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HYDROGEOLOGY OF SOLID WASTE DISPOSAL SITES IN NORTHEASTERN ILLINOIS

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Illinois State Geological Survey

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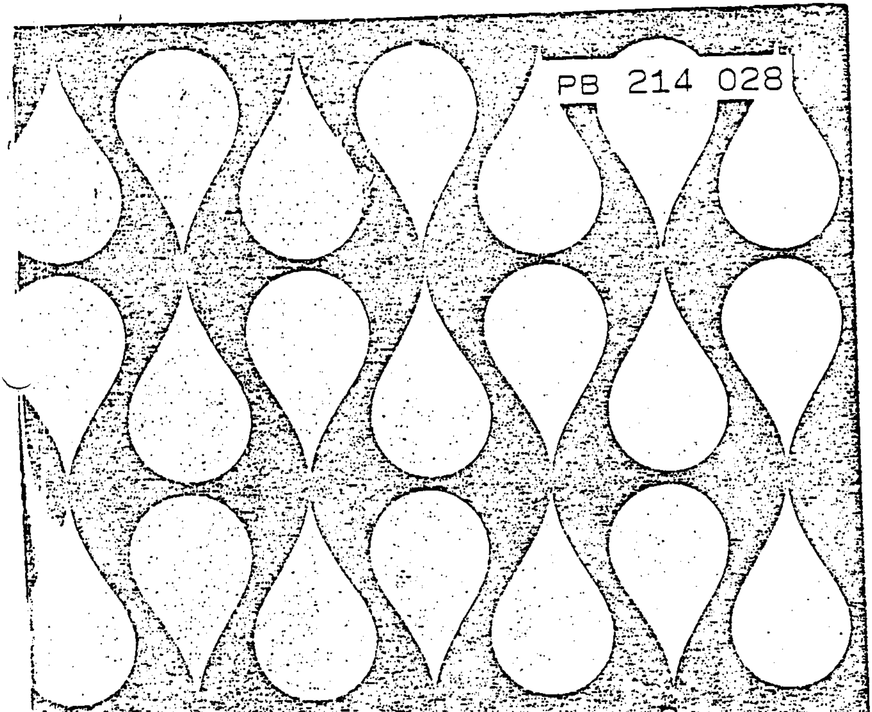

Hydrogeology of Solid Waste Disposal Sites in Northeastern Illinois

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HYDROGEOLOGY OF SOLID WASTE DISPOSAL SITES IN NORTHEASTERN ILLINOIS

A Final Report on a Solid Waste Demonstration Grant Project

This report (SW-12d) was prepared
by G.M. HUGHES, R.A. LANDON, and R.N. FARVOLDEN
the Illinois State Geological Survey, Urbana, Illinois
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FOREWORD

This is the final report on a study supported in part by the Solid Waste Management Office under one of the demonstration grants (No. G06-EC-00006) authorized by the 1965 Solid Waste Disposal Act. The study, conducted mainly by personnel of the Illinois State Geological Survey, was sponsored by the Survey, the Illinois Department of Public Health, and the University of Illinois at Urbana. The period of the original grant was from June 1, 1966, through May 31, 1968, and the grant was extended for an additional two years through May 31, 1970.

This demonstration study attacks one of the problems inherent in disposing of refuse on land: the ever-present danger that—unless properly engineered in a sanitary landfill—the wastes will adversely effect groundwater resources. The initial objective of the investigation was to obtain hydrogeologic information about landfills. After the first two years of work, however, it was apparent that a considerable amount of precise data on water quality could be gathered with relatively little effort or expense, and this was emphasized during the final year of the project. The present volume includes both the early and later data and thus supersedes an interim report on the project published by the Solid Waste Management Office in 1969. Although the conclusions reported apply specifically to the soil types that were tested, the procedures and methods used for the testing are applicable for future hydrogeologic-landfill research.

—RICHARD D. VAUGHAN
Deputy Assistant Administrator
for Solid Waste Management

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ABSTRACT

Hydrogeologic and water quality studies of five landfills in northeastern Illinois were carried out over a four-year period. The distribution and concentration of dissolved solids in the vicinity of four of these landfills was found to be controlled by the configuration of the ground-water flow system. The major factors influencing the attenuation of the dissolved solids after they have left the landfill appear to be the particle size of the earth materials through which these dissolved solids move and the distance that they move.

Precipitation in northeastern Illinois is adequate to infiltrate a completed landfill and to leach the refuse. Where the natural environment is not capable of containing or assimilating this leachate the landfilling operation can probably be made safe by lining the disposal site, by collecting and treating the leachate, or by other relatively simple engineering procedures.

SUMMARY OF RESULTS AND CONCLUSIONS

(1) Sanitary landfill designs in most of northeastern Illinois need not include protective measures to prevent ground water pollution, because the hydrogeologic environment is naturally protective. Where this is not the case, it should be feasible to incorporate protective measures into the site design.

(2) Under typical landfill conditions approximately one-half of the yearly precipitation infiltrates the surface. Infiltration begins by channeling through the refuse before the moisture content of the refuse has reached field capacity. This water, in the form of refuse leachate, leaves the disposal site either in the subsurface or on the surface.

(3) Preliminary work indicates that in refuse more than 5 to 9 years old and up to at least 21 years old, there is a yearly decrease in specific yield (effective porosity) of 1 to 1½ percent.

(4) Ground water mounds formed below the disposal sites studied. The presence of such mounds is proof of infiltration and downward movement of ground water. The mounds are caused by the reduction of the horizontal permeability along the margins of the landfill during construction. The seepage of minor amounts of leachate from the sides of the old DuPage County and Winnetka landfills is caused by the formation of the ground water mound.

(5) The migration of the dissolved solids in refuse leachate is related to time, age of refuse, distance, and earth materials. Fine-textured tills were found to be effective in removing dissolved solids from refuse leachate. This effectiveness decreased rapidly as the grain size of the involved materials increased.

(6) At each of the sites studies, ground water flow patterns are relatively simple, and the hydrogeologic factors responsible for these patterns can, in most cases, be readily understood. The distribution of dissolved solids in the ground water is in general accord with the flow system determinations, the dissolved solids from the various landfills moving in a predictable manner. The hydrogeologic approach used in this investigation should, therefore, be applicable to proposed disposal sites.

(7) Dissolved solids which originated in the landfill are present in the shallow earth deposits below and around the four landfills. At the Elgin landfill these dissolved solids have migrated to affect a shallow domestic well between the landfill and the Fox River. The shallow deposits at the other three sites are not being, and probably will not be, used for water supplies.

RECOMMENDATION FOR FURTHER WORK

(1) Determine the effects of slope, vegetation, and materials on infiltration through landfill covers by study of existing landfills.

(2) Determine the effectiveness of earth liners by study of existing landfills with earth liners.

(3) Determine the effects of earth and of other types of liners by encouraging their installation on new landfills and initiating a monitoring program on these landfills.

(4) Initiate a laboratory and field study to determine the mechanisms by which dissolved solids are removed from refuse leachate during its migration through the earth and the effect of refuse leachate on the physical properties of fine-textured materials that could be used as liners.

(5) Investigate methods of leachate treatment.

(6) Investigate methods of collecting and analyzing samples of leachate.

(7) Confirm the analyses of trace elements presented in this report by running additional samples. Run additional analyses for organic components in the leachate.

HYDROGEOLOGY OF SOLID WASTE DISPOSAL SITES IN NORTHEASTERN ILLINOIS

A FINAL REPORT ON A SOLID WASTE DEMONSTRATION GRANT PROJECT

This report presents the results of a detailed hydrogeologic and water quality investigation of four landfills in northeastern Illinois and initial results from the study of a fifth landfill. These investigations were carried out to develop guidelines that could be used to evaluate the pollution potential of existing and proposed landfill sites.

Well points and piezometers were installed around, within, and below existing landfills to determine the pattern of ground water flow and then samples of ground water were collected from selected points in the flow field and analyzed. Data were collected on the dissolved solids leached from refuse of various ages and on the attenuation of these dissolved solids as they moved away from the disposal site. Guidelines for appropriate site designs in various hydrogeologic environments are presented together with a discussion of various techniques and procedures that can be applied to these designs.

Hydrogeologic and climatic conditions in most of Illinois, northern Indiana, northern Ohio, Iowa, northern Missouri, North Dakota, and eastern South Dakota are comparable to those in northeastern Illinois, and hence, most of the results of this investigation are directly applicable in those areas as well.

Hydrogeologic conditions in the karst (limestone solution) areas of Kentucky, parts of Tennessee, Missouri, southern Indiana, southern Illinois, and Florida, where ground water moves through channels and fractures and turbulent flow is possible, are not, however, comparable to those in northeastern Illinois nor is the climate in the semiarid southwestern United States. Here the results of this investigation apply poorly or not at all. Data from this report may or may not apply in other areas, depending on local conditions.

The tables for this report are assembled together from data gathered in the investigation. Detailed descriptions of the field and analytical methods used to gather and interpret the water quality and hydrogeologic data are presented in the appendices.

ACKNOWLEDGMENTS

The writers wish to thank the owners and operators of the landfills studied, as well as the owners of adjacent property for granting us access to their land, tolerating the inconvenience of our operation, and providing us with the background information. Machinery operators and attendants on the various fills were particularly helpful.

Thanks are also due to the personnel of the State Water Survey for advice and the use of their equipment, to Dr. John R. Sheaffer of the Center for Urban Studies at the University of Chicago for critically reviewing the manuscript, and to Professor B. B. Ewing of the University of Illinois at Urbana and the Illinois Water Resources Center for the use of chemical supplies and a portable power auger.

In addition, we are grateful to the personnel of Layne-Western Company, and in particular to Bob Johnson, for their interest and advice.

Chemical analyses were made under the direction of John Murray of the Illinois Department of Public Health, and chemical and gas analyses under the direction of Dr. Neil F. Shimp, John A. Schleicher, Dr. Rodney R. Ruch, William J. Armon, and Wayne F. Meents of the Illinois State Geological Survey. Clay mineral analyses were done under the direction of Dr. Herbert D. Glass and textural analyses and engineering properties determined under the direction of Dr. W. Arthur White and Mrs. Cheryl W. Adkisson. The authors also wish to thank the summer assistants who worked on this project and in particular Charles R. Lund, Daniel E. McMeen, Michael J. Miller, Thomas E. Jensen, Stephen S. Palmer and Gary C. Brown.

Special equipment for this project was made under the direction of R. J. Helfinstine and Walter E. Cooper of the Illinois State Geological Survey.

THE SOLID WASTE PROBLEM

SCOPE

We are currently (1967) generating more than 360 million tons of household, commercial, industrial, and municipal solid wastes per day, which are disposed of at a cost of 4.5 billion dollars per year (Black *et al.*, 1968, p. 48 and 50). Of budgeted community funds, 80 percent is spent for collection of solid wastes and only 20 per cent for disposal (Black *et al.*, 1968, p. 14).

Household refuse—consisting of food wastes, packaging, containers, lawn trimmings, and discarded furniture and appliances—is the largest single source of solid waste generated. Most industrial waste, with the exception of paper and wood packaging, does not become mixed with household waste. Industrial waste was not considered in this report, although the results of this study will, in most cases, apply to the near-surface disposal of these types of material.

Solid waste disposal is a widespread problem that is most acute in the metropolitan areas, which are characterized by concentrations of people and intense competition for land. Disposal sites in use are being filled rapidly. In addition sprawling urbanization is making it more difficult to develop new sites. Efforts to find remote sites have encountered similar difficulties.

