GROUNDWATER POLLUTION HAZARD NEAR SANITARY LANDFILLS ON THE GLACIATED PLAINS, NORTH DAKOTA--A STUDY OF THE LANGDON, NORTH DAKOTA SANITARY LANDFILL

by

B. Michael Arndt

North Dakota Geological Survey

Open-file Report OF-1

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A study of the Langdon, North Dakota Sanitary Landfill

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INTRODUCTION

General

The sanitary landfill owned and operated by the city of Langdon, North Dakota, is located 4 miles west and 0.5 mile north of town (fig. 1). The present site is a rectangular area covering 15 acres. Another 15 acres immediately north of the present site is available for future expansion. The landfill has been in operation since 1972 and is estimated to be usable until 1980 at present rates of disposal.

The landfill serves the communities of Langdon and Nekoma and the rural citizens of the area. Daily intake of refuse into the landfill is about 30 cubic yards, consisting mostly of household and commercial wastes. No car bodies or other large bulky items are allowed. Disposal of tires, herbicide and pesticide containers, and trees are restricted to certain areas of the landfill. Tree cuttings and branches are burned before burial.

Shortly after operation of the landfill began, some of the residents of the Langdon area became concerned that the landfill might affect domestic water wells in the area. A public meeting, held at the Cavalier County Courthouse in the fall of 1972, was attended by city, county, and state officials and concerned citizens. In January, 1973, as a result of that session, Dr. Dale Anderson, then director of the North Dakota Water Resources Research Institute, called a meeting to consider the possibilities of a groundwater study in the vicinity of the Langdon landfill. This meeting was attended by Dr. Dale Anderson and Dr. Thor Hertsgaard, both of W.R.R.I.; Drs. Michael Arndt and Stephen R. Moran, North Dakota Geological Survey; Dr. Joe K. Neel, Department of Biology, U.N.D.; Mr. G. O. Fossum, Department of Civil Engineering, U.N.D.; Dr. John Vennes, Department of Microbiology, U.N.D.; and Mssrs. W. Van Heuvelen and Raymond Rolshoven, North Dakota State Department of Health.

As a result of the meeting, a two-year study of the Langdon landfill was undertaken, funded principally by W.R.R.I., with the State Geological Survey contributing both personnel and equipment to the project. The objectives of the study were: (1) to define the geologic and hydrologic setting of the sanitary landfill site near Langdon; (2) to gather information about the quantity, types, and migration of dissolved solids from the landfill into the groundwater flow system; and (3) to evaluate the applicability of the results of the study of this landfill to other landfill sites in North Dakota.

This report is the result of that study.

Previous Research

Major investigations of the production and movement of contaminants from landfill sites have been conducted primarily in Illinois and California. Hughes (1967; 1972), Cartwright and Sherman (1969), and Bergstrom (1968) have discussed various geologic and hydrologic settings that can influence solid waste disposal methods and practices. Williams

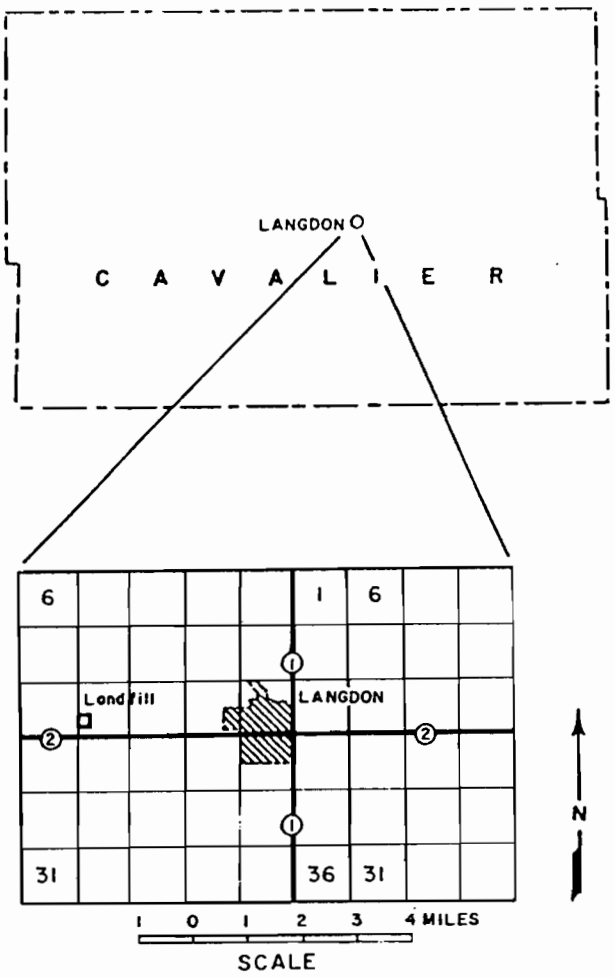


Figure 1. Map of Cavalier County and the Langdon area showing the location of the Langdon landfill.

and Wallace (1970) have discussed the hydrogeologic environments commonly considered safest for waste disposal in Idaho. Reports on specific solid waste disposal sites have been published by Hughes, Landon, and Farvolden (1972), McCormick (1966), the University of Southern California (1954), and Waldrip and Ruhe (1974).

Investigations of landfills in North Dakota have been limited to studies of waste disposal operations at the Mandan landfill (Weaver and Keagy, 1952). Butler (1973) studied the hydrogeologic environment of the Mandan landfill. Moran (1971) investigated migration of salts from brine disposal pits. Arndt and Moran (1974) discussed geologic factors affecting landfill site selection in Cass County, North Dakota, and Clay County, Minnesota.

Pollution Hazards Associated with Landfills

One of the most important concerns with any solid waste disposal program is the potential for contamination of water supplies. Water that

comes into contact with refuse may set up chemical reactions that produce leachate, which can appreciably alter water quality. A sanitary landfill is a more desirable method of solid waste disposal than an open garbage dump because the chance of leachate production is substantially less.

Leachate produced at a waste disposal site may seep into nearby streams, or it can enter the groundwater. In a setting where refuse is buried above the water table, water percolating through the refuse, producing leachate, may move downward into the groundwater. In some places refuse is buried at or below the water table and the refuse is in direct contact with the groundwater. In this instance, the possibility of rapid leachate generation is much higher than if the refuse is buried above the water table.

Leachate entering the groundwater is usually of greater concern than leachate entering surface water. Groundwater contamination is much more difficult to detect and to correct than surface-water contamination. Locating a point source for surface-water contamination is relatively easy, and the contamination of the water from such a point source is significantly reduced as soon as that point source is shut off. Contamination in groundwater, because it moves so slowly, may not be detected in nearby wells for several years. Removal of contaminants in this system, once detected, will require at least as much time to be removed as it took for them to move from the source to that well.

Many factors are involved in the pollution potential of a sanitary landfill, but these may be divided into two primary categories: (1) those factors that promote the production of leachate; and (2) those factors that contribute to the migration of leachate. The two categories overlap considerably.

The most important factor in the production of leachate is the character of the waste material itself. Waldrip and Ruhe (1974), Williams and Wallace (1970), and Butler (1973) all emphasize that the nature and volume of the refuse is a determining factor of the amount of leachate that can be produced. Weaver and Keagy (1952) and the British Ministry of Housing and Local Government (1961) have conducted studies describing the composition of solid wastes. Both the physical and chemical compositions of refuse are highly variable and indirectly dependent on factors such as geographic location, economic standards of the community, and season of the year (Hughes, Landon, and Farvolden, 1971).

Other factors involved in the production of leachate include temperature, availability of oxygen and moisture, and the length of time since burial. The interaction of these factors is discussed in detail by Butler (1973) and Waldrip and Ruhe (1974).

Factors that are involved in the migration of contaminants away from a landfill include the hydrogeologic setting of the landfill, local topography, nature of the sediment in which the refuse is placed, and the amount of precipitation at the site.

If a landfill is located in a discharge area where groundwater movement is upward, any leachate produced will not enter the groundwater flow system. In a recharge area where groundwater movement is downward, any leachate produced will migrate into the groundwater flow system. Where groundwater flow is horizontal, leachate may enter the flow system where refuse intersects the water table. A more detailed discussion on groundwater flow is given in a later section of this report.

The amount of precipitation at a landfill site controls the amount of water that will infiltrate into the refuse. Precipitation not only provides some of the moisture necessary for leachate production, but it also is the mechanism for migration of dissolved chemicals into the groundwater flow system. Williams and Wallace (1970) determined that in Idaho an annual precipitation rate of 14 inches is sufficient to penetrate a landfill. Butler (1973), however, found that, even during a heavy thunderstorm, the wetting front rarely moved below 3 to 6 feet at the Mandan, North Dakota, landfill, where annual precipitation is about 16 inches.

It is not clear whether precipitation entering into, or groundwater moving through, a landfill is the prime triggering mechanism in leachate generation. Williams and Wallace (1970) believe that the major source of groundwater contamination occurs when groundwater is in contact with refuse. Rain water percolating through refuse will produce leachate, but unless the refuse is below the water table, the amount of such leachate is minimal. Farvolden's (1973) studies indicate that the infiltration of rain water is far more important than groundwater in the generation of leachate. He further concludes that the relative importance of rain water compared with groundwater depends on, among other things, the geographic location, climate, and method of disposal.

The topography of a landfill site affects runoff and infiltration. Flat or low areas may result in ponding, and during a period of rainfall much of the water may be available for infiltration. In hilly areas runoff generally exceeds infiltration.

The composition of the sediment near the landfill affects rates of runoff, infiltration, leachate migration, and, to some extent, leachate attentuation. Fine-grained sediment generally retards the movement of liquids. In coarse-grained sediment infiltration can considerably exceed runoff, a condition that is undesirable in a landfill. If precipitation is the main cause of leachate production, the large amount of moisture available by infiltration through coarse-grained sediment will result in a large amount of leachate. The rate of groundwater movement, and therefore leachate migration, is a function of the grain size of the sediment. In fine-grained sediment, such as clay or silt, groundwater moves at rates of only inches a day or inches a year. In coarse-grained sediment, such as sand and gravel, water moves at rates that can exceed several feet a day, or faster.

Fine-grained materials have a great capacity for retaining dissolved solids in refuse leachate (Hughes, Landon, and Farvolden, 1971). Refuse leachate may also be attenuated by ion exchange with clay minerals. A common ion exchange that takes place is the exchange of calcium from groundwater for sodium from clay particles as the groundwater moves through sediment that contains considerable amounts of clay minerals. Studies have shown that such contaminants as ammonia, nitrogen, nitrate, and phosphate are substantially reduced as the groundwater containing them moves through fine-grained sediment (Williams and Wallace, 1970).

PHYSICAL SETTING

Physiography and Climate

Langdon is located in central Cavalier County in northeastern North Dakota (fig. 2). Nearly all of Cavalier County is an area of gently rolling to undulating topography. Elevations range from 1680 feet above sea level

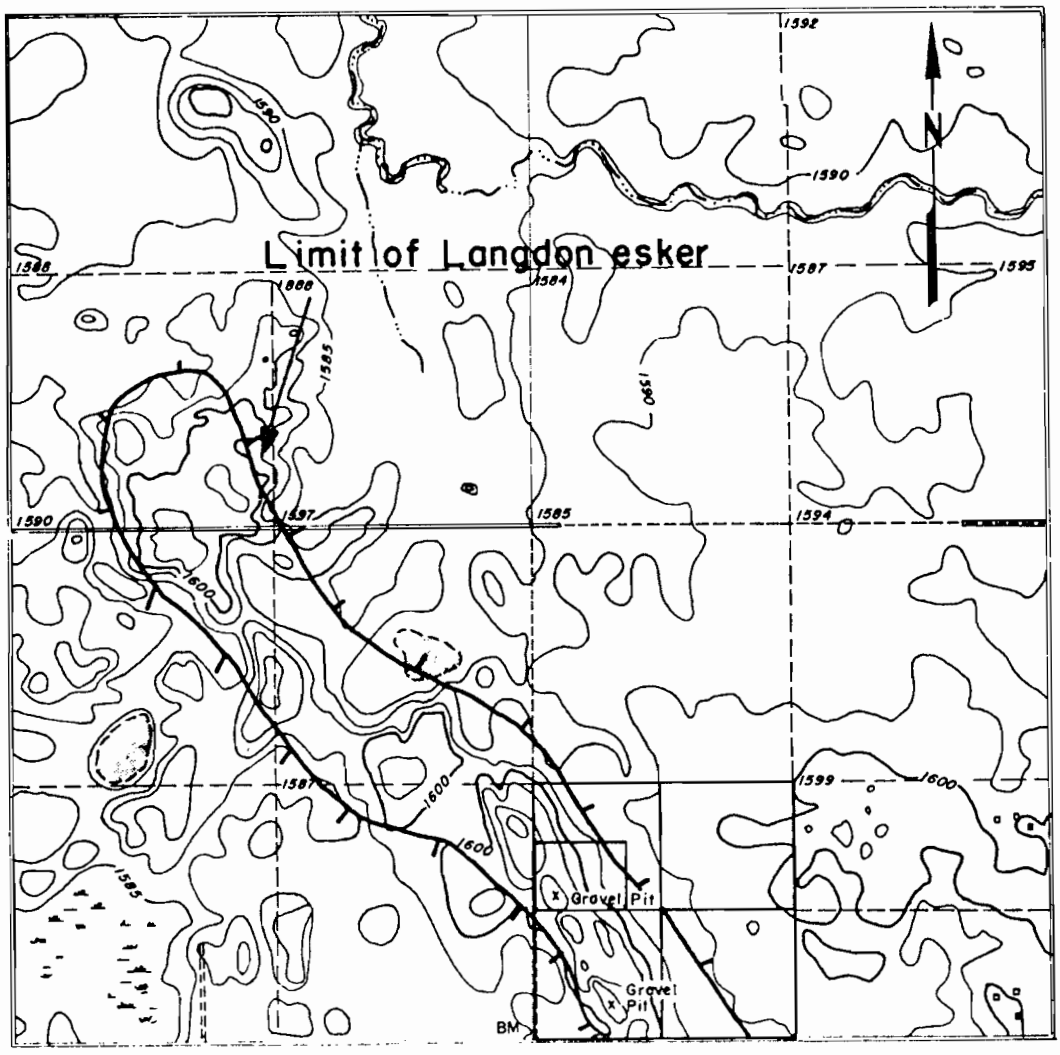


Figure 2. Surface topography in the Langdon area. The map shows the extent of the Langdon landfill.

south of Langdon to less than 1200 feet at the top of the Pembina Escarpment along the eastern edge of the county. Near the landfill, elevations range from 1615 feet to 1595 feet. Streams are uncommon; many are intermittent, flowing only after storms or during spring runoff. The topography in the Langdon area is a result of deposition of materials by the glaciers that traversed the area about 15,000 years ago.

Langdon lies within the dry, subhumid climatic zone. Average annual precipitation is about 19 inches per year (Jensen, 1974). Well over half that precipitation falls between April and August (Bavendick, 1952). The warmest months are July and August with a mean temperature of about 68 degrees Fahrenheit, and the coldest month is January with a mean temperature of about 2 degrees. About 60 days a year are 0 degrees or below. Freezing temperatures do not occur about 110 days a year (Jensen, 1974).

The Pierre Formation is dark gray to black marine shale that is about 300 feet thick in the Langdon area. The formation is comprised of four members. From bottom to top, they are the Pembina Member, Gregory Member,

DeGray Member, and the Odanah Member (Gill and Cobban, 1965). The two upper members, which make up more than half the total thickness of the formation, are predominantly hard, siliceous gray shale. The two lower members are mostly bentonite-rich, dark gray and black shale. Fractures are common in the upper part of the formation because of the siliceous nature of the shale.

The Coleharbor Group is largely till, which is a homogeneous mixture of clay, silt, sand, pebbles, cobbles, and boulders. The till is nonindurated to poorly indurated, exhibits jointing in outcrops, but has no other visible structure, such as bedding or sorting. In the Langdon area, till is the dominant surface material, but small amounts of clay, silt, sand, and gravel also occur (fig. 3).

Sediment consisting mostly of clay and silt, and of a younger age than Coleharbor sediment, occurs in depressions in the Langdon area.

Geology of the Langdon Landfill Site

The Langdon landfill is in an abandoned gravel pit in an esker (fig. 3). The esker is about 5 miles long, trends in a generally southeasterly direction, and is about 15 to 25 feet higher than the surrounding land surface. Sand and gravel, which is the surface sediment over the entire site, is from 2 to 30 feet thick. It is underlain by about 5 to 10 feet of till (fig. 4). Depth to bedrock ranges between 5 and 45 feet.

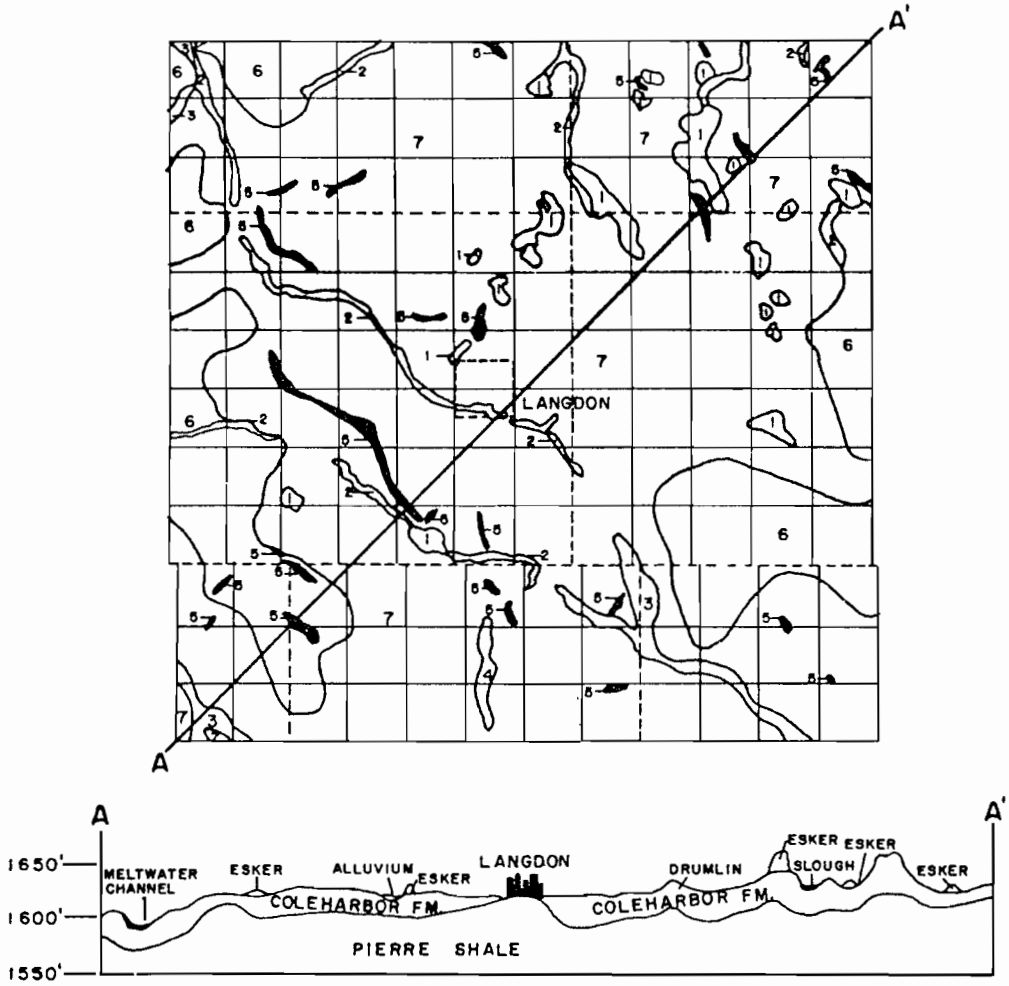
The sand and gravel is generally poorly sorted, but it does include some lenses of clean, well sorted, coarse sand. Clay lenses are also common. Shale fragments that range from clay size to cobble size comprise a large portion of the sediment. The underlying till is clayey and is rich in shale. The non-shale pebbles are predominantly limestone. The near-surface shale is weathered and, because the overlying till is so shale-rich, the contact between the two is difficult to determine from drill cuttings. Material other than shale that was found in the cutting samples was described as till. Cuttings containing nothing but angular shale fragments were identified as bedrock.

GROUNDWATER GEOLOGY

General

One purpose of this study was to determine the movement of groundwater through the Langdon landfill. The occurrence and movement of groundwater is probably the most important single factor affecting the use of the site for solid waste disposal. Groundwater not only helps to generate leachate, but it is also the agent by which leachate moves away from the landfill site.

Groundwater is that portion of the subsurface water which fully saturates the pore spaces of the rock and unconsolidated sediment and which behaves in response to gravitational force (Strahler and Strahler, 1973). Near the surface these pore spaces are filled with air. The water table is defined as the boundary between the unsaturated and saturated zone. The water table rarely has a flat profile; it is more commonly a subdued replica of the surface topography. Marshes and lakes that persist throughout the year occur where the water table intersects the land surface or is above it.



