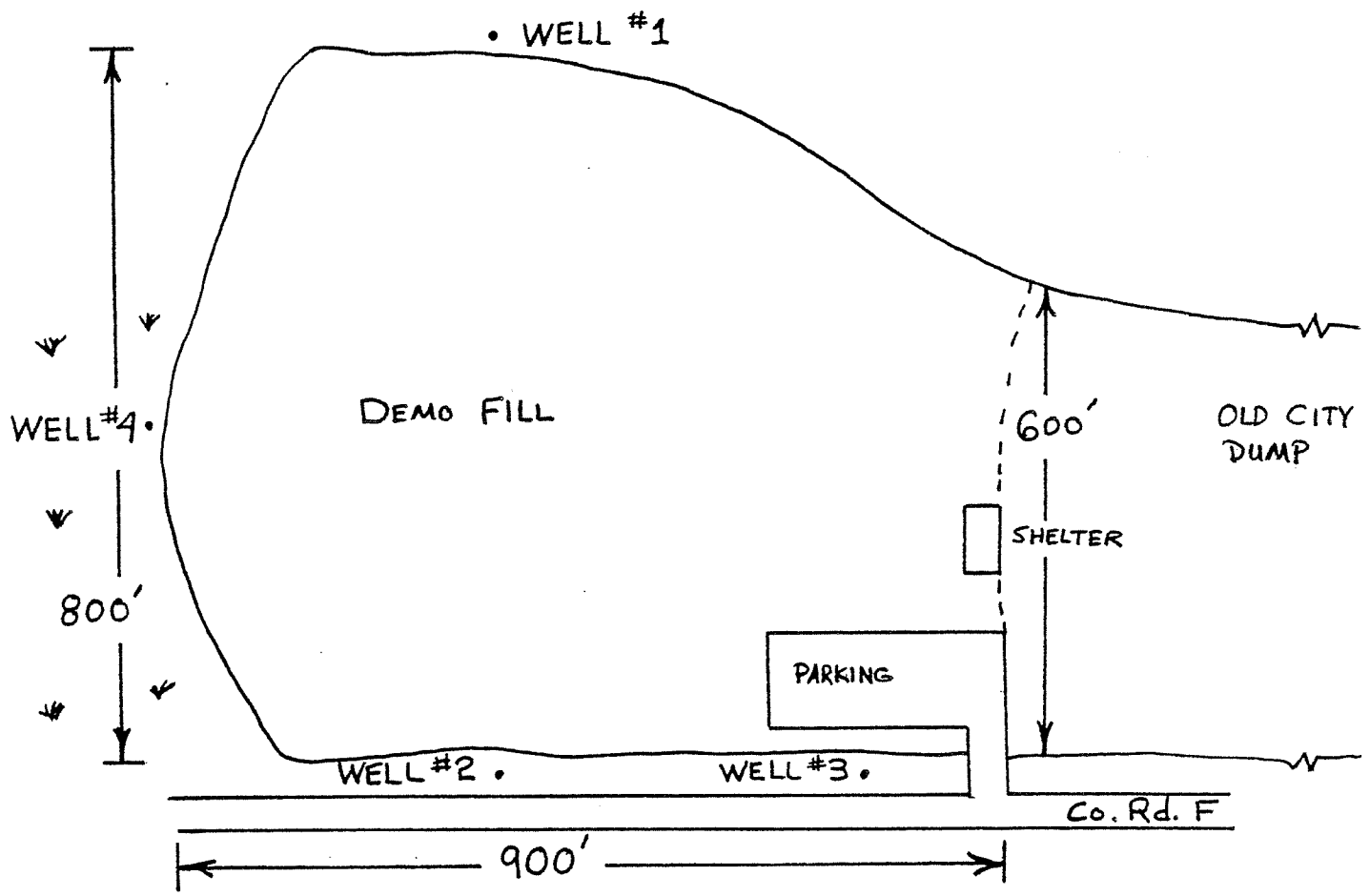
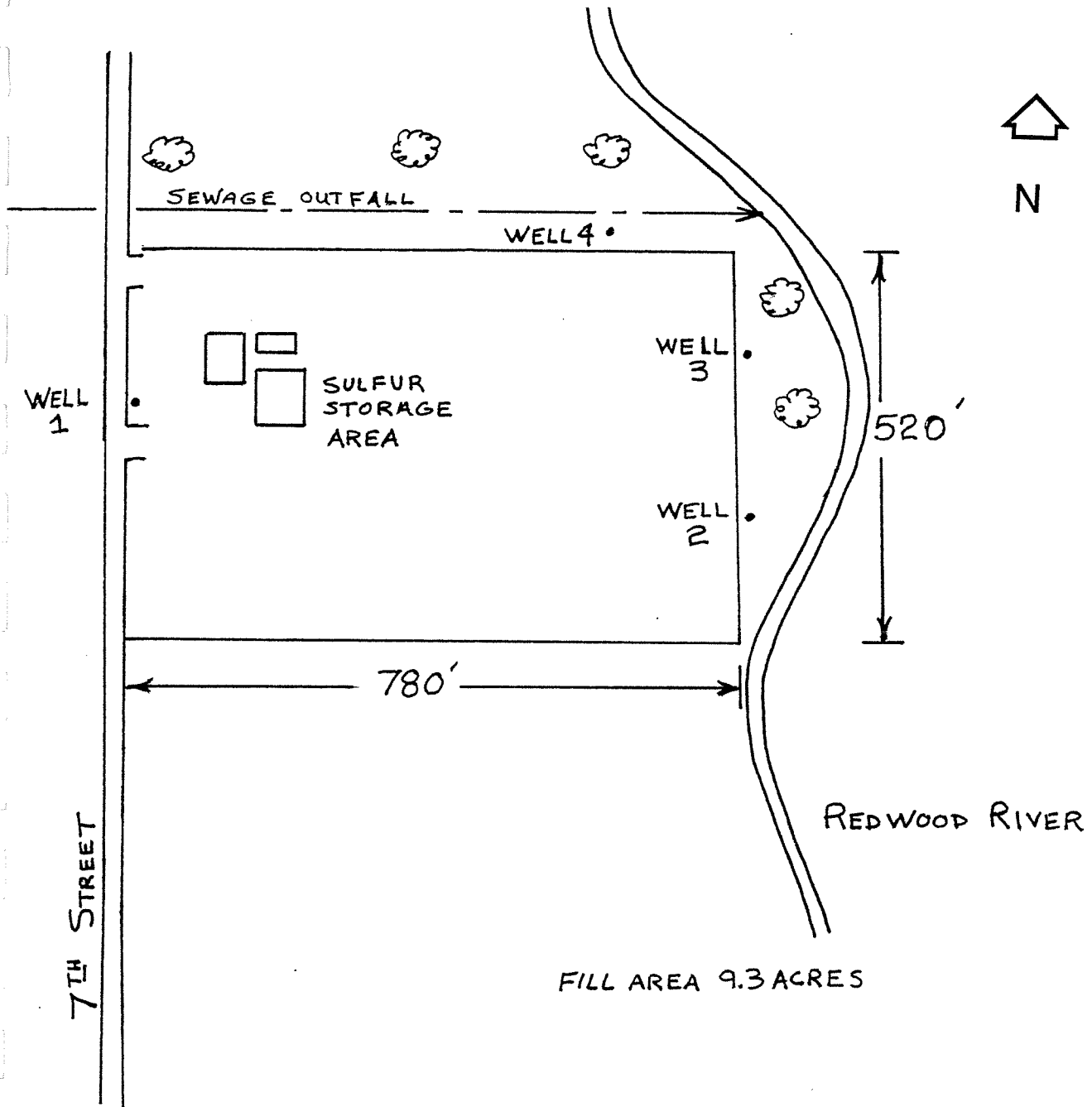