The landfill is the most commonly used approved method of solid waste disposal and has in most areas replaced the open burning dump. A sanitary landfill is defined by the American Society of Civil Engineers as "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and cover it with a layer of earth at the conclusion of each day's operation or such more frequent intervals as may be necessary" (American Society of Civil Engineers, 1959, p. 1). This definition implies that if a landfill is truly a "sanitary landfill" it will not adversely affect the quality of surface or ground water, and most regulations involving landfills prohibit their location where this is likely to occur.

Besides the sanitary landfill other approved methods of solid waste disposal include incineration and composting. Incineration is most commonly used in the metropolitan areas in order to obtain a significant volume reduction of the waste; however, incineration produces an ash residue that also requires disposal, and a landfill is still necessary. Composting of refuse is practiced on a very limited basis owing to the small market for the compost material.

PREVIOUS RESEARCH

Major investigations have been done on the production and migration of contaminants leached from buried solid waste. Only those particularly related to this project are discussed here. A comprehensive bibliography on sanitary landfills has been compiled by Steiner and Kantz (1968), and a series of bibliographies on refuse collection and disposal has been prepared by the U. S. Public Health Service (Van Derwerker and Weaver, 1951; U. S. Department of Health, Education, and Welfare, 1954; Williams, 1958; Williams and Black, 1961; Black and Davis, 1963; Weaver, 1963; Black et. al., 1966).

Some of the earliest landfill investigations were in New York (Carpenter and Setter, 1940; Eliassen, 1942a,b). Existing fills of various ages were sampled to determine the composition of the refuse, leachate, and gases produced.

Major studies were made in California. The University of Southern California (1952) published the results of an investigation of leaching in incinerator ash dumps. The quantity, quality, and ion exchange characteristics of leachate produced by water percolating through cylinders filled with ash were determined and a field study was made at a manhole installed in an existing ash dump from which leachate was collected from various depths within the ash. The semiarid climate of southern California made it necessary to apply water at the surface to produce a leachate.

The University of Southern California also carried out a study of leaching in a sanitary landfill from 1952 to 1960 (University of Southern California, 1954, 1955, 1956, 1958, 1960). Wells were installed and samples of the ground water in the vicinity of the landfill were collected and analyzed. Percolation of water through bins of refuse, gas production, and the temperature of the refuse were also studied.

Other studies of shrinkage, gas production, and temperature of refuse in drums or in specially constructed cells have been made in the same area (Merz, 1964; Merz and Stone, 1963a, 1964, 1965, 1966).

A series of investigations was made by Engineering-Science Inc. for the California State Water Quality Control Board. The first of these (Engineering-Science Inc., 1961) reviewed the available information on the effect of refuse dumps on ground water quality and included discussions of vertical and horizontal movement of leachate, decomposition processes, and gas production and movement. Additional (Engineering-Science Inc., 1963-1966) studies were primarily field studies concerned with the production and migration of gases produced at fill sites and with landfill construction (1969).

In Great Britain, a comprehensive laboratory and field study (Ministry of Housing and Local Government, 1961) was made of the quantity and quality of refuse leachate produced under saturated and unsaturated conditions and the changes in this leachate as it moved through sand and gravel filters. Bevan (1967) reviews the science and practice of the controlled tipping of refuse in Britain, including discussion of specific case histories. Because of climatic similarities, the results of this study are generally applicable to northeastern Illinois.

Several papers (McCormick, 1966; Sawinski, 1966; and Andersen and Dornbush, 1967) were published on the study of a landfill in South Dakota. This study made use of bored sampling points to describe the envelope of dissolved solids that had moved from a landfill located in a shallow sand above a clay unit that had relatively low permeability.

Fairly comprehensive investigations on the chemical quality of leachate (Qasim, 1965), acid and gas production (Lin, 1966), and microbiology (Cook, 1966) of landfills have been done at West Virginia University.

In Pennsylvania, investigations of the decomposition of refuse and the production and migration of leachate from landfills are being conducted at the Drexel Institute of Technology (Fungaroli et al., 1968, 1968a, 1968b, 1968c) and at the Pennsylvania State University (Lane and Parizek, 1968). These studies are similar to those conducted in Illinois and described in this report inasmuch as they examine the movement of leachate through the subsurface and the amount of renovation of the leachate.

An investigation of the hydrogeology of solid waste disposal sites is being conducted in Madison, Wisconsin (Kaufmann, 1969) that is also similar to this study but that considers different hydrogeologic environment.

COMPOSITION OF SOLID WASTES

Both the physical and chemical compositions of refuse are highly variable and dependent on factors such as geographic location, economic standard of the generating community, and season of the year. A typical breakdown of the physical and chemical compositions of household refuse is given in table 1 (Fungaroli et al., 1968b, p. 11).

A basic reason for the tremendous increase in the volume of waste generated today is the individual packaging of foodstuffs and the near elimination of returnable containers. This has resulted in a greater percentage of paper and paper products in the waste and the abundance of glass bottles, aluminum cans, and plastic containers. Prepared foodstuffs and household garbage disposal units have reduced the actual garbage content in today's refuse. Conversion to oil and gas heating has also reduced the ash content of domestic wastes.

PROCESSES AND PRODUCTS OF DECOMPOSITION

Natural decomposition of organic refuse is performed by bacteria or other microorganisms that use the refuse as food to convert it to their own cell substances through the biochemical process of respiration. The basic decomposition is aerobic in the early stages but soon becomes anaerobic. Engineering-Science, Inc. (1961) gives a full account of the decomposition process and Bevan (1967, p. 24) gives a detailed chart showing the process and products of the decomposition of household refuse (table 2).

Refuse decomposes at various rates, sugars, starch, fats, foodstuffs, and proteins being easily metabolized and fibrous cellulose materials such as wood and paper being more slowly decomposed. In addition to the composition of the refuse itself, the major factors controlling the rate of decomposition are the presence or absence of oxygen, time of burial, the age of the landfill, compaction, the temperature, and the moisture content. Eliasson (1942b) found that increased amounts of paper in the refuse resulted in a decrease of refuse breakdown and that the breakdown was dependent on moisture content, the optimum moisture content being 40 to 80 percent. The various organic and inorganic substances in refuse can be leached by--water moving through the refuse--either ground water or water from precipitation. This leachate can be described as a liquid high in dissolved solids and in chemical and biological oxygen demand. A portion of the leachate is derived immediately after implacement during the initial compaction and settlement of the refuse.

Gas generated by the decomposition of refuse is released both to the atmosphere through the cover material and to the surrounding ground and ground water and carbon dioxide and methane are the most important gases produced. Carbon dioxide increases the hardness and acidity of the water, which in turn adds to the solution and leaching of acid-soluble constituents in the refuse. Methane forms a flammable mixture in air (5 to 15 percent).

ATTENUATION AND MIGRATION OF DISSOLVED SOLIDS IN THE SUBSURFACE

As refuse leachate migrates through the ground it is attenuated by ion exchange*, dilution, dispersion, complexing, and filtration. Fine-textured materials have a high capacity for retaining the dissolved solids in refuse leachate and, owing to their low permeability, permit only a low rate of ground water movement. Sands and gravels have less capacity to retain the dissolved solids, and higher rates of movement are possible. Fractured rocks retain relatively small amounts of the dissolved solids, and extremely high rates of ground-water movement are possible.

The amount of ion exchange a particular ion undergoes depends on several factors, including the following: (1) the type of material involved; (2) the ions already present on the surface of the clays; (3) the other elements in solution and their concentration.

Laboratory experiments to determine how much exchange will take place as a solution is passed through a given material may yield useful results, although extrapolation to field conditions requires care (McHenry et al., in de Laguna, 1955, p. 190). In such experiments most of the soil is in contact with the solution, but under field conditions, in which permeability varies because of minor sand bands or fractures, this may not be the case.

Considerable work has been done on ion exchange on soils in relation to radioactive wastes disposal (de Laguna, 1955). For more basic understanding of ion exchange on clay minerals, the reader is referred to Grim (1953, 1962).

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*Grim (1953, p. 126) explains ion exchange as follows: "The clay minerals have the property of sorbing certain anions and cations and retaining these in an exchangeable state, i.e., these ions are exchangeable for other anions or cations by treatment with such ions in a water solution . . . ."

In studies of a landfill in Britain, self purification, particularly of organic matter, was shown to take place within the landfill itself (Ministry of Housing and Local Govt. 1961, p.26). The degree of purification was thought to depend on the length of time the refuse leachate remains in the fill. The same study (p. 23) established that by passing refuse leachate through sand and gravel filters "general purification from organic matter can be effected under anaerobic conditions." Purification from chlorides, sulfates, and ammonia was found to be much less complete. Although aerobic purification would be more efficient, it is not likely to be effective in ground waters.

Investigation by McCormick (1966, p. 41-45) in South Dakota disclosed that the hardness of leachate-contaminated ground water was substantially reduced as the water passed through a small surface pond. Although no use has been made of this phenomenon, it may be worth considering in the selection of disposal sites.

According to McKee and Wolf (1963, p. 19), less dilution and dispersion of contaminants will take place in ground water than in surface waters because ground water flow is almost always laminar, whereas flow of surface water is generally turbulent. For this reason, the total volume in a ground water reservoir cannot be considered effective for diminishing the concentration of contaminants. McKee and Wolf (1963, p. 20) also pointed out that the low travel velocities and diffusion rates in ground water reservoirs can produce serious consequences when contamination occurs. Contamination may not be noticed for years or decades, and consequently no complaints are registered. Even after contamination is discovered, the quality of water is already degraded and the damage cannot be repaired merely by stopping the source of contamination. A longer time may be required to purify ground water than to contaminate it.

POLLUTION OF GROUND WATER

If dissolved solids are allowed to migrate from a disposal site, they may reduce ground water quality below recommended drinking water quality standards. Relatively few instances of well pollution from solid wastes have, however, been described in the literature. A partial explanation for this is that most water quality analyses focus on the bacteriologic aspects and few chemical analyses are undertaken. Moreover, inorganic contaminants generally must be at relatively large concentrations before they can be tasted, and funds are seldom available to investigate reported instances of "bad water."

Lang (1932), Lang and Bruns (1940 p. 8), Rossler (1951), and Schlinker (1956) report instances of ground water contamination from solid waste disposal sites in Germany. Two instances of pollution of water wells by landfills have been reported in Illinois (Walker, 1969, p. 38, 39).

These examples of ground water pollution have resulted from the emplacement of refuse in materials that allowed for the rapid movement of dissolved solids and little attenuation. They indicate the importance of hydrogeologic conditions present at the disposal site.

REGULATORY VERSUS OPERATIONAL ATTITUDES

Because ground water pollution can result from the land disposal of solid wastes, a potential public health problem exists. Thus there is a need for regulations to protect the public interest when a site is proposed for a landfill operation. The various regulatory agencies—local, county, or State health departments—are concerned with the overall operation of the landfill and among other things with the migration of leachate and its effect on the ground water. Landfill operators, on the other hand, are more concerned with the economics of site acquisition, local zoning requirements, and general public acceptance.

Conflict about the suitability of a proposed landfill site can be attributed to several factors. Until recently, criteria did not exist within the regulatory agencies for evaluating the suitability of a proposed landfill site from a water pollution control standpoint. Presently a limited number of states have published standards and rules and regulations governing landfill operations. Some of these, however, are incomplete or unrealistic with regard to specific hydrogeologic criteria.

Probably the primary reason that suitable site selection has been difficult for both the regulatory agency and the landfill operator is that the site is seldom treated as an engineered installation, such as a dam or a building. This would entail a determination of existing geologic and hydrogeologic conditions by borings and a landfill operation designed to use the natural conditions where possible and subject to modifications where necessary. It could also entail the control and monitoring of dissolved solids migrating within the ground water flow system with possibly the collection and treatment of affected ground water to ensure an efficient operation acceptable to the regulatory agencies. Regulation is apt to be strongest in areas where water use is high, alternate sources of water are not readily available, and the environment itself is not protective. Here pollution may be very expensive to remedy.