Map Unit

Walsh Formation	1.	Clay, black, highly organic, plastic. Occurs in undrained depressions and along intermittent streams. Pond, swamp, and slough deposits.
	2.	Clay, locally silty to sandy, sorted. The sediment, which is generally less than two feet thick, overlies pebbly loam. This is a modern stream deposit.
Coleharbor Formation	3.	Pebbly loam, clayey; locally clayey sand and gravel; this unit occurs as small, shallow valleys which were cut by water from the melting glacier. Modern intermittent streams occupy some of these valleys. Glacial till deposited in former meltwater channels.
	4.	Clay and silt, moderately well sorted black to brown layers. Surrounded by a raised rim of pebbly loam. This sediment was deposited in a pro-glacial pond.
	5.	Sand and gravel, stratified, poorly sorted, high shale content. This deposit, which occurs as a linear ridge (esker) or a scries of low mounds, may be overlain by several feet of pebbly loam.
	6.	Pebbly loam; lithologically similar to unit 3. Ridges and trenches are common. Local relief ranges from 20 to 30 feet. Depressions are very abundant, numbering between 20 and 30 per square mile. Drainage is non-integrated to poorly integrated. Glacial till deposited by glaciers.
	7.	Pebbly loam; chiefly a homogenous mixture of silt, clay, and sand containing abundant limestone, granite, dolomite, shale, and metamorphic boulders, cobbles, and pebbles. Lignite fragments are present in the sand function. The color of this pebbly loam ranges from yellowish-brown to olive gray. Local relief, which is commonly less than 15 feet, may exceed 40 feet. Ponds and sloughs are few to absent. Drainage is nonintegrated to poorly integrated. Glacial till deposited by glaciers.

Figure 3. Map showing the geology in the Langdon area. Generalized cross-section A-A' trends from southwest to northeast.

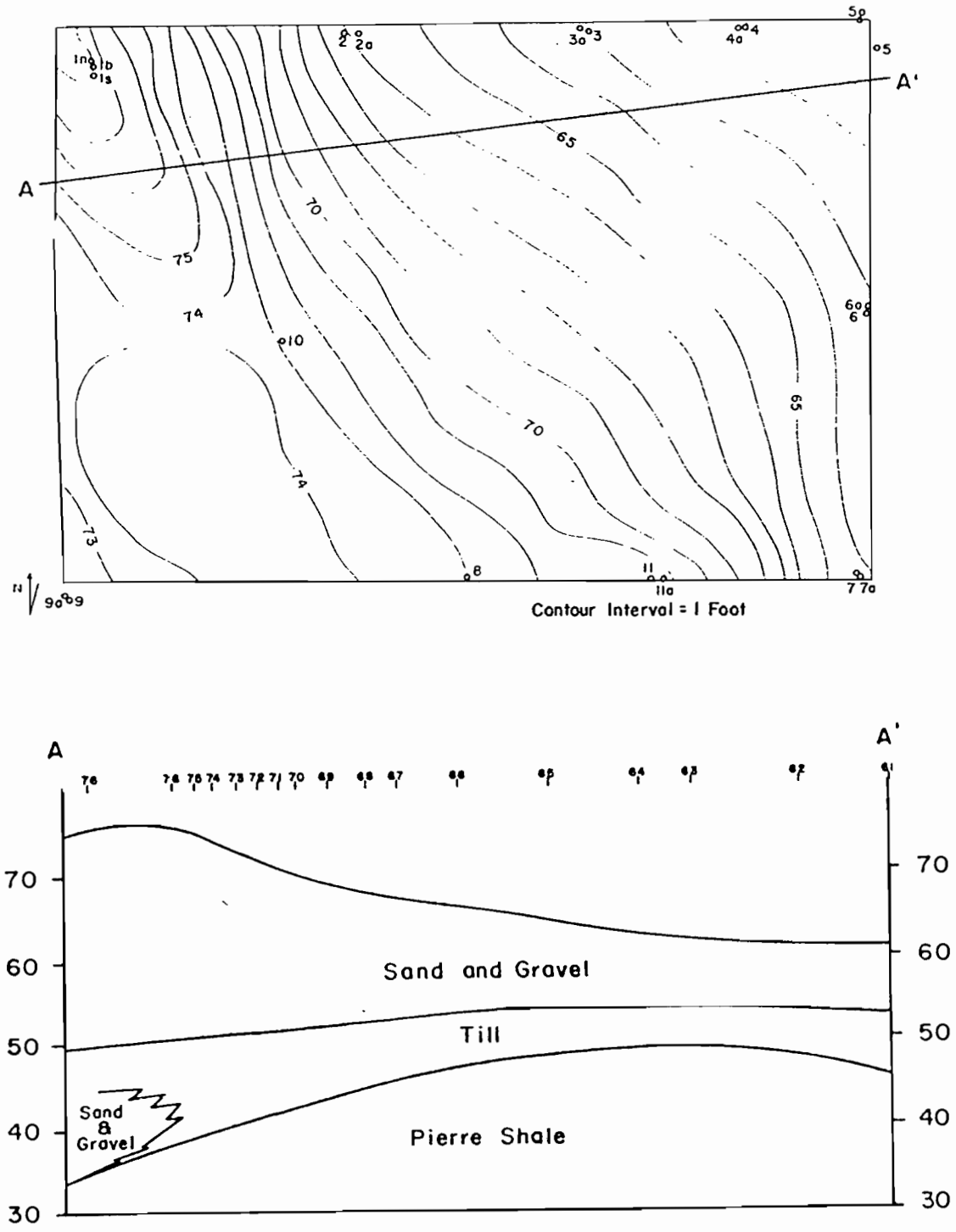


Figure 4. Surface topography and east-west cross section through the Langdon landfill. Surface elevations along the line of cross section are shown above the cross section.

The position of the water table is not stationary. It moves up or down depending on climatic or other conditions. The water table is substantially lowered during periods of extended drought, when no precipitation can infiltrate to recharge the groundwater system. Pumping from wells can also lower the water table, at least near the pumping well. However, once pumping has stopped, the water table will move back to its original position assuming pumping has not been excessive. During spring runoff and snow melt the position of the water table is higher than in late fall or winter when little or no surface water is recharging the system.

Groundwater flows in response to a difference in energy potential. That is, groundwater flows from a level of high energy to a level of lower energy. This potential at any point in the flow system can be described mathematically by the Bernoulli equation for a slowly moving fluid as:

$$\Phi = gZ + \frac{dP}{p}$$

where g is the acceleration due to gravity, Z is the height above sea level, P is pressure of the fluid, and p is density of the fluid. The Bernoulli equation also contains a function for velocity, but in groundwater this is so small it is negligible. The Bernoulli theorem assumes four conditions: (1) flow is along a streamline; (2) the fluid is incompressible; (3) fluid flow is frictionless; and (4) the system is in a steady state (Domenico, 1972). Condition (3) is true only for an ideal fluid; therefore, this relationship is not constant along a given flow line, but decreases in the direction of flow. The density (p) of groundwater can be considered constant, so the equation can be reduced to:

$$\phi = gZ \text{ or}$$
$$\phi = gh$$

where h is the elevation to which water rises in an observation well or piezometer inserted at some point in the system. Acceleration due to gravity (g) is also constant so the equation can be reduced to:

$$\phi = h$$

This means the potential energy at any point in the system can be determined simply by determining the elevation of the water level in a piezometer. Under water table conditions the energy potential between any two points in the system can be determined from the position of the water table. Movement of groundwater is from areas where the elevation of the water table is high to areas where the elevation of the water table is low. Areas in which groundwater flow is downward or away from the water table are referred to as recharge areas. Discharge areas are those in which groundwater flow is upward or toward the water table.

The rate at which groundwater moves through sediment is a function of the hydraulic gradient and porosity and permeability of the sediment. Hydraulic gradient is equivalent to the difference in energy potential along a flowpath, and it can also be determined by the slope of the water table. The steeper the slope of the water table, the greater the driving force for the movement of water. Porosity is defined as the ratio of the

volume of pore space to the total volume of a soil mass. Permeability depends on the size, number, and degree of interconnection of pores and cracks. In sand and gravel the pore spaces are large and relatively well connected so groundwater flows readily through this type of sediment. Clay and shale have a large amount of pore space, but the pores are very small and poorly interconnected, so groundwater moves slowly through this sediment. As mentioned before, groundwater can move at rates of several feet a day in gravel to less than one inch a day in clay.

Groundwater Flow at the Langdon Landfill

Twenty-one wells were installed at 11 sites at the Langdon landfill (fig. 5). These include 10 one-inch (inside diameter) piezometers and 11 four-inch (inside diameter) water-sampling wells. Of the four-inch wells, 10 are located around the perimeter of the landfill and one is located near the center of the site and completed in refuse. Each site, except sites 1 and 8, consists of a sampling well and a piezometer. Only a four-inch well is installed at site 8. Two piezometers and one four-inch well are located at site 1. Geologic descriptions of each well are included in Appendix A.

The multiple well installations were designed so that water sampling would not interfere with water-level measurements in the piezometers. It was thought that water-level recovery after sampling would not be sufficiently rapid to give meaningful water-level measurements for extended periods of time following sampling. In addition, small-diameter wells respond more rapidly to changes in groundwater level than do large-diameter wells. It was found, however, that the permeability of the sediment at the landfill site is great enough that the water-sampling wells recovered quickly from sampling disturbance and can be used as piezometers.

All the piezometers (both one-inch and four-inch) are below the zone of saturation and 18 of them are high enough in the flow system that the measured water levels can be treated as water table conditions (fig. 6). Figures 7 through 18 are contour maps of the water table at different times during 1974 and 1975. These data confirm the initial assumption that groundwater flow at the landfill site is generally from the topographic high along the western part of the site, northeastward toward the topographic low (fig. 19).

Water-level elevation in well 9A is consistently lower than in 9B. The same is true for wells 1S and 1N compared to 1B, although 1N is a special case. These 3 wells (1S, 1N, 9A) are all deeper in the flow system, and the lower water-level elevations indicate a downward flow component. Both sites 1 and 9 are at or near the crest of the esker, which appears to be coincident with a groundwater divide. Wells 9A and 1S intersect that part of the flow system in which the direction of flow is southwesterly. Again, groundwater flow coincides with the topographic setting, flowing from a topographic high to a topographic low. Appendix B shows periodic water levels.

Wells 9A and 1S, and possibly 1N, also indicate a flow component in a northerly direction (fig. 20). Well 9A has a consistently higher water-level elevation than 1S, indicating flow in that direction.

The June to September, 1974, water levels indicate a steeper water table gradient than during June to September, 1975 (figs. 7, 8, 9, 11, 12, 13, 14). The possible reasons for this occurrence are: (1) change in precipitation and (2) change in infiltration due to refuse emplacement and compaction.

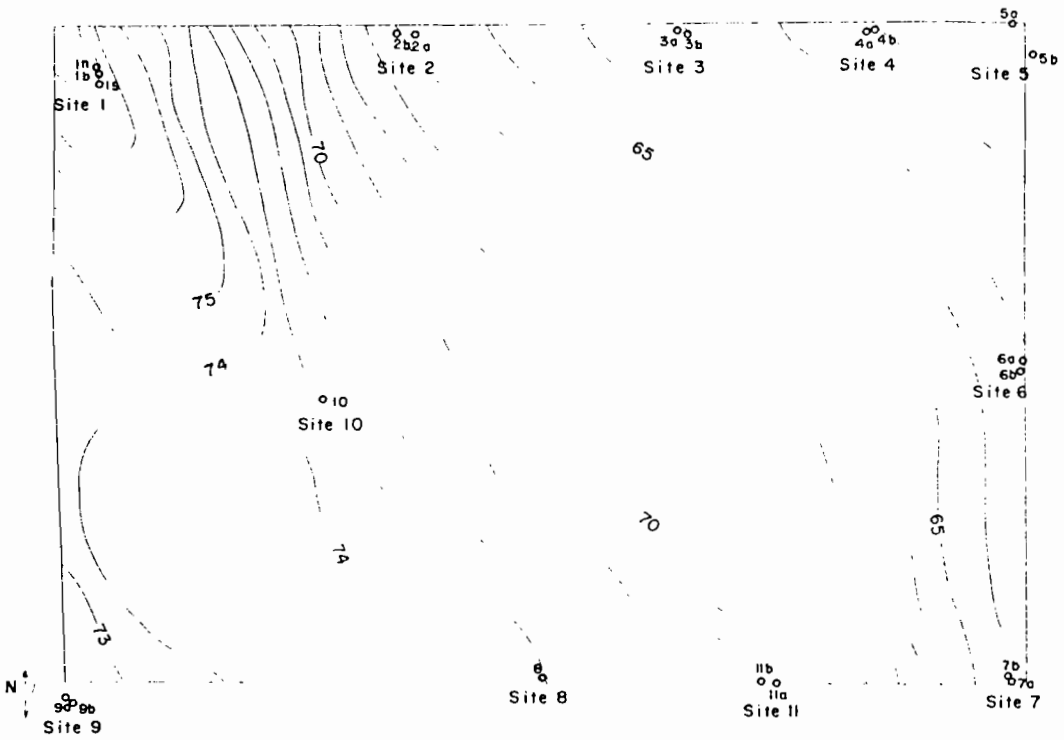


Figure 5. Location of well sites at the Langdon landfill.

Precipitation records for the preceding months of April and May for both years show a substantial difference in precipitation, which in turn affects the amount of water available for infiltration (pl. 1). The two-month precipitation total in 1974 was 8.41 inches, which is 4.61 inches above the annual average for this time period (U.S. Dept. of Commerce, 1974). For the same two-month period in 1975, precipitation totaled only 2.88 inches, or about one inch less than average. Although there is no quantitative data to support it, the snow cover in the Langdon landfill was observed to be much deeper in 1974 than in 1975. Even as late as April 1974 it was impossible to take water level measurements on some of the wells because they were buried in snow. As early as February in 1975 all wells were accessible. The substantially greater amounts of water available for infiltration in 1974 led to a general increase in water levels in the landfill area.

Refuse does affect infiltration capacity into a landfill site (Waldrip and Ruhe, 1974). The importance of this factor at the Langdon site is unknown. During the summer of 1974, only the western quarter of the landfill was used, that part near well 10. By the following summer, at least one layer of refuse, buried and compacted in several cells, had been deposited in over half and probably as much as three-fourths of the site. A second lift of refuse had been placed in part of the western half of the landfill. The action of burying and covering of refuse tends to (by compaction) decrease the permeability of both refuse and cover material. This general lowering of permeability tends to decrease infiltration capacity.

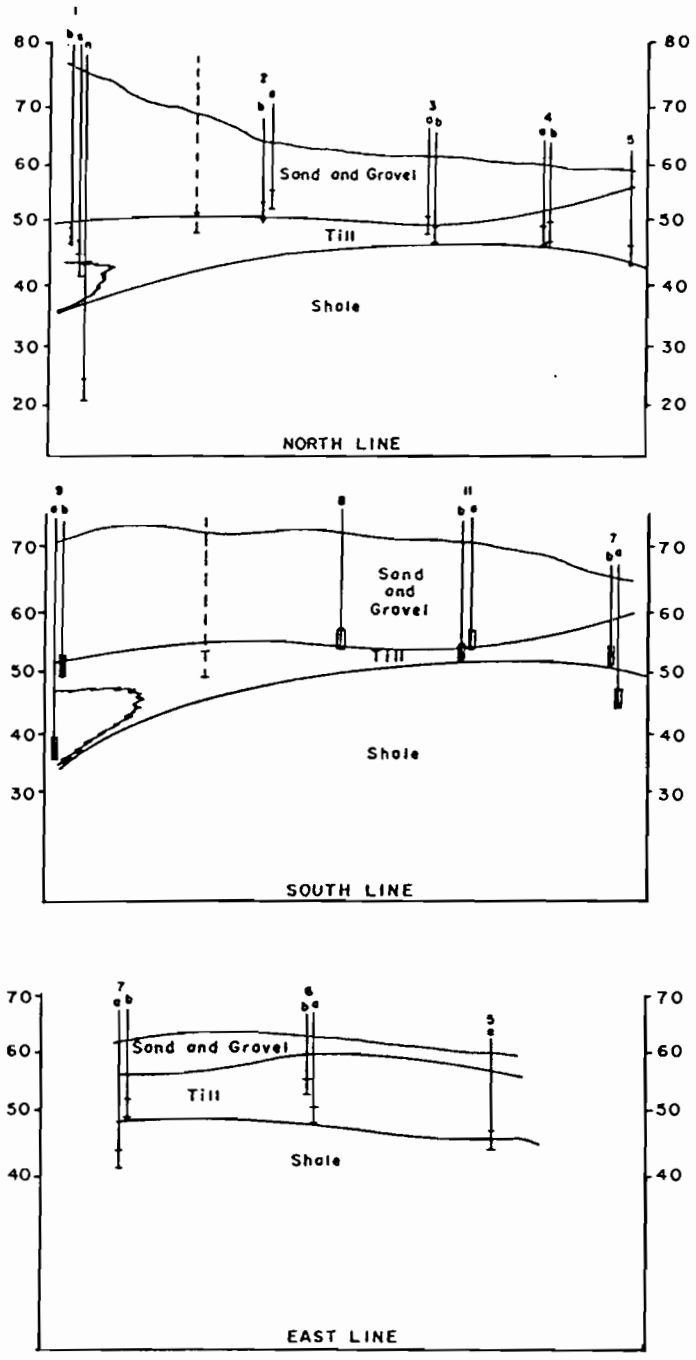


Figure 6. Cross sections of the landfill showing well installations and the units in which wells are completed. Uppermost cross section is along the north edge of the landfill; middle one is along the south edge; lower one is along the east edge.

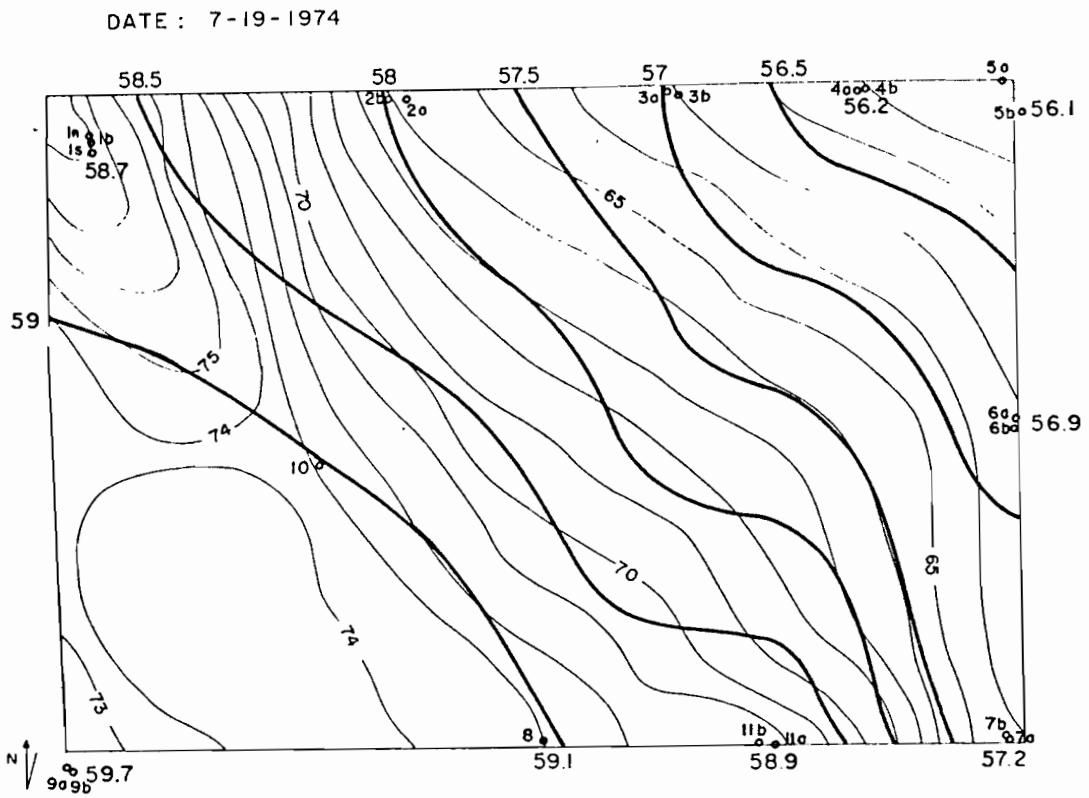


Figure 7. Configuration of the water table at the Langdon landfill on July 19, 1974.