FIGURE 14 - MARSHALL CITY DUMP
T112N R41W SECTION 28
LYON COUNTY



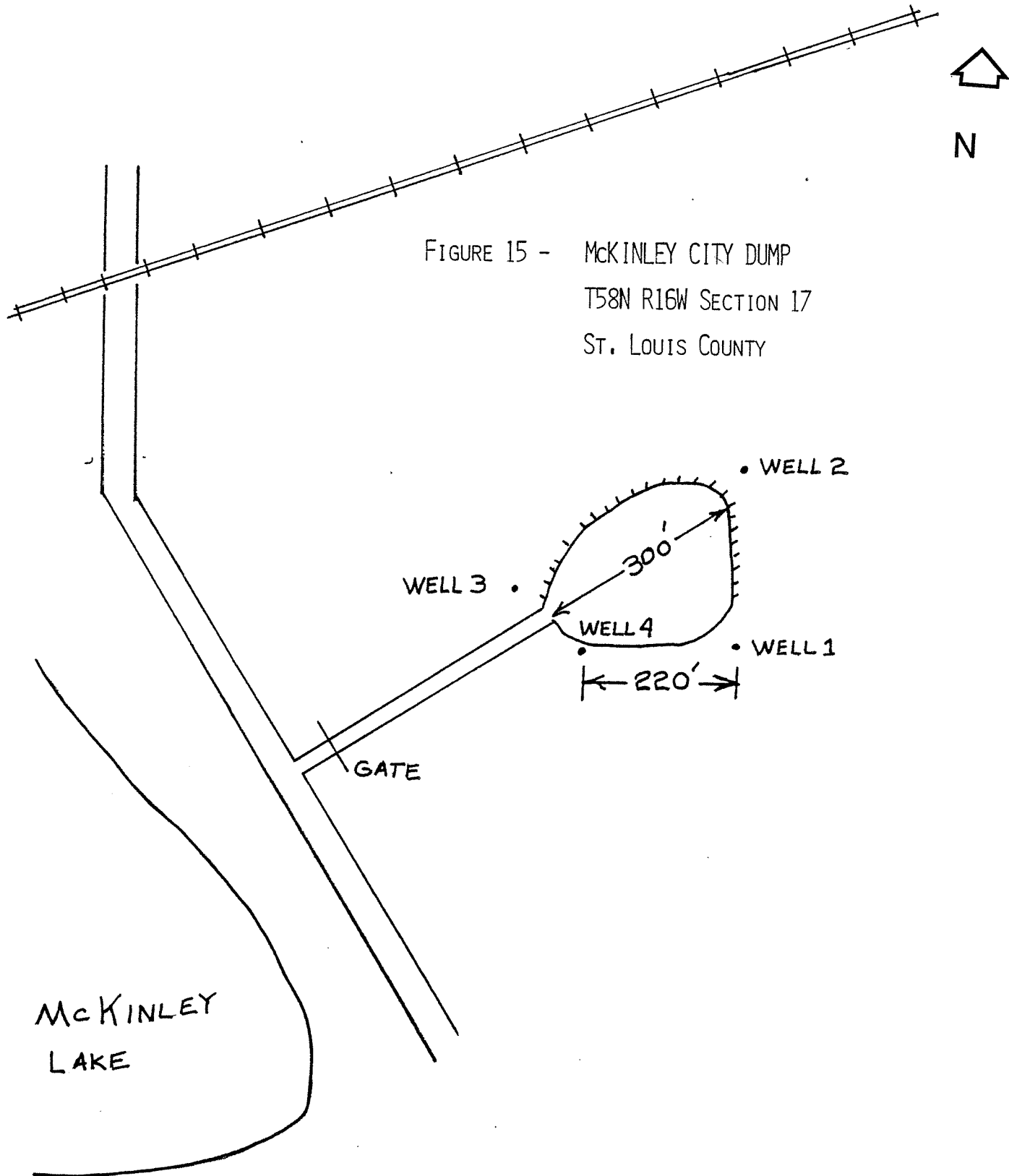
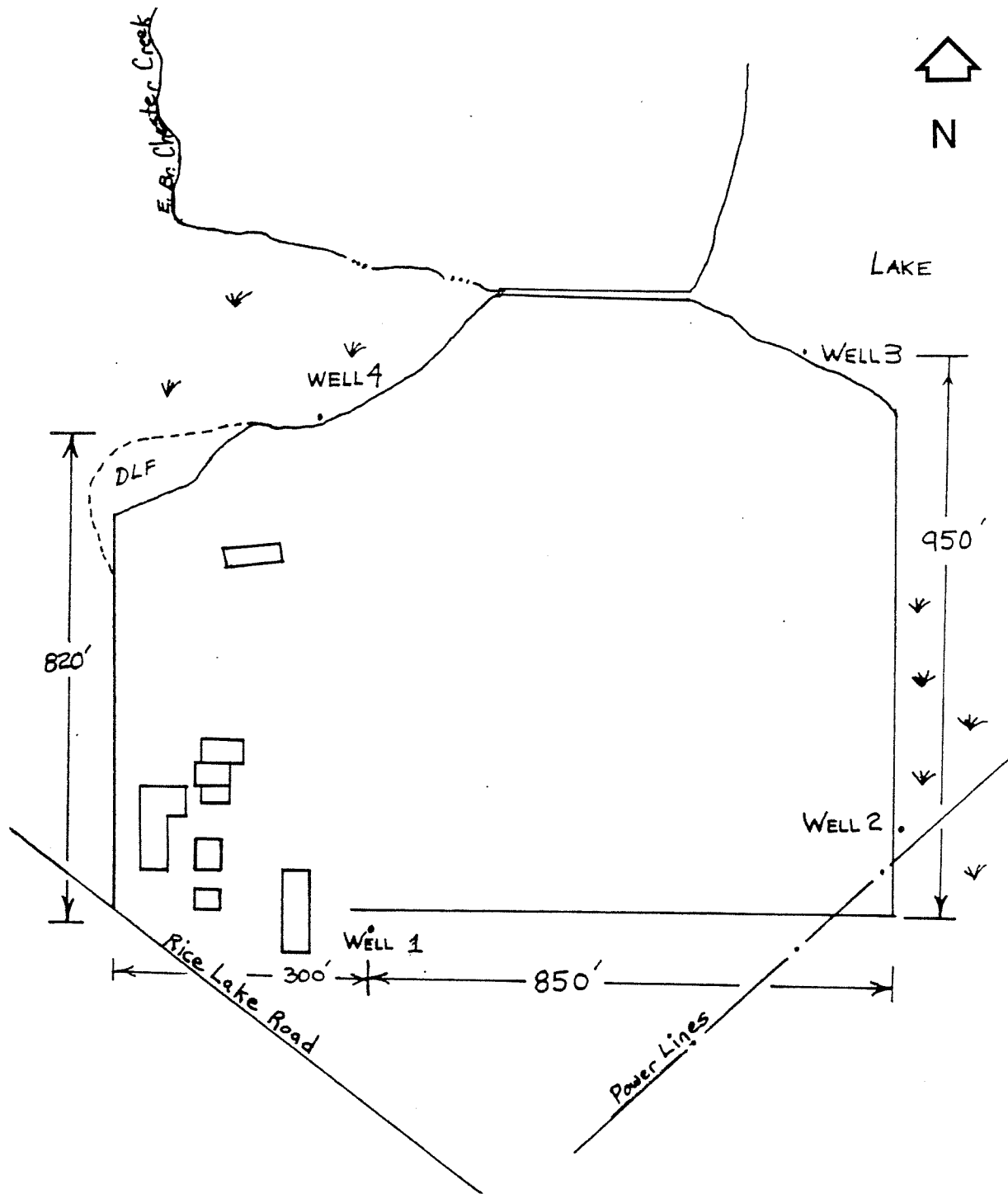


FIGURE 15 - MCKINLEY CITY DUMP
T58N R16W SECTION 17
ST. LOUIS COUNTY

FIGURE 16 - DULUTH CITY DUMP
T50N R14W SECTION 8
ST. LOUIS COUNTY



B. Evaluation of Key Variables

The following discussion compares the ground water impact from groups of dumps with contrasting characteristics. There were two main categories of variables with the potential to influence ground water quality. Physical factors such as population size, size of the dump, geology, and hydrology could not be changed, however, the management practices including burning, cover material and control of waste types were things the responsible party should have control over.

1. Geology and Hydrology

The dump sites included in this study can be divided into four groups. 1) Shallow water table sand and gravel; 2) deep water table sand and gravel; 3) clay sites with seasonably high water table, and; 4) glacial till with shallow water table. The sites were grouped by geohydrology in part A, each site was compared to the group of sites with similar water table-aquifer characteristics. Average concentrations for the four different geohydrologic groups of dump sites are presented in Appendix C. The most noticeable difference between the four groups was that even background concentrations of the inorganic parameters were much higher at the clay dump sites. Apparently the clay mineralogy has an affect but there may also be some leachate contamination on all wells at the clay sites. Greater infiltration in the waste fill area may result in ground water mounding causing contaminated water to be forced away from the dump in all directions. The low permeability of the clay retards the movement of the leachate and also made it nearly impossible to determine the (gradient) direction of ground water flow. Overall the average concentrations at the deep sand and gravel water table sites (Henning, Fifty Lakes) were equal to or lower than the other geologic groups. The shallow sand and gravel water table concentrations were usually higher than the deep water table for most parameters measured. The clay and till sites normally had higher overall concentrations than the two groups of sand and gravel dumps. There are so many factors that influence the dumps impact on ground water that it was very hard to draw additional conclusions from a geohydrologic comparison of this type. The most useful information came from comparing the dumps with similar geohydrology as presented in part A.

2. Influence of Burning on Ground Water

The fifteen sites were divided into groups that included burning as a management technique and those that did not purposely set fires in the waste. Six sites were classed as "non burn" sites and nine were considered as burned sites (See Table in Appendix C).

There are two major reasons why waste was burned at an open dump. First, it was an effective means of volume reduction resulting in lower operating cost and use of less land area. Second, as a substitute for daily or frequent addition of cover material, burning helped to control odors, rodents, litter and other nuisance conditions. Burning did have its drawbacks among which were the danger of fire spreading to adjacent land and smoke which was a nuisance for nearby residents. Spontaneous

and accidental fires did occur at "non burn" dump sites, however a small percentage of the total waste volume was exposed and subject to fire at any one time. Volume reduction was of greatest economic importance at those sites which used the trench method of disposal. The cost for digging a trench was a large portion of the operating cost and burning extended the life of each trench.

Water quality data from downgradient wells was grouped according to the predominant management technique for burn and non-burning situations. Average concentrations were higher in approximately half of parameters measured for the group of burned dumps while the other half of the parameters had a lower average concentration. Average specific conductivity in ground water from burned sites was higher. The average pH from non-burn sites was lower than burned sites by two to three tenths of a pH unit. Average chloride concentration was also higher in the burned sites. The average concentration was two times higher in the burned sites, but, when the extreme value of 1600 mg/l at Dilworth was removed, the average dropped to 104mg/l Cl for burn sites compared to 82.5 mg/l Cl for non-burn sites. Average ammonia nitrogen decreased slightly for burned sites while average nitrate levels increased. Average total alkalinity and COD were higher for the burned sites. Average COD for the burned sites were skewed by two high values at Brainerd (Wells 2 and 3); if those values were removed average COD was actually lower for the burned dumps which seems logical since large amounts of organic matter would be removed from the system in a burned dump. Average arsenic concentrations were higher for burned sites; influenced mainly by high concentrations at three of the nine sites. The average heavy metal concentrations for cadmium, chromium, lead, and mercury were similar for both burn and non-burn dumps. Average zinc and manganese concentrations were higher at burned sites. Average total dissolved solids, calcium, magnesium, iron and sulfate concentrations were lower at burned dumps. Average total solids, potassium and sodium were higher at the burned dumps.

An overview of volatile organic compounds (VOC) found in ground water at the dump sites does not show any trends which can be related to burned versus non-burned dumps. One hypothesis was that fewer volatile organics would be present in ground water at burned dump sites because they would have been consumed or driven off by the burning. This clearly was not the case because some of the burned dumps had a greater variety and higher concentrations of VOCs in ground water than similar non-burn sites. Burning may have reduced the amount of VOCs or liquid organics may infiltrate into the soil, out of the fires influence but neither could be verified by this study.

In summary, there were several leachate indicator parameters (Cl, T, Alk, K, Na) which were higher in the group of burned dumps. This was offset somewhat by the fact that several other common leachate indicators (TDS, pH, Ca Mg Fe) were lower for burned dumps. There was no discernible difference in the heavy metals and ammonia between the two groups. Therefore, the data does not allow one to conclude that burning as a management practice had either a positive or negative impact on ground water quality.

3. Influence of Cover Material

The use of cover material, generally soil, to bury waste deposited in modern landfills is a daily management practice. Open dumps usually did not apply cover material on a regular basis. Dump operators were probably aware of some of its benefits, however, the cost of placing cover material on the waste and the sacrifice of fill space caused many to avoid the practice. Addition of cover material to a waste site has two main functions:

1. cover will isolate the waste from wind and the blowing of refuse as well as from animals and other forms of nuisance;
2. cover will stabilize the waste, aid in compaction, and sloping the surface will increase rainfall runoff thereby decreasing the amount of water leaching through the waste.

Leachate water from the waste contaminates ground water. The impact on ground water quality is also dependent on the age of the refuse, seasonal fluctuations and the natural variations in water quality. Cover material influences the rate of decomposition in the waste. Cover will keep the waste drier, cooler and slow down decomposition. Lack of cover material will cause the waste to mature faster, meaning the pollutants will leach out faster resulting in lower concentrations when measured at a later time.

The fifteen dump sites were divided into two groups for the discussion of cover material (See Table in Appendix C). Eight dumps which had the least amount of cover material ("uncovered") were compared to the remaining seven sites with more frequent additions of cover ("covered") to determine if as a group ground water quality varied significantly. "Uncovered" dumps consisted of those sites covered once quarterly or less. Frequently "covered" were classed once per month, once per week or more frequent. The two sites with heavy clay soils fell into the uncovered group, however, because of the special soil conditions they will be discussed separately.

Average concentration at the downgradient wells for sixteen of the twenty-two parameters measured were significantly lower for the "uncovered" sites or sites with the most infrequent addition of cover material. If it is assumed that this is a valid comparison of the sites, then the difference between the average concentrations of the two groups could be attributed to one hypothesis or to elements of both of the following hypotheses:

- H1 Since uncovered sites were exposed to more leaching due to lack of cover material and compaction, a large portion of the pollutant load has been leached and moved away from the site with the ground water, leaving less concentrated water to be measured at this point in history. The converse of this hypothesis would be that sites with better cover material decreased the rate of leaching and delayed the release of pollutants over a longer period of time. This hypothesis must assume that as a whole all other variables remain constant.