HYDROGEOLOGIC INVESTIGATION OF THE LANDFILLS

THE HYDROGEOLOGIC APPROACH AND FLOW SYSTEMS

The specific objectives of this study were to study landfill sites in northeastern Illinois in various hydrogeologic environments, to determine the effect of geologic and hydrogeologic factors on the flow system at these sites, and to gather information concerning the quantity, types, and attenuation of dissolved solids moving from the fill area. An understanding of ground water and contaminant movement in three dimensions is necessary for evaluating the suitability of a site for use as a sanitary landfill.

A ground water flow system describes the progressive movement of water through the earth. In the shallow subsurface of a humid region such as northeastern Illinois ground water occupies all the openings in the earth materials below the top of the zone of saturation or the water table. Above the water table the openings are filled with both water and air. Rain or other water that has entered the ground in what is called a "recharge area" moves downward to the top of the zone of saturation and becomes part of the ground water reservoir. This water is discharged again to the surface in a "discharge area," where it forms the base flow in streams and, together with surface runoff, is the source of water in permanent swamps, marshes, and lakes. The driving force for ground water movement is gravity. The direction of ground water movement is a function of pressure. A set of flow lines that remain adjacent throughout their path from the recharge to the discharge area form a ground water flow system (Toth, 1962). More comprehensive discussions of flow systems are given by Hubbert (1940), Toth (1962), Meyboom (1966), Meyboom, Van Everdingen, and Freeze (1966), and Freeze and Witherspoon (1966, 1967, 1968).

In any flow system, the discharge area is at a lower elevation than the recharge area. Figure 1 illustrates a hypothetical flow system that could exist in northeastern Illinois. It is composed of small local systems superimposed on larger systems. A small system might include only a small pond acting as a discharge area for the uplands immediately adjacent to it, which would be the recharge area. This small system could be superimposed on a secondary system that discharges into a secondary stream and receives recharge from a much larger system that in turn discharges into a major stream or Lake Michigan. The foregoing is not the complete picture of conditions, because the shallow aquifer systems

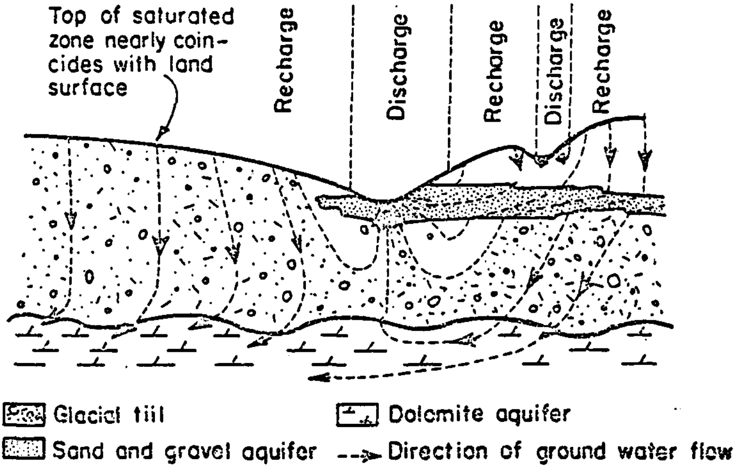

Figure 1. A hypothetical flow system that could exist in northeastern Illinois. Contaminants cannot enter the ground water flow system in discharge areas, because in these areas, water moves toward the water table's surface, and this upward flow prevents leachate from waste disposal operations near the ground surface from moving downward to pollute deeper aquifers.

are penetrated by pumping wells. These pumping wells have, to some extent, distorted the natural flow system by creating discharge areas in the subsurface in the form of pumping cones. The actual travel path of the ground water is controlled by a number of factors; the major ones are the following: (1) the sequence and hydrologic properties of the earth materials, (2) the topography and elevation of the top of the zone of saturation, and (3) the pumpage in the area.

In northeastern Illinois nearly all the recharge to the shallow aquifers originates as precipitation in upland areas. After entering the ground, this water migrates downward to the top of the zone of saturation and then in the direction of the potential gradient (or from a point of higher head to a point of lower head) to discharge at the surface at a lower elevation, provided, of course, that it is not intercepted by a well. In the recharge area migration down the potential gradient corresponds to movement away from the water table surface whereas in a discharge area the water is moving towards the water table surface.

In some parts of northeastern Illinois a general flow system can be determined from information obtained from two or three piezometers installed at depths of less than 30 feet. In other parts of the area determination may be more complicated and expensive.

A concept of ground water flow that considers only flow in the plane of the water table surface or parallel to the slope of the ground surface can be misleading. A third dimension, the vertical component of flow, must also be considered, even though it may be much less obvious than the horizontal component. Where there is an upward component to ground water flow, dissolved solids from waste disposal operations near the ground surface cannot move downward to pollute deeper aquifers but may move into surface waters. Where a downward component of flow is present, the possibility that dissolved solids will move downward must always be considered.

PHYSICAL SETTING OF NORTHEASTERN ILLINOIS

PHYSIOGRAPHY. Northeastern Illinois is near the center of the physiographic Central Lowland Province, a glaciated lowland with generally low relief. The maximum elevation is 1,192 feet above mean sea level in northwestern McHenry County, the minimum is 505 feet where the Des Plaines River leaves western Will County. The present level of Lake Michigan to the east is about 580 feet above sea level.

A low north-south-trending drainage divide is present a few miles west of Lake Michigan. West of this divide, drainage is into the Mississippi River system. Natural drainage east of the divide was originally into Lake Michigan; however, much of this has been diverted to the west into the Mississippi River system. In the flatter parts of the area, most of the drainage has been improved initially for agricultural development and as urbanization spread for the alleviation of flooding problems. Much of the morainal or hilly country is without integrated drainage, and swamps and lakes are common.

CLIMATE. The climate of Chicago is continental (U.S. Weather Bureau, 1962). The mean annual temperature is 51° F, with monthly normal means ranging from 26° F in January to 76° F in July. The mean annual precipitation is 33.18 inches with monthly means from 1.60 inches in February to 4.07 inches in June. The mean annual snowfall is 36 inches. Mean annual evapotranspiration (Jones, 1966, p. 5) is approximately 25 inches, with a potential evapotranspiration of 28 inches.

During the 1938-1957 period the region averaged 90 days per year with mean daily temperatures below freezing. The growing season for the Chicago region ranges from 150 to 180 days with most of the region in the 160- to 170- day range (Suter et al., 1959, p. 13).

GEOLOGY. Unconsolidated deposits overlie the bedrock in most of the region. They range from less than 1 foot to more than 400 feet thick and include recent and glacial deposits.

The major unconsolidated deposit is glacial till, an unsorted mixture of clay, silt, sand, and boulders deposited directly from the glacial ice. The uppermost bedrock is a fractured dolomite of Silurian Age, a major aquifer in the region. The structure of the area is relatively simple, the rocks dipping eastward at 10-15 feet per mile.

More detailed descriptions of the geology of this area are presented in reports of Suter et al (1959), Willman (1962), Zeizel et al. (1962), and Buschbach (1964).

GROUND WATER. Ground water is an important resource in northeastern Illinois. In 1963, 24 percent of the population obtained water from this source (Sheaffer and Zeizel, 1966, p. 62). There are three major sources of ground water in this area, the deep bedrock aquifer system, the shallow bedrock aquifer system, and the glacial drift aquifer system. The glacial drift aquifer system and the shallow bedrock aquifer system are most susceptible to pollution from solid waste disposal because they are at or near the ground surface. Susceptibility of the shallow bedrock aquifer system is further increased because it is composed of fractured rocks. Recharge to the glacial drift and shallow bedrock aquifer systems is locally derived from precipitation or surface water.

The top of the zone of saturation (or the water table) is generally within 5 to 10 feet of the ground surface except in places where the presence of permeable materials at or near the ground surface has allowed drainage.

INVESTIGATIVE AND ANALYTICAL PROCEDURES

SITE SELECTION. Four sites were studied during the first 2 years of the investigation and one, the Blackwell Forest Preserve site, in late 1968 (Figure 2). These were selected from a list of disposal sites in northeastern Illinois compiled by Sheaffer et al. (1963, p. 70-71). Existing sites were chosen because they are in environments typical of those likely to be used for future sites, they represent common hydrogeologic environments in northeastern Illinois, and the altered ground water leaving them provides a tracer to verify hydrogeologic findings. Selection of the sites was based on their hydrogeologic environment, age, access, and extent of the fill.

During the final years more emphasis was placed on the water quality aspect of this investigation. Additional borings were installed at the DuPage County and Winnetka sites, where the hydrogeology was simple and would not obscure water quality relationships, and one boring was installed in a high above-ground landfill in the Blackwell Forest Preserve.

DATA COLLECTION AND ANALYSIS. The investigation of each site included field examination supplemented by study of maps and air photos, surveying, searching for leachate springs, and discussion with operators.

At each site, except Blackwell, initial subsurface information was obtained by drilling a series of four holes to bedrock with standard rotary equipment. Drill cuttings were collected and described, and an electric log, with a conventional self potential and resistivity curve, was run for each hole. Subsequent borings were made by a hollow-stem auger rig, an air drilling rig, two small power augers, and by wash boring.

After each boring had been completed, one or more piezometers or well points were installed and the hole was backfilled.

A piezometer is a screen or permeable plastic tip fastened to the end of a pipe or tube. This screen or tip is installed in a boring, and the annulus above it is sealed so that water level measurements or water samples obtained from this installation apply only to a restricted area in the bottom part of the boring below the seal in the annulus. A well point is similar to a piezometer except that there is no seal in the annulus and therefore measurements or water samples obtained from a well point may reflect conditions over a large vertical interval.

Many of the piezometers installed by contract boring are multiple completions; that is, several piezometers, at different depths, are installed in one bore hole and separated hydraulically from one another by an impermeable sealing plug above and below the screen.

Drilling, sampling, and piezometer construction procedures are described in some detail in appendix A, and descriptions of samples from

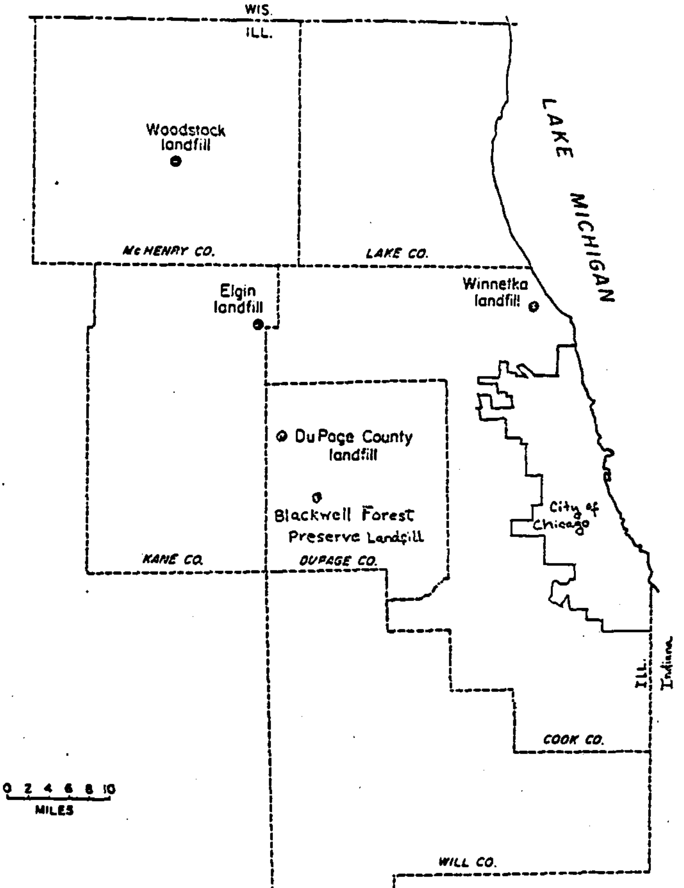

Figure 2. Solid waste disposal sites in northeastern Illinois investigated during the first two years of the study. These sites were chosen on the basis of their hydrogeologic environment, age, ease of access, and extent of fill.

the various contract borings are given in appendix B. Table 3 gives construction details of the various well points and piezometers, and tables 4 and 5 give the results of textural and clay-mineral analysis.