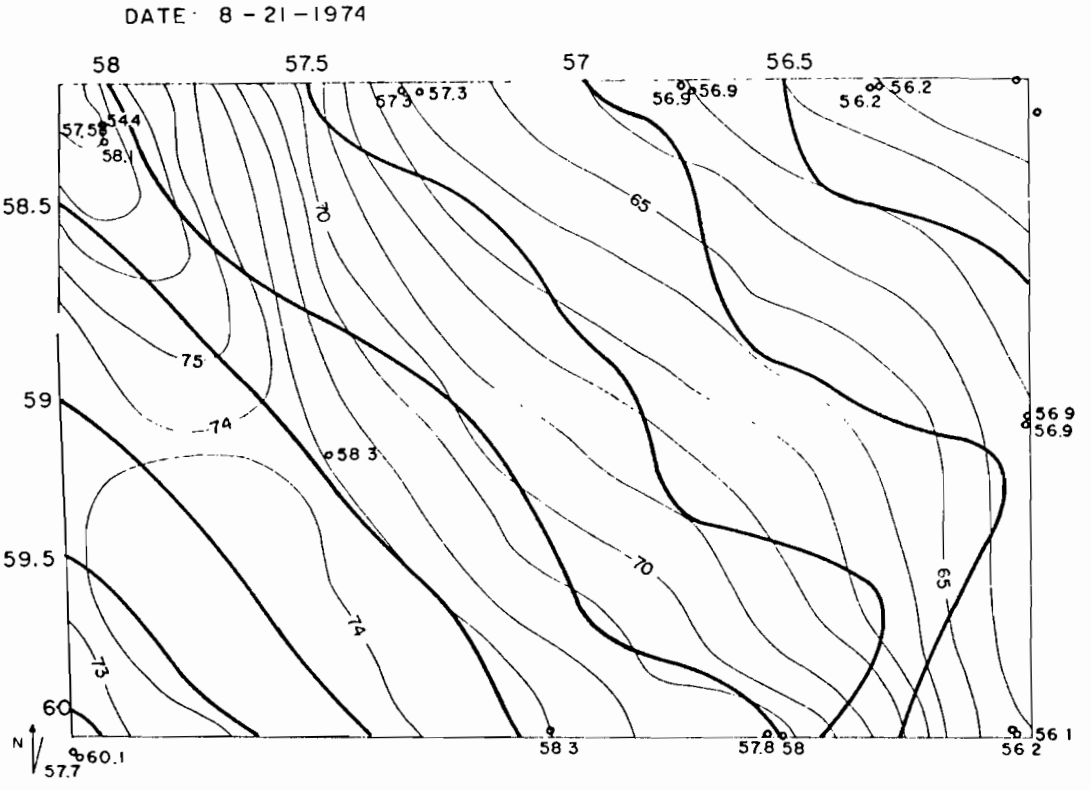


Figure 8. Configuration of the water table at the Langdon landfill on August 8, 1974.

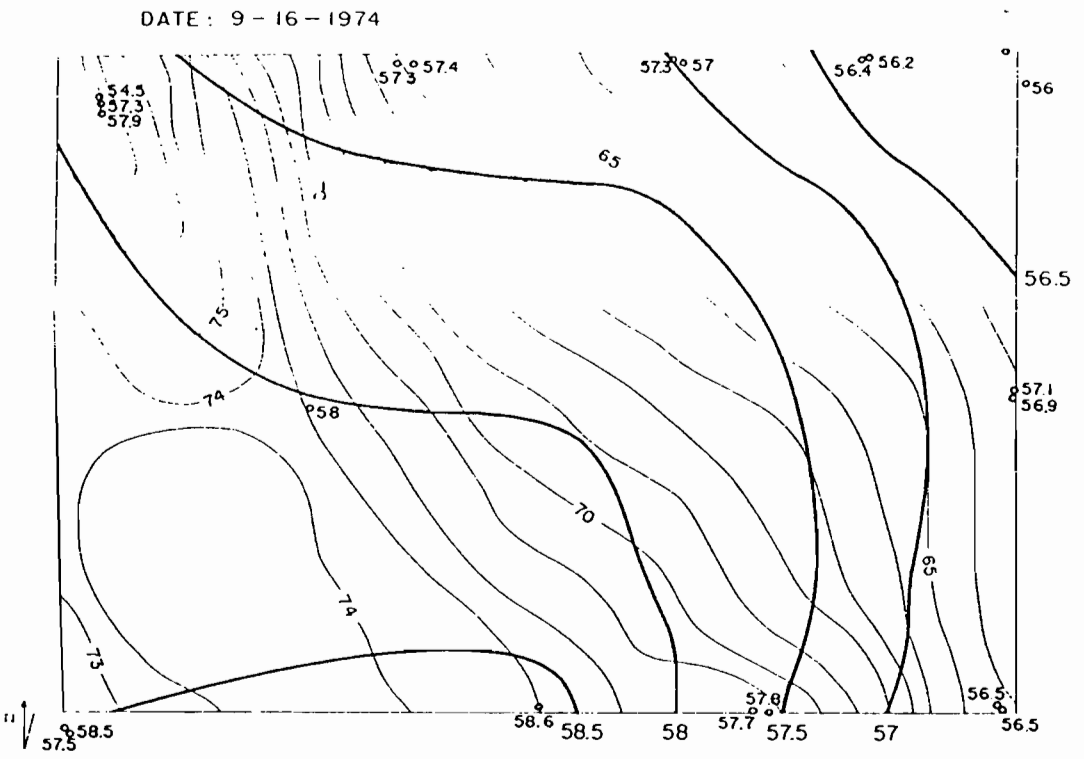


Figure 9. Configuration of the water table at the Langdon landfill on September 16, 1974.

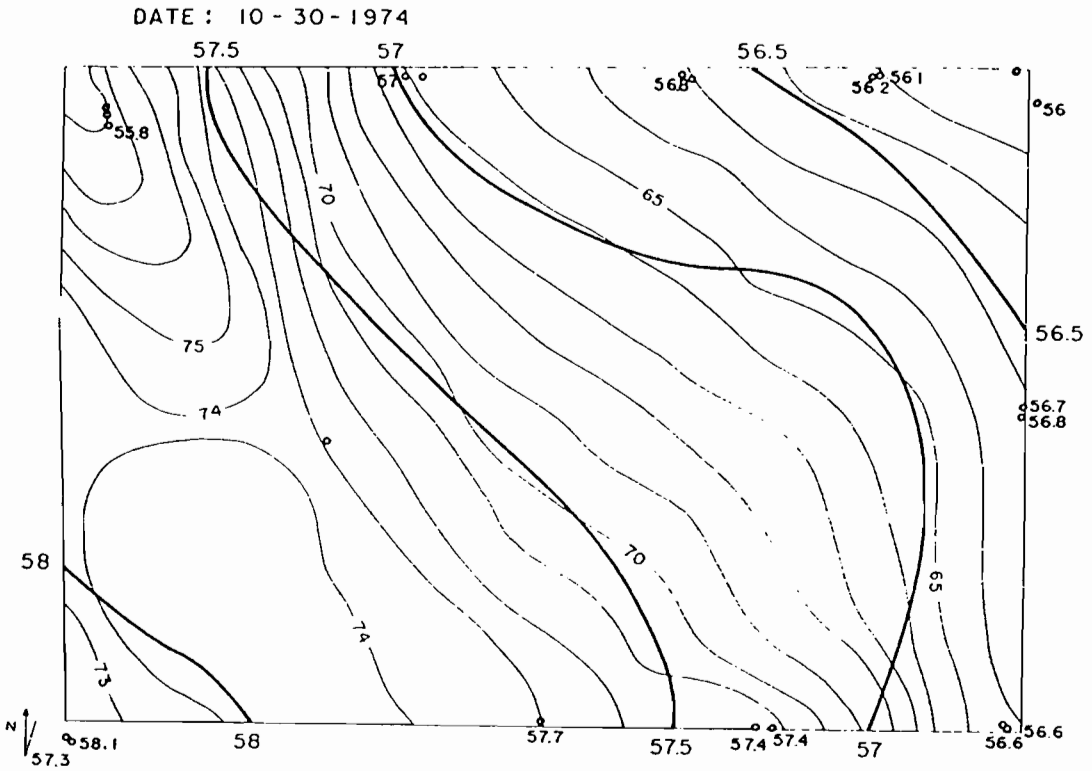


Figure 10. Configuration of the water table at the Langdon landfill on October 30, 1974.

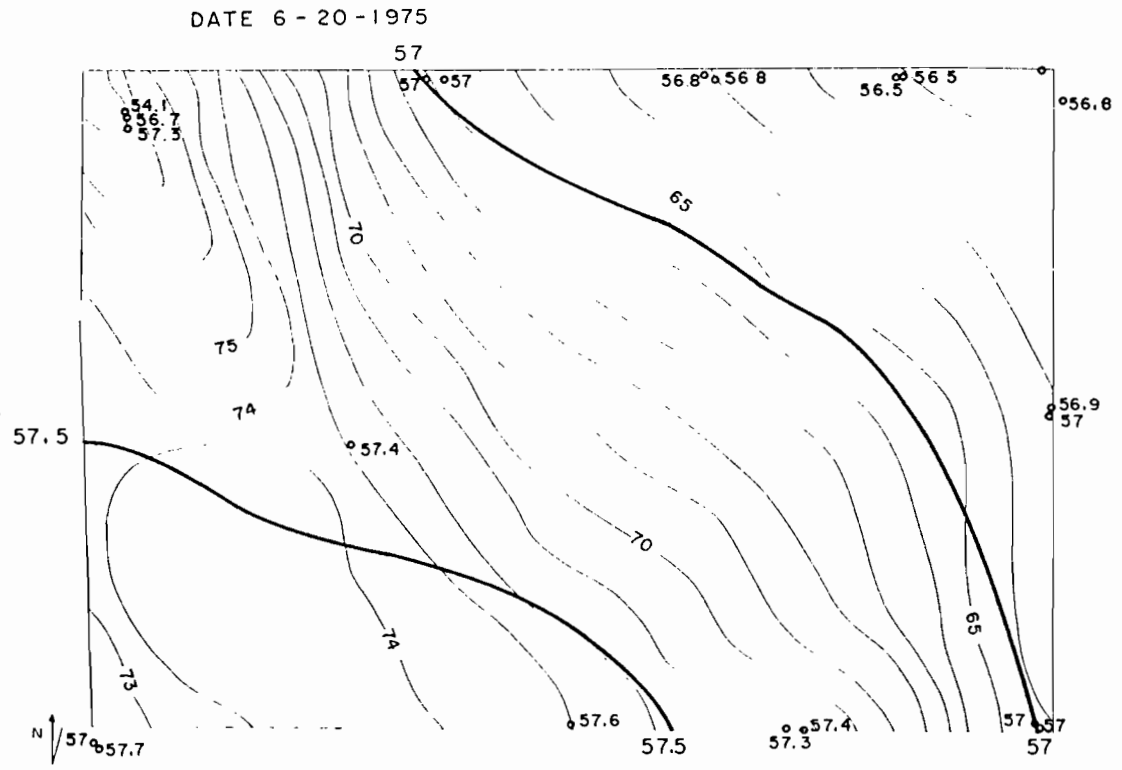


Figure 11. Configuration of the water table at the Langdon landfill on June 20, 1975.

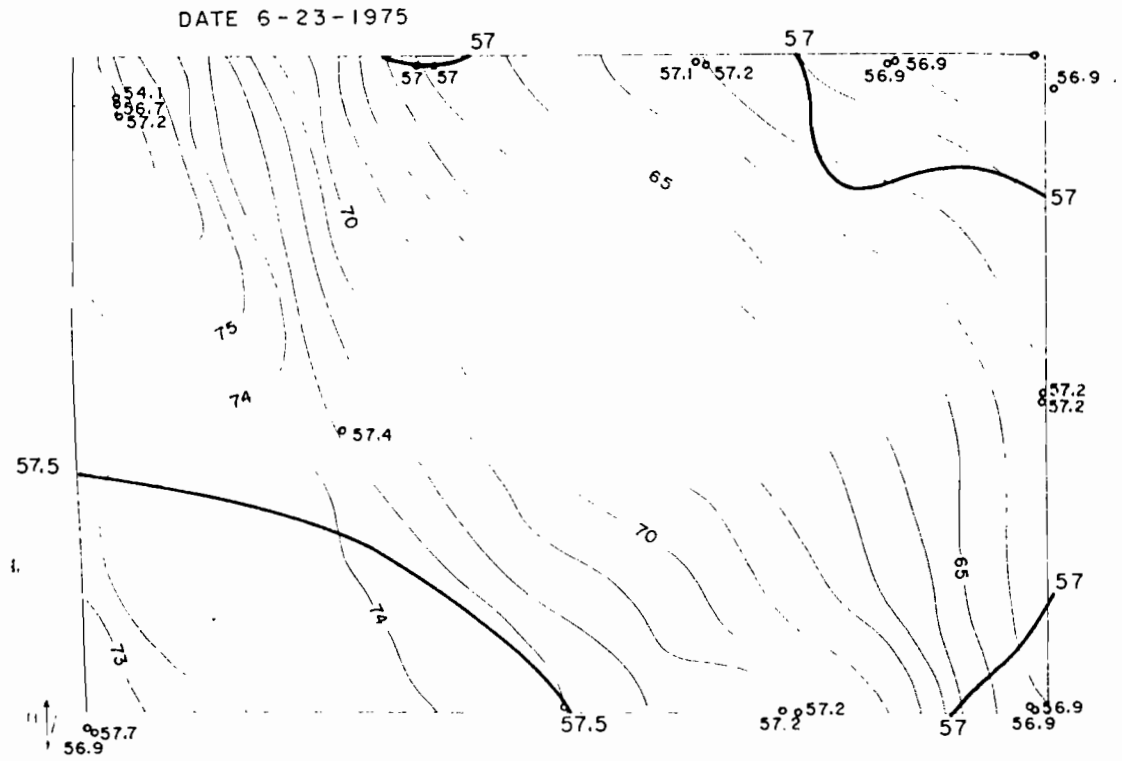


Figure 12. Configuration of the water table at the Langdon landfill on June 23, 1975.

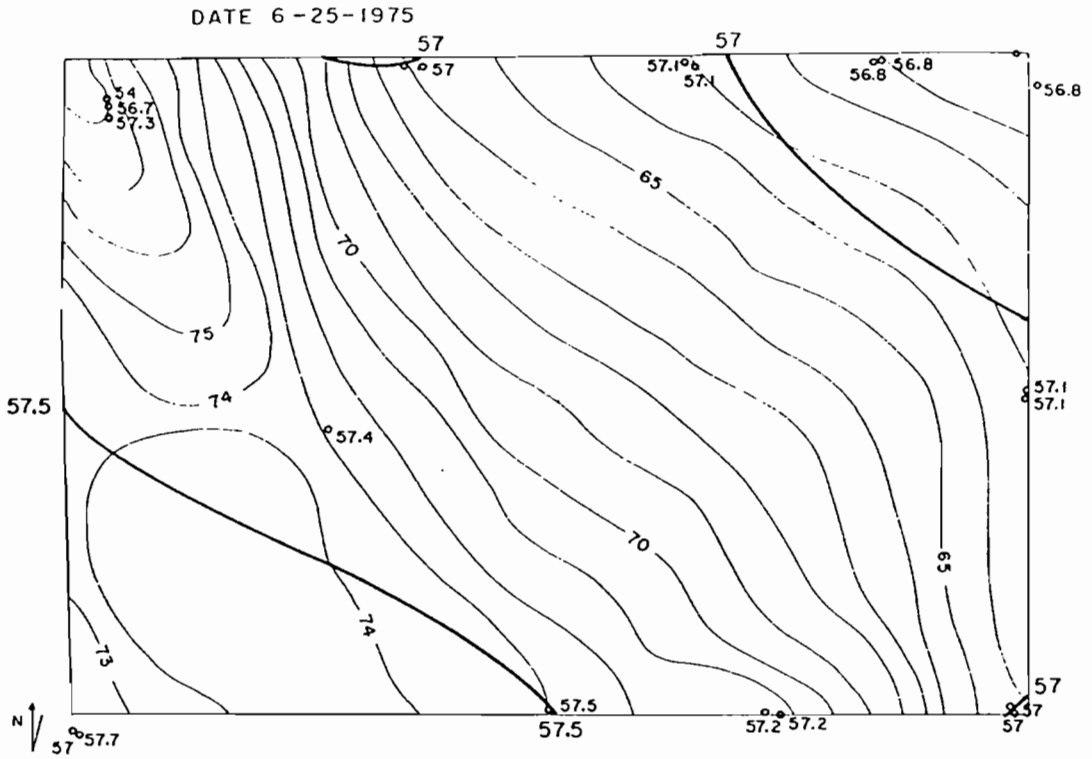


Figure 13. Configuration of the water table at the Langdon landfill on June 25, 1975.

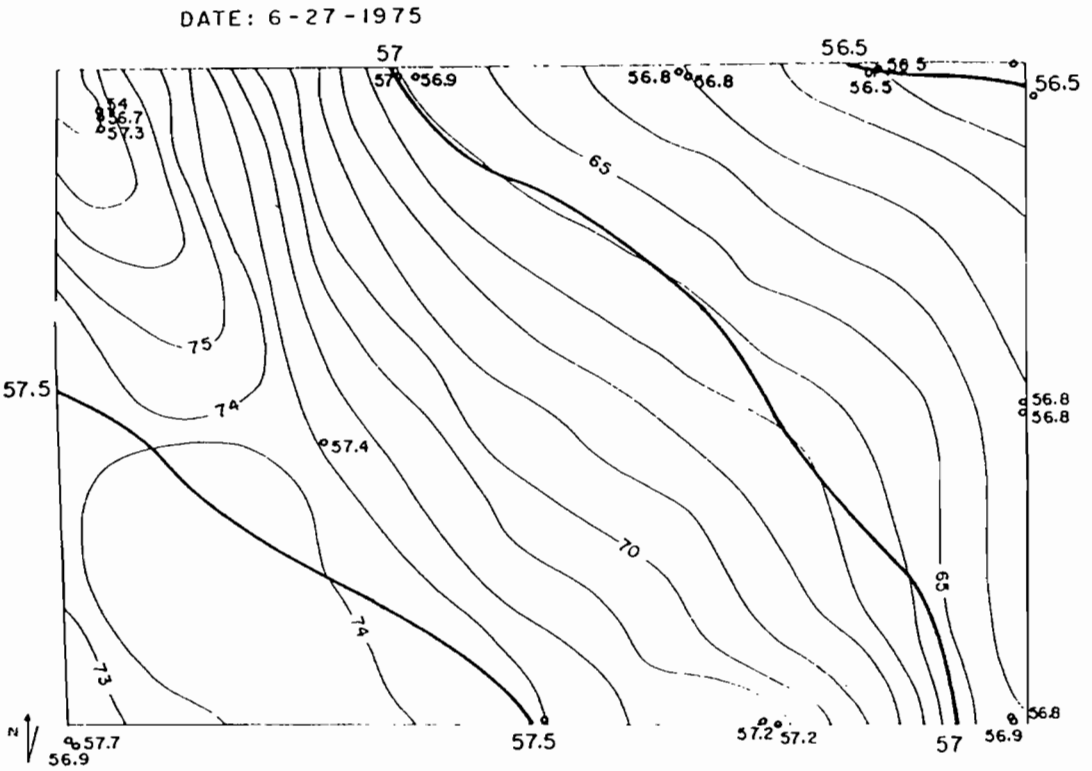


Figure 14. Configuration of the water table at the Langdon landfill on June 27, 1975.

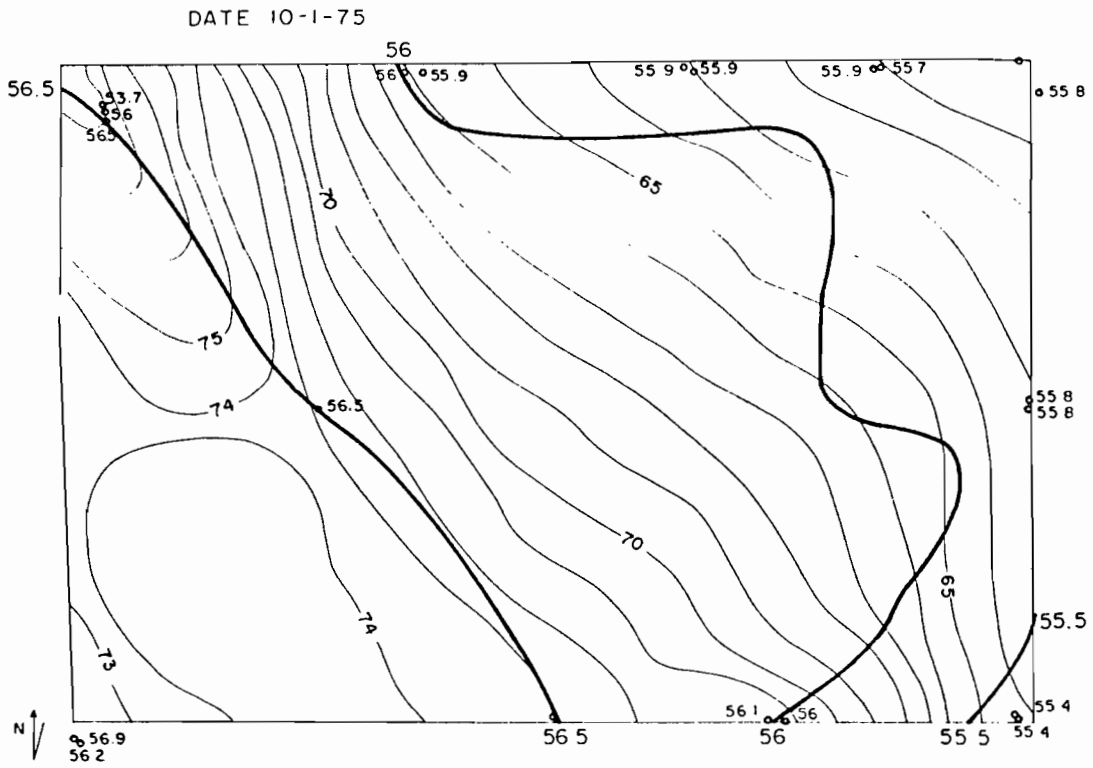


Figure 15. Configuration of the water table at the Langdon landfill on October 1, 1975.