- H2 This approach would assume that potential for ground water contamination remains similar for both groups but lack of cover material and poor compaction has increased the infiltration of water through the waste (in the uncovered group) and in effect caused the pollutant load to be diluted by the additional water.

There is no way of knowing for sure what the pattern of pollutant concentration has been during the history of these dumps, they may have been very high at one time, the hypotheses are based on limited knowledge of what happens at sanitary landfills. It appears that at this point in time the poorly covered dumps are having less impact on ground water than the dumps which had more frequent cover. It should be stated the "more frequent cover" which occurred in dumps is still substandard compared to requirements of present day landfills.

Dumps located in low permeability soils, do not fit into either of the hypotheses above. Cover material (of clay soils), if added, would be very effective at reducing infiltration and stabilizing the waste. If cover is not used at a clay site the water enters the fill but can not move away from the site, except very slowly, unless via fractures or thin sand lenses. The low permeability of clay soils slows down the water movement holding the leachate contaminated ground water in and around the dump for a much longer time. Thus, higher average concentrations observed at the clay sites are due in part to low soil permeability and to higher background levels of some parameters present in the clay soil itself and thereby over shadowing the affects of cover and burning.

4. Old Dumps Versus More Recent Dumps

For purposes of this discussion all sites were divided into two groups. The "old" sites (Table 1) have been closed three to ten years or more than ten years. "New" sites were active during the course of the study or closed in the past few years. By comparison, the average concentrations for 16 of the 23 parameters in the "old" group were decidedly higher than the new group. This observation is inconsistent with what would logically be expected and contrary to principles discussed previously about cover material. Variables other than age of the dump appear to dominate the pattern created by grouping the sites in this manner. For example, the size of the dumps in the "old" group are much larger and they also tend to be associated with larger towns. The type of waste, geology, and management also contribute to the persistence of the concentrations observed in ground water at the older sites.

V. Summary and Conclusions

The purpose of this project was to do a survey of open dumps to determine to what extent, if any, unregulated solid waste dumps have contaminated ground water. In most cases after installing four monitoring wells at each site and taking three samples from the wells, a very basic picture of the ground water quality emerged. The extent to which one can draw conclusions from this very basic picture of ground water is severely limited by the amount of data available. The objective of this study was to provide information needed to make decisions regarding closure of active dump sites, the need for continued monitoring by responsible parties, and the need for cleanup measures. All of the questions could not be answered about each site and in some cases additional questions were raised by the study. The evaluation of the ground water quality data show that open dumps, have in the past and continue to, degrade ground water quality. The amount of contamination and the potential impact are site specific and much more difficult to answer. The site by site analysis pointed out each parameter which exceeded ambient mean concentrations and the drinking water standards. Out of the study group as a whole, the only national primary drinking water standard exceed was for nitrate; four dump sites had wells which were over the nitrate standard which is a common background occurrence. Two of the eight wells with high nitrate were upgradient wells not affected by the dump. Only one of the national primary drinking water standard (NPDWS) for heavy metals was exceeded in the well samples. Minnesota standard for arsenic is lower (10 ug/l) than the NPDWS level (50 ug/l). Two sites had samples with arsenic levels over the Minnesota (10 ug/l) drinking water standard. One dump site had a single sample which exceeded the NPDWS drinking water standard for cadmium.

Secondary Drinking Water Standards (SDWS) represent esthetic levels above which water becomes more objectionable from a taste and odor perspective. Ground water from monitoring wells at the dump sites exceeded these secondary standards more frequently than the primary standards. Many of the same parameters included in the SDWS group are used as indicators for detection of leachate from buried waste. Manganese and total dissolved solids in downgradient well samples were over the SDWS at nearly all of the dump sites. Approximately half of the dump sites had levels of iron, sulfate and pH which exceed the SDWS. Chloride concentrations were over the SDWS at five dump sites. In general, the inorganic parameters for ground water near open dump sites indicate that ground water quality has been degraded as a result of the dump but that the concentrations, even at the dump margin, are not above the health related (PDWS) standards. The esthetic standards (SDWS) indicate that, in general, the ground water near a dump would not be of a quality considered desirable.

While it is possible to make some definitive statements about the ground water quality and suitability for domestic consumption based on inorganic parameters, there is more uncertainty associated with volatile organic compounds (VOC) both in the interpretation of laboratory data and in risk assessment. In the ground water samples, organic contaminants appear in very small quantities. They are difficult to sample and analyze accurately, and the concept of what levels constitute a risk are continually being modified. The tendency then is to error on the conservative side when discussing organics. VOCs were detected in ground water at thirteen out of

fifteen dump sites sampled and all of those sites had at least one priority pollutant reported. Many of the VOCs "detected" were peaks reported by the gas chromatograph but detected only at levels below the "lower reporting limit" established for the equipment and methods used by the laboratory. Other VOCs were reported as a peak present indicating the compound was probably present but the amount could not be quantified. Three sites had reported VOCs in ground water with concentrations greater than or equal to the 10^{-5} cancer risk level. Eleven sites had organic compounds present in the ground water above the health goal limit of zero, called the Recommended Maximum Contaminant Level (RMCL). One site had levels of benzene which was over the Threshold Effect Level (TEL). (Refer to Appendix D for an explanation of terms used to describe organics and a summary table of the compounds detected). The number of VOCs measured at a site ranged from none detected at a site to 38 different compounds detected at another. Seven dump sites had 5 or more VOCs detected in ground water.

The presence of VOCs in the ground water could be considered the deciding factor in determining an open dump's ultimate impact upon ground water. The inorganics did not reveal much contamination beyond the esthetic parameters but did document some degree of degradation. One very important factor to remember at this point is that the survey represents a picture of ground water quality at one small point in time in the history of each dump. There may be a plume of contamination which exists and was not detected by the monitoring wells placed at the margin of the dump. There may be concentrations in the ground water downgradient from a dump much higher than those detected in this study.

Those dump sites where ground water has been degraded only slightly and no significant organics are found are not likely to be a threat to the aquifer or to public health in the future although they probably represented a greater threat in the past. There were a few dumps identified where a combination of circumstances require a closer look at the impact on the aquifer. The factors considered should include those surveyed in this study plus a more detailed look at the aquifer, potential use, and the health implications. General observations on the origin of the waste making up the dump seem to correlate well with the nature of ground water contamination. Dumps with the greatest impact on ground water were near the larger urban areas and have some form of commercial or industrial waste component. The smaller old dumps with the major waste component from rural, residential or recreational sources appear to be currently having minimal impact on ground water quality.

APPENDIX A

1. Sampling Procedures
2. Sampling Protocol
3. Well Construction

VI. Appendices

Appendix A. Methods

Sampling Procedures

Three sampling events were scheduled to collect ground water samples for this survey. The sampling periods were timed to observe ground water at three different phases of the annual hydrologic curve. The first (March 26 to April 12) came in early spring before all the frost and snow was gone and before a large amount of seasonal ground water recharge had occurred. The second sampling event (June 25 to July 9) came during the period of heaviest monthly precipitation resulting in recharge and higher ground water elevations. The third and final event (September 17 to October 5) was prior to freeze up and before the system reached the more static winter phase. Water levels in the final round were similar to those recorded in the first round.

Each well was developed by the contractor and then a stabilization test was performed on each well. This provided some pre-sampling information which was used in establishing sampling protocol. The information included water table elevations, pH, specific conductivity, temperature and volume of water pumped or bailed which identified the slow recharge wells.

For the first sampling round, the order in which wells were sampled at each site was based on water elevations (used to obtain assumed ground water flow direction) and stabilization test results. The objective was to begin with the wells expected to have the best quality water and end with the worst to lessen the chance of cross contamination. The sampling order for some wells were modified after the first round of laboratory results was evaluated. A second stabilization test was performed on each well on the third sampling round to verify and gather additional information about each well. This stabilization test was done with a new piece of equipment fabricated to allow continuous flow through measurement of pH, temperature and conductivity.

Sampling Protocol

Water level measurement was the first thing done at each well. This was done to determine the volume of water in the well casing and to calculate the approximate volume of water to be removed, usually three well volumes, before sampling. The amount removed prior to sampling should thoroughly evacuate the stagnant water and allow collection of fresh aquifer water. Field data collected at the time of sample collection included temperature, specific conductivity, pH and observations on sample clarity and sediment content.

There were three types of pumps used during the course of the study. Ideally one pump would have introduced fewer variables into the evaluation, however, equipment breakdown and portability forced the use of three different pumps. The Well Wizard, a non-contact gas driven teflon bladder pump, was used whenever possible on the first and third sample rounds. The Johnson Keck electric submersible pump was used most frequently during the second sample round. A Masterflex peristaltic pump was used where maximum portability was necessary.

Samples were collected directly from the pump in separate polyethylene bottles for general chemistry parameters, nutrients, metals, and mercury. Nutrients were preserved with 20 ml of 10% H₂SO₄ to pH < 2, mercury preserved with 6.0 ml 10% HNO₃ and 1% W/V K₂Cr₂O₇ and other metals preserved with 7.5 ml of 10% HNO₃. Samples were then placed in a cooler at 4°C for storage and transport to the laboratory. Samples were delivered or shipped via commercial bus lines to the Minnesota Department of Health Analytical Laboratory usually within one or two days for analysis. Volatile hydrocarbons in water (volatile organics) samples were collected in 40 ml glass vials with a teflon septum and plastic screw caps. Sample vials were over-filled without entrapped air bubbles to form a positive meniscus before cap was placed on the bottle. Volatile organic samples were taken directly from the pump by reducing the flow rate or by dividing the flow several times.

Samples to be analyzed for dissolved metals were field filtered directly from the pump discharge. The filtering apparatus used was a Gelman plate filter (142 mm diameter filter size). The filter apparatus was cleaned after each well and the filter membrane (Metricel Filter 0.45 mm) was replaced. The filter was cleaned by:

1. disassembling the filter,
2. flushing all parts thoroughly with deionized water,
3. installing a new filter membrane,
4. reassembling the filter apparatus.

Sampling progressed from the cleanest to the most contaminated well. Before collecting the sample, a minimum of 200 ml of well water was run through the filter to remove all deionized water which could dilute the sample. After each site was completed, another step was added to the cleaning procedure. Before installing a new filter membrane (Step 3) the filter was reassembled and flushed with 200 ml of 5% nitric acid, let stand for 10-20 minutes and then flushed with deionized water. The filter then had to be disassembled flushed with deionized water before the filter membrane was replaced and reassembled for sampling at the next site.

Laboratory Procedures

All ground water quality analyses were done by the Minnesota Department of Health, Section of Analytical Services. Laboratory procedures were performed according to U.S. Environmental Protection Agency approved methods. The parameters, methods, and references are listed in Appendix B.

Well Construction

The Minnesota Pollution Control Agency, through the competitive bid process, contracted for the services of a private engineering and soil boring company to install monitoring wells at each of the 15 selected open dump sites. Each well was installed using a six inch hollow stem auger and a CME 650 drilling rig at the margin of the dump or as close as possible. No drilling mud or fluids other than clean water were used. Soil samples were collected every five feet, or more often if necessary to identify significant changes

in the soil profile, with a split spoon sampler according to ASTM:D 1586-67. Soil samples were field logged and classified (ASTM:D 2488-67) and returned to the contractors laboratory for verification (ASTM:D 2487-69).