After a preliminary determination of the flow system had been made, additional well points and piezometers were located to give the maximum amount of information on both the hydrology and the composition of the ground water. During the last year most of the installations were located to sample leachate of various ages and to investigate changes in the composition of affected ground water over short horizontal and vertical distances within the same geologic unit.

The steps used for collecting samples from the well points and piezometers varied with the sampling point involved and are discussed in appendix A.

Water quality analyses by the Illinois Department of Public Health are presented in table 6, by Allied Laboratories in table 7, and by the State Geological Survey in table 8. Table 9 presents the results of more detailed chemical analyses, most of which were by Tenco Hydro/Aerosciences, Inc. The laboratory procedures used in the chemical analyses are discussed in appendix C.

Analyses of soluble salts in the materials associated with the landfills are presented in tables 10 and 11, chemical analyses of the till itself in table 12, and analyses of cation exchange capacity and exchangeable cations in table 13.

Under the direction of Professor I. Edgar Odom, Department of Geology, Northern Illinois University, extracts of soluble salts were obtained from the materials underlying the landfills and submitted to a fluorescence analysis. These data are presented in appendix D.

Gas samples were pumped from a perforated iron pipe driven approximately 3 feet into the ground. The pipe hoses and pump were flushed with landfill gas and then the sample was collected by displacing water in a submerged mason jar. The results of the analyses of these gases are presented in table 14.

The Illinois State Geological Survey also conducted approximately 200 field conductivity measurements, 300 field sodium chloride tests with a Hach Kit, and 50 field tests for methane. These data are on file at the State Geological Survey.

Hydrographs, or graphs of water levels, were necessary in the hydrogeologic analysis. Water levels were recorded by float-activated recorders in borings with 4-inch-diameter casing and by electronically activated recorders in borings with smaller diameter casings.

In the second study year three recorders were available. These were moved about to gather specific data. During the last year eight permanent recorder installations were constructed: two each at the old DuPage County, Winnetka, and Woodstock landfills and one each at the Elgin and Blackwell landfills. In other piezometers periodic measurements of water levels were made with a measuring tape, and hydrographs were constructed from these measurements. These hydrographs were begun when the well was completed and have been continued to the present, with measurements at various intervals.

Microbarographs were obtained by recording barometers installed at each site. The records were necessary for correcting the hydrographs for barometric effect. Precipitation records from automatic rain gauges and manual rain gauges at each site were also obtained and checked against those from the U.S. Weather Bureau stations at Wheaton, Aurora, Elgin, O'Hare Field, and Antioch. Hydrographs, microbarographs, and rainfall data from the investigation are on file at the Illinois State Geological Survey. The hydrographs are interpreted in some detail in appendix E.

Slug tests were run to determine the permeability of materials associated with the landfills. This is accomplished by lowering metal cylinders into a boring to displace the water level upward and then measuring the subsequent decline in water level with a steel tape.

Results were checked by measuring the rise in water level after the metal cylinders had been removed. Slug tests were also run by adding or removing water from the bore hole, but this method is less convenient. The results of these tests are presented in table 15.

Pumping tests were conducted to verify the results obtained from the slug tests, and, in addition, a sample of the till similar to that at the DuPage County site was subjected to a laboratory permeability test. The results of permeability testing are discussed in appendix F.

To calculate the amount of water infiltrating into the landfill, the effective porosity or specific yield of refuse was determined by filling a 110-gallon container with water and refuse and then measuring the amount of water that would drain from the mixture. This procedure is discussed further in appendix E.

Resistivity and temperature studies as well as a study of effect of storage on leachate were also conducted. These are described in appendix F and G of the interim report of this project (Hughes *et al.*, 1968).

Also included as appendices are calculations of the flow into and out of the landfills and discussions of the analytical methods used in the water balance estimate and permeability calculations (appendix H).

THE OLD DUPAGE COUNTY LANDFILL

GENERAL DESCRIPTION. The old DuPage County landfill is located in the NW¼ of sec. 32, T. 40 N., R. 9 E., DuPage County, on both sides of the Chicago Great Western Railroad where it crosses Powis Road, south and east of the county airport. Figure 3 is a map of the general area with a cross section showing the topography and general geologic sequence.

The old DuPage County landfill lies on a flat upland area between the Minooka Moraine on the west and the West Chicago Moraine on the east. The elevation is about 750 feet above mean sea level. The area was originally swampy and much of the drainage was through tiles emptying into Kress Creek, which flows to the south along the eastern side of the fill area.

Before filling operations began, the southeastern part of the landfill was used as a holding area for livestock enroute to Chicago. Filling, which was by the trench and fill method, began in September 1952 and was completed in November 1966. Initially, there was controlled burning of wood or paper on the north side of the fill, but this was discontinued. Figure 4 shows the history of the filled areas.

According to the operator, trenches were dug to the top of the water table and were as much as 6 feet deep. At times these trenches contained water. On the south side of the railway, refuse was piled 6 to 8 feet above the original ground surface in a single lift, or layer, and north of the railway, refuse was piled about 15 feet above original ground surface in two lifts.

Household and garden refuse was the major component of the fill, but small amounts of spent battery acid, construction debris, and sewage sludge were also buried at this site. The daily cover material was at least 6 inches thick and the final cover 2 to 3 feet thick. The cover material is primarily silt loam, clay, silty clay loam, and clay loam (designation of soils from U.S. Department of Agriculture classification of soils) although many stones are present in some parts.

Fine-textured waste material from an asphalt plant is being used to fill low areas on the north side of the railway.

Weeds cover most of the surface of the landfill. The east half of the south side supports a fairly dense growth of trees, predominantly cottonwoods but with some white ash and black cherry. Trunk diameters of the trees on the berms between the filled trenches are up to 4 inches at 4 feet above ground level. Smaller trees are present over the trenches, but most of these die before their trunks reach 2 inches in diameter. An unsuccessful attempt at farming was made on the western part of the south side of the fill, but according to the farmer the cover material was too stony. We hope to investigate further the factors affecting plant growth on landfills.

The central part of the landfill is relatively flat, but slopes increase towards the edges, be-

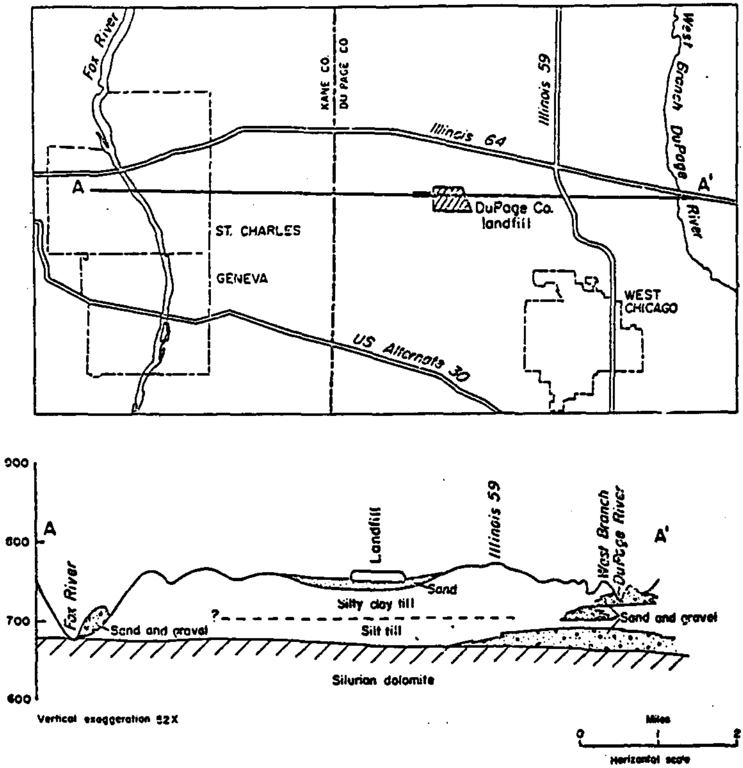

Figure 3. Map (top) shows the general area surrounding the old Du Page County landfill. Cross section (bottom) shows the topography and general geologic sequence of the area between A and A′ on the map.

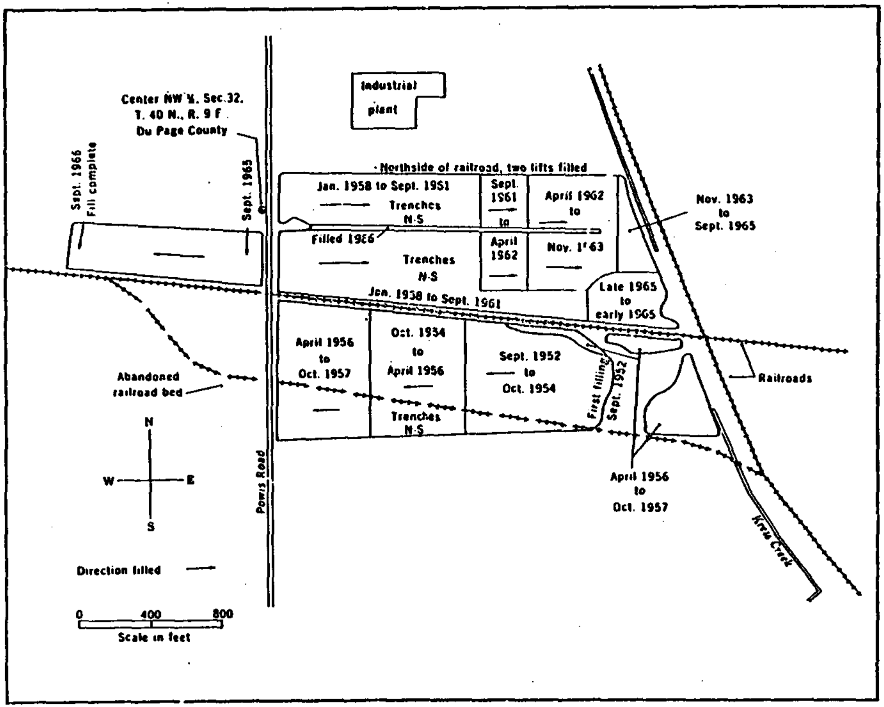

Figure 4. History of filling at the old Du Page County landfill. The filling, which was by trench and fill methods, was begun in 1952 and completed in 1966.

come quite steep, and are eroded slightly along all but the southern margin. Since the surface is poorly drained and there is little runoff, most of the precipitation infiltrates or evaporates.

A fairly simple sequence of geologic materials is present. Beginning with the surface, it is as follows:

Cover material on landfill–2 to 3 feet of clay loam, clay, silty clay loam, and silt loam.

Surface material around landfill–generally 2 to 3 feet of silty clay loam and clay loam.

Upper sand (surficial sand)–sandy silt to silty sand, generally present surrounding and below the landfill. As much as 21 feet thick below the landfill; generally about 10 feet thick along the southern edge; thins at the northern edge, the western edge, and in the field south of the landfill; absent in the northeastern corner. Sand and gravel bar present in the southeastern corner and other bars are scattered in the field south of the fill. Probably represents a thin outwash from the West Chicago Moraine Approximately 1 mile to the east.

Upper till–clayey silt till, 5 to 25 feet thick, similar to the predominant surficial deposit throughout the entire region east to Lake Michigan.