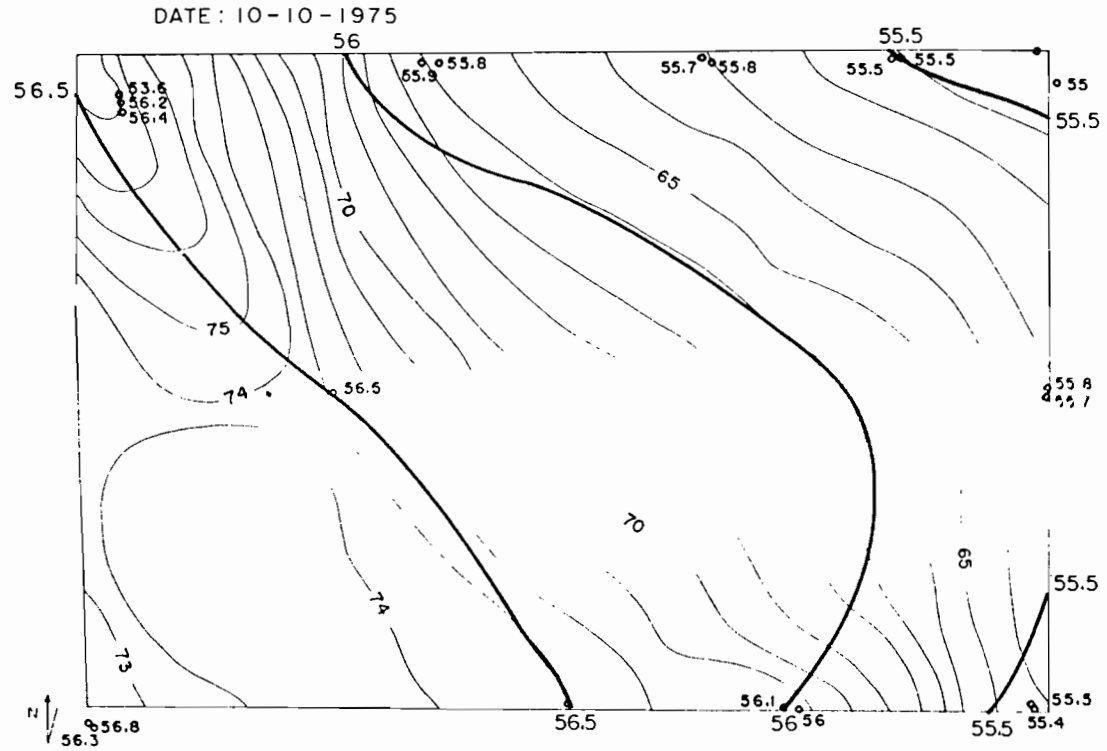


Figure 16. Configuration of the water table at the Langdon landfill on October 10, 1975.

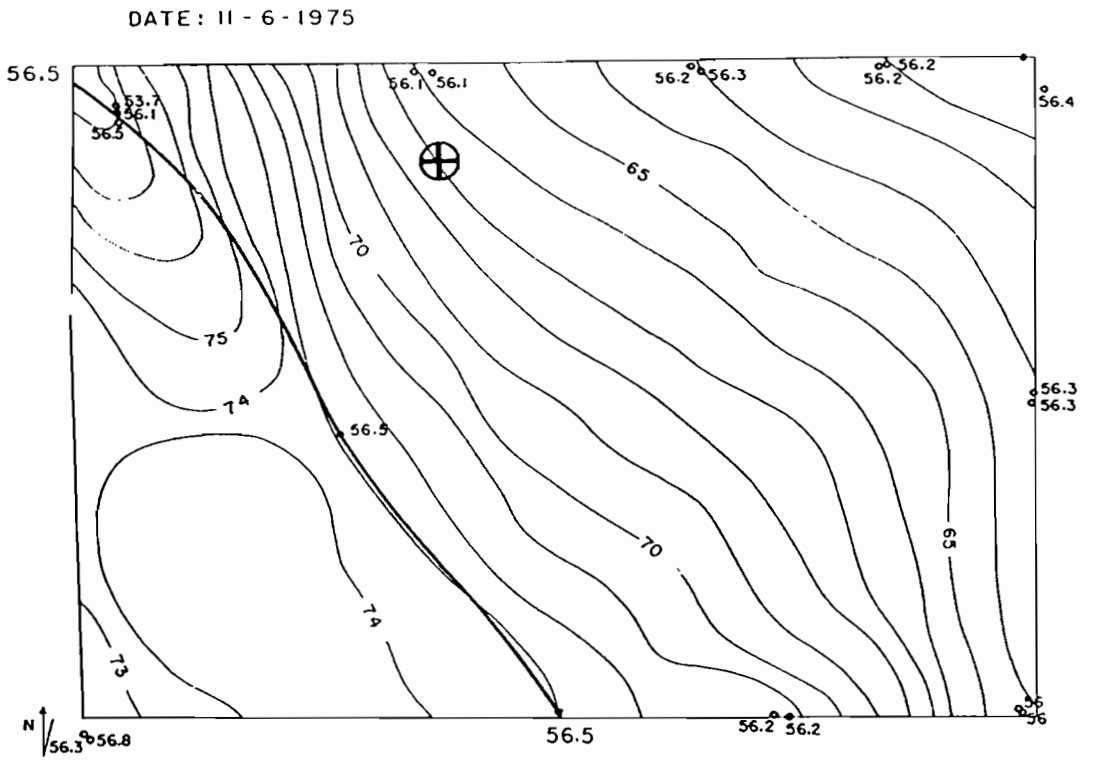


Figure 17. Configuration of the water table at the Langdon landfill on November 6, 1975.

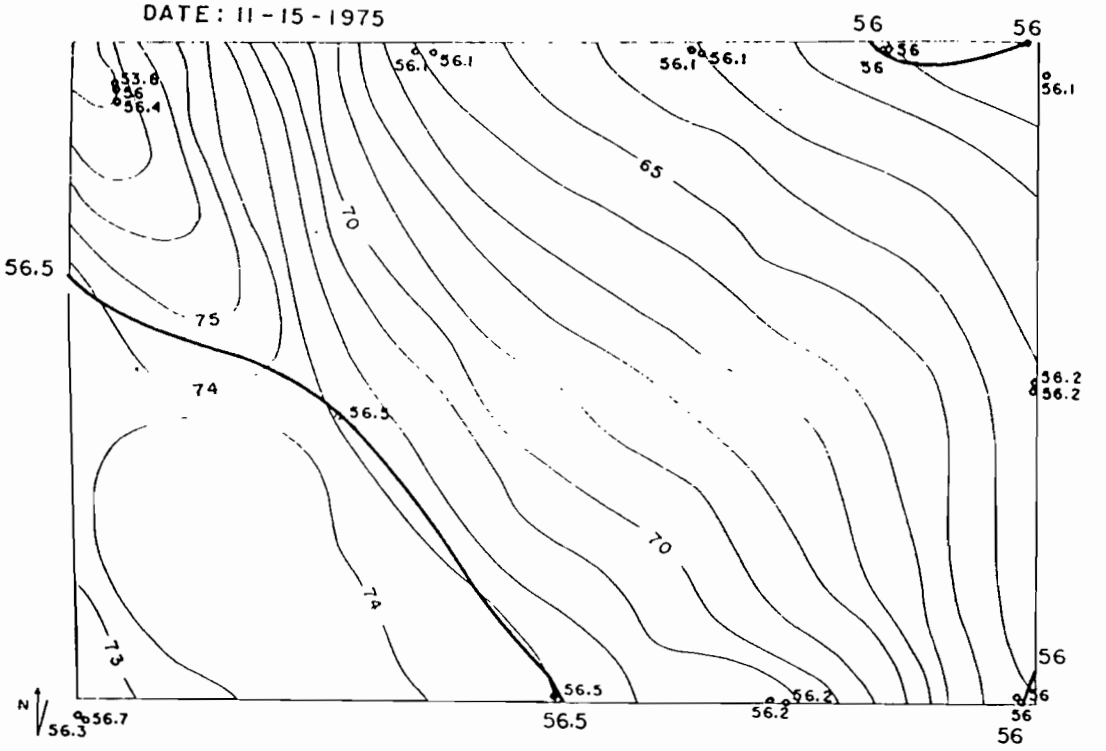


Figure 18. Configuration of the water table at the Langdon landfill on November 15, 1975.

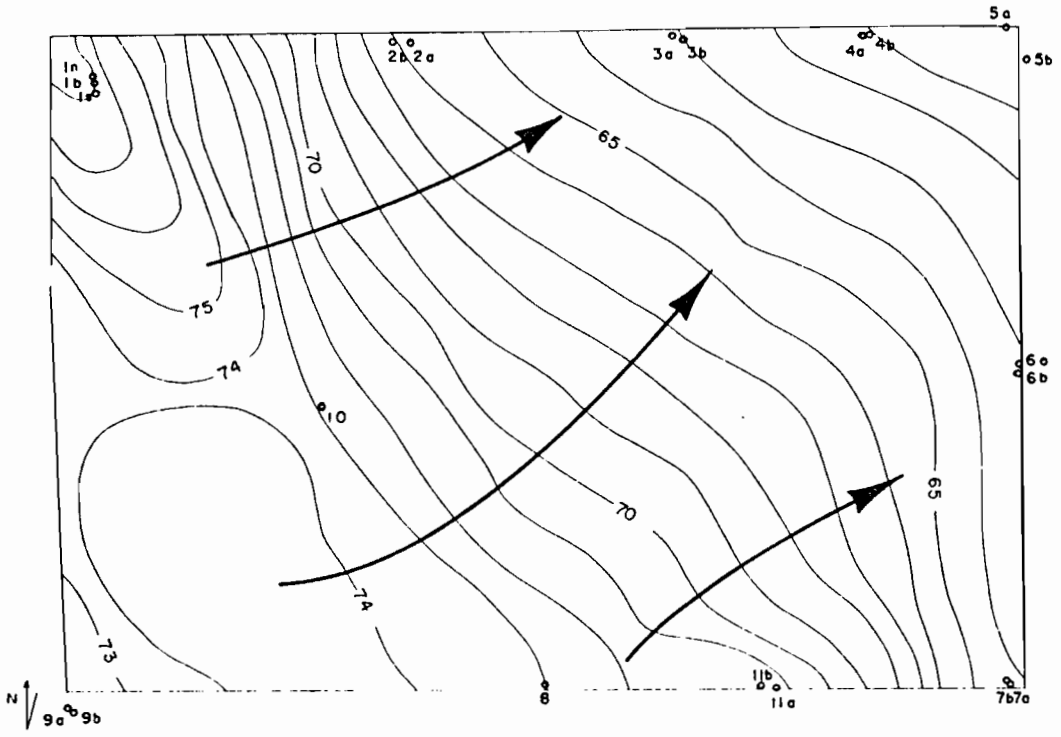


Figure 19. Major groundwater flow components at the Langdon landfill.

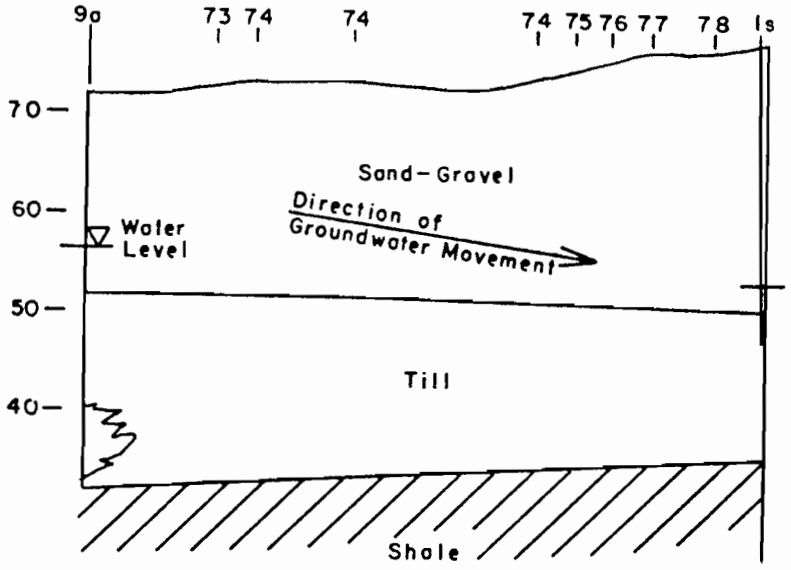


Figure 20. North-south cross section along the west side of the aquifer showing the northerly flow of the groundwater. North is to the right.

Nearly all the water entering the landfill moves through the sand and gravel deposits overlying the till. Most of the recharge occurs in the western part of the landfill site, which is the topographic high. The area immediately east and northeast of the landfill site is the discharge zone for this flow system. Wet conditions exist there for most of the year and the soil is somewhat saline. Both these conditions are indicative of an area of groundwater discharge.

The velocity of water moving through the Langdon landfill can be determined from a modified form of the Darcy Equation:

$$v = \frac{K}{n} i$$

where v equals the velocity, K is the hydraulic conductivity (permeability), n is porosity, and i is the hydraulic gradient. Hutchinson (1973) reports hydraulic conductivities of 5.4, 10.2, 16.7, and 18.7 feet per day for gravelly sediments similar to those that occur at the landfill. Poorly sorted sand and gravel, such as that which occurs at the Langdon landfill, has a porosity generally less than 30 percent. The hydraulic gradient varies as a function of amount of recharge and time of year (figs. 21 and 22). The hydraulic gradient for June, 1974 (fig. 21), was about 0.004. In June, 1975 (fig. 22), potential gradient was about 0.0007. Assuming a maximum porosity of 0.3 (30%), and the gradients determined above, and using different conductivity values, a range of average velocities can be determined.

n = .3	i	K(ft/day)	v(ft/day)
	0.004	5.4	0.07
	0.004	10.2	0.14
	0.004	16.7	0.22
	0.004	18.7	0.25
	0.0007	5.4	0.01
	0.0007	10.2	0.02
	0.0007	16.7	0.03
	0.0007	18.7	0.04

Table 1: Calculated velocities of groundwater through the Langdon landfill.

The range of velocity of groundwater moving through the landfill is between about 0.25 and 0.01 feet per day. In using a given permeability value it is assumed that the entire landfill has the same degree of uniformity as the part that has been analyzed. The sediment in the landfill is very poorly sorted and has uneven grain-size distribution. The higher permeability values used in the calculations were from repacked field samples analyzed in the laboratory. These values are generally higher than those which actually exist under field conditions. Therefore, the lower values are expected to be more representative than the higher values.

Well numbers 10 and 5 can be used for determining how fast any leachate that is produced moves through the landfill. Well number 10 is in the center of most of the refuse, and well number 5 is downgradient in the principal flow direction and near the discharge point of groundwater moving through the system. Under the worst-case conditions (steepest gradient and highest conductivity), a given volume of water

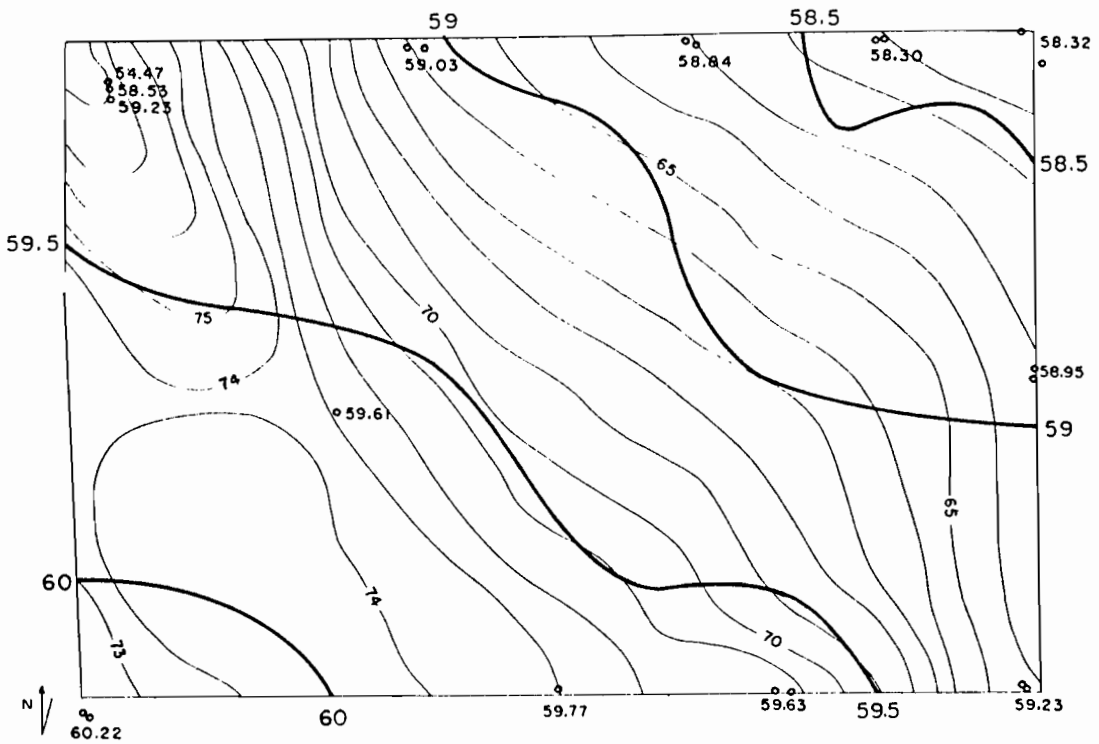


Figure 21. Configuration of the water table at the Langdon landfill during June, 1974.

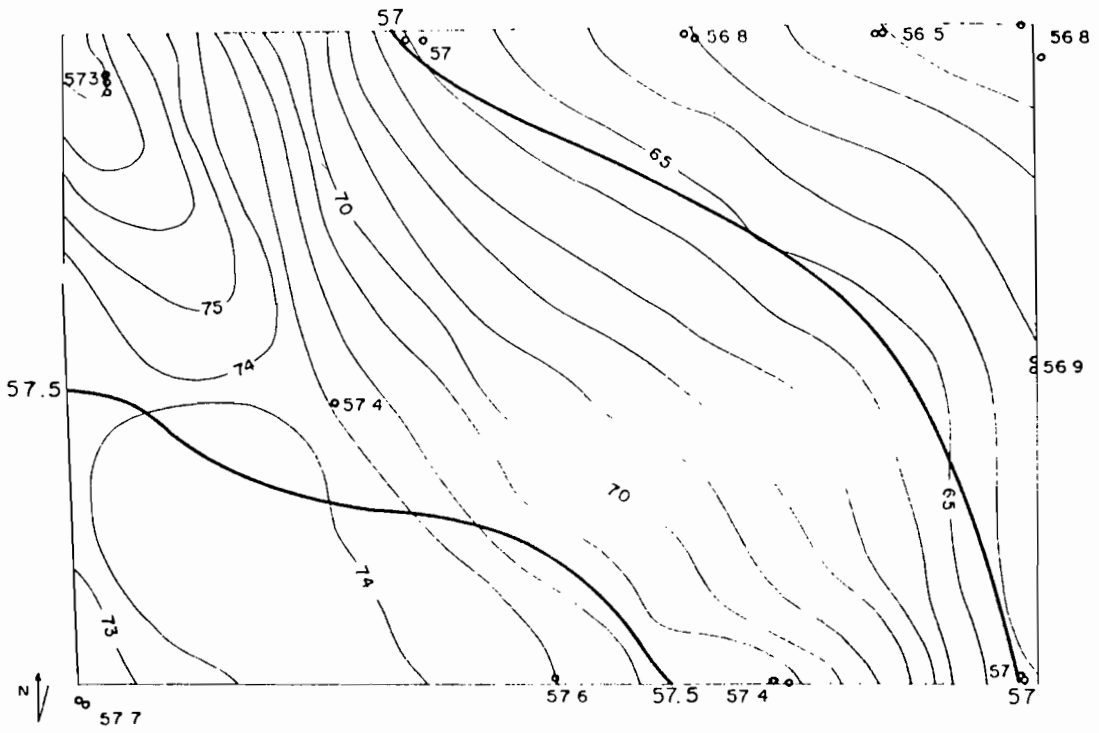


Figure 22. Configuration of the water table at the Langdon landfill during June, 1975.

flowing from well 10 to well 5 at a rate of 0.25 feet per day will reach well 5 in 3,120 days, or about 8 years. Assuming the best-case conditions (flattest gradient and lowest conductivity), that same volume of water will move from well 10 to well 5 in 78,000 days, or about 214 years.

Groundwater Quality

Groundwater Chemistry

Chemical analyses of groundwater can be used for interpreting groundwater flow. Analyses carried on at periodic intervals are used to detect changes in water quality and identify possible contamination problems. At the Langdon landfill, water from the large-diameter wells was analyzed. Some of these wells are upgradient from the refuse and some are downgradient, and well 10 is completed in the refuse. This distribution allows for the monitoring of water quality changes as water moves through the site. Not all changes in water quality, however, can be attributed to the presence of the refuse. Changes in water quality may only be due to normal changes that take place as water moves through natural materials. There is generally an increase in total mineralization of water that is roughly proportional to the length of its flow path (Chebotarev, 1955).

Analyses of groundwater from each well at the Langdon site is used to describe what type of groundwater flows through the site, what changes occur in the water quality as water moves through, and what effect the refuse has on water quality. The major ions analyzed in water samples from each well include magnesium, calcium, potassium, sodium, bicarbonate, nitrate, phosphate, sulfate, and chloride. Other determinations include specific electrical conductance, chemical oxygen demand, biological oxygen demand, total hardness, ammonia, pH, and temperature. Water samples for these analyses were collected at about one-month intervals from each of the large-diameter wells between October, 1973, and June, 1975 (Appendix C).