Each well was constructed using two inch diameter polyvinyl chloride (PVC) casing. The casing material was schedule 80 (ASTM F-480 200 psi rating) flush on inside and out, water-tight threaded joints without use of PVC cements, glues, oils, or other contaminating materials. Well screens were five or ten feet long, two inch diameter 20 slot PVC. Tops of screens were ideally set at one or two feet above the water table. The annular space from the bottom of the screen to one foot above the top of the screen was filled with a medium grain sand pack. Above the sand pack, a seal, minimum two feet thick, of bentonite or neat cement was installed. The remainder of the annular space was filled with native material allowed to cave and with neat cement in any space remaining unfilled to within two feet of the ground surface. All wells were fitted an orange protective steel casing, 4 inch diameter embedded in two feet of neat cement, with an overlapping steel cap and lock.

Each well was developed using the surge block method followed by pumping with a two inch electric submersible pump. Elevations of land surface at the well and the top of each PVC casing were surveyed and referenced to an arbitrary bench mark on site. The drilling rig and equipment were thoroughly steam cleaned prior to entry to each of the sites and in a few cases augers were cleaned between holes when extremely contaminated conditions were encountered. The order of well installation at each site was selected to allow construction of the wells with least potential for contamination first working toward areas of greater contamination.

APPENDIX B

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM

by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT⁽¹⁾</u>	<u>REFERENCE</u>
Acetone	81552	Gas Chromatography/ Photo Ionization Detector (GC/PID)	10 ug/l	3,5
Alkalinity	00410	Titration Bromo Cresol Green End Point	10 mg/l	1
Allylchloride	78109	GC/Hall Detector (GC/HD)	0.5 ug/l	3,6
Arsenic, Total*	01002	Atomic Absorption-	1 ug/l	4
Arsenic, Dissolved	01000	(Furnace AA)	1 ug/l	4
Atrazine (Aatrex)	39630	GC/Electron Capture Detector (GC/ECD)	2 ug/l	2
Barium, Total	01007	Furnace AA	5 ug/l	4
Benzene*	34030	GC/PID	0.5 ug/l	3,5
Bicarbonate	00425	Calculation	1 mg/l	1
Boron, Total	01022	Curcumin Colorimetric	0.05 mg/l	1
Bromodichloromethane*	32101	GC/HD	0.5 ug/l	3,6
Bromoform*	32104	GC/HD	1 ug/l	3,6
Bromomethane*	34413	GC/HD	No quantitation standard	3,6
1 Butanol	77034	GC/PID	50 ug/l	3,5
Cadmium, Total*	01027	Furnace AA	0.01 ug/l	4
Cadmium, Dissolved	01025	Furnace AA	0.01 ug/l	4
Calcium, Total as CaCO ₃	00910	Atomic Absorption-	10 mg/l	4
Calcium, Dissolved as CaCO ₃	00915	Direct Aspiration (Flame AA)	10 mg/l	4

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM
by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT(1)</u>	<u>REFERENCE</u>
Carbon Tetrachloride*	32102	GC/HD	0.2 ug/1	3,6
Chloride, Total	00940	Mercury Thiocyanate- Colorimetric	0.5 mg/1	4
Chlorobenzene*	34301	GC/HD	0.5 ug/1	3,6
Chlorodibromomethane*	34306	GC/HD	1.0 ug/1	3,6
Chloroethane*	34311	GC/HD	No quantitation standard	3,6
2-Chloroethylvinyl Ether*	34576	GC/HD	1.0 ug/1	3,6
Chloroform*	32106	GC/HD	0.2 ug/1	3,6
Chloromethane*	34418	GC/HD	No quantitation standard	3,6
Chromium, Total*	01034	Furnace AA	0.5 ug/1	4
Chromium, Dissolved	01030	Furnace AA	0.5 ug/1	4
Cis-1,2- Dichloroethylene*	77093	GC/HD	0.2 ug/1	3,6
Cis-1,3-Dichloro-1- propene*	34704	GC/HD	0.2 ug/1	3,6
Chemical Oxygen Demand (COD)	00340	Ampule Colorimetric	5 mg/1	4
Coliform, Fecal	31615	Multiple Tube Technique	2 MPN/100 ml	1
Coliform, Total	31505	Multiple Tube Technique	2.2 MPN/100 ml	1
Conductance, Specific	00095	Wheatstone Bridge	umhos/cm @ 25°C	1
Copper, Total*	01042	Furnace AA	0.5 ug/1	4
Copper, Dissolved	01040	Flame AA	50 ug/1	4

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM
 by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT⁽¹⁾</u>	<u>REFERENCE</u>
Counter (Terbufos)	82088	GC/ECD	0.20 ug/l	2
Dibromochloromethane	32105	GC/HD	0.5 ug/l	3,6
Dibromomethane	77596	GC/HD	1.0 ug/l	3,6
1,2-Dibromoethane	77651	GC/HD	0.5 ug/l	3,6
Dichloroacetonitrile	78110	GC/HD	2.0 ug/l	3,6
1,1-Dichloro-1-propene	77168	GC/HD	0.2 ug/l	3,6
2,3 Dichloro-1-propene	77166	GC/HD	0.5 ug/l	3,6
1,2-Dichlorobenzene*	34536	GC/HD	1 ug/l	3,6
1,3-Dichlorobenzene*	34566	GC/HD	1 ug/l	3,6
1,4-Dichlorobenzene*	34571	GC/HD	1 ug/l	3,6
Dichlorodifluoromethane*	34668	GC/HD	No quantitation standard	3,6
1,1-Dichloroethane*	34496	GC/HD	0.2 ug/l	3,6
1,2-Dichloroethane*	32103	GC/HD	0.2 ug/l	3,6
1,1-Dichloroethylene*	34501	GC/HD	0.2 ug/l	3,6
Dichlorofluoromethane		GC/HD	No quantitation standard	3,6
1,2-Dichloropropane*	34541	GC/HD	0.2 ug/l	3,6
1,3-Dichloropropane	77173	GC/HD	3.0 ug/l	3,6
Ethanol	77004	GC/PID	50 ug/l	3,5
Ethyl Acetate	81585	GC/PID	50 ug/l	3,5
Ethylbenzene*	34371	GC/PID	0.5 ug/l	3,5

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM
 by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT⁽¹⁾</u>	<u>REFERENCE</u>
Ethyl ether	73010	GC/PID	1.0 ug/l	3,5
Cumene (Isopropyl benzene)	77223	GC/PID	0.5 ug/l	3,5
Fecal Streptococci	31673	Membrane Filter	9 KF/100 ml	1
Fluoride, Total	00951	Selective Ion Electrode	0.01 mg/l	1
Hardness, Total as CaCO ₃	00900	EDTA Titration		4
		Selective Ion Electrode Summation Summation of Cat Mg	10.0	4
Iron, Total	01045	Flame AA	50 ug/l	4
Iron, Dissolved	01046	Flame AA	50 ug/l	4
Lasso (Alachlor)	46317	GC/ECD	2 ug/l	2
Lead, Total*	01051	Furnace AA	0.2 ug/l	4
Lead, Dissolved	01049	Furnace AA	0.2 ug/l	4
<u>m</u> -xylene	77134	GC/PID	0.5 ug/l	3,5
Magnesium, Total as CaCO ₃	00920	Flame AA	10 mg/l	4
Manganese, Total Manganese, Dissolved	01055	Flame AA	20 ug/l	4
	01056	Flame AA	20 ug/l	4
Mercury, Total*	71900	Atomic Absorption, Cold Vapor	0.10 ug/l	4
Methyl Ethyl Ketone	81595	GC/PID	5 ug/l	3,5
Methyl Isobutyl Ketone	81596	GC/PID	1 ug/l	3,5
Methylene Chloride*	34423	GC/HD	1 ug/l	3,6
Nickel, Total*	01067	Furnace AA	1 ug/l	4

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM
 by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT(1)</u>	<u>REFERENCE</u>
Nitrogen, Nitrate + Nitrite	00630	Cadmium Reduction, Colorimetric	0.01 mg/l	1
Nitrogen, Ammonia	00610	Automated Ammonia Oxidation	0.02 mg/l	1
Nitrogen, Total Kjeldahl	00625	Colorimetric Automatic Block Digester AA11 Salicylate/ Nitroprusside	0.1 mg/l	1
Pentachloroethane	81501	GC/HD	2.0 ug/l	3,6
pH	00403	Electrode	N.A.(2) pH Units	1
Phenols	32730	Colorimetric, Automated 4AAP	2 ug/l	1
Phosphorus, Total	00665	Colorimetric, Automated Block Digester	0.005 mg/l	1
Potassium, Total	00937	Flame AA	0.5 mg/l	4
Potassium, Dissolved	00935	Flame AA	0.5	4
1-Propanol	77018	GC/PID	50 ug/l	3,5
2-Propanol	77015	GC/PID	50 ug/l	3,5
<u>p</u> -xylene + <u>o</u> -xylene	78121	GC/PID	0.5 ug/l	3,5
Selenium, Total*	01147	Furnace AA	1 ug/l	4
Silica, Total Reactive	00956	Colorimetric Molybdosilicate	0.5 mg/l	1
Sodium, Total	00929	Flame AA	0.5 mg/l	4
Sodium, Dissolved	00930	Flame AA	0.5 mg/l	4
Solids, Total Dissolved 180°C (TDS)	70300	Gravimetric, Dried at 180°C	0.5 mg/l	1

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM
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<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT(1)</u>	<u>REFERENCE</u>
Solids, Total Volatile	00505	Gravimetric, Ignition at 550°C	0.5 mg/l	1
Styrene	77128	GC/PID	1 ug/l	3,5
Sulfate, Total	00945	Turbidimetric Barium Sulfate	5 mg/l	1
Temperature	00136	Measurement of control in cooler at the time samples are delivered to the laboratory	0°C	
1,1,1,2-Tetrachloroethane	77562	GC/HD	0.2 ug/l	3,6
1,1,2,2-Tetrachloroethane*	34516	GC/HD	2 ug/l	3,6
1,1,2,2-Tetrachloro- ethylene*	34475	GC/HD	2 ug/l	3,6
Tetrahydrofuran	81607	GC/PID	5 ug/l	3,5
Thimet (Phorate)	46313	GC/ECD	0.15 ug/l	2
Total Organic Carbon (TOC)	00680	Beckman Catalytic Combustion TOC Analyzer	1 mg/l	4
Toluene*	34010	GC/PID	0.5 ug/l	3,5
Trans-1,2-Dichloro- ethylene*	34546	GC/HD	0.2 ug/l	3,6
Trans-1,3-dichloro-1- propene*	34699	GC/HD	0.2 ug/l	3,6
1,1,1-Trichloroethane*	34506	GC/HD	0.2 ug/l	3,6
1,1,2-Trichloroethane*	34511	GC/HD	0.2 ug/l	3,6
1,1,2-Trichloroethylene*	39180	GC/HD	0.2 ug/l	3,6

*Priority Pollutant

TESTING PROCEDURES USED FOR MPCA GROUND WATER QUALITY MONITORING PROGRAM

by Section of Analytical Services, Minnesota Department of Health, 1985

<u>PARAMETER</u>	<u>STORET NUMBER</u>	<u>METHOD</u>	<u>LOWER REPORTING LIMIT⁽¹⁾</u>	<u>REFERENCE</u>
Trichlorofluoromethane*	34488	GC/HD	0.2 ug/l	3,6
1,1,2-Trichlorotrifluoro-ethane	81611	GC/HD	0.5 ug/l	3,6
1,2,3-Trichloropropane	77443	GC/HD	2 ug/l	3,6
Vinyl Chloride*	39175	GC/HD	No quantitation standard	3,6
Zinc, Total*	01092	Furnace AA	0.2 ug/l	4

*Priority pollutant.