Middle till–sandy silt till, 12 to approximately 20 feet thick. Not continuous beneath the site.

Interbedded sand–sand and fine gravel, 1½ to 5 feet thick. Not continuous beneath the site; limited to the eastern half and probably associated with the sandy silt till already mentioned.

Lower till–silt till at base of section; 20 feet thick. Unit has also been recognized in western DuPage County.

Bedrock–fractured dolomite of Silurian age. A major aquifer in the area.

HYDROGEOLOGIC ENVIRONMENT. Figure 5 is a plan view of the landfill and surrounding area showing the location of the borings and the contours of the top of the zone of saturation.

A ground water mound 6 feet high has developed below the landfill. The reasons for its formation are discussed at the end of this section. This mound is the major feature of the ground water surface, and, because of it, springs or seeps have developed along the sides of the fill, particularly to the south. The area with springs seems to be growing larger, and standing puddles of leachate from these springs are present south of the landfill area. Flow from the springs along the south side of the landfill was measured at 1½ gallons per minute on July 15, 1969.

The formation of the mound indicates that precipitation has infiltrated the fill surface and is moving through the refuse. Springs develop where the ground surface intercepts the top of the zone of saturation, commonly along the margin of the fill where the ground slopes more steeply than the slope of the ground water mound.

The configuration of the contours on the top of the zone of saturation south of the filled area has probably been influenced by drainage through field tiles. Some of these tiles were broken during construction of the factory south of the landfill. Tiles east of this factory were about 2 feet deep with a total flow estimated at 5 gpm on June 19, 1969. A tile located immediately north of the factory was broken during the spring of 1969. It was about 5 feet deep and reported to be flowing at a substantial rate when broken.

Figure 6 shows vertical sections across the filled area with lithology and equipotential lines. Section A-A' shows predominantly lateral movement with a downward component through the surficial sand and a nearly vertical gradient downward through the underlying till. This high downward gradient through the glacial drift may reflect the lowering of ground water potentials in the underlying dolomite aquifer by pumping at the industrial plant immediately north of the site. Section B-B' shows the influence of Kress Creek on the configuration of the flow system along the east side of the landfill.

QUANTITATIVE EVALUATION. Infiltration into the DuPage County landfill was calculated by the method described by Williams and Lohman (1949, p. 127-129). This method is based on the premise that the cumulative annual

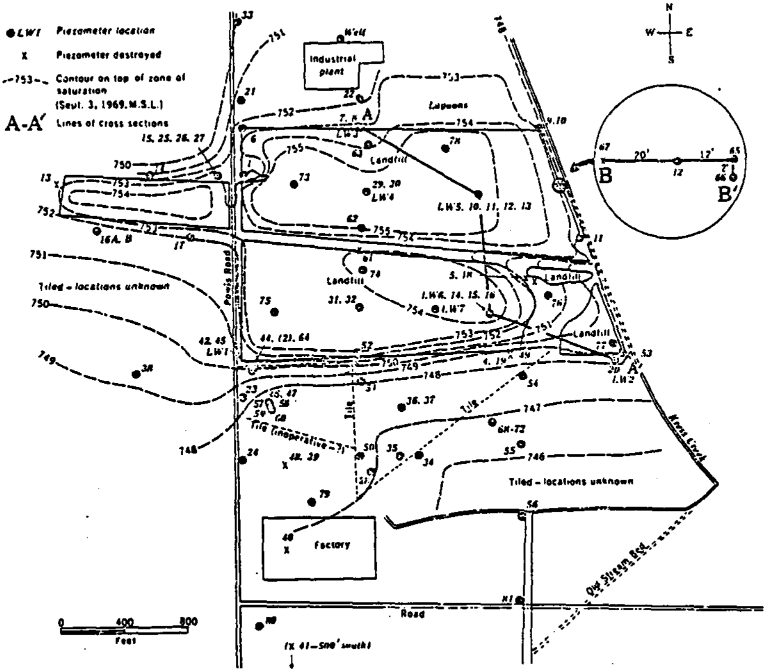

Figure 5. Plan view of the old Du Page County landfill and surrounding area, showing locations of borings and the contours of the top of the zone of saturation. A ground water mound 6 feet high has developed beneath the landfill, and ground water movement is away from the landfill in all directions.

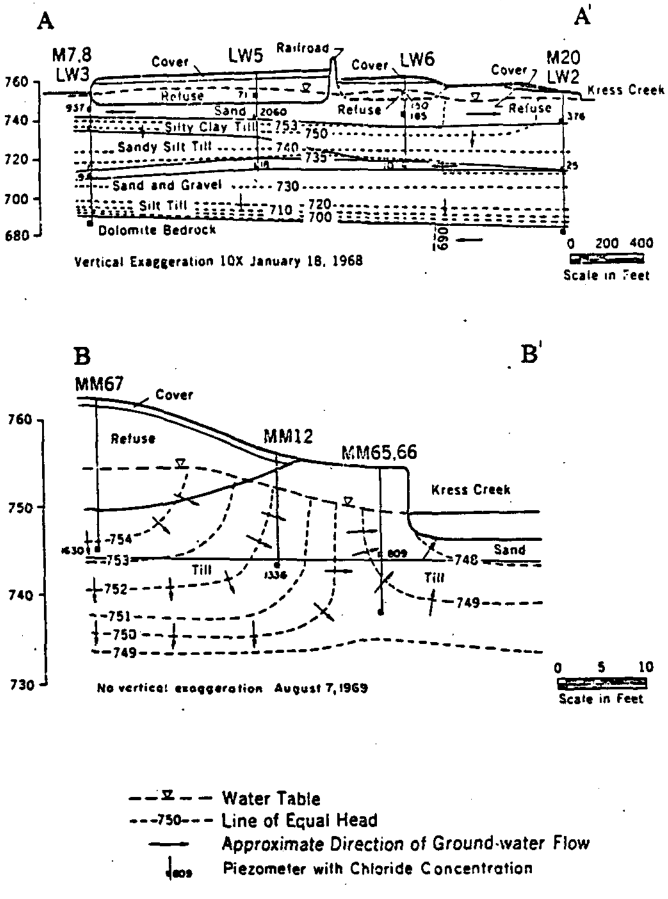

Figure 6. Verticle sections across the filled area of the old Du Page County landfill with lithology and equipotential lines. Section A-A' shows predominantly lateral ground water movement with a downward component through the surficial sand and a nearly verticle gradient downward through the underlying till. This high downward gradient through the glacial drift may reflect the lowering of ground water potentials in the underlying dolomite aquifer by pumping. Section B-B' shows the influence of Kress Creek on the configuration of the flow system along the east side of the landfill.

rise at the top of the zone of saturation, multiplied by the specific yield of the materials involved, represents the annual ground water recharge. Discharge occurring concurrently with recharge is not considered, but the error is probably not significant in the present study.

Infiltration calculated by this method was 90,000 gpd. Of the 28.58 inches of rain that fell from October 1, 1968, through September 30, 1969, approximately 15.6 inches infiltrated. This is higher than the percentage measured in a British study (Ministry of Housing and Local Government, 1961, p. 11), in which approximately 40 percent of precipitation was reported to have infiltrated.

Discharge from the landfill was calculated to be 100,000 gpd, 87,000 gpd moving laterally through the surficial sands and 13,000 moving downward through the till beneath the landfill. Water discharging as springs has not been considered. As discussed in appendix G much of the laterally moving water also moves downwards through the glacial till outside the margins of the landfill. The figure obtained for infiltration into the landfill is 10,000 gpd lower than the obtained for discharge from the landfill. This discrepancy does not mean that more water leaves the fill than infiltrates but reflects inaccuracies in our data. The figure obtained for infiltration, 90,000 gpd, is more accurate. This is discussed further in appendices F and H.

The velocity of fluid moving through the surficial sand south of the fill was calculated to be approximately 60 feet per year. The reliability of these velocity calculations is discussed in appendix H.

WATER QUALITY. Figure 7 presents selected chloride concentrations in the surficial deposits in the vicinity of the old DuPage County landfill. Chlorides were selected to illustrate the migration of dissolved solids from the landfill because they are an excellent tracer; that is, they are not readily attenuated during migration, and since a reasonable quantiative analysis of chlorides is relatively simple, a large amount of data on the distribution of this element was gathered. These data show a general decrease in the chloride concentration with distance from the landfill.

Chlorides have moved at least 600 feet but not more than 900 feet southward from the landfill. The landfill along this side when sampled was about 11 to 16 years old. On the assumption that chlorides move at a velocity of 60 feet per year (appendix G) time has been adequate for them to have migrated this distance.

Road salt is believed responsible for the high chloride values in MM 33 and MM 80, inasmuch as these wells are adjacent to the road.

Water from the broken tiles south of the landfill has a chloride content of 90 ppm. These tiles are apparently collecting some leachate from the landfill; however, because they are shallow and do not fully penetrate the surficial sand they would not completely block the southward migration of all the leachate.

Table 16 lists the wells that best illustrate the movement or lack of movement of chloride from the landfill into the till underneath the landfill. It appears that chlorides have reached LW 15 and LW 16, which are 4.3 and 2.6 feet respectively below the landfill (LW 10 has a leaky seal), but have reached none of the other wells. These data are discussed in more detail in the section on geochemical studies.

According to our hydrogeologic data approximately 4.5 x 10^4 gpd of water is moving out of the east side of the landfill (fig. 6, cross section B-B'). If this water contains 809 ppm chloride as is present in MM 65 and it all enters Kress Creek to be diluted 39 times (appendix G), it would raise the chlorides in Kress Creek by about 20 ppm. This has not occurred, because as shown in figure 6, only part of the leachate that leaves the east side of the landfill moves into the creek.

A few wells were sampled on November 11, 1967, and again on February 19, 1969. Only in MM 12 was an appreciable change in water quality noted. In this case the concentration of dissolved solids rose.

WINNETKA LANDFILL

GENERAL DESCRIPTION. The Winnetka landfill is located in Cook County in SE¼ sec. 19, T.42 N., R.13 E., on Willow Road east of

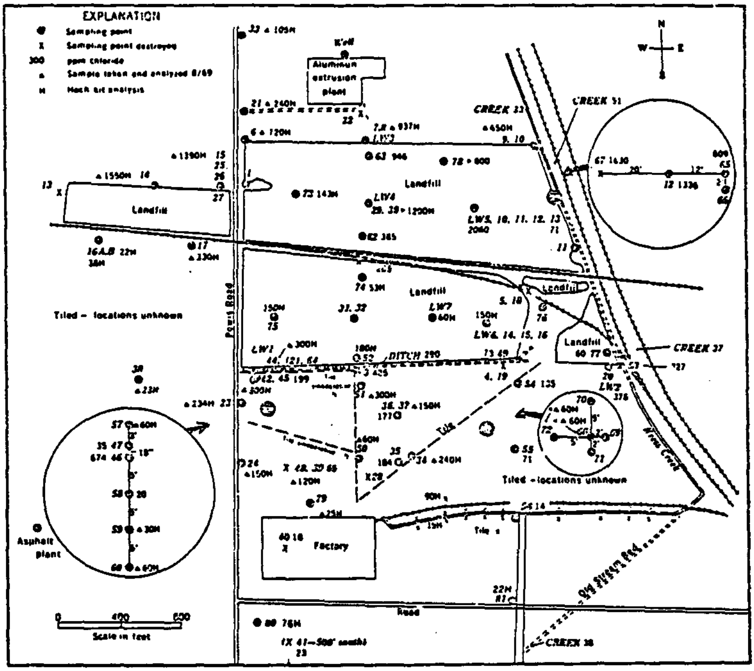

Figure 7. Selected chloride concentrations in surficial sand and gravel at the old Du Page County landfill. Quantitative analyses of this tracer material indicate the migration of leachate; that is, there is a general decrease in chloride concentrations with increasing distance from the landfill.

the Skokie River. The topography is flat and the elevation is 620 feet above sea level. The landfill itself is the highest point in the vicinity. Figure 8 is a map of the area, with an east-west cross section showing the topography and general geologic sequence.