The water moving through the landfill site is classified primarily as either calcium-bicarbonate-sulfate type or magnesium-bicarbonate-sulfate type (fig. 23). Bicarbonate-sulfate type groundwater suggests a relatively short flow path (Chebotarev, 1955) such as movement from the topographic high on the western side of the landfill to the topographic low toward the east and northeast. These data support the piezometric data described in the section on groundwater flow. In some wells the dominant cation is calcium and in others it is sodium and potassium (fig. 23). The distribution appears random and suggests ion exchange by clay minerals. Whether sodium is exchanged for calcium, or vice versa, depends on the relative abundance of each ion in both the groundwater and in the clay mineral structures. If ion exchange were not taking place, then a somewhat uniform change in the direction of flow would be expected.

The piezometric data show that the major component of flow at the landfill site is to the northeast. Wells either upgradient from or outside the influence of the solid waste can be used to determine the quality of the groundwater before moving through the refuse. Wells 1 and 9 are upgradient from the refuse. Wells 7, 8, and 11 are located so that water moving through waste material flows away from these sites. Wells 2, 3, 4, 5, and 6 are downgradient from the refuse and may intercept groundwater that has flowed through the refuse (fig. 24). Well 10, located in the refuse, should give an indication of the chemical products that are being produced at the source.

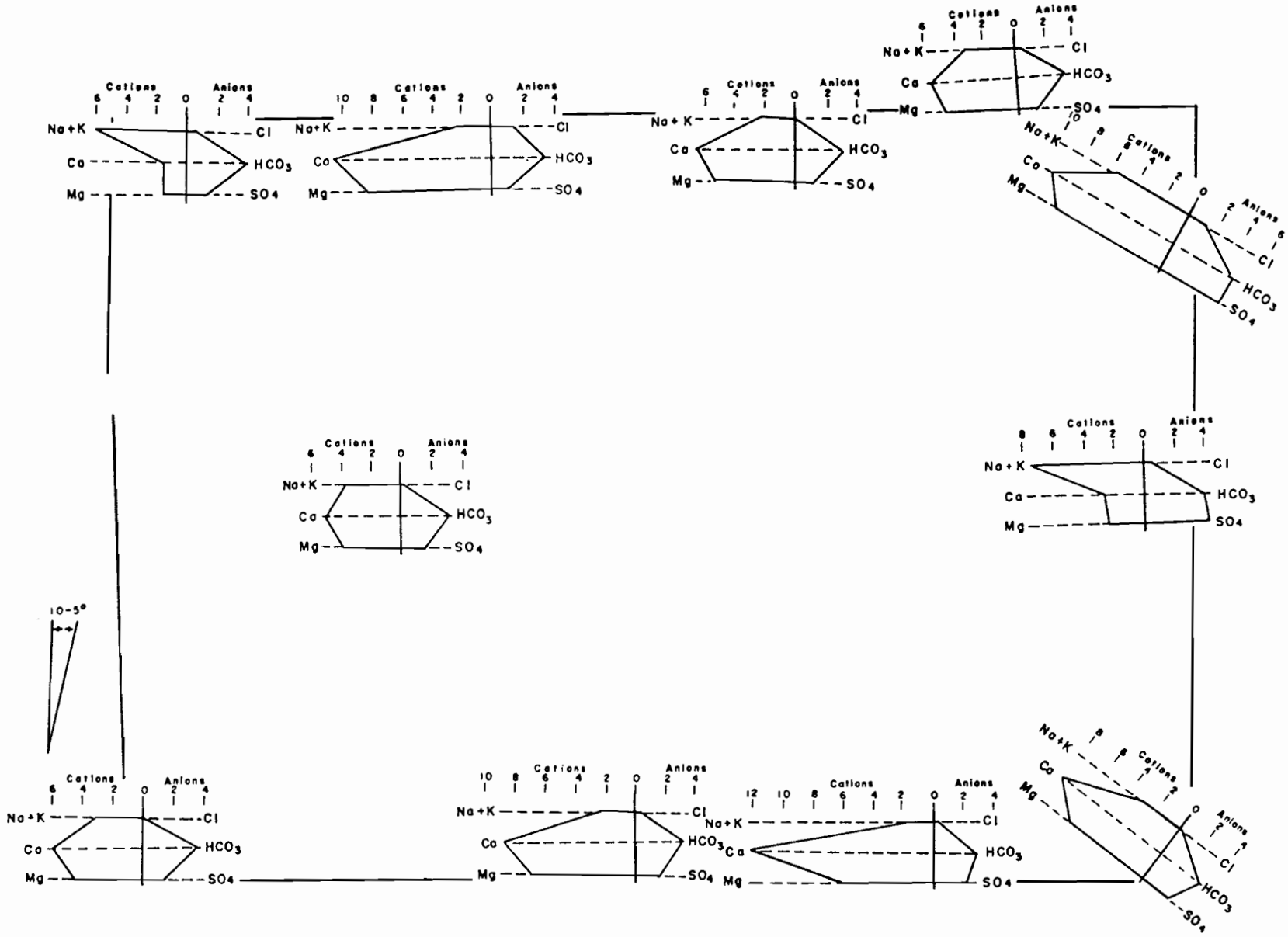


Figure 23. Map of the Langdon landfill showing relative concentrations of dominant ions in the groundwater at each of the testholes at the landfill. To the right of the axis on each Stiff diagram, major cations are compared; to the left, anions are compared. Concentrations are in equivalents per million, arrived at by dividing the atomic weights by the valence for each ion. Sodium and potassium are combined. The use of Stiff diagrams facilitates rapid comparison of analyses.

Figures 25 through 34 show the distribution of some of the ions in the groundwater at the Langdon landfill. The concentration of each ion is based on an average value for all analyses over the 18-month period at each well site. An analysis of the distribution of the various ions in the groundwater gives an indication of possible directions of sources for these ions. Generally, ions tend to increase in direction of flow. At the landfill the upgradient part has generally lower values than the downgradient or discharge part of the landfill. Some of the high values at some points do not necessarily mean that these points are downgradient in the flow path. These high values, particularly in the recharge area, may indicate a source for contamination.

The values of concentration of the various ions near well 10 show that the refuse does not significantly affect groundwater quality. If significant alteration were due to the presence of the refuse, generally high concentrations of most ions would be expected. Chloride, for example, is commonly used as an indicator for groundwater contamination. Solid waste products generally contain materials that yield relatively large amounts of chloride, and it is not readily attenuated during migration (Hughes, Landon, and Farvolden, 1973). Figure 30 shows what is probably a normal increase in chloride concentration in the direction of flow. The high chloride concentrations along the northern edge of the landfill might be due, in part, to the presence of the refuse. However, in the section dealing with groundwater flow, it was stated that the major flow component is toward well 5, in a northeasterly direction. Well 2 could be affected by this flow path, but not well 1. It seems reasonable, then, to attribute the high chlorides to a source other than the refuse.

The refuse may be contributing some ammonia and phosphate to the groundwater (figs. 29 and 33). However, both these ions have higher concentrations around parts of the perimeter of the landfill. These high concentrations, particularly along the southern edge, cannot be due to the refuse because they are upgradient from it. The high ammonia and phosphate concentrations along the northern edge could be due partially to flow through the refuse. However, the highest concentrations are only partially downgradient from well 10. It seems likely that the major sources of these ions are from something other than the refuse. The land surrounding the landfill is cropland that is fertilized during the growing season, and this fertilizer is the likely source for the ammonia and phosphate.

Most common fertilizers contain ammonia, phosphate, and nitrate. Nitrate concentrations are generally highest along the southern perimeter (fig. 34). In general, those wells closest to the surrounding field show the highest concentrations of these ions (table 2). These ions also show a seasonal fluctuation (pls. 2, 3), that is, an increase in the summer months, which is probably due to some fertilizer getting into the groundwater system. It should be pointed out, however, that even the highest nitrate level recorded at any one time (11 ppm, well 2), is still below Public Health Standards, which allow a maximum of 45 parts per million nitrate (table 3).

A temporary increase in nitrate occurred in some of the wells in the winter months of 1974-1975 (pl. 3). Chloride and phosphate, and to a certain extent, bicarbonate, magnesium, and calcium, also increased. It is unlikely that these increases are due to groundwater recharge. During the winter months the frost depth of about 3 to 5 feet substantially decreases near-surface permeability. The recharge would have to be either in the form of rain or melting snow; weather records

Well No.	Sp. Cond.	Mg	Ca	K	Na	HCO_3	NO_3	PO_4	SO_4	Cl	pH	COD	BOD	NH_3	Hard-ness
1	521	17	31	4.6	140	254	.15	6.1	55	27	7.9	21	5.7	.66	48
2	572	95	202	4.1	34	244	2.68	5.9	46	53	7.7	37	14.0	1.07	298
3	431	60	121	3.4	47	189	1.21	4.1	64	12	7.7	15	2.1	.15	181
4	481	55	104	3.4	74	198	1.70	6.7	79	12	7.5	12	4.7	.15	159
5	860	95	182	7.4	123	276	0.14	3.3	224	48	7.7	29	9.7	.86	277
6	725	30	55	6.8	168	231	1.49	5.8	197	14	7.7	14	3.1	.10	80
7	568	70	159	4.6	59	198	2.62	4.1	107	12	7.6	10	3.6	.11	229
8	521	81	169	5.5	45	197	3.79	4.5	93	13	7.8	36	6.6	.82	250
9	471	55	119	4.7	63	221	0.26	4.0	72	7	7.7	14	12.7	.73	174
10	474	42	95	5.0	78	201	0.24	6.2	80	13	7.7	20		.49	138
11	516	69	231	4.0	18	182	5.10	7.2	114	14	7.6	14		.38	300

Table 2. Average quality of groundwater from wells at the Langdon landfill.

Constituent	Upper Limit (ppm)
Lead	0.1
Fluoride	1.5
Arsenic	0.05
Selenium	0.05
Chromium	0.05
Copper	3.0
Iron and Manganese	0.3
Magnesium	125
Zinc	15
Chloride	250
Sulfate	250
Phenol	0.001
Total dissolved solids	1000
Nitrate	45

Table 3. Recommended U.S. Public Health Standards for drinking water.

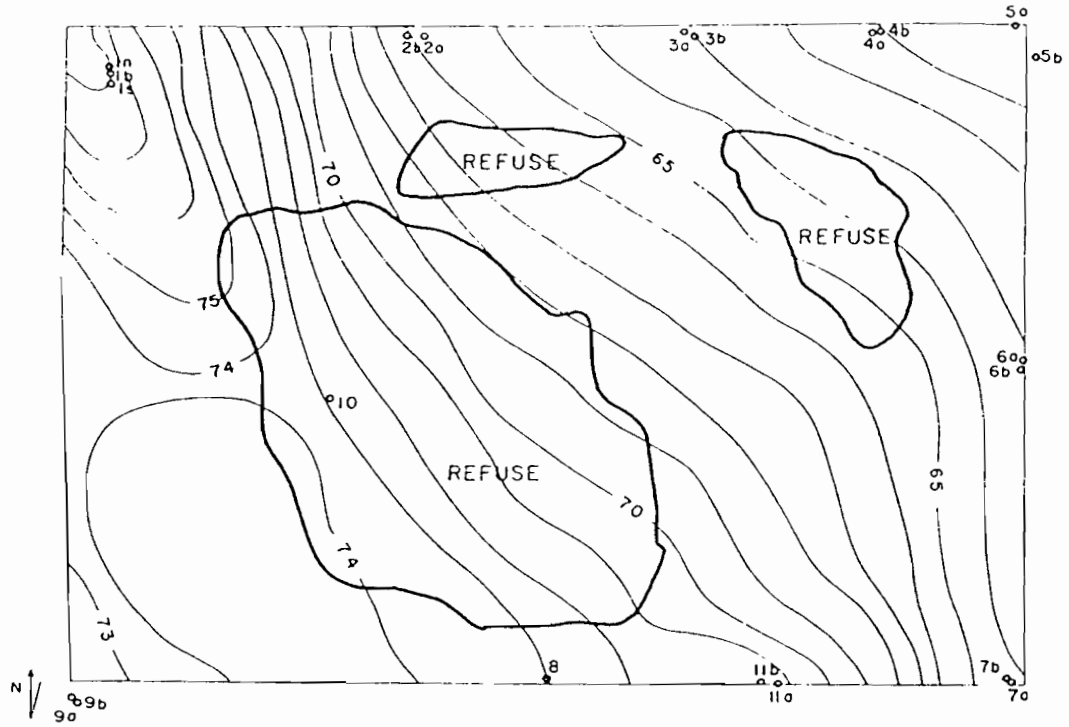


Figure 24. Distribution of wells in the landfill with reference to the placement of refuse.

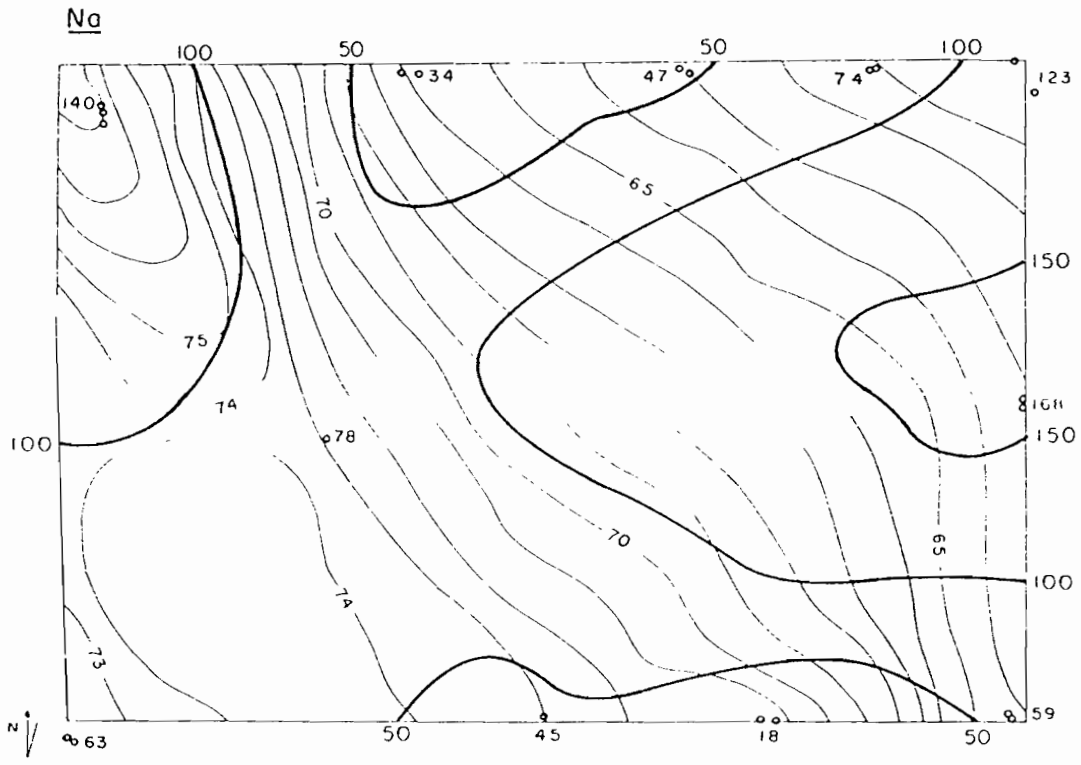


Figure 25. Concentration of sodium ion in the groundwater at the Langdon landfill in parts per million.

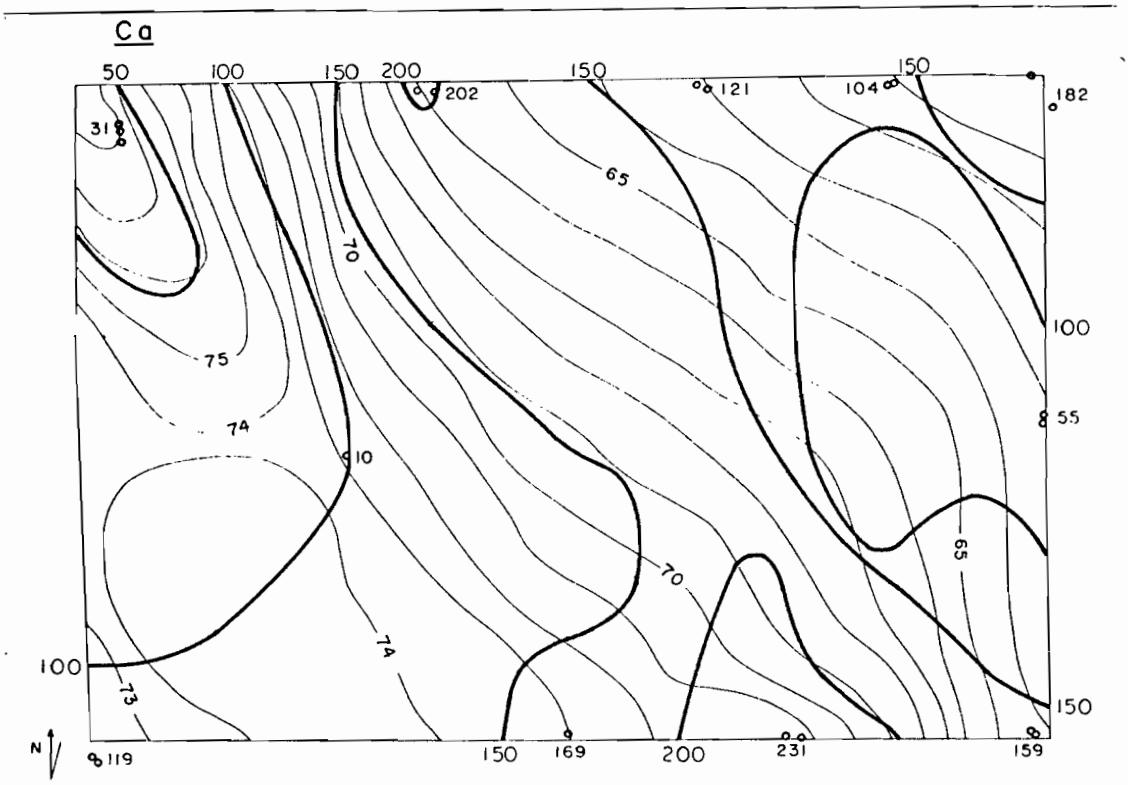


Figure 26. Concentration of calcium ion in the groundwater at the Langdon landfill in parts per million.

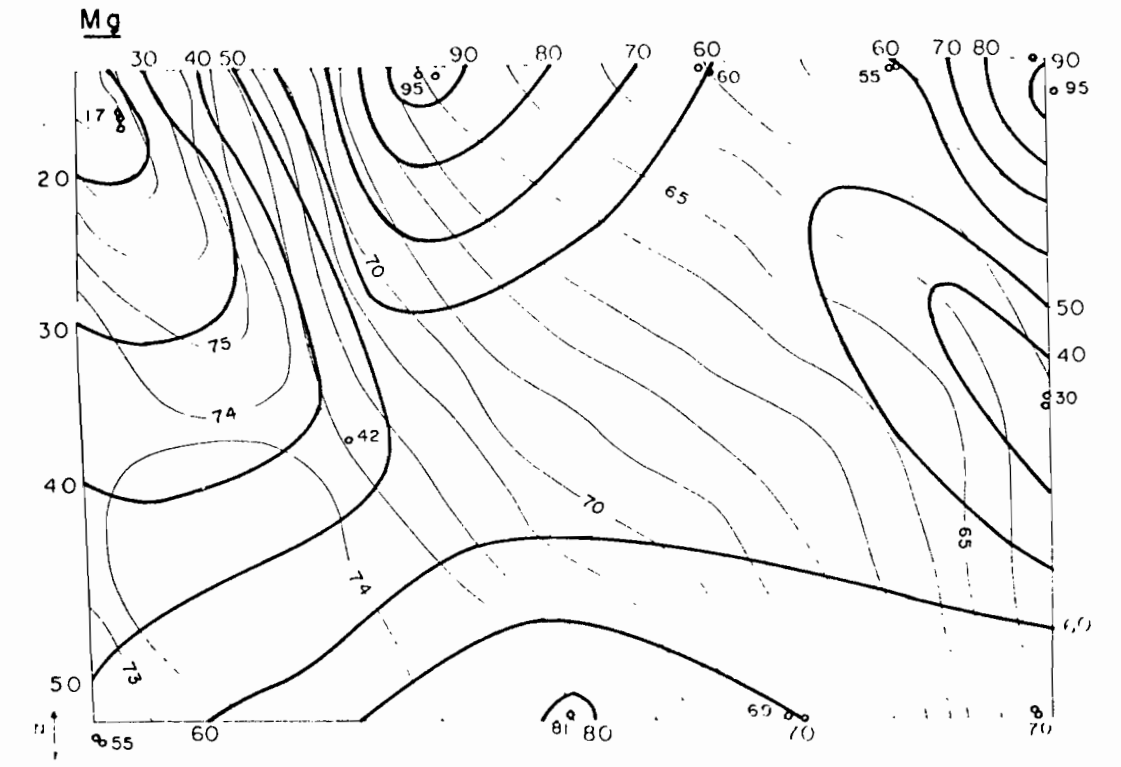


Figure 27. Concentration of magnesium ion in the groundwater at the Langdon landfill in parts per million.