NOTE: On occasion GC/HD method will be followed up by additional analysis by using the Finnigan Model 4000 Gas Chromatograph/Mass Spectrometer GC/MS Purgeables in Water: EPA Method 624.

(1)The lower reporting limit is that concentration below which a specific quantitative datum is deemed not to be of sufficient reliability to be reported. The reporting limit is always equal to or greater than the detection limit and is subjectively established by the laboratory.

(2)N.A.-Not Applicable.

REFERENCES

- 1) American Public Health Association, et al., Standard Methods for the Examination of Water and Waste Water, 15th edition, 1980
- 2) Federal Register, Guidelines Establishing Test Procedures for the Analysis of Pollutants; Proposed Regulations, December 3, 1979.
- 3) Minnesota Department of Health, Determination of Volatile Organics in Water by Purge and Trap Method (465B), January 10, 1983.
- 4) U.S. Environmental Protection Agency (USEPA), Methods for Chemical Analysis of Water and Wastes, 1979.
- 5) USEPA Research and Development, The Analysis of Aromatic Chemicals in Water by the Purge and Trap Method (Method 503.1), EPA #600/4-81-057, April, 1981.
- 6) USEPA Research and Development, The Determination of Halogenated Chemicals in Water by the Purge and Trap Method (Method 502.1), EPA #601/4-81-059, April, 1981.

MINNESOTA DEPARTMENT OF HEALTH
SECTION OF ANALYTICAL SERVICES
GAS CHROMATOGRAPH/MASS SPECTROMETER
(GC/MS) PURGEABLES IN WATER

20 ML of sample is analyzed by purge and trap on a Finnigan Model 4000 Gas Chromatograph/Mass Spectrometer System. The analysis is carried out in accordance with EPA Method 624.

Compounds shown on the quantitation list on the first two pages of each report are searched for by comparison to a quantitation library using a computerized data system. The amount found column on the reporting form lists those compounds that were matched by both GC retention time and mass-spectral comparison (indicated with parenthesis on data summary). A blank space in the amount found column indicates the compound was below the quantification limit. The quantification limit column on the reporting form lists the detection limit of the system for each of the compounds.

A third page of the reporting form lists those compounds that were tentatively identified by comparison to the National Bureau of Standards Mass-Spectral Library. Standards for these compounds are not currently available for confirmation and quantitation.

APPENDIX C - DATA TABLES

TABLE C-1	Summary by Hydrogeology
TABLE C-2	Statistical Summary For: <ul style="list-style-type: none">a. Burning vs. Non Burning Dumpsb. Covered vs. Not Coveredc. Newer vs. Older Dumps
TABLE C-3	Background Water Quality
TABLE C-4	Downgradient Wells (total minus wells in Table C-3)
TABLE C-5	Summary of Ground Water Degradation (based on means for only wells with the highest concentrations at each dump)

TABLE C-1b

SUMMARY BY HYDROGEOLOGY

Lower Report L.L.	01000	01025	01030	01043	01056	71890	01090	70100	00915	00925	01046	00935	00930	00945
	D.Arsenic	D.Cadmium	D.Chrom.	D.Lead	D.Mangan.	I.Mercury	D.Zinc	D.Solids	D.Calcium	D.Magnes.	D.Iron	D.Potas.	D.Sodium	Sulfate
1	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l	ug/l	mg/l	mg/l	mg/l
Average	1.1	1.4	1.3	0.9	1057	0.14	15	1242	368	264	5753	16	53	321
Std. Dev.	0.3	2.9	1.4	1.3	1731	0.12	15	1325	330	387	18964	31	90	678
Maximum	44.0	29.0	7.2	10.0	13000	0.99	95	6300	1500	2100	130000	130	430	3400
Minimum	1.0	0.0	0.2	0.2	20	0.10	10	45	10	1	50	1	2	2
Count	139.0	140.0	140.0	140.0	138	131.00	139	124	62	61	62	62	62	62
D.W. Std.	50.0	10.0	50.0	50.0	50	2.00	5000	500	180	89	2325	2	8	250
Amb Sur Sand	7.4	0.4	1.3	2.9	326	0.25	104		245	150	1841	4	46	236
Amb Bur Sand	15.5	0.2	1.2	3.7	287	0.34	150							
DEEP WT. S&G														
Average	1.1	1.0	1.5	0.5	1410	0.10	10	423	232	100	6663	3	9	38
Std. Dev.	0.3	0.6	1.7	0.4	3380	0.01	1	161	104	55	16792	5	12	54
Maximum	2.0	2.3	6.7	1.9	13000	0.15	14	720	400	2100	48000	15	38	170
Minimum	1.0	0.0	0.5	0.2	20	0.10	10	150	64	1	50	1	2	10
Count	17.0	19.0	19.0	19.0	17	17.00	18	15	8	8	8	8	8	8
SHALLOW WT. S&G														
Average	3.9	1.8	1.3	0.8	892	0.12	16	676	258	138	4073	24	31	93
Std. Dev.	8.3	4.0	1.5	1.3	1612	0.07	18	1800	176	117	10985	42	43	149
Maximum	44.0	29.0	7.2	10.0	8000	0.51	95	526	690	2100	47000	130	180	550
Minimum	1.0	0.1	0.5	0.2	20	0.10	10	45	10	1	50	1	2	5
Count	63.0	60.0	63.0	63.0	62	55.00	63	55	29	29	29	29	29	29
SHALLOW WT-CLAY														
Average	1.3	1.2	1.4	1.3	1138	0.15	16	1425	403	291	10785	7	54	424
Std. Dev.	0.5	2.1	1.2	1.7	960	0.16	13	1600	357	517	31445	8	89	916
Maximum	2.6	9.9	5.0	7.5	3000	0.99	67	6300	1300	2100	130000	28	330	3400
Minimum	1.0	0.0	0.5	0.2	20	0.10	10	79	22	1	50	1	4	2
Count	34.0	34.0	33.0	34.0	34	32.00	34	34	17	17	17	17	17	17
SHALLOW WT-CLAY														
Average	3.3	1.1	1.2	0.7	720	0.18	17	3105	828	907	239	17	172	1209
Std. Dev.	5.7	0.7	0.9	0.8	1123	0.16	12	972	453	345	408	22	156	869
Maximum	27.0	3.7	3.8	2.9	3500	0.71	57	4300	1500	2100	1300	70	430	2200
Minimum	1.0	0.1	0.2	0.2	0	0.10	10	1500	270	1	50	5	8	240
Count	24.0	24.0	23.0	24.0	24	24.00	24	20	8	7	8	8	8	8

TABLE C-1a

SUMMARY BY HYDROGEOLOGY

00010 Eld. Temp 00095 Conduct. Field 00400 Field pH 00403 Lab pH 00904 Chloride 00610 NH3-N 00615 ND2+ND3-N 00410 T. ALK. 00335 COU

Lower Reporting Limit Units :	NA	NA	NA	NA	NA	NA	0.5 mg/l	0.02 mg/l	0.01 mg/l	10 mg/l	5 mg/l
ALL SITES											
Average	10.8	1018.9	1413.2	1440.7	6.8	7.0	103.9	3.9	4.6	429.1	31.3
Std. Dev.	3.8	939.5	1286.3	1315.3	0.4	0.4	234.3	11.6	11.4	320.3	37.2
Maximum	22.0	5875.0	6000.0	6000.0	7.8	7.9	1800.0	89.6	68.0	2400.0	240.0
MINIMUM	1.5	32.3	50.0	50.0	5.4	6.0	0.5	0.0	0.0	18.0	4.5
Count	176.0	176.0	0.0	176.0	163.0	175.0	177.0	177.0	177.0	123.0	161.0
DEEP WATER TABLE S&G											
Average	10.2	440.2	632.9	645.2	6.7	6.8	18.4	0.5	0.9	317.1	17.8
Std. Dev.	2.2	207.6	315.2	291.1	0.6	0.6	14.7	1.2	1.3	159.6	21.9
Maximum	14.0	1343.8	1200.0	1200.0	7.4	7.6	54.0	3.5	4.8	610.0	87.0
MINIMUM	7.0	220.6	240.0	240.0	5.4	6.0	0.7	0.0	0.0	100.0	5.0
D.W. Std.			6.5-8.5				250.0		10.0		
Count	22.0	22.0	0.0	21.0	18.0	22.0	22.0	22.0	22.0	14.0	18.0
SHALLOW WATER TABLE S&G											
Average	10.8	667.0	919.6	968.6	6.8	7.1	49.1	4.2	7.6	403.8	26.3
Std. Dev.	4.0	532.2	702.4	756.0	0.4	0.4	70.0	14.7	15.1	390.6	42.9
Maximum	21.0	2987.8	3100.0	3100.0	7.8	7.9	320.0	89.6	68.0	2400.0	240.0
MINIMUM	1.5	32.3	50.0	50.0	5.8	6.4	0.5	0.0	0.0	18.0	4.5
Count	84.0	84.0	0.0	85.0	80.0	83.0	85.0	85.0	85.0	54.0	81.0
SHALLOW WT. in TILL											
Average	11.0	1200.0	1661.2	1597.4	6.7	6.9	76.3	6.5	1.0	485.2	43.1
Std. Dev.	3.6	1059.7	1452.4	1478.8	0.4	0.4	127.0	10.4	3.3	303.7	34.0
Maximum	18.5	4933.3	5100.0	5100.0	7.7	7.8	460.0	45.0	17.0	1230.0	120.0
MINIMUM	4.5	63.3	110.0	110.0	5.6	6.1	2.1	0.0	0.0	32.0	5.0
Count	46.0	46.0	0.0	46.0	44.0	46.0	46.0	46.0	46.0	33.0	38.0
SHALLOW WT. in CLAY											
Average	11.2	2434.2	3380.9	3508.3	6.7	7.1	429.5	1.1	4.4	519.0	39.3
Std. Dev.	4.6	727.4	977.5	900.7	0.4	0.2	490.2	2.4	8.6	147.1	22.0
Maximum	22.0	5875.0	6000.0	6000.0	7.3	7.5	1800.0	8.2	34.0	790.0	83.0
MINIMUM	4.0	2307.7	2200.0	2200.0	5.5	6.9	34.0	0.1	0.0	340.0	9.0
Count	24.0	24.0	0.0	24.0	21.0	24.0	24.0	24.0	24.0	20.0	24.0
Drinking Water Standards			6.5-8.5	250.0							
Ambient Surf Sand Aq. MEAN	553.0	523.0	7.3	11.3	4.9	214.0	12.6				
Ambient Bur. Sand Aq. MEAN	921.0	886.0	7.4	26.6	2.2	333.0	13.7				

in µg/l unless specified

Nitrate + Nitrite (NO₂) ions
↓

TABLE C-4 Downgradient Wells : Mean Values For Three Sample Events (values in table 2 of text minus upgradient wells)