Filling was begun in January of 1947, and the landfill is still operating. Figure 9 shows the history of the various parts of the fill. With the exception of the southwest corner, which was used for materials such as bricks and concrete, and some ash in the western third, the area was used for the disposal of household refuse, grass, leaves, and commercial packaging. Filling was done in trenches, 5 to 6 feet deep, the refuse being piled 6 to 8 feet above the original land surface in two lifts.

The cover materials consist of clay loam, loam, and sandy loam. Weeds cover most of the fill surface, which is relatively flat, poorly drained, and has steep slopes at the edges. During the winter of 1968-1969 a dike was constructed on the top of the landfill along the east side.

A simple sequence of geologic materials is present at the Winnetka site. From the surface down, it is as follows:

Cover on landfill–1½ to 3 feet of clay loam, loam, and sandy loam.

Topsoil adjacent to landfill–1½ to 4½ feet of silt loam and loam, some cinders and roadfill from construction.

Alluvium–sandy clay and silt–5 to 11 feet thick (thins to the west) with minor amounts of silty sand and gravelly sand; probably of alluvial origin and related to flooding by the Skokie River.

Transition zone–5 to 6 feet thick, interbedded fine sand, silt, and silty clay.

Tills–silty clay till 96 to 100 feet thick, sandier and stonier at depth.

Sand and silt–thin interbedded sand and silt stringers, gravelly in places; less than 2 feet thick; commonly 6 inches to 1 foot thick interbedded with the till; cannot be correlated from one boring to another with certainty; response to pumping also indicates short lateral extent.

Bedrock–fractured dolomite of Silurian age; a major aquifer in the area.

HYDROGEOLOGIC ENVIRONMENT. Figure 10 is a plan view of the fill and surrounding area, showing the location of the borings with contours of the top of the zone of saturation.

As at the DuPage County landfill, a ground water mound approximately 8 to 10 feet high has formed below the filled area. The slope on the west side of this mound is steep, showing the influence of the deep sewer line. The slope is less abrupt on the southeast part of the fill in the more recent refuse.

Cross sections of the filled area, showing the lateral and downward flow through the surficial alluvium and downward gradients through the underlying till, appear in figure 11. Minor sand and silt beds within the till section are not shown, because they cannot be correlated from boring to boring.

The location of the sewer on the west side of the filled area is shown on cross section B-B'. This sewer distorts the flow system and serves as a collector for part of the water moving from the west side of the landfill.

A series of piezometers (MM 15-23 inclusive) were installed west of the southwest corner of the Winnetka landfill to determine whether fracturing could be detected in the tills. Each of these installations was completed and sealed in the same manner, and slug tests were run on each. The permeability values obtained should be high for any of these piezometers open to fractures. No firm evidence of fracturing was obtained in these wells, nor in any of the other sealed piezometers which were installed in the tills during this project.

QUANTITATIVE EVALUATION. Infiltration into the Winnetka landfill was calculated to be 28,300 gpd. Of the 35.20 inches of rain that fell from October 1, 1968, to September 30, 1969, approximately 15.6 inches infiltrated.

Discharge from the landfill was calculated to be 31,800 gpd, 30,000 gpd of this moving laterally through the alluvium and 1,800 gpd moving downward through the till beneath the landfill. As discussed previously, the higher figure obtained for discharge reflects inaccuracies in our data.

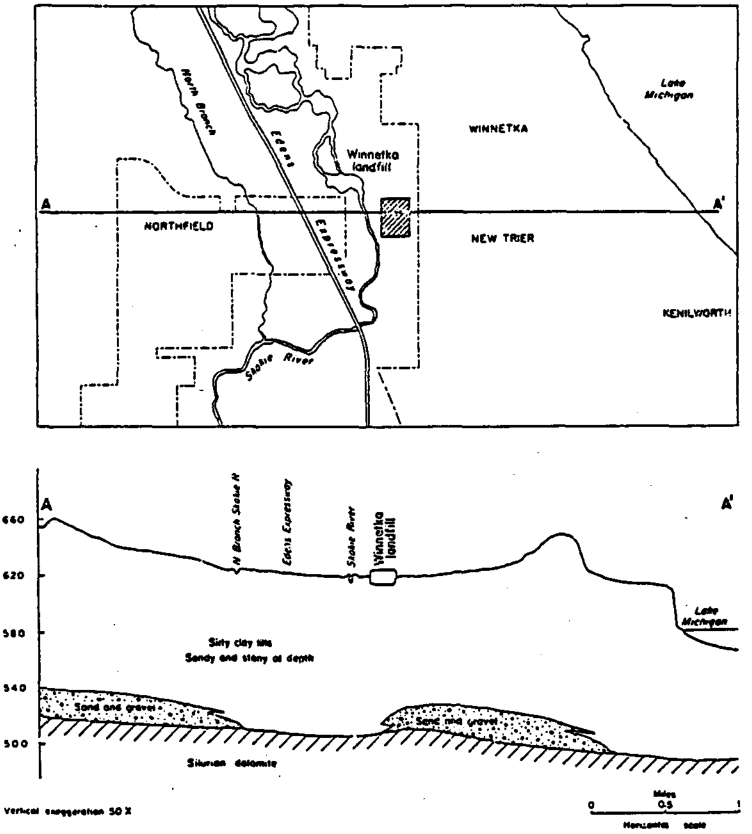

Figure 8. Map of the general area of the Winnetka landfill (top), and east-west cross section A-A' (bottom) showing the topography and general geologic sequence.

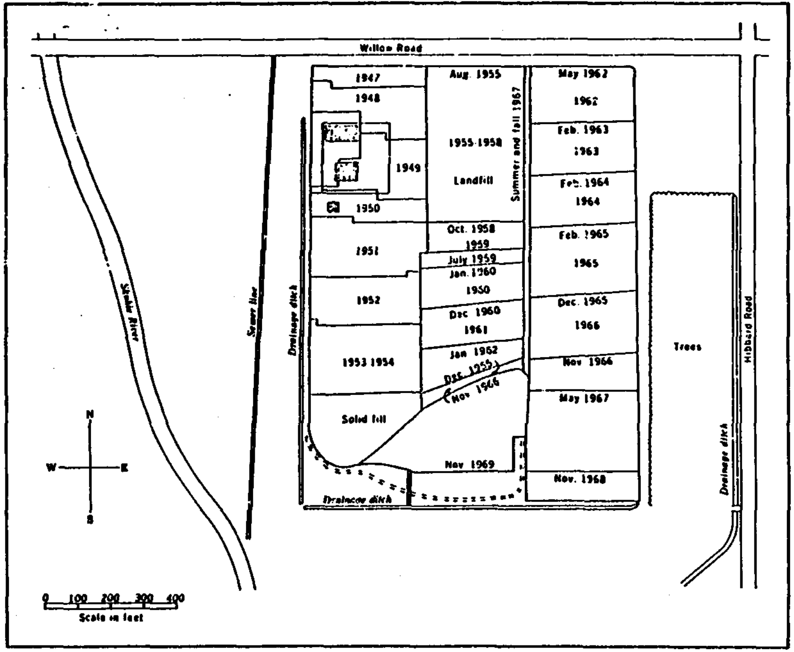

Figure 9. History of filling at the Winnetka landfill from the beginning, in 1947, to the present. With the exceptions of the southwest corner, which was used for materials such as bricks and concrete, and of the western third, which contains some ash, the area was used for the disposal of household refuse, grass, leaves, and commercial packaging. Filling was done in 6-to-6 foot deep trenches, the refuse being piled 6 to 8 feet above the original land surface in two lifts.

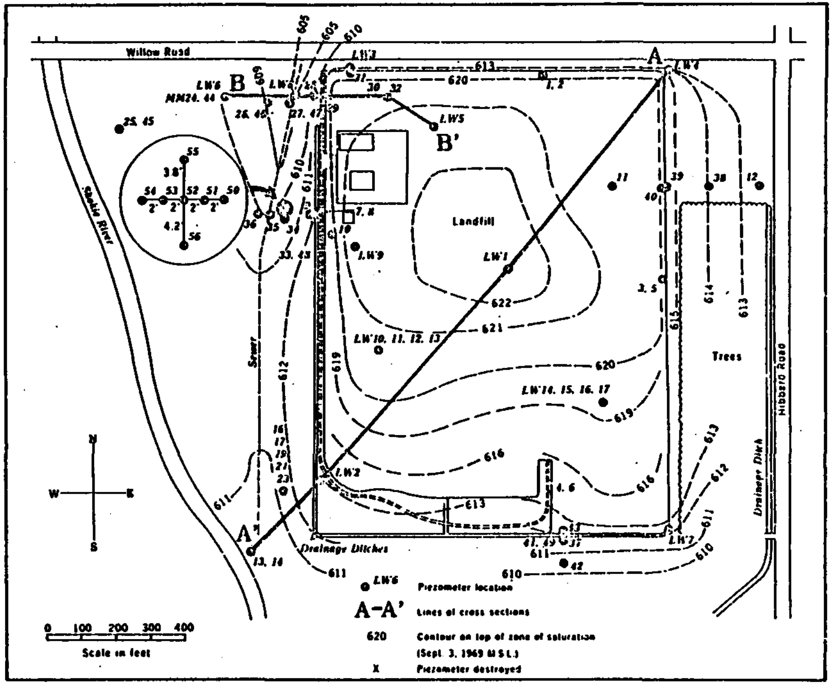

Figure 10. Plan view of the Winnetka landfill and surrounding area, showing locations of borings and the contours of the top of the zone of saturation. A ground water mound about 8 to 10 feet high has formed beneath the landfill, and ground water movement is away from the landfill in all directions.

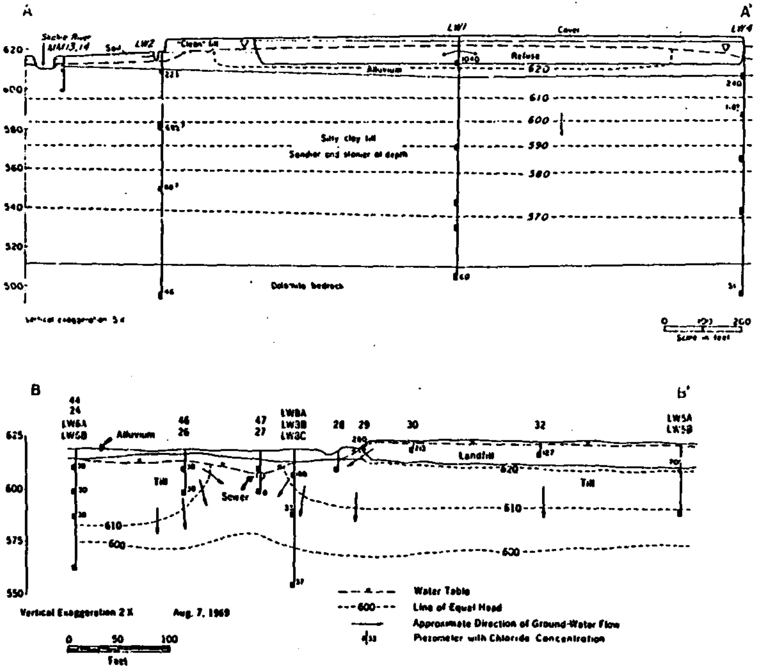

Figure 11. Cross sections A-A' (top) and B-B' (bottom) of the filled area of the Winnetka landfill, showing the lateral and downward flows of ground water through the surficial alluvium and downward gradients through the underlying till. Minor sand and silt beds within the till section are not shown, because they cannot be correlated from boring to boring. The location of the sewer on the west side of the filled area is shown on cross section B-B'. This sewer distorts the flow system and collects part of the water moving from the west side of the landfill.