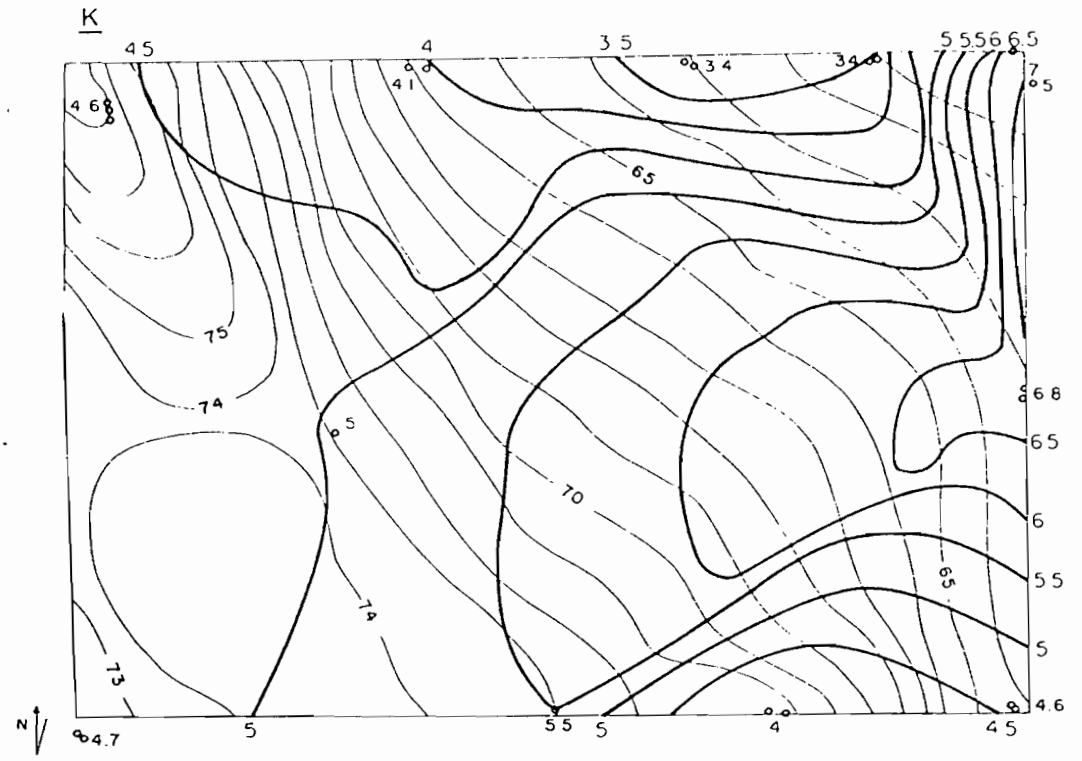


Figure 28. Concentration of potassium ion in the groundwater at the Langdon landfill in parts per million.

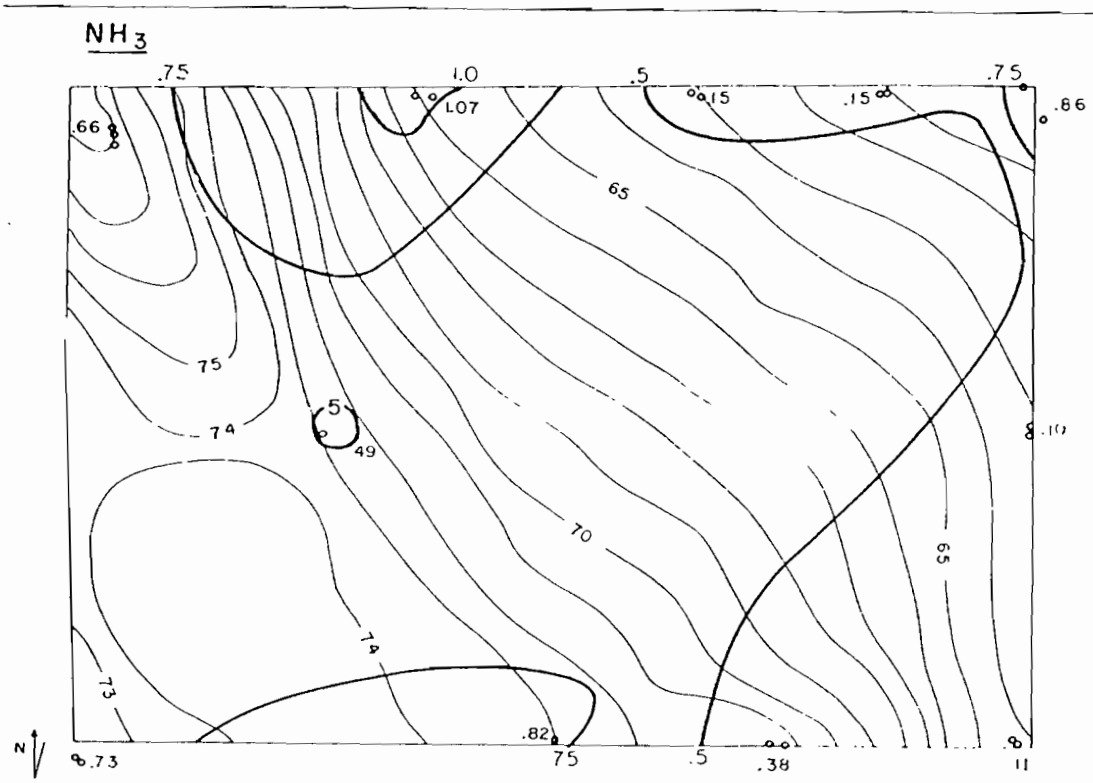


Figure 29. Concentration of ammonia ion in the groundwater at the Langdon landfill in parts per million.

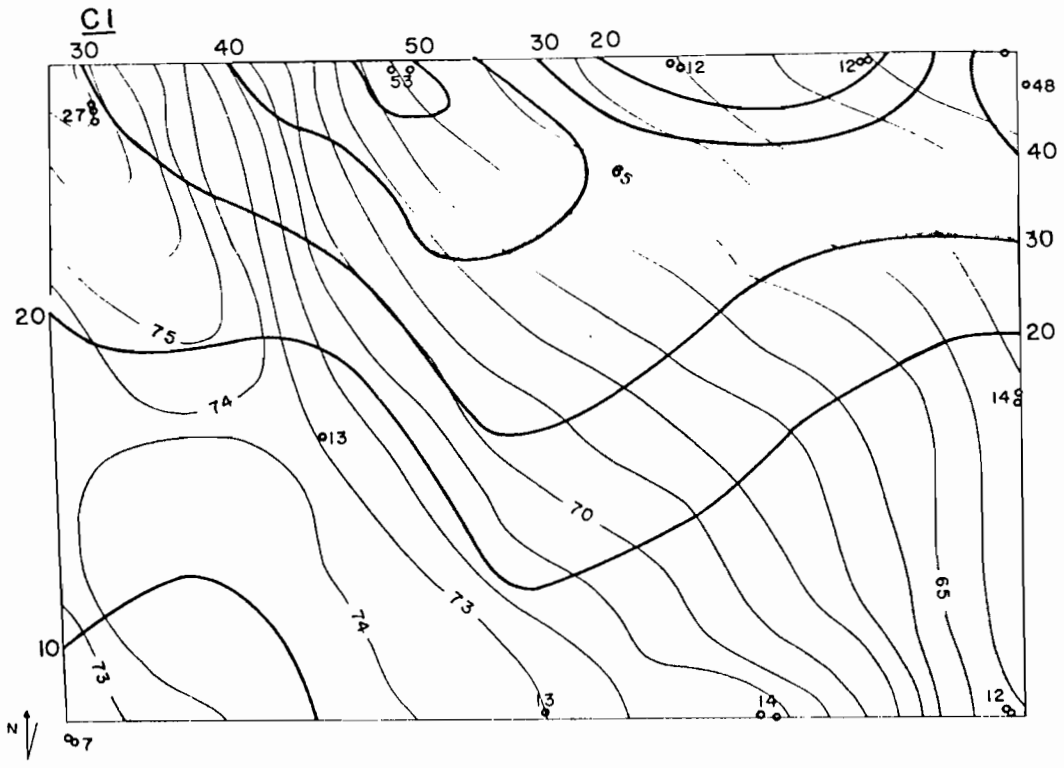


Figure 30. Concentration of chloride ion in the groundwater at the Langdon landfill in parts per million.

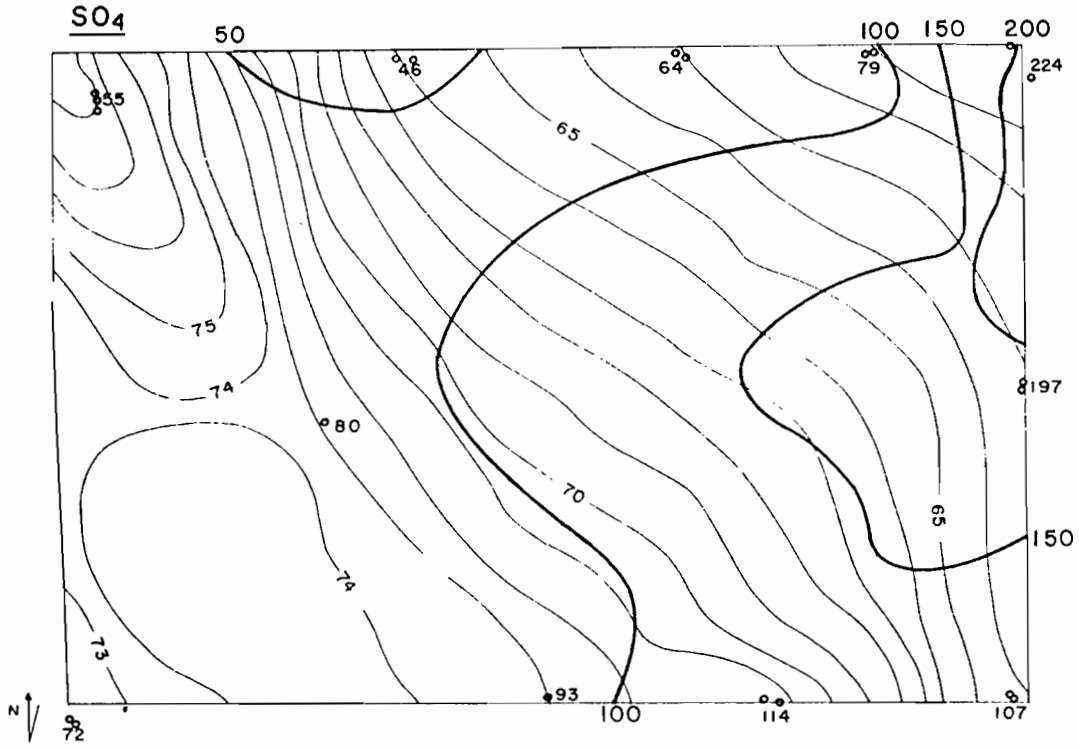


Figure 31. Concentration of sulfate ion in the groundwater at the Langdon landfill in parts per million.

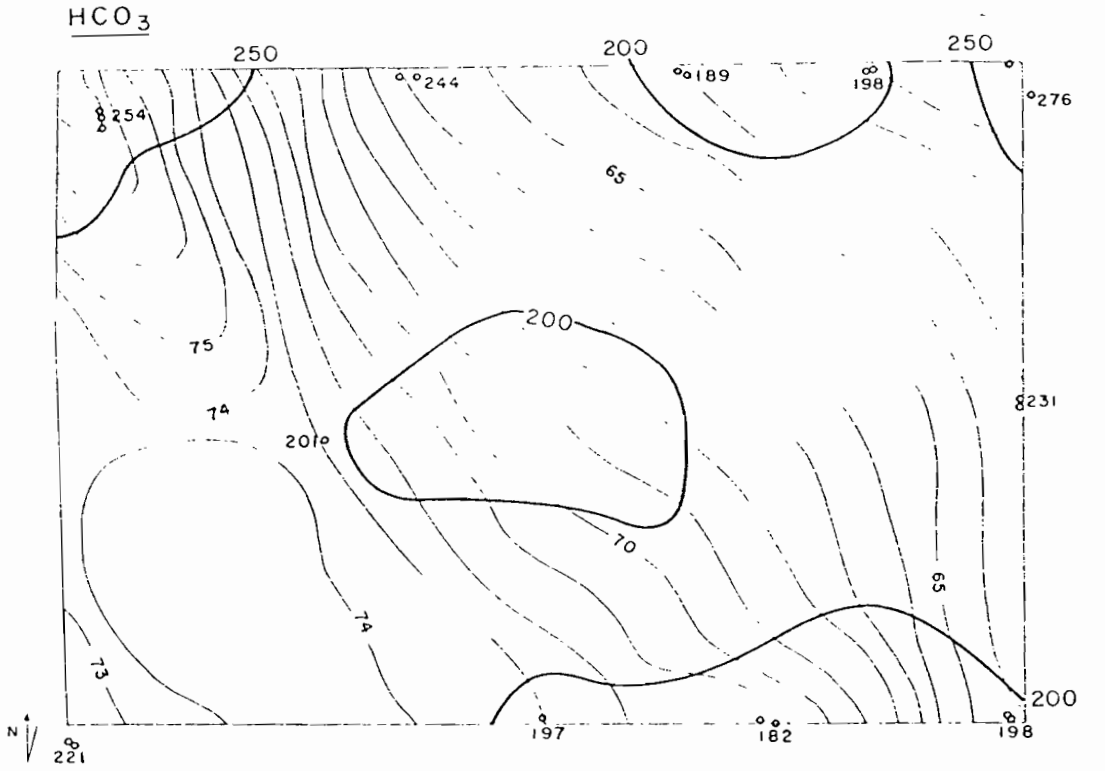


Figure 32. Concentration of bicarbonate ion in the groundwater at the Langdon landfill in parts per million.

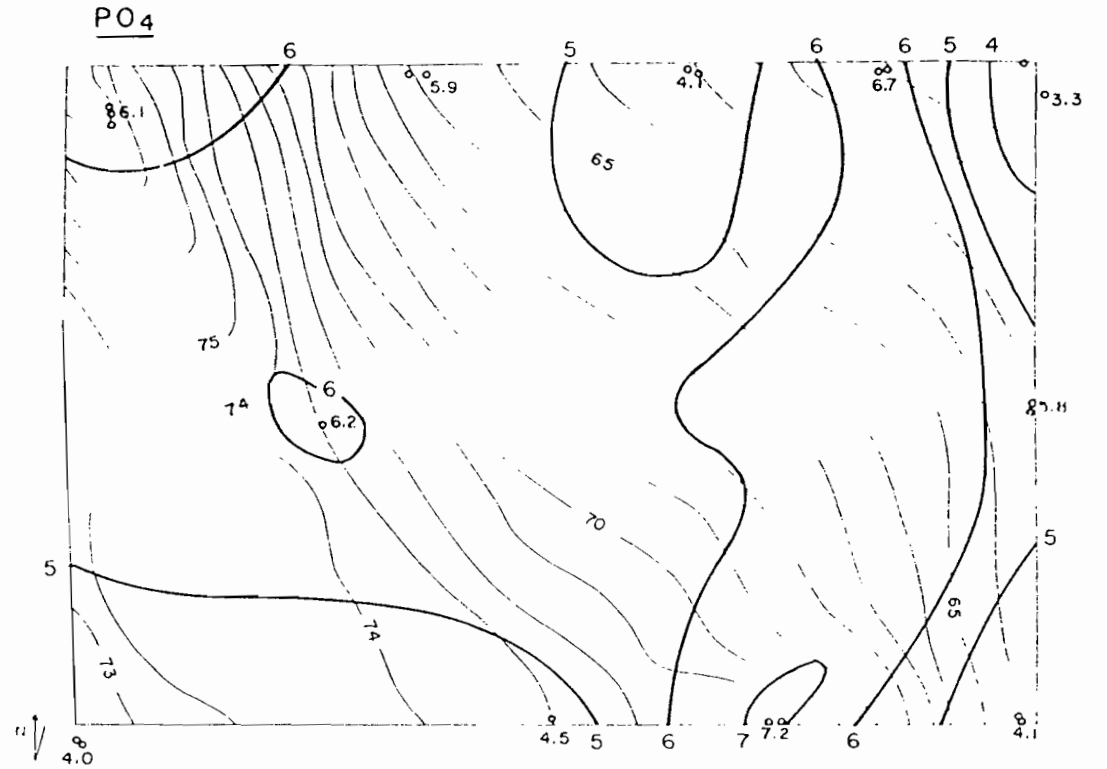


Figure 33. Concentration of phosphate ion in the groundwater at the Langdon landfill in parts per million.

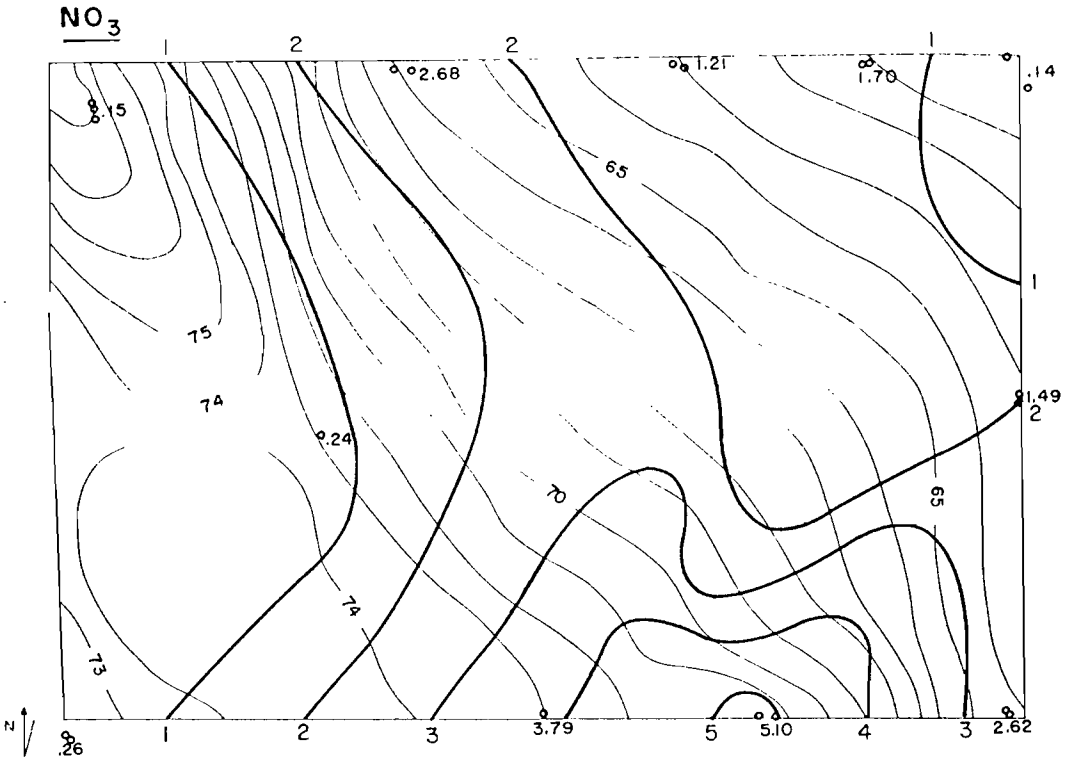


Figure 34. Concentration of nitrate ion in the groundwater at the Langdon landfill in parts per million.

do not indicate either. A particularly severe snirt storm (snow and dirt) occurred during this particular winter. A large volume of airborne dust was transported by this storm, and it is likely that some of this wind-blown material sifted into the wells around well tops, resulting in the temporary higher concentrations of these ions in the wells.

In summary, the distribution of the chemical constituents in groundwater in the vicinity of the Langdon landfill tends to reflect groundwater flow directions. In general, groundwater is more mineralized on the eastern side of the landfill. This coincides with that part of the landfill that is either in or near the discharge zone. Conversely, in the recharge zone, or that part of the landfill along which flow paths are short, the groundwater is less mineralized. Some areas within the landfill site appear to contain contaminated groundwater. However, apparently the refuse does not significantly affect groundwater quality. Appendix C gives water-quality data.

Organisms in Groundwater

Water from each of the 11 wells was analyzed for bacteria content (Appendix D). The significance of the presence of these bacteria in the groundwater is not clear. Bacteria do not generally survive under the anaerobic conditions found in a groundwater system, and they rarely exist over more than just a short distance from a contaminating source. It is possible that the bacteria found in these wells are a result of stagnant water in the well column. The sampling wells were disturbed only during sampling, and because groundwater movement through the landfill is so

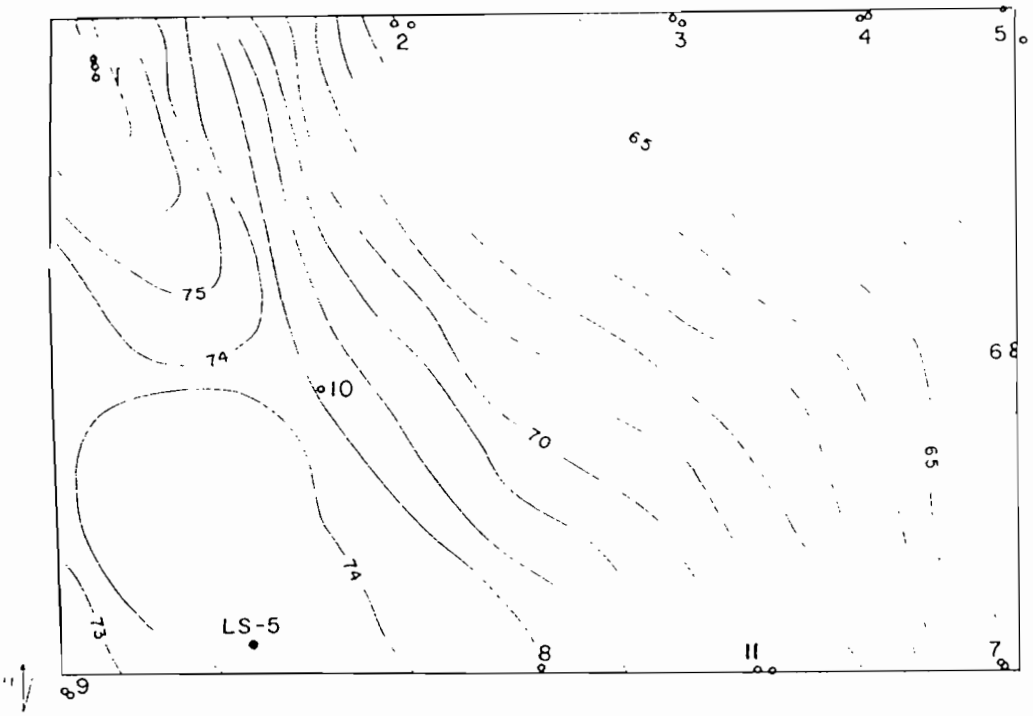


Figure 35. Location of testholes drilled at the Langdon landfill site.

slow, a stagnant water column could easily result in each well. The bacteria are from nonhuman sources; they may or may not be a result of the presence of refuse. Bacteria counts are as high, or higher, in water sampled from wells upgradient from the refuse, indicating that the refuse is not a significant factor.