		F.Cond	L.Cond	F.pH	L.pH	Cl	NH3	NO3	T.Alk	COD	As	Cd	Cr	Pb	Mn
		<i>Field & Lab Conductivities</i>		<i>Field</i>	<i>Lab</i>			<i>etc</i>							
Northfield	2	645	690	6.8	7.1	1.4	0.27	0.5	360	12.7	1	0.65	0.5	0.4	190
	3	726	720	6.9	7.2	10.6	0.26	0.12	343	23	1	1.3	0.9	1.1	190
	4	2200	2200	6.7	7	42	9.5	0.1	836	6	6.4	1.3	1.4	0.3	6233
Edgerton	2	1016	1233	6.9	7.2	75	0.27	0.44	369	17.7	1	1.4	0.6	0.45	250
	3	1168	1067	7.1	7.3	55	0.26	35	306	7.3	1	0.73	0.8	0.35	305
	4	2353	2367	6.9	7	183	9.5	0.01	518	26.7	1	1	0.7	0.8	905
Park. Prairie	2	1068	1100	6.6	6.9	65	0.13	2.8	510	29	1	0.42	0.9	0.4	20
	3	1811	1800	6.6	6.8	153	1.3	0.1	730	50	1	0.18	1.1	0.2	3367
	4	443	370	6.7	6.9	20	0.39	0.1	158	41	1.4	1.2	1.1	0.5	1287
Osage	1	895	900	6.7	6.9	3.1	0.03	0.64	280	8.9	1	1.3	1.1	0.3	260
	3	722	713	6.8	7.1	33	0.03	1.76	365	7.5	1	10.2	0.87	1.1	33
	4	670	653	6.8	7.2	5.3	0.05	3.8	260	5.6	1	1.9	0.8	0.6	20
Perham	2	338	403	7.3	7.7	58	0.023	3.1	170	5	1	0.48	1.2	0.5	20
	3	1556	1537	6.8	7.3	123	0.05	38.7	240	12.8	1	0.25	1	0.25	210
	4	1144	1167	7.1	7.2	41	0.05	35	310	11	1	0.8	0.5	0.67	1367
Brainard	2	1351	1900	6.9	7.3	30	0.05	0.71	460	22	2.3	3.1	1.7	1.4	780
	3	2390	2767	6.5	6.8	293	70	0.01	1110	203	24	0.95	5.6	0.9	1403
	4	1733	1867	6.5	6.6	87	35	0.39	840	113	30	4.5	2.7	4	1653
Lavell	4	91	100	6.6	7.1	3.5	0.02	0.013	37	7.7	1	1.1	2.8	0.37	20
Henning	1	1005	1023	6.7	6.9	29	0.03	1.5	485	7.7	1	0.83	0.73	0.3	80
	3	905	877	7	7.1	20	0.16	0.01	435	11.8	1	0.48	0.53	0.2	233
Fifty Lakes	2	813	813	6.3	6.3	40	3.4	0.01	386	72	1.03	1	0.63	0.47	67
	3	563	563	6	6.2	29	0.03	3.4	123	30	1.5	0.92	5.1	0.63	46500
	4	270	270	5.8	6.1	19	0.03	0.29	100	12	2	0.5	0.5	0.25	20
Clinton	1	3512	3534	6.7	7.1	143	0.21	1.5	543	50	2	1.5	1.3	1.2	240
	3	3854	4100	6.7	7.2	223	0.22	25	403	26	2	1.2	1.4	0.57	147
Dilworth	1	5514	5333	6.7	6.9	1600	0.3	0.01	605	65	1	0.92	1.5	0.77	2800
	2	2401	2433	6.9	7.2	287	7.2	1	775	48	1.5	1.7	0.73	0.9	1377
	3	2870	2900	6.7	6.9	530	0.43	0.11	705	56	15.8	1	0.67	0.93	3233

Hg	Zn	mg/l TDS	mg/l T.S.	mg/l Ca	mg/l Mg	mg/l Fe	mg/l K	mg/l Na	mg/l SO4	Cation	Anion	%BAL
0.1	14	390	410	220	120	430	2.8	6.5	23	7160	7700	-7
0.1	12	400	580	230	140	730	1.9	5.5	50	7690	8510	-9.6
0.1	12	1400	1800	570	450	19000	130	4.8	490	25890	27460	-5.7
0.1	38	777	880	350	200	50	4.8	20	150	12000	12170	-1.4
0.1	10	703	920	370	220	50	3.6	18	120	12690	13740	-7.7
0.1	11.5	1734	1700	690	470	50	6.2	58	550	25910	22400	13.6
0.1	10	545	750	360	180	50	6.1	37	15	12590	13120	-4.1
0.1	10	1300	1400	470	270	14000	97	120	150	22000	22680	-3
0.1	10	265	200	40	17	1800	20	9.8	16	2290	2290	-8.9
0.1	10	1100	1100	470	120	50	1	4	14	12000	10960	8.7
0.1	10	490	2300	290	110	50	1.3	22	35	9000	9090	-1
0.1	10	1800	2200	200	96	50	1	4.1	44	6130	6400	-4.3
0.1	10	240	260	84	42	50	2	39	5	4290	8410	-49
0.1	10	1200	1200	300	180	50	100	120	250	17480	17730	-1.4
0.1	10	795	730	260	140	50	43	33	86	10570	10850	-2.6
0.1	40	1200	1300	350	310	50	130	62	430	19310	19420	-0.6
0.12	20	1400	1400	350	160	33000	72	180	11	19990	25740	-22.3
0.4	35	1015	1300	470	170	47000	76	68	85	17770	20040	-11.4
0.11	10	90	230	18	11	50	0.7	3.8	12	770	880	-12.6
0.1	10	625	610	330	170	50	2.1	5	41	1027	1085	-5.3
0.1	10.3	505	450	220	150	5000	3	5.8	30	7730	8250	-6.2
0.1	10	410	560	220	58	48000	15	38	14	13060	13990	-6.6
0.1	10.6	490	930	400	150	50	1.1	8.9	170	5980	6820	-12.3
0.1	10	150	160	64	25	50	1.5	8.5	9.6	2190	2440	-10.1
0.5	33	3433	5600	1000		50	9.8	8.4	1800	44600	47750	-6.6
0.23	14	4067	4700	1500	1200	50	9	66	2200	57140	59650	-4.2
0.01	12	4000	15000	820	1300	410	11	430	750	61600	71600	-14
0.18	12	1500	8100	270	530	50	70	220	240	27500	28620	-3.9
0.15	12	1800	2100	340	470	1200	8.4	340	240	31380	33020	-5

Hg	Zn	TDS	T.S.	Ca	Mg	Fe	K	Na	SO4	Cation	Anion	%BAL
0.6	10	900	1100	580	200	130000	5.7	27	2.7	16940	19620	=13
0.7	10	677	1400	540	220	23000	6.6	16	12	16080	19320	-16.8
0.12	20	5067	6200	1100	2100	50	21	220	3400	74230	7300	1.7
0.24	10	1850	1500	680	200	50	9.9	7.8	730	18200	18300	-0.5
0.17	19	3967	4500	1300	1000	50	28	330	2000	61250	63900	-4.2
0.1	10	220	240	100	47	50	1.7	5.1	78	3210	3300	-2.8
0.12	34	403	1900	95	34	500	1.6	38	28	4290	4270	0.6
0.55	39	545	1600	280	140	50	4.1	36	68	10090	13940	-27.6
0.12	10.3	280	660	280	64	130000	13	13	2.1	6910	12350	-44
0.1	16	1200	940	240	140	140	13	100	13	12340	14460	-14.7
0.2	15.5	1254.7	2023.3	421.8	305.4	11676	24.0	70.2	368.3	18494.3	18194.2	-8.0
0.01	10	90	160	18	11	50	0.7	3.8	2.1	770	880	-49
0.7	40	5067	15000	1500	2100	130000	130	430	3400	74230	71600	13.6
2E-02	9E+01	1E+06	7E+06	1E+05	2E+05	9E+08	1E+03	1E+04	5E+05	3E+08	3E+08	1E+02
0.2	9.4	1212.3	2735.5	330.3	418.1	30044	36.3	102.8	724.6	17818.9	16564.4	11.5
39	39	39	39	39	38	39	39					

APPENDIX D

VOLATILE ORGANIC CHEMICAL ANALYSIS

1. Discussion of Terms
2. Transformation/Biodegradation
3. Summary Table for VOC Sample
4. Frequency of Volatile Organic Chemicals
5. Complete Listing of VOCs
Reported by Gas Chromatograph (GC)
Analysis

Appendix D

The following terms were used for the discussion of volatile organic chemicals in the report and in the attached summary table:

*denotes priority pollutant from a list of 129 chemicals U.S. EPA, 1980 Water Quality Criteria Documents, available in Volume 45 Federal Register 79318-79379, November 28, 1980.

LRL "Lower Reporting Limit" or "Detection Limit" is the lowest concentration that is reported by the laboratory with the equipment and methodology for the analysis.

T&O level at which most people detect taste or odor from this chemical.

RMCL Recommended Maximum Contaminant Levels were established for volatile synthetic organic chemicals (VOCs) in drinking water. RMCLs for noncarcinogens are proposed based upon chronic toxicity data, and RMCLs for carcinogens are proposed at the zero level. Additional RMCLs for VOCs not listed in this table may be proposed later. RMCLs are nonenforceable health goals which are set at levels which would result in no known or anticipated adverse health effects with an adequate margin of safety; based on proposed rules published in Federal Register Volume 49 - Number 114, Tuesday, June 12, 1984.

10-5 Risk Level - The probability that there would be one death in 100,000 people due to cancer after a life time (70 years) consumption of water at the specified level.

LOR Level of Response; from EPA suggested Level of Response to states, April 29, 1981.

TEL Threshold Effect Level - from the Summary Tables for U.S. EPA Priority Pollutants, May 15, 1981.

Biological Transformation/Biodegradation of Organic Pollutants in Ground Water

Recent investigations published in the scientific literature discuss the possibilities of microorganisms in the shallow water table interacting with organic pollutants. The research shows that there are high numbers of these microorganisms naturally present in the ground water and that under the right conditions they may transform many organics that enter the system. The idea that these microbes may aid in treating ground water or clean it up is encouraging. However, instead of total destruction of the organics, they may alter the organics creating new forms of organic pollutants adding to confusion about the source. The fact that we realize this may be happening is helpful when looking at test results for ground water samples. This is a relatively new area but there is literature available to document transformations; for example: Tetrachloroethene transformed to cis- and trans-1,2-dichloroethene and chloroethene (Parsons et al Journal AWWA February 1984). Laboratory and field experiments have verified that biodegradation/transformation takes place creating new organics which were not present in the original product.