The velocity of the water moving laterally through the alluvium was calculated to be approximately 85 feet per year at the edge of the landfill where gradients are steepest.

WATER QUALITY. Figure 12 shows the chloride concentrations in water from the surficial alluvium in the vicinity of the Winnetka landfill. As at the old DuPage County landfill these data show a general decrease in chloride concentration with distance from the landfill. A reasonable value for the velocity of chloride migration through the surficial alluvium along the north, east, and west sides of the landfill is 85 feet per year, and at this velocity time has been adequate for dissolved solids from the landfill to reach MM 25, 36, and 12. The velocity along the southern edge of the landfill, where the ground water gradient is lower, is approximately 50 feet per year, a rate adequate for chlorides to have reached MM 6, but apparently not MM 43. It is believed that the relatively high chloride values in MM 37 and LW 7 are from polluted water migrating south from a ditch along the south side of the landfill. This ditch contained polluted storm water pumped out of the landfill trenches during filling operations.

Data gathered west of the landfill in the vicinity of LW 8 indicate that the sewer is acting as an interceptor for the shallow ground water. Wells west of MM 9 contain little chloride. The permeability of the alluvium is lower in this area (appendix F), and this indicates finer textured sediments and consequently a greater attenuation of the chlorides moving through them.

Table 17 lists the wells that best illustrate the movement or lack of movement of chlorides from the landfill into the till beneath the Winnetka landfill. Large concentrations of chlorides are present in LW 9A, LW 10A, and LW 12.

We have no reason to suspect that leachate is leaking down the annulus of Winnetka LW 10A, and we must therefore assume that a reliable sample was obtained and that chlorides have migrated to this depth through 18.8 feet of alluvium and transition zone and 14.5 feet of till. The rate of movement of chlorides through the till appears to be greater here than at the old DuPage County landfill and could be approximately 1 foot per year or more. A more exact estimate is not possible without knowledge of the rate of travel through the transition zone and alluvium, which might contain localized channels of high permeability.

The presence of large concentrations of chlorides in LW 9A is more difficult to explain. The following possibilities exist:

(1) This hole was drilled with air. During the drilling the annulus was plugged and air pressure built up enough to fracture the ground and force air (or methane) to the ground surface up to 20 feet away from this boring. These fractures could allow downward migration of leachate into this sampling point.

(2) The seal leaks or the pipe is broken.

LW 12 is 0.9 foot below the top of the till and is separated from the refuse by a total of about 9 feet of alluvium and "transition zone," a unit containing fine sand stringer. Since the landfill is 16 years old at this point it is not surprising that chlorides have migrated this far.

A few wells were sampled on December 4, 1967, and again on February 25, 1969. In some of these the quality of water changed appreciably. LW 8A and 9A showed an increase in chlorides, sulfate, calcium, magnesium, and hardness, and LW 8B showed an increase in chlorides. These wells should be resampled before we attribute these increases to the migration of leachate.

Explanation of the water quality data at this site requires more speculation than we would like. It is hoped that subsequent studies will confirm the conslusions we have drawn.

ELGIN LANDFILL

GENERAL DESCRIPTION. The Elgin landfill is located in Kane County, in SW¼ sec. 35T. 42 N., R8E., off the Frontage Road north of the Northwest Tollway, on the west side of the Fox River

The elevation at the fill is approximately 750 feet above sea level, and the ground surface slopes to the south and east towards the Fox River. Figure 13 is a map of the general area of the landfill with an east-west cross section showing the sequence of materials and topography.

The site was originally a gravel pit. A berm of tailings from this operation forms the eastern side of the landfill, and other trenches and berms are present in the northeastern part of the

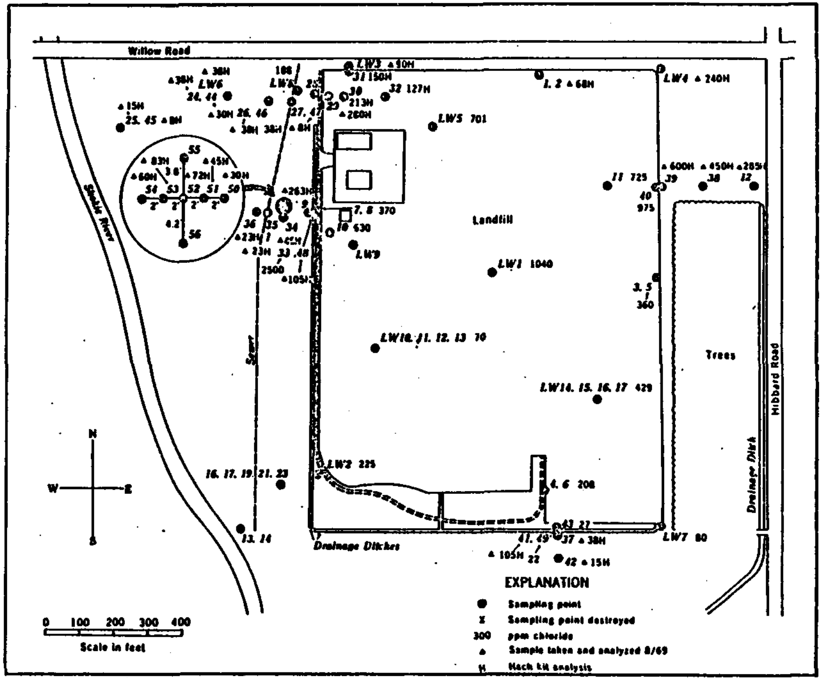

Figure 12. Selected chloride concentrations in the alluvium at the Winnetka landfill. Quantitative analyses of this tracer material indicate the migration of leachate; that is, there is a general decrease in chloride concentrations with increasing distance from the landfill.

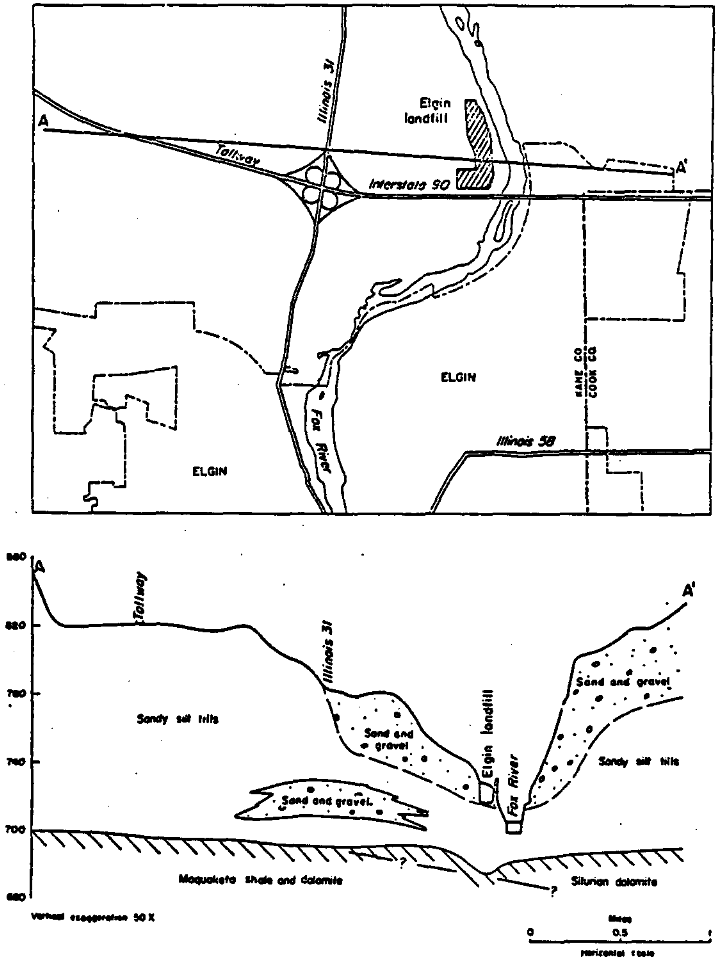

Figure 13. Map (top) of the general area of the Elgin landfill, and an east-west cross section A-A′ (bottom) showing the topography and the sequence of materials.

site.

Filling was begun in 1948, and the site was operated as an open burning dump, primarily in the western half of the area. Recent excavation in this part of the fill exposed approximately 3 feet of ash covering the original soil. In May 1964, the site was converted to a sanitary landfill, and 10- to 15-foot trenches were excavated and filled along the eastern side and the northern part of the site. More recently sections of the southwest and northern part of the site have been excavated and refilled with new refuse, the excavated ash being used for cover. In 1968 and 1969 a new lift was placed over the central and north-central parts of the landfill.

Forty percent of the fill material is reported to be household and garden refuse, and 60 percent industrial waste. Some acid waste has also been buried, and several lime sludge pits are present in various parts of the landfill.

The surface of the landfill is smoothly graded. Refuse is covered daily with loam and clay loam, and grass is planted on the older, completed parts.

Figure 14 shows the age of the refuse in various parts of the site. This map is of questionable accuracy because records were not kept in the early stages of filling, and since then, parts of the older fill have been excavated and refilled.

The sequence of geologic materials from the surface down is as follows:

Cover material on landfill--2 feet loam and clay loam with some sand, gravelly in part.

Topsoil adjacent to landfill–clayey silt to sandy silt 2 to 3 feet thick.

Sand and gravel–generally coarser textured between the landfill and the river; 8 feet thick west of the fill, 3 to 9 feet thick beneath the fill (most removed in gravel operation), as much as 20 feet thick east of the fill, and approximately 10 feet thick near the river.

Tills–several sandy silt tills 5 to 39 feet thick (generally 15 feet) underlying the sand and gravel; peat or soil zone at depth of 16 feet in the tills adjacent to the Fox River.

Basal sand and gravel–thin (2 to 5 feet) sand and gravel overlies bedrock beneath the fill; thickness 2 to 5 feet at the river to 17 feet west of the fill.

Bedrock – fractured dolomites of Silurian age beneath the site; dolomite and shale of the Maquoketa Group 5 feet at the river to 17 feet west of the fill.

Bedrock – fractured dolomites of Silurian age beneath the site; dolomite and shale of the Maquoketa Group present immediately west of the site.

HYDROGEOLOGIC ENVIRONMENT. Figure 15 is a plan view of the Elgin landfill and surrounding area, showing the location of borings and contours of the top of the zone of saturation. There is no evidence of a ground water mound at this site, and the water table slopes relatively smoothly to the east and southeast towards the Fox River.

Figure 16 shows east-west sections through the fill area. Section A-A', the northern section, shows predominantly lateral movement with a downward component, except for the area near the Fox River, where movement is upward. Section B-B', the southern section, shows upward movement dominant in the deeper till unit and lateral movement in the shallow sands. It also shows that the lower part of the refuse at LW 7 is saturated.

The Elgin site is located in the discharge area bordering the Fox River, and since the Fox River is one of the major drainages in northeastern Illinois, this is probably a major discharge area.

QUANTITATIVE EVALUATION. Infiltration into the Elgin landfill was calculated to be 66,000 gpd. Of the 26.62 inches of rain that fell from October 1, 1968, to September 30, 1969, approximately 15 inches infiltrated.

The hydrogeology at this site is more complicated than that at the old DuPage County and Winnetka sites, and the data did not warrant estimating the output from the filled area.