SUMMARY AND CONCLUSIONS

The objectives of the study of the Langdon landfill were threefold: (1) to define the geologic and hydrologic setting of the landfill site; (2) to gather information pertaining to quantity, types, and migration of dissolved solids from the landfill into the groundwater flow system; and (3) to evaluate the criteria used in the study of this landfill and their applicability to landfill sites in similar geologic settings in North Dakota.

The Langdon landfill is located in glaciated terrain that is typical for much of North Dakota. The landfill is located in an abandoned gravel pit in a part of an esker. Groundwater flow through the landfill site is primarily controlled by the topography. Recharge occurs mostly on the topographic high at the landfill site. Most of the groundwater moves through the surface sand and gravel and discharges near the base of the esker immediately outside the landfill site. Because of the very poorly sorted nature of the esker deposit, groundwater velocity is estimated to be between 0.25 and 0.01 feet per day. If any leachate is generated at

the landfill, it would take between 8 and 214 years to be identified outside the landfill.

Eleven water-sampling wells placed in the landfill site were periodically sampled over an 18-month period for water-quality analyses. These analyses included Ca, Na, K, NH_3, HCO_3, PO_4, SO_4, Cl, COD, BOD, pH, electrical conductivity, and total hardness. The analyses indicate no significant alteration of groundwater quality as a result of the presence of refuse. Some contamination of groundwater by ammonia, phosphate, and nitrate occurs in those wells near the perimeter of the landfill. The landfill site is surrounded on three sides by cropland, and those wells closest to this land indicate alteration as a result of crop fertilization. However, in no case are Public Health Standards for drinking water exceeded.

The findings of this study suggest that groundwater contamination by proper solid waste disposal methods is not a serious threat in most of North Dakota, a conclusion that seems valid for at least the glaciated parts of the state. The Langdon landfill is atypical of many landfill sites in the state because it is located in a gravel pit. Many landfills are located in glacial sediment that has substantially lower hydraulic conductivities, thereby decreasing even more the rate at which groundwater can move through a site.

Although leachate generation appears to be of little consequence at the Langdon landfill, continued periodic monitoring should be undertaken. The generation of leachate in settings typical of North Dakota may be a much longer-term process than was originally anticipated. Specifically, at the Langdon site, three wells should be sampled on an annual or semi-annual basis and analyzed for the major cations and anions plus nitrate and ammonia. One well should be upgradient of the refuse, one in the refuse, and one downgradient of the refuse. This will allow for the detection of changes in water quality as a result of solid waste disposal. It is recommended that this same kind of water-quality monitoring program be part of every sanitary landfill operation in North Dakota.

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APPENDIX A

Well Installation and Testhole Descriptions

Testholes were drilled at the Langdon landfill site with the use of the N.D. Geological Survey truck-mounted auger drill. Testholes were drilled at eleven sites and the descriptions of the materials encountered are described below. At some sites more than one hole was drilled to permit the installation of 2 wells. The piezometers consist of one-inch diameter plastic pipe that was slotted on the bottom 3 feet. The pipe was installed to the bottom of the testhole and enough gravel pack poured down the annulus to cover the slotted-screen interval. Cement was then poured on top of the gravel pack to provide at least a six-foot plug. The hole was backfilled with drill cuttings to within 3 feet of the surface. More cement was poured on top of these cuttings to ground surface. The same procedure was followed in the four-inch diameter well installations. It is felt that this procedure minimizes the possibility of leakage around the outside of the casing and that the water-level and water-quality determinations made represent groundwater that has flowed from the recharge area to that well point.

The entire landfill is located in T. 161 N., R. 60 W., sec. 17, SW¼, NW¼, SW¼. Figure 35 shows the locations of the sites drilled.

The elevations listed for each site are based on an arbitrary datum of 100 feet elevation of a point outside the landfill.

	Description	Depth
Site 1	Sand and gravel; very poorly sorted, mostly	0-29
Elev.: 77 feet	shale, some sandy lenses, gray-brown to dark gray.	
	Till; clayey, shaly, some limestone pebbles, dark gray.	29-35
	Sand, saturated, poor sample return, gray, some till at base.	35-45
	Shale, clayey, blocky fragments.	45-
Site 2	Sand and gravel; very poorly sorted, sand	0-14
Elev.: 65 feet	lenses, some clayey zones, very poorly sorted, gray-brown to gray.	
	Till; clayey, shaly, dark gray.	14-21
	Shale.	21-
Site 3	Sand and gravel; very poorly sorted, clay	0-11
Elev.: 62 feet	stringers, gray-brown to gray.	
	Till; clayey, shaly, limestone pebbles, dark gray.	11-16
	Shale.	16-
Site 4	Sand and gravel; very poorly sorted, mostly	0- 9
Elev.: 60 feet	shale, gray-brown-gray.	
	Till; clayey, shaly, dark gray.	9-15
	Shale.	15-

	Description	Depth
Site 5 Elev.: 60 feet	Sand and gravel; silty, clayey, very poorly sorted, gray-brown.	0- 3
	Till, clayey, shaly, some limestone pebbles, dark gray.	3-16
	Shale.	16-
Site 6 Elev.: 62 feet	Sand and gravel; very poorly sorted, gray-brown.	0- 3
	Till; clayey, shaly, limestone pebbles, dark gray.	3-19
	Shale.	19-
Site 7 Elev.: 64 feet	Sand and gravel; very poorly sorted, gray-brown to gray.	0- 7
	Till; clayey, shaly, dark gray.	7-14
	Shale.	14-
Site 8 Elev.: 72 feet	Sand and gravel; clay stringers, sand lenses, very poorly sorted, gray-brown to dark gray.	0-20
	Till, clayey, shaly.	20-25
	Shale.	25-
Site 9 Elev.: 71 feet	Sand and gravel; very poorly sorted, sand lenses, clay and silt zones, gray-brown to dark gray.	0-20
	Till; clayey, shaly, dark gray.	20-25
	Sand, saturated, poor sample return, dark gray, about 2 feet of till at base.	25-39
	Shale.	39-
Site 10 Elev.: 73 feet	Sand and gravel, very poorly sorted.	0- 5
	Refuse and zones of sand and gravel.	5-20
	Till, clayey, shaly, dark gray.	20-
Site 11 Elev.: 70 feet	Sand and gravel, very poorly sorted, sand lenses, clay stringers, gray-brown to gray.	0-18
	Till, clayey, shaly, dark gray.	18-21
	Shale.	21-

APPENDIX B

Water-level Measurements

ELEVATION OF WATER

Langdon Landfill

Well No. Date

	9-1-73	9-29-73	10-8-73	10-24-73	11-18-73	1-18-74	4-10-74	5-13-74	6-21-74	7-19-74	8-21-74	9-16-74
1N	34.96	35.65	25.05	31.90	39.67			52.98	54.47	54.38	54.38	54.49
1S	51.19	54.36	52.06	56.52	56.25	56.81			58.53	58.07	57.48	57.27
1B *	56.09	56.05	56.08	56.61	56.20	56.65		59.09	59.23	58.69	58.08	57.86
2A		55.46	55.76	56.74	56.59	55.44	55.41	58.25	58.95	58.00	57.26	57.44
2B *		Dry	53.22	55.03	56.60	55.86	55.37	58.26	59.03	58.09	57.31	57.31
3A		56.24	57.39	57.54	56.69	55.47	55.05	59.27	58.84	57.04	56.92	57.16
3B *		56.09	56.04	57.32	56.55	55.23		59.19	59.62	56.87	56.86	56.98
4A		56.19	55.86	57.53	56.22	54.80	54.46	58.89	58.30	56.04	56.20	56.45
4B *		56.10	55.79	57.45	56.18	54.40	54.31	56.88	58.47	56.01	56.19	56.16
5A												
5B *			48.13	48.34	56.36	54.39		58.99	58.32	56.15		55.97
6A		56.33	55.23	57.79	56.82	55.53	55.13	59.82	58.95	56.90	56.93	57.12
6B *		56.25	56.14	58.08	56.86			59.86	58.98	56.93	56.87	56.90
7A		56.75	56.74	58.47	57.58			59.64	59.19	57.25	56.14	56.54
7B *		56.73	56.72	58.47	57.61			59.74	59.23	57.24	56.20	56.53
8B *		61.57	56.41	57.10	57.24			59.76	59.77	59.07	58.30	58.56
9A		54.70	49.44	55.30	56.22	55.89	55.09	57.49	58.74	58.31	57.71	57.49
9B *		56.43	56.65	57.12	57.54	57.45	57.68	58.57	60.22	59.68	60.12	58.54
10B *		56.70	56.26	56.96	57.09	56.74	56.38	58.72	59.61	59.04	58.33	58.04
11A								58.94	59.63	58.89	57.99	57.8
11B *						57.16		58.46	59.63	58.88	57.84	57.74

* 4" dia. well

ELEVATION OF WATER

Langdon Landfill

Well No. | Date

	10-30-74	2-20-75	5-27-75	6-20-75	6-23-75	6-25-75	6-27-75	10-1-75	10-10-75	11-6-75	11-15-75
1N	54.51		53.64	54.07	54.07	54.05	53.98	53.72	53.62	53.71	53.78
1S	57.04	56.93	56.40	56.71	56.67	56.68	56.67	55.95	56.25	56.06	56.07
1B *	55.84	57.20	56.74	57.34	57.24	57.27	57.26	56.47	56.43	56.49	56.43
2A	56.92	55.49	58.34	56.98	56.96	56.98	56.94	55.92	55.84	56.09	56.02
2B *	56.97	55.52	55.88	57.00	57.00	57.04	56.99	55.95	55.89	56.14	56.09
3A	56.83	54.88	57.31	56.85	57.08	57.06	56.80	55.87	55.72	56.22	56.06
3B *	56.77	54.69	57.31	56.85	57.15	57.12	56.85	55.94	55.76	56.28	56.11
4A	56.16	53.88	56.97	56.52	56.91	56.77	56.48	55.9	55.49	56.21	55.98
4B *	56.12	53.86	56.91	56.51	56.92	56.79	56.49	55.73	55.54	56.23	56.00
5A											
5B *	56.00		56.86	56.82	56.87	56.77	56.50	55.78		56.35	56.13
6A	56.71	54.79	57.56	56.91	57.16	57.09	56.81	55.77	55.78	56.33	56.16
6B *	56.78	54.90	57.56	56.97	57.18	57.13	56.85	55.84	55.73	56.35	56.17
7A	56.62	55.12	57.56	57.0	56.94	56.96	56.84	55.44	55.5	56.03	55.99
7B *	56.62	55.05	57.60	57.0	56.94	56.97	56.86	55.41	55.4	56.01	55.95
8B *	57.66	56.51	57.46	57.58	57.46	57.48	57.46	56.51	56.46	56.54	56.48
9A	57.29	56.48	56.71	56.99	56.94	56.95	56.94	56.22	56.28	56.28	56.32
9B *	58.06	57.04	57.77	57.74	57.71	57.72	57.72	56.87	56.81	56.77	56.74
10B *		56.50	57.41	57.43	57.43	57.44	57.42	56.46	56.46	56.51	56.46
11A	57.40	56.20	57.23	57.39	57.23	57.23	57.21	56.05	56.04	56.21	56.16
11B *	57.37	56.21	57.47	57.26	57.21	57.23	57.21	56.12	56.08	56.25	56.22

* 4'' dia. well

APPENDIX C

Water-quality Data

Date June 23, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	500	10	17		8.0	252	30	20	4.2	142	0	0.15	.25	.60	2.8	65		10
2	915	80	33		7.7	222	430	350	3.4	40	0.085	0	.46	.40	1.0	97		7
3	530	55	5		8.0	186	155	100	3.0	55	0	0.692	.23	.40	1.7	75		10
4	458	45	20		7.6	194	150	105	2.8	71	0.038	0.450	.14	.60	7.8	110		11.5
5																		
6	700	25	13		7.8	230	80	55	5.0	166	0	0.232	.09	.50	9.4	225		8.5
7	464	60			7.6	186	185	125	3.8	60	0.032	0.860	.26	.25	1.8	80		8
8	544	65	31		8.0	216	245	180	4.4	51	0	1.18	.07	.50	4.4	75		8.5
9	455	50	13		7.9	206	175	125	4.1	57	0	0.104	.45	1.30	7.4	75		8
10	445	40	11		7.9	182	120	80	4.0	73	0	0.320	.12	.50	9.8	70		10
11	508	80	8		7.9	192	305	225	3.0	15	0.091	0.653	.21	.25	2.7	125		8

Notes: 1. Units are milligrams per liter, except for specific conductance (micromhos per cm.) and for pH.
2. Total alkalinity and total hardness are expressed as calcium carbonate.

Date May 27, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	483	20	11		8.3	268	45	25	4.4	148	0	0.1	.78	.60	2.0	70	32	6
2	660	95	37		7.9	240	380	285	4.9	41	0.227	0	.25	1.3	1.0	62	165	7
3	442	80	1		7.7	182	200	120	3.7	56	0	0.2	.125	.30	3.0	75	20	7
4	456	90	7		7.8	192	190	100	3.6	73	0.019	0.319	.22	.85	7.4	75	19	7
5																		
6	644	25	9		7.8	230	80	55	5.0	164	0	0.044	.15	.59	1.0	200	18	5.5
7	451	45	4		7.7	160	205	160	4.5	65	0.028	0.816	.32	.60	1.0	85	9	6
8	560	95	24		7.8	194	305	210	6.1	58	0.011	1.65	.03	.15	6.6	85	33	8
9	456	35	1		7.9	200	185	150	4.6	68	0	0.08	.23	.80	2.6	85	9	10
10	438	95	2		7.7	176	185	90	4.4	79	0.012	0.28	.52	.59	7.6	65	14	7
11	535	80	8		7.6	172	325	245	4.0	22	0.02	0.768	.24	.65	2.8	112	10	7

Date April 28, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	464	20	14		8.0	254	50	30	4.2	148	0.013	0.006	.775	.30	15.75	85	12	7
2	546	90	58		7.4	218	285	195	5.1	41	0.089	1.44	.995	.25	31.25	90	80	3.5
3	409	50	12		7.5	1.88	145	95	3.5	62	0	0.76	.145	.10	20.75	70	12	5
4	454	65	13		7.4	1.92	155	90	4.3	82	0	3.18	.285	.25	19.50	73	13	4
5																		
6	651	30	11		7.5	234	75	45	4.6	177	0	0.052	.105	.8	17.00	157	8	3
7	449	30	7		7.5	184	145	115	4.5	79	0	0.34	.200	0	20.75	113	7	4
8	498	32			7.5	178	205	155	5.6	58	0.023	6.16	.040	0	10.50	80	5	7
9	409	18			7.6	202	175	90	4.3	75	0.006	0.054	.175	.25	12.75	45	4	6.5
10	444	17			7.5	184	140	115	4.2	87	0	0.35	.145	.29	8.50	70	7	6.5
11	515	80	26		7.4	162	275	195	3.9	22	0.026	9.12	.155	.05	20.75	75	7	5

Date April 7, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	425	20	8		7.8	256	50	30	4.0	145	0	0.172	.32	0.26	23.5	40	8	8
2	650	100	38		7.6	294	355	255	6.9	38	0.05	2.64	.13	1.15	13.2	50	59	2
3	466	55	3		7.6	192	165	110	3.1	54	0	0.066	.11	5.30	12.5	53	9	2
4	440	25	9		7.5	202	115	90	2.8	71	0	0.220	.125	1.15	25.2	77	11	1
5																		
6	592	40	20		7.7	242	80	40	8.2	162	0	0.038	.09	0.22	6.65	2.50	7	1.5
7	430	85	12		7.6	190	185	100	4.4	68	0	0.39	.04	0.26	7.75	.05	7	2.5
8	458	85	38		7.8	190	250	165	8.6	54	0.003	7.21	.062	1.20	13.7	122	4	4.5
9	420	70	4		7.6	218	175	105	4.0	73	0	0.52	.063	0.50	7.5	66	4	6
10	417	40	9		7.8	206	125	85	3.8	80	0	0.39	.085	0.85	12.3	66	6	6
11	496	70	15		7.7	182	300	230	4.1	17	0.003	6.80	.131	0.40	12.7	122	6	4

Date February 17, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	523	10	16		8.2	246	40	30	4.6	162	0	0.096	.78	1.9	3.2	.05	67	8
2	738	180	15		7.8	352	435	255	4.9	45	0	11.04	.23	1.9	3.1	96	100	5.5
3	455	35	10		7.7	192	155	120	3.9	60	0	5.08	.15	1.8	3.2	105	29	4
4	518	60	11		7.4	198	175	115	3.3	84	0	3.68	.15	0.5	3.7	125	21	5
5																		
6	724	30	19		7.6	228	85	55	6.6	177	0	1.60	.13	1.8	14.5	180	15	4
7	500	45	16		7.5	194	175	130	4.9	71	0	0.80	.05	2.2	5.1	105	16	4
8	532	110	13		7.7	180	255	145	5.5	54	0.016	9.12	.19	0.8	2.1	113	10	5
9	492	20	12		7.8	218	135	115	5.4	76	0.020	0.24	.63	0.35	3.7	88	9	4.5
10	455	40	8		7.7	188	120	80	5.1	87	0	0.29	.17	2.6	28.0	96	12	6.5
11	455	65	16		7.6	182	295	230	4.3	20	0.023	8.08	.20	0.25	3.1	137	15	5

Date January 20, 1975

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	490	10	141		8.1	254	40	30	5.4	128	0	0.21	0.33	1.0	7.5	55	100	7
2	722	95	26		7.8	330	375	280	4.4	40	0	5.5	0.07	0.25	5.9	30	165	5
3	442	45	26		7.5	192	165	120	3.7	52	0	1.4	0.06	0.35	4.5	63	40	4
4	450	65	6		7.4	196	170	105	3.1	65	0	4.4	0	0.25	5.6	63	24	5
5																		
6	715	35	21		7.6	232	80	45	6.3	157	0	2.9	0.04	0.25	5.9	183	28	4
7	513	30	7		7.5	190	165	135	5.0	65	0	0.85	0	0.10	3.9	125	21	5
8	526	105	7		7.6	182	250	145	4.9	49	0.010	9.0	0	0.30	3.7	113	20	5.5
9	482	60	8		7.6	224	160	100	4.8	62	0	0.34	0.55	0.35	4.6	75	16	6.5
10	455	40	7		7.5	194	120	80	4.8	75	0	0.58	0.02	0.50	5.4	75	14	5.5
11	554	45	3		7.6	190	305	260	4.0	14	0.015	7.2	0.52	0	5.8	133	33	5.5

Date December 16, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	534	20			8.0	256	40	20	4.5	139	0.005	0.05	0.72	0.65	13.8	40	29	6.5
2	770	120			7.5	334	410	290	4.2	38	0	3.5	0.17	0.15	4.9	62	133	6.5
3	452	60			7.5	188	185	125	3.6	52	0	1.1	0.08	0.63	5.2	62	32	5.5
4	484	44			7.3	194	165	121	3.0	65	0	4.4	0.02	0.85	10.0	62	22	5.5
5																		
6	725	20			7.7	234	85	65	8.8	162	0	1.5	0	1.25	13.8	200	24	4.5
7	511	45			7.4	192	170	125	5.3	65	0	0.53	0.02	0.20	6.6	80	15	5.5
8	520	75			7.6	172	220	145	5.5	40	0.016	3.0	0.04	0.20	10.6	62	13	5.5
9	507	52			7.7	224	162	110	5.5	60	0	1.2	0.72	0.50	6.5	80	9	5
10	447	25			7.6	190	115	90	4.7	75	0	0.54	0.14	0.85	11.4	80	12	6
11	546	60			7.6	192	295	235	4.6	19	0	3.1	1.2	0.20	2.5	92	.4	5.5