VOLATILE HYDROCARBONS IN WATER
 HALOGENATED AND NON-HALOGENATED
 (* DENOTES PRIORITY POLLUTANT)

SUMMARY OF COMPOUNDS DETECTED

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
Lavell 6/27/84									
Well #3 Field Blank: #140113 9/19/84	None Observed								
Well #4 Field Blank: #140175	* METHYLENE CHLORIDE	2.2	S	1.0			1.9	150- 130000	
	* 1,1,2-TRICHLOROETHYLENE	0.3	S	0.2	500	0		72- 2000	
Duluth 6/25/84									
Well #4 Field Blank: #140113	ETHYL ETHER	1.3	F	1.0					
	* CHLOROMETHANE	PP	F				1.9	72- 2000	
	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0		1600- 100000	
	DI CHLORODIFLUOROMETHANE	PP	F				1.9		
	* DI CHLOROFLUOROMETHANE	PP	S				1.9		
9/20/84									
Well #4 Field Blank: #140175	ETHYL ETHER	3.0	F	1.0					
	* TOLUENE	PP	F	0.5	1000			100- 120000	14300
	* CHLOROMETHANE	PP	F				1.9		
	* VINYL CHLORIDE	PP	F			0	10		
	* DI CHLOROFLUOROMETHANE	PP	S				1.9		
9/20/84									
Field Blank: #140175									
Lepac Well	* 1,2-DICHLOROETHANE	PP	S	0.2	2900	0	9.4		

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	§§	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
McKinley 6/5/84									
Well #1 Field Blank: ¹ #130531	* METHYLENE CHLORIDE	1.6	S	1.0			1.9	150- 130000	
	* 1,1,2-TRICHLOROETHYLENE	0.4	S	0.2	500	0	27	72- 2000	
Well #2 Field Blank: #130531	None Observed								
Well #3 Field Blank: #130531	* METHYLENE CHLORIDE	3.1	S	1.0			1.9	150- 130000	
	* 1,1,2,2-TETRACHLOROETHYLENE	P<	S	2.0	300	0	8	20- 2300	
Well #4 Field Blank: #130531	* METHYLENE CHLORIDE	1.6	S	1.0			1.9	150- 130000	
6/26/84									
Well #4 Field Blank: #140113	CIS-1,2-DICHLOROETHYLENE	P<	S	0.2					
No Sample 9/19/84									
Fifty Lakes 6/27/84									
Well #2 Field Blank: #140113	* CHLOROMETHANE	PP	F				1.9	1600- 100000	
	DICHLORODIFLUOROMETHANE	PP	F				1.9		
9/18/84 Field Blank: #140175	None Observed								

¹Analysis of 1 Field Blanks found at end of table.

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
Brainerd									
Well #3	ETHYL ETHER	77.0 (76)	F	1.0					
Field Blank: #140113	* BENZENE	5.1 (10)	F	0.5		0	6.7	350	6.6
	* TOLUENE	2.7 (5.2)	F	0.5	1000			100-	14300
	CUMENE	1.5 (3.2)	F	0.5				120000	
	M-XYLENE	7.4 (16)	F	0.5	1100			3200-	
	TETRAHYDROFURAN	51.0 (49)	F	5.0				6100	
	* ETHYLBENZENE	4.4 (12)	F	0.5	100				1400
	O-XYLENE	9.9 (27)	F	0.5	1800				
	P-XYLENE		F	0.5	500				
	* CHLOROMETHANE	PP	F				1.9		
	* VINYL CHLORIDE	PP (P)	F			0	10		
	* CHLOROETHANE	PP (P)	F						
	* METHYLENE CHLORIDE	1.7	S	1.0			1.9	150-	130000
	* 1,1-DICHLOROETHANE	0.4 (0.3)	S	0.2					
	CIS-1,2-DICHLOROETHYLENE	0.6 (0.7)§	S	0.2					
	* 1,2-DICHLOROETHANE	P ₂	S	0.2	2900	0	9.4		
	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0	27	72-	2000
	* DICHLOROFLUOROMETHANE	PP	S				1.9		
	* 1,2-DICHLOROPROPANE	0.6 (0.7)	S	0.2	1.4				
	* 1,4-DICHLOROBENZENE	3.6 (2.7)	S	1.0	.3	.00075		130	400
	DIISOPROPYL ETHER	0.9	F						
	* ETHYLBENZENE	12.0	F	0.5	100				1400
	PROPYLBENZENE	0.5							
	SEC-BUTYLBENZENE	0.2	F						
	1,3,5-TRIMETHYLBENZENE	1.0	F						
	* CHLOROBENZENE	0.4	S	0.5	100			72	488
	2-(2 HYDROXYPROPOXY)-1-PROPANOL								
	NONANOL								
	1,3,3-TRIMETHYL-2-OXABICYCLO								
	[2.2.2]OCTANE								
	1,7,7-TRIMETHYL-BICYCLO[2.2.1]								
	HEPTAN-2-ONE								
	2-ETHENYLTOLUENE								
	2-METHYL-4-OCTANONE								
	2-ETHYLTOLUENE								
	PROPYLBENZENE								

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	§§	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL	
9/17/84										
Well #4 Field Blank: #140175	ETHYL ETHER	41.0 (61)	F	1.0						
	* BENZENE	9.6 (14)	F	0.5		0	6.7	350	6.6	
	* TOLUENE	2.6 (4.6)	F	0.5	1000			100-	14300	
	CUMENE	1.2 (1.7)	F	0.5				120000		
	M-XYLENE	41.0 (52)	F	0.5	1100			3200-		
	* ETHYLBENZENE	7.8 (11)	F	0.5	100			6100	1400	
	O-XYLENE	46.0 (61)	F	0.5	1800					
	P-XYLENE		F	0.5	500					
	* CHLOROMETHANE	PP	F					1.9		
	* VINYL CHLORIDE	PP	F				0	10		
	* CHLOROETHANE	PP (1.3)	F							
	* 1,1-DICHLOROETHANE	1.6 (1.6)	S	0.2						
	CIS-1,2-DICHLOROETHYLENE	0.4 (0.4)§	S	0.2						
	* 1,1,1-TRICHLOROETHANE	0.2	S	0.2			.00075	220	184000	
	* 1,1,2-TRICHLOROETHYLENE	0.4 (0.6)	S	0.2	500		0	27	72- 2000	
	* DICHLOROFUOROMETHANE	PP	S					1.9		
	* 1,2-DICHLOROPROPANE	2.6 (4.1)	S	0.2	1.4					
	* CHLOROBENZENE	0.3 (0.4)	S	0.5	100				72	488
	* 1,4-DICHLOROBENZENE	2.8 (4.1)	S	1.0	.3		.00075		130	400
	* METHYLENE CHLORIDE	(3.3)	S	1.0				1.9	150- 130000	
	TETRAHYDROFURAN	(5.5)	F	5.0						
	PROPYLBENZENE	(0.8)								
	SEC-BUTYLBENZENE	(0.5)	F							
1-CHLOROPROPANE										
2-(2-HYDROXYPROPOXY)-1-PROPANOL										
2-METHYL-3-PENTANONE										
M-ETHYLTOLUENE										
(1-METHYLETHYL)-BENZENE										

Osage 6/29/84

Well #3 Field Blank: #140113	* 1,1,2-TRICHLOROETHYLENE	0.3	S	0.2	500	0	27	72- 2000	
	DICHLORODIFLUOROMETHANE	PP	F				1.9	1600- 100000	
	* TRICHLOROFUOROMETHANE	PP	S	0.2			1.9	2200- 25000	

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
9/24/84									
Well #4									
Field Blank:	* TRICHLOROFLUOROMETHANE	0.6	S	0.2			1.9	2200-	
#140200	* 1,1,1-TRICHLOROETHANE	0.2	S	0.2		.00075	220	25000	184000
Dilworth									
6/29/84									
Well #1	ETHYL ETHER	20.0	F	1.0					
Field Blank:	* CHLOROMETHANE	PP	F				1.9		
#140113	* CHLOROETHANE	PP	F						
	* 1,1-DICHLOROETHANE	0.3	S	0.2					
	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0	27	72-	
	DICHLORODIFLUOROMETHANE	PP	F				1.9	2000-	
	* DICHLOROFLUOROMETHANE	PP	S				1.9	1600-	100000
9/25/84									
Well #4	None Observed								
Field Blank:									
#140200									
Perham 7/1/84									
Well #4	None Observed								
Field Blank:									
#140113									
9/26/84									
Well #3	None Observed								
Field Blank:									
#140200									

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
Henning 7/2/84									
Well #1	* 1,1,1-TRICHLOROETHANE	3.3	S	0.2		.00075	220		184000
Field Blank: #140129	* 1,1,2-TRICHLOROETHYLENE	0.4	S	0.2	500	0	27	72- 2000	
	DICHLORODIFLUOROMETHANE	PP	F				1.9	1600- 100000	
	* TRICHLOROFLUOROMETHANE	0.4	S	0.2			1.9	2200- 25000	
	* 1,1-DICHLOROETHYLENE	0.6	S	0.2		0	2.3		
9/26/84									
Well #4	ETHYL ETHER	1.0	F	1.0					
Field Blank: #140200	* CHLOROMETHANE	PP	F				1.9		
	* DICHLOROFLUOROMETHANE	PP	S				1.9		
	* TRICHLOROFLUOROMETHANE	PP	S	0.2			1.9	2200- 25000	
	* 1,1-DICHLOROETHANE	0.5	S	0.2					
	CIS-1,2-DICHLOROETHYLENE	4.3	S	0.2					
	* 1,1,1-TRICHLOROETHANE	0.3	S	0.2		.00075	220		184000
	* 1,1,2-TRICHLOROETHYLENE	0.4	S	0.2	500	0		72- 2000	
Parkers Prairie 7/2/84									
Well #3	* CHLOROMETHANE	PP	F				1.9		
Field Blank: #140129	DICHLORODIFLUOROMETHANE	PP	F				1.9	1600- 100000	
	* DICHLOROFLUOROMETHANE	PP	S				1.9		
	* 1,1-DICHLOROETHANE	0.3	S	0.2					
	* 1,1,2-TRICHLOROETHYLENE	PP	S	0.2	500	0		72- 2000	
9/27/84									
Well #2	ETHYL ETHER	6.3 (9.6)	F	1.0					
Field Blank: #140200	* CHLOROMETHANE	PP (PP)	F				1.9		
	* CHLOROETHANE	PP (PP)	F						
	* METHYLENE CHLORIDE	1.6	S	1.0			1.9	150- 130000	
	* 1,1-DICHLOROETHANE	1.3 (1.3)	S	0.2					
	CIS-1,2-DICHLOROETHYLENE	1.5(1.2)§	S	0.2					
	* 1,1,1-TRICHLOROETHANE	1.6(1.4)	S	0.2		.00075	220		184000

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
	* 1,1,2-TRICHLOROETHYLENE	0.8 (0.7) (0.9)	S	0.2	500	0	27	72- 2000	
	CUMENE	(PP)	F	0.5					
	1,1,2-TRICHLOROTRIFLUOROETHANE	P<	S	0.5					
	* DICHLOROFLUOROMETHANE	PP	S				1.9		
	O-XYLENE	(0.2)	F	0.5	1800				
	P-XYLENE		F	0.5	500				
	* TRICHLOROFLUOROMETHANE	0.9(2.3)	S	0.2			1.9	2200- 25000	
	* 1,1-DICHLOROETHYLENE	0.4	S	0.2		0	2.3		
	1,1,2-TRICHLOROTRIFLUOROETHANE	(14)	S	0.5					
Clinton 7/5/84									
Well #1									
Field Blank: #140200	* 1,1,2-TRICHLOROETHYLENE	0.3	S	0.2	500	0	27	72- 2000	
10/3/84									
Well #3									
Field Blank: #140225	* METHYLENE CHLORIDE	1.2	S	1.0			1.9	150- 130000	
	CIS-1,2-DICHLOROETHYLENE	0.2	S	0.2					
	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0		72- 2000	
Marshall 7/6/84									
Well #4									
Field Blank: #140129	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0	27	72- 2000	
	* TRICHLOROFLUOROMETHANE	0.4	S	0.2			1.9	2200- 25000	
	* CHLOROFORM **	P<	S	0.2			1.9		
10/2/84									
Well #1									
Field Blank: #140225	* METHYLENE CHLORIDE	1.4	S	1.0			1.9	150- 130000	