Date November 18, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	532	15	19		7.8	250	40	25	4.2	130	0.006	0.126	0.39	.95	6.1	45	10.5	10
2	705	130	9		7.8	302	380	250	3.8	40	0.062	1.36	0.14	.80	2.3	49	72	10
3	447	70	4		7.7	190	180	110	3.0	50	0	1.28	0.03	.50	4.8	62	12.5	9.5
4	492	55	7		7.3	188	155	100	2.5	62	0	3.04	0.10	.55	13.2	62	11	10
5	950	125	17		7.6	294	310	185	7.1	140	0	0.112	0	.55	10.0	280	72	10
6	714	40	4		7.8	232	90	50	5.0	168	0	0.060	0	.90	3.2	186	16	10
7	526	50	10		7.7	188	175	125	4.0	65	0	0.116	0	.54	2.0	105	10.5	10
8	544	105	20		7.7	190	315	210	4.2	20	1.24	0.696	3.4	.54	2.0	105	19	10
9	518	45	3		7.7	220	180	135	4.4	65	0.006	0.250	0.83	.52	5.5	80	10	8
10	483	35	2		7.6	190	130	95	4.3	73	0	0.140	0.20	.52	8.5	72	12.2	9.5

Date October 29, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	534	20	31		7.9	228	50	30	4.4	152	0.007	0.032	0.5	0.47	1.56	32	8.5	10
2	675	100	11		7.7	256	310	210	3.9	38	0.011	2.04	0.33	0.21	0.47	49	29A	10
3	454	50	14		7.7	192	175	125	2.9	45	0.017	0.42	0.05	0.31	1.41	89	5.5	9.5
4	490	65	6		7.5	184	155	90	2.5	62	0	1,5	0	0.40	3.1	63	5.5	10
5	935	95	31		7.5	302	285	190	7.3	119	0.006	0,10	0.19	0.19	3.5	277	40	10
6	720	35	44		7.6	226	95	60	5.4	159	0	0.13	0.01	0	0.70	189	8.9	10
7	524	55	14		7.5	184	175	120	3.8	65	0.023	0.08	0,06	0.06	0.59	107	7.3	10
8	550	75	58		7.6	244	285	210	4.0	19	0.56	1.8	3.35	0.12	0.82	121	7.7	10
9	515	60	5		7.6	210	190	130	4,4	56	0	0.06	0.69	0.21	2.0	92	4.8	8
10	472	35	4		7.4	182	130	95	5.4	65	0.011	0.26	0.11	0.24	4.2	107	7.4	9.5

Date September 26, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	534	20	4		8.0	256	50	30	4.5	137	0	0.01	0.87	.08	1.62	42.6	9.5	
2	580	110	10		7.9	250	330	220	4.0	33	0.004	2.63	0.91	.34	0.71	35.5	22.8	
3	428	60	1		7.8	190	190	130	3.0	44	0	0.70	0.09	.22	0.77	74.6	6.3	
4	470	40	3		7.8	186	150	110	2.9	65	0	0.97	0.03	.37	1.63	81.6	4.8	
5	928	135	10		7.6	312	335	200	6.7	137	0	0.08	0.47	.34	1.49	218	47.8	
6	716	30	9		7.7	234	90	60	6.3	166	0	0.09	0	.32	0.93	210	9.5	
7	502	60	6		7.6	188	175	115	4.5	62	0	0.03	0.1	.22	0.71	81.6	18.5	
8	536	75	115		7.9	240	270	195	5.1	16	0.10	0.22	2.6	.21	1.19	113	7.7	
9	474	60	8		7.8	214	185	125	4.7	57	0.04	0.05	0.87	.22	2.14	89.1	4.2	
10	460	20	9		7.8	190	115	95	5.1	76	0.005	0.07	0.41	.21	2.12	104	7.6	

Date August 21, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	508	25	12		8.0	250	55	30	4.8	142	0.04	0.024	2.5	0.25	1.2	38	18.3	12.5
2	425	95	14		7.4	226	275	180	3.8	31	0.031	2.0	2.2	0.35	0.75	23	22.4	14
3	362	50	13		7.5	172	190	140	3.6	44	0.09	0.80	0.33	0	0.85	57	5.2	15
4	402	45	14		7.3	180	155	110	3.4	68	0.017	1.12	0.65	0.24	1.1	65	5.4	17
5	692	95	32		7.5	164	280	185	7.6	135	0.01	0.05	1.3	0.62	1.7	240	50	14
6	705	40	18		7.6	226	95	55	8.2	177	0.01	1.75	0.5	0.40	3.5	250	11.4	14
7	485	45	10		7.5	186	175	130	4.9	61	0	2.08	0.15	0.35	1.4	123	8.0	13
8	454	50	169		7.9	208	220	170	5.1	50	0	0.35	3.25		1.5	73	18.5	13
9	456	40	3		7.5	228	190	150	4.5	54	0.014	0.05	0.98	0.65	2.1	73	4.3	13
10	441	45	4		7.5	184	135	90	4.9	76	0.036	0.12	0.44	0.45	3.5	75	18.5	.4

Date July 23, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	647	25	26	7	7.7	272	55	30	4.5	139	0.05	35	0.3	1.6	1.6	38	11.6	
2	637	90	Tr	3	7.8	238	270	180	3.6	31	0.005	4.38	0.75	0.6	1.6	22.5	22.9	
3	517	50	Tr	2	7.7	184	190	140	3.3	41	0.032	1.3	0.1	0.9	1.4	75	6.2	
4	575	60	Tr	2	7.6	206	170	110	3,1	64	0.042	2.84	0	0.6	1.0	72,5	7.7	
5	1114	90	7	4	7.8	346	295	205	6.9	128	0	0.075	1.0	0.6	1.1	160	62.5	
6	950	10	Tr	2	7.8	230	85	75	7.8	168	0.03	4.30	0.1	0.8	1,6	135	9,8	
7	660	65	Tr	3	7.8	212	235	170	4.5	54	0	0.53	0	1.0	1.3	135	8.2	
8	630	65	3	3	7.8	192	225	160	4.8	45	0	5.25	0	0.7	0.8	90	4.3	
9	590	60	9	3	7.8	232	205	145	4.3	54	0	0.42	0.75	0.6	1,3	92,5	4,5	
10	580	45	7	3	7.9	218	150	105	4.8	73	0.008	0.06	0.05	0,5	3.3	75	7,5	

Date June 27, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	623	25	12		7.8	264	50	25	4.3	135	0.079	0.22	0.5	1.5	13.7	42		13
2	512	65	18		7.5	190	200	135	3.1	29	0.007	3.31	0.6	0.1	0.5	13		13
3	513	50	10		7.6	200	190	140	3.4	38	0.067	1.07	0.1	1.6	1.6	45		18.5
4	552	60	12		7.4	192	185	125	3.0	66	0.019	2.42	0.05	0.1	0.7	77		18
5	940	65	3		7.6	288	235	170	6.9	125	0.007	0.29	1.5	0.05	0.7	165		15
6	855	35	14		7.5	224	75	40	6.2	173	0.018	1.65	0.05	0	0.8	185		17
7	733	135	18		7.4	206	320	185	3.9	49	0.083	5.0	0.05	0	0.7	127		15
8	626	70	22		7.6	200	225	155	5.4	48	0.017	3.78	0	0	0.7	70		14
9	530	50	23		7.5	220	170	120	4.3	54	0	0.36	0.8	0	0.6	60		13
10	576	55	22		7.5	208	150	95	4.6	76	0	0.66	0.35	0	0.9	96		14

Date May 28, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	440	15	10	2	8.0	266	40	25	3.9	127	0.035	0.3	0.1	1.3	1.1	31	9.5	3
2	335	65	18	6	7.7	182	180	115	2.2	27	0.005	2.9	0.5	0.9	2.2	21	13.5	3
3	365	75	6	1	7.7	188	185	110	2.9	44	0	0.9	0.1	1.4	1.1	21	4.9	3
4	400	55	7	2	7.6	192	150	95	2.5	60	0.012	2.5	0.1	0.9	2.3	45	6.5	3
5																		
6	585	10	5	1	7.8	218	70	60	5.4	157	0.007	1.3	0.2	1.3	3.8	178	10.2	3
7	540	125	10	1	8.0	198	310	185	3.4	52	0.015	6.3	0.2	1.2	1.3	91	9.3	3
8	455	75	4	2	7.8	194	220	145	4.6	52	0.015	5.9	0.2	0.8	3.2	70	6.3	3
9	400	65	3	1	7.8	208	170	105	3.8	55	0	0.2	0.8	0.8	1.3	45	5.5	3
10	400	45	4	2	7.7	198	120	75	4.0	72	0.008	0.18	1.0	1.6	2.2	49	8.2	4

Date April 23, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	455	15	14	4	7.8	252	50	35	4.4	133	0.006	0.50	0.25	2.6	2.8	35	7.6	6
2	420	115	19	3	7.7	204	245	130	3.8	27	0.006	3.4	1.0	4.3	4.7	35	11.8	6
3	375	105	15	2	7.6	192	245	140	3.4	41	0.009	1.4	0.05	1.8	5.9	60	5.3	6
4	415	75	21	3	7.4	192	175	100	3.2	61	0.01	2.8	0.15	3.8	3.7	70	10.5	6
5																		
6	605	30	10	2	7.6	238	90	60	6.3	155	0.003	1.1	0.10	3.1	5.4	175	15.4	6
7	535	60	13	4	7.5	228	225	165	4.8	51	0.01	6.1	0.10	2.3	5.3	129	21.2	6
8	460	65	19	3	7.7	212	220	155	5.5	50	0.03	4.0	0.20	2.9	4.5	102	17.4	6
9	430	85	7	2	7.7	222	210	125	4.8	60	0.003	0.14	1.0	1.6	5.9	70	6.7	10
10	445	25	7	2	7.7	220	125	100	5.1	87	0.003	0.16	1.2	2.2	3.3	70	10.5	9

Date March 11, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1																		
2	405	70	14	3	7.7	214	235	165	3.9	31	0.02	0.94	2.0	2.1	3.5	53	15	
3	395	100	7	2	7.7	200	225	125	2.8	40	0.03	0.47	0.25	4.4	1.4	56	5	
4	410	75	6	2	7.7	200	185	110	2.6	64	0.05	1.0	0.10	7.9	4.2	56	6	
5	805	115	26	3	7.9	325	295	180	7.5	137	0	0.04	1.0	4.0	1.7	241	42	
6																		
7																		
8																		
9	440	60	15	4	7.7	230	165	105	5.1	72	0	0.05	1.6	5.2	0.9	91	5	
10	445	50	9	1	7.6	220	135	85	4.9	87	0	0.03	1.1	4.7	1.8	91	9	

Date February 11, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1																		
2	440	75	6	4	7.6	222	195	120	3.9	27	0.25	0.97	4.0	1.81	19.5	31.5	11.3	3
3	415	55	10	2	7.6	202	195	140	2.9	38	0.01	1.5	0.1	1.19	3.8	45.5	5	3
4	530	55	10	4	7.6	230	160	105	4.3	96	0.01	0.27	0.2	1,90	4.9	98	11.1	3
5	800	100	34	4	7.6	296	295	195	6.9	124	0	0.16	1.6	0.92	3.4	238	41.7	3
6																		
7																		
8																		
9	465	55	19	13	7.7	232	150	95	4.6	67	0	0.04	1.6	1.29	3.2	56	5.4	3
10	490	50	17	9	7.7	224	150	100	4.9	83	0	0.03	1.2	1.68	4.4	80.5	11.5	4

Date January 15, 1974

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hardness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	480	15	17	4	7.8	252	45	30	3.9	143	0	0.022	0.6	1.5	3.4	28	12.5	4
2	420	60	70	25	7.7	224	195	135	4.0	31	0.006	0.034	4.8	1.7	11.4	42	13.4	3
3	400	40	6	4	7.6	212	180	140	3.1	39	0.011	1.27	0.2	2.1	3.1	37	6.1	3
4	540	55	32	7	7.5	222	165	110	4.5	96	0.010	0.034	0.4	1.7	4.7	82	18.4	3
5	810	65	30	12	7.7	284	270	205	7.5	131	0.029	0.081	2.0	2.1	4.8	193	40	3
6																		
7																		
8																		
9	455	75	28	21	7.7	250	180	105	4.9	67	0	0.022	1.0	1.9	4.0	49	4.4	2.5
10	485	55	31	18	7.5	222	145	90	5.7	88	0	0.018	1.2	1.4	6.4	70	10.6	3

Date December 3, 1973

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp ^oC
1	530	20	12	12	7.8	266	50	30	5.0	123	0	0.15	1.2	5.5	7.7	40	11	3
2	415	30	86	50	7.6	206	175	145	3.9	26	0.22	2.00	1.8	2.4	2.1	25	10.5	2
3	415	65	29	1	7.6	184	160	95	4.0	39	0.01	1.44	0.8	1.1	1.2	120	7	2
4	575	55	15	5	8.0	210	155	100	4.9	110	0.01	0.12	0.2	1.4	3.6	135	16	2.5
5	890	70	54	18	7.8	278	260	190	7.7	117	0	0.11	1.0	1.7	2.0	270	32	2.5
6	890	35	17	1	7.8	248	100	65	9.9	180	0.02	3.63	0.2	1.6	2.4	245	12	2
7	710	95	19	1	7.8	230	385	290	5.1	39	0.01	8.49	0.3	1.3	2.0	100	9	2
8	530	65	15	6	7.8	202	220	155	5.7	43	0.08	3.12	0.8	1.0	1.0	100	6	2.5
9	485	55	39	44	7.8	254	170	115	5.5	55	0	0.21	1.0	1.4	1.7	70	5.5	2
10	535	40	117	32	7.7	254	150	110	7.1	76	0	0.18	0.8	1.1	2.3	90	20	2.5

Date October 22, 1973

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	510	20	0	7.1	7.9	254	50	30	4.3	128	0	0.03	0.4	1.9	3.5	50	15	5
2	380	50	191	18.3	7.8	182	190	140	4.0	28	0.04	3.6	0.1	6.5	7.0	40	11.5	
3	390	50	100	2.0	7.7	178	155	105	3.7	42	0.007	1.9	0	3.8	5.6	30	9.5	
4	490	35	12	12.4	7.5	218	130	95	4.0	80	0	0.24	0.1	3.2	9.0	90	6	
5	855	90	100	19.4	7.5	252	260	170	7.3	117	0.004	0.16	0.1	1.7	5.0	240	31	
6	785	30	0	4.4	7.6	226	85	55	6.7	177	0.01	5.2	0	1.4	6.3	205	16	
7	675	120	0	4.6	7.6	218	340	220	4.3	41	0.12	8.9	0.05	3.6	6.5	125	13	
8	480	55	24	17.6	7.8	176	200	145	7.3	47	0.07	3.7	0.3	1.9	6.2	110	9.5	
9	460	40	52	18.6	7.7	218	165	125	5.7	67	0.06	0.48	0.3	1.6	2;3	65	7	
10	520	40	108	6.8	7.5	208	165	125	6.1	74	0	0.13	0.6	1.4	4.2	80	25	
11																		

Date October 1, 1973

Well No.	Specific Electrical Conductance	Mg	COD	BOD	pH	Total Alkalinity	Total Hard-ness	Ca	K	Na	Nitrite N	Nitrate N	Ammonia	Ortho-PO_4	Total PO_4	SO_4	Cl	Temp °C
1	680	5	16	3.7	8.0	214	80	75	7.0	165	0	0.056	1.0	1.8	3.5	160	100	2.5
2																		
3	375	50	12	3.0	7.9	160	165	115	4.0	45	0.007	1.6	0.1	1.8	2.1	60	165	6
4	485	35	16	4.8	7.8	192	135	100	4.7	88	0	0.28	0.1	1.3	8.7	68	135	2.5
5	605	100	280	8.2	7.85	170	205	105	9.3	70	0.009	0.46	0.2	1.3	4.7	160	65	6
6	775	40	28	4.2	8.0	220	85	45	10.3	183	0.036	1.2	0.05	1.3	6.9	195	20	7.5
7	720	115	24	3.8	7.9	224	375	260	6.4	45	0.29	4.9	0	2.4	5.5	110	20	5.5
8	475	175	33	12.0	8.0	162	375	200	6.4	45	0.145	2.0	0.15	1.1	5.5	70	20	3.5
9	450	40	45	4.7	7.8	202	165	125	4.7	60	0.036	0.66	0.2	1.7	2.4	64	11.3	5
10	520	40	191	10.8	7.9	192	165	125	7.3	70	0.005	0.29	0.5	0.9	5.1	100	39	4
11																		

APPENDIX D

Bacteriological Data

Date of Sampling	Well #										
	1	2	3	4	5	6	7	8	9	10	11
	Total Bacteria/ml x 10^{-2}										
1973											
10/1	500		280	460		300	3110	200		700	
10/22	300	980	1850	8680	1600		75	370	760	5330	
12/3	140	75	415	90	100	330	90	70	145	5400	
1974											
1/15											
2/11		34	110	66	270				10	63	
3/11		360	92	48	170				13	410	
4/23	230	330	1900	1700	580	210	290	49	180		
5/28	2100	5900	850	620			6000	170	2700	1100	
6/27	2900	1800	1000	2300	4000	4000	700	340	6400	980	
7/22	16000	7500	1900	6400	1700	8600	220	1200	4500	4400	
8/19	1500	4000	940	3300	680	6300	420	2200	5900	12000	
9/25	6200	4700	1100	350	750	1400	6300	5900	11000	9100	
10/21	850	2600	1900	670	3600	5200	790	1500	4300	2600	
11/18	2900	380	250	26	150	27	550	510	1100	1800	
12/16	660	350	47	150		350	100	120	1200	550	180
1975											
1/20	1200	290	88	26		260	220	270	160	230	70
2/17	270	120	6	3		50	120	92	260	85	16
4/7	480	220	170	80		17	84	270	170	66	32
4/28	260	2200	330	560		150	1080	540	800	540	710
5/27	130	1200	180	350		280	760	1100	1500	490	420
6/23	13000	5500	2400	800		3730	1850	850	7800	1200	1960

Date of Sampling	Well #										
	1	2	3	4	5	6	7	8	9	10	11
	Enterococci/100 ml										
1974											
8/19	<2	2	2	2	6	2	<2	<2	52	<2	
9/25	10	800	<2	2	2	218	24	10	124	18	
10/21	2	<2	<2	<2	16	<20	<2	<2	<2	2	
11/18	<2	<2	<2	<2	4	<2	<2	<2	20	2	
12/16	<2	<10	<2	<2		<20	<4	<2	<2	<2	<4
1975											
1/20	<4	<4	4	<2		<20	<4	<4	<2	4	<2
2/17	<2	<2	<2	<2		<2	<2	<2	<2	<2	<2
4/7	2	<2	<2	<2		<2	<2	<2	<2	<2	<2
4/28	<2	410	6	<2		14	<2	<4	8	16	<2
5/27	<2	14	<2	<2		230	<2	<2	<2	<2	4
6/23	12	4	<2	<2		20	<2	<2	64	12	<2

Date of Sampling	Well # 1	2	3	4	5	6	7	8	9	10
	Staphylococcus/100 ml									
1973										
10/1	<1		<1	<1		<2	6*	<2		<2
10/22	100	70	12	70	220	40	90	<10	130	<100
12/3	<2	2	<2	<2	<2	<2	<2	<10	<10	<100
1974										
1/15	<10	<10	<10	<10	<10				<100	<100
2/11		<100	<10	<100	<100				<10	<10
3/11		<100	<2	<2	<2				<10	230

*Coagulase Negative

Date of Sampling	Well # 1	2	3	4	5	6	7	8	9	10
	Pseudomonas/100 ml									
1973										
10/1	<1		<1	<2		<2	<2	<2		<2
10/22	10^4	10^4	10^3	10^3	10^5	10^4	10^4	10^3	10^3	10^3
12/3	<100	<100	<100	<100	<100	100	<1000	<100	<100	1000
1974										
1/15	<100	<100	<100	<100	<100				<100	<100
2/11		<100	<100	<100	<100				<100	<100
3/11		<100	<100	<100	200				<20	<20

Date of Sampling	Well #										
	1	2	3	4	5	6	7	8	9	10	11
	Coliforms/100 ml										
1973											
10/1	<2		<2	<2		<2	<2	<2		200	
10/22	<2	<20	<20	40	<2	80	<2	<2	2	20	
12/3	<2	<2	<2	8	<2	<2	<2	<2	<2	22	
1974											
1/15	<2	<2	<2	20	<2				<2	<2	
2/11		<2	<2	<2	<2				<2	<2	
3/11		<2	<2	<2	<2				<2	<2	
4/23	<2	2	<2	<2	<2	<2	<2	<2	<2		
5/28	<2	80	6	<2			<2	<2	<2	<2	
6/27	<2	2	<2	<2	<2	<2	<2	4	<2	<2	
7/22	<2	240	<2	<2	<2	<2	<2	<2	8	<2	
8/19	<2	20	<2	<2	2	<2	2	2	82	<2	
9/25	<2	340	<2	<2	<2	10	<2	<2	<2	<2	
10/21	<2	10	<2	<2	<2	<10	<2	<2	<2	<2	
11/18	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	
12/16	<2	<10	<2	<2		<10	<4	<2	<2	<2	<4
1975											
1/20	<20	<20	<4	<2		<20	<4	<4	<2	<4	<2
2/17	<2	<2	<2	<2		<2	<2	<2	<2	<2	<2
4/7	<2	2	<2	<2		<2	<2	<2	<2	<2	<2
4/28	<2	140	2	28		<2	<2	<4	<4	<4	<2
5/27	<2	90	<2	<2		<2	<2	<2	<2	<2	<2
6/23	<2	46	<2	<2		<2	<2	<2	18	<2	<2