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
Edgerton 7/6/84 No Sample									
10/1/84									
Well #2 Field Blank: #140225	* METHYLENE CHLORIDE	3.5	S	1.0			1.9	150- 130000	
Well #4 Field Blank: #140225	* METHYLENE CHLORIDE	1.3	S	1.0			1.9	150- 130000	
Northfield 7/10/84									
Well #4 Field Blank: #140156	* 1,2-DICHLOROETHANE	0.9	S	0.2	2900	0	9.4		
	* 1,1,2-TRICHLOROETHANE	0.4	S	0.2			6		
	* VINYL CHLORIDE	PP	F			0	10		
	* METHYLENE CHLORIDE	1.3	S	1.0			1.9	150- 130000	
10/4/84									
Well #4 Field Blank: #140225	* METHYLENE CHLORIDE	2.1	S	1.0			1.9	150- 130000	
	CIS-1,2-DICHLOROETHYLENE	0.6	S	0.2					
	* 1,1,2-TRICHLOROETHYLENE	0.6	S	0.2	500	0	27	72- 2000	
	* 1,1,2-TRICHLOROETHANE	PK	S	0.2			6		
Vadnais Heights 7-9-84									
Well #3 Field Blank: #140156	* 1,1,2-TRICHLOROETHYLENE	0.2	S	0.2	500	0	27	72- 2000	

Floating on surface (Density) Lower reporting limit

Taste + odor limit

Recommended maximum

10⁻⁵ risk level

Level of response

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
10/5/84									
Well #2 Field Blank: #140225	* METHYLENE CHLORIDE	1.6	S	1.0			1.9	150- 130000	
Field Blank: #130531	* METHYLENE CHLORIDE	2.0	S	1.0			1.9	150- 130000	
Blank #140200 9/24 through 9/27/84	None Observed in Blank								
Field Blank: #140225	* METHYLENE CHLORIDE	1.2	S	1.0			1.9	150- 130000	
Field Blank: #140156	* METHYLENE CHLORIDE	6.4	S	1.0			1.9	150- 130000	
Field Blank: #140129	None Observed								
Field Blank: #140175	None Observed								
Field Blank: #140225	METHYLENE CHLORIDE	1.2							
Field Blank: #140113	None Observed								

Footnotes:

1. Obsrvd. Conc. = GC or GC/MS concentration in ()
 2. LRL = Lower Reporting Limit
 3. T&O = Taste and Odor Level
 4. RMCL = Recommended Maximum Contaminant Levels; Fed. Reg. June 12, 1984, Vol. 49, No. 114
 5. 10⁻⁵ = 10⁻⁵ Risk Level
 6. LOR = Level of Response
 7. TEL = Threshold Effect Level
- * Denotes priority pollutant
 ** Sum of Trihalomethanes must meet NPDWS of < 100 ug/l
 All units micrograms per liter
 P< Peak detected below the "less than" value or "lower reporting limit"
 PP Peak present, but not quantified
 ()§ = t = both cis/trans
 §§ -- Floating (F) or Sinking (S) in water based on density

FREQUENCY OF VOLATILE ORGANIC CHEMICALS OCCURRING IN SAMPLES
 (Number of Samples with each VOC Out of Possible 32)

	<u># SAMPLES</u>
* BROMODICHLOROMETHANE **	0
* CARBON TETRACHLORIDE	0
* BROMOFORM **	0
* CHLOROFORM **	1
* TOLUENE	3
* BENZENE	2
* CHLOROBENZENE	1
* CHLORODIBROMOMETHANE **	0
* CHLOROETHANE	4
* ETHYLBENZENE	3
* BROMOMETHANE	0
* CHLOROMETHANE	9
* METHYLENE CHLORIDE	15 4/8 Field blanks
* 1,1,2,2-TETRACHLOROETHYLENE	1
* TRICHLOROFLUOROMETHANE	6
* 1,1-DICHLOROETHANE	6
* 1,1-DICHLOROETHYLENE	2
* 1,1,1-TRICHLOROETHANE	5
* 1,1,2-TRICHLOROETHANE	2
* 1,1,2,2-TETRACHLOROETHANE	1
* 1,2-DICHLOROETHANE	3
* 1,2-DICHLOROBENZENE	0
* 1,2-DICHLOROPROPANE	2
* TRANS-1,2-DICHLOROETHYLENE	0
* 1,3-DICHLOROBENZENE	0
* 1,4-DICHLOROBENZENE	2
* 2-CHLOROETHYL VINYL ETHER	0
DICHLORODIFLUOROMETHANE	5
* TRANS-1,3-DICHLORO-1-PROPENE	0
* CIS-1,3-DICHLORO-1-PROPENE	0
* VINYL CHLORIDE	4
* 1,1,2-TRICHLOROETHYLENE	17
CIS-1,2-DICHLOROETHYLENE	7
* DICHLOROFLUOROMETHANE	10

	<u># SAMPLES</u>
M-XYLENE	0
O-XYLENE	3
2,3-DICHLORO-1-PROPENE	0
1,1-DICHLORO-1-PROPENE	0
1,3-DICHLOROPROPANE	0
CUMENE	3
1,2,3-TRICHLOROPROPANE	0
1,1,1,2-TETRACHLOROETHANE	0
DIBROMOMETHANE	0
1,2-DIBROMOETHANE	0
ALLYLCHLORIDE	0
DICHLOROACETONITRILE	0
O-XYLENE	3
P-XYLENE	3
PENTACHLOROETHANE	0
ACETONE	0
ETHYL ETHER	7
METHYL ETHYL KETONE	0
METHYL ISOBUTYL KETONE	0
TETRAHYDROFURAN	
1,1,2-TRICHLOROTRIFLUOROETHANE	2

EXTENDED LIST FROM GC/MS

DIISOPROPYL ETHER	1/2
* ETHYLBENZENE	1/2
PROPYLBENZENE	1/2
SEC-BUTYLBENZENE	2/2
1,3,5-TRIMETHYLBENZENE	1/2
* CHLOROBENZENE	1/2
2-(2 HYDROXYPROPOXY)-1-PROPANOL	2/2
NONANOL	1/2
1,3,3-TRIMETHYL-2-OXABICYCLO	1/2
[2.2.2]OCTANE	1/2
1,7,7-TRIMETHYL-BICYCLO [2.2.1]	1/2
HEPTAN-2-ONE	1/2
2-ETHENYLTOLUENE	1/2
2-METHYL-4-OCTANONE	1/2
2-ETHYLTOLUENE	1/2
PROPYLBENZENE	2/2

	<u># SAMPLES</u>
1-CHLOROPROPANE	1/2
2-METHYL-3-PENTANONE	1/2
M-ETHYLTOLUENE	1/2
(1-METHYLETHYL)-BENZENE	1/2

FOOTNOTES:

- * Denotes priority pollutant
- ** Sum of trihalomethanes must be ≤ 100 ug/l to meet NPDWS

COMPLETE LISTING OF COMPOUNDS REPORTED ON GAS CHROMATOGRAPH ANALYSIS

VOLATILE HYDROCARBONS IN WATER
 HALOGENATED AND NON-HALOGENATED
 (* DENOTES PRIORITY POLLUTANT)

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	SS	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
	* BROMODICHLOROMETHANE **		S	0.5			1.9		
	* CARBON TETRACHLORIDE		S	0.2		0	4	20-	
	* BROMOFORM **		S	1.0			1.9	200	
	* CHLOROFORM **		S	0.2			1.9		
	* TOLUENE		F	0.5	1000			100-	
	* BENZENE		F	0.5		0	6.7	120000	14300
	* CHLOROBEZENE		S	0.5	100			350	6.6
	* CHLORODIBROMOMETHANE **		S	1.0			1.9	72	488
	* CHLOROETHANE		F						
	* ETHYLBENZENE		F	0.5	100				1400
	* BROMOMETHANE		S				1.9		
	* CHLOROMETHANE		F				1.9		
	* METHYLENE CHLORIDE		S	1.0			1.9	150-	
	* 1,1,2,2-TETRACHLOROETHYLENE		S	2.0	300	0	8	130000	
	* TRICHLOROFLUOROMETHANE		S	0.2			1.9	20-	
	* 1,1-DICHLOROETHANE		S	0.2				2300	
	* 1,1-DICHLOROETHYLENE		S	0.2		0	2.3	2200-	
	* 1,1,1-TRICHLOROETHANE		S	0.2		.00075	220	25000	
	* 1,1,2-TRICHLOROETHANE		S	0.2			6		184000
	* 1,1,2,2-TETRACHLOROETHANE		S	2.0			1.7		
	* 1,2-DICHLOROETHANE		S	0.2	2900	0	9.4		
	* 1,2-DICHLOROBEZENE		S	1.0	10				400
	* 1,2-DICHLOROPROPANE		S	0.2	1.4				
	* TRANS-1,2-DICHLOROETHYLENE		S	0.2					
	* 1,3-DICHLOROBEZENE		S	1.0	20				400
	* 1,4-DICHLOROBEZENE		S	1.0	.3	.00075		130	400
	* 2-CHLOROETHYL VINYL ETHER		S	1.0					
	DICHLORODIFLUOROMETHANE		F				1.9	1600-	
	* TRANS-1,3-DICHLORO-1-PROPENE		S	0.2				100000	87
	* CIS-1,3-DICHLORO-1-PROPENE		S	0.2					87
	* VINYL CHLORIDE		F			0	10		
	* 1,1,2-TRICHLOROETHYLENE		S	0.2	500	0	27	72-	
	CIS-1,2-DICHLOROETHYLENE		S	0.2				2000	
	* DICHLOROFLUOROMETHANE		S				1.9		

ALL UNITS UG/L

Site	Organic Compound	Obsrvd. Conc.	§§	LRL	T&O	RMCL	10 ⁻⁵	LOR	TEL
	M-XYLENE		F	0.5	.1100			3200-6100	
	O-XYLENE		F	0.5	1800				
	2,3-DICHLORO-1-PROPENE		S	0.5					87
	1,1-DICHLORO-1-PROPENE		S	0.2					87
	1,3-DICHLOROPROPANE		S	3.0					
	CUMENE		F	0.5					
	1,2,3-TRICHLOROPROPANE		S	2.0					
	1,1,1,2-TETRACHLOROETHANE		S	0.2					
	DIBROMOMETHANE		S	1.0			1.9		
	1,2-DIBROMOETHANE		S	1.0			.55		
	ALLYLCHLORIDE		F	0.5					
	DICHLOROACETONITRILE		S	0.5					
	O-XYLENE		F	0.5	1800				
	P-XYLENE		F	0.5	500				
	PENTACHLOROETHANE		S	2.0					
	ACETONE		F	10					
	ETHYL ETHER		F	1.0					
	METHYL ETHYL KETONE		F	5.0					
	METHYL ISOBUTYL KETONE		F	1.0					
	TETRAHYDROFURAN		F	5.0					
	1,1,2-TRICHLOROTRIFLUOROETHANE		S	0.5					

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All units micrograms per liter

P< Peak detected below the "less than" value or "lower reporting limit"

PP Peak present, but not quantified

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§§ -- Floating (F) or Sinking (S) in water based on density