On the assumption that 66,000 gpd of ground water from this landfill enters the Fox River it would be diluted approximately 120 times at low flow and 7,400 times at average flow. Since low flow is likely to be accompanied by low ground water levels and therefore by low output from the fill, the higher figure for dilution is probably more representative. This appraisal does not consider that the ground water leaving

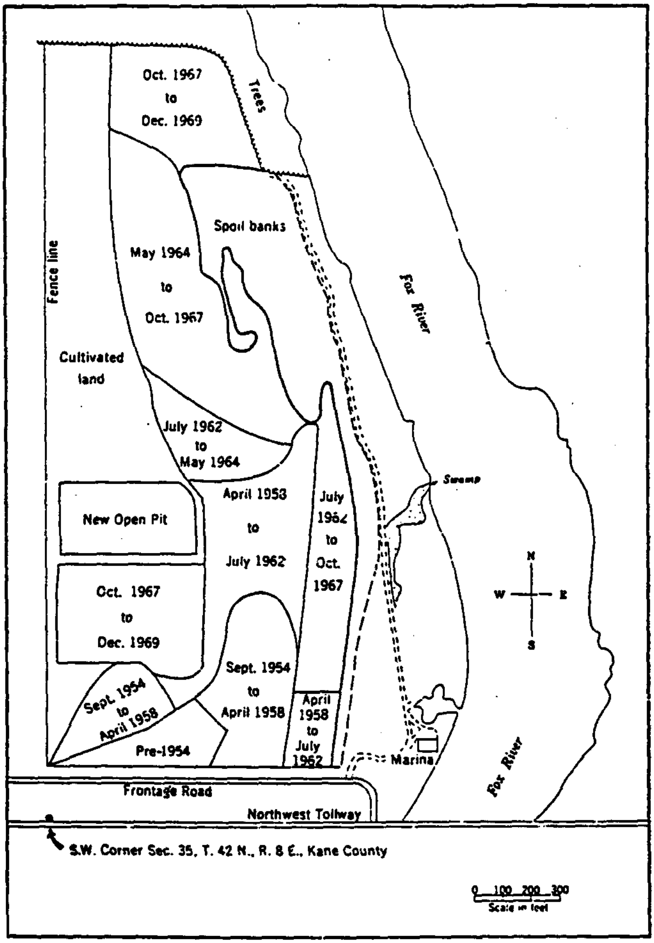

Figure 14. History of filling at the Elgin landfill. This landfill was begun in 1948 and completed in 1970. This map is of questionable accuracy because records were not kept in the early stages of filling, and since then, parts of the older fill have been excavated and refilled.

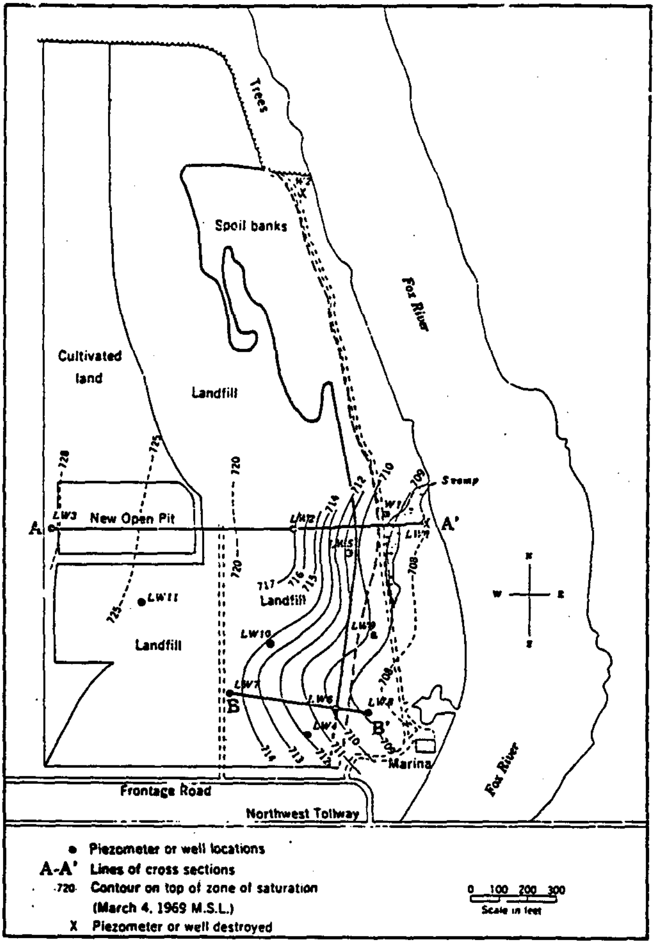

Figure 15. Plan view of the Elgin landfill and surrounding area, showing locations of borings and the contours of the top of the zone of saturation. There is no evidence of a ground water mound at this site. The water table slopes relatively smoothly to the east and southeast toward the Fox River.

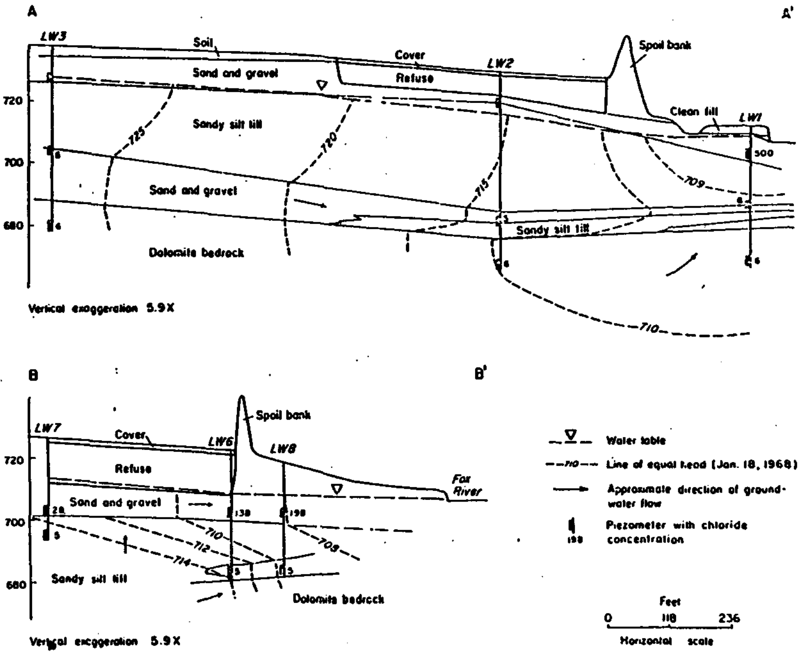

Figure 16. East-west cross sections A-A' (top) and B-B' (bottom) of the filled area of the Elgin landfill. Section A-A', the northern section, shows predominantly lateral ground water movement with a downward component, except for the area near the Fox River, where movement is upward. Section B-B', the southern section, shows upward movement dominant in the deeper till unit and lateral movement in the shallow sands. It also shows that the lower part of the refuse at LW 7 is saturated.

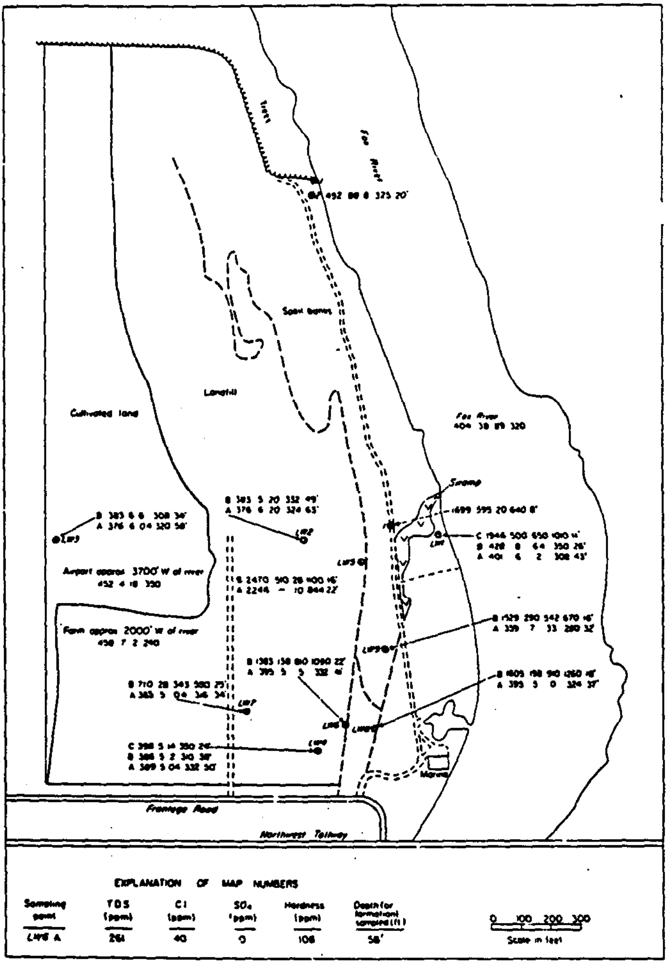

Figure 17. Water quality data for the Elgin landfill. Dissolved solids from the landfill are not present in the deeper aquifers, because ground water movement is mainly upward or lateral under the site.

the landfill has been diluted by ground water moving into the landfill from the west.

WATER QUALITY. Figure 17 shows water quality near the Elgin landfill. The correlation between distance from the landfill and the water quality is not as good as that at the other sites. This is probably because variations in the permeability of the shallow sands and gravels allow differential lateral movement.

Dissolved solids have not and cannot move downward through the tills, because ground water movement is mainly upward or lateral under the site. The anomalous quality in LW 4C, LW 5B, and LW 6B can be accounted for by leakage between piezometers in the same borehole. Unpolluted water is moving upward from LW 4B to LW 4C, and LW 5A and LW 5B are so closely spaced and poorly sealed that samples are not representative.

On the assumption that the water in LW 1C, with a total dissolved solid content of 2,000 ppm, is representative of that entering the Fox River from the landfill, it would raise the dissolved solids level in the river by approximately 0.30 (2,000÷7,400) ppm, half of which is hardness.

The data shown in figure 17 were gathered on November 28, 1967. Analyses of samples taken on February 25, 1969, show no significant changes other than an increase in dissolved solids in water from well Number 1. The significance of this increase is not known.

WOODSTOCK LANDFILL

GENERAL DESCRIPTION. The Woodstock landfill is in McHenry County in NE¼ sec. 17, T. 44N., R. 7E., south of Davis Road. The elevation of the landfill is between 920 and 940 feet above sea level. It is in morainic topography, possibly on a stagnant-ice moraine, and lies on the top and south flank of an east-west-trending linear upland and in the swampy lowland to the south of this upland. Figure 18 is a plan view and cross section of the region.

The site was first operated as an open burning dump, beginning in June 1940. It was converted to sanitary landfill in 1965, and operations are continuing. Early filling was in the swampy southern part of the area. The eastern and southeastern parts of the area are currently being filled. The material in the fill is reported to be about 40 percent household and garden refuse and 60 percent industrial refuse. Lime soda sludge is disposed of in the southern and southeastern parts of the fill area. Records of filling (figure 19) are not as reliable here as at the old DuPage County and Winnetka landfills.

Daily cover material is at least 6 inches thick with a final cover of 2 to 3 feet. Cover over most of the fill is loam, silt loam, silty clay loam, and sandy loam. The present landfill surface at the base of the upland is gently undulating, with patches of weeds and grass. The upland part of the landfill has a more irregular surface.

The sequence of geologic materials, from the surface downward is as follows:

Cover on landfill—approximately 2 feet of loam, silt loam, sandy loam, and silty clay loam, gravelly in part.

Topsoil adjacent to landfill—1 to 2 feet of loam and sand at northern end; 1 to 4 feet of silty clay over the reamainder of the site.

Swamp—peat and nonorganic silts (5 to 19 feet thick) in marshy areas around and below most of southern two-thirds of the site; thickest in the field between the landfill and the Kishwaukee drainage west of the site.

Sand and gravel—5 to 19 feet of sand and gravel generally becoming finer textured at base; sand and gravel and sandy silt till deposits present on the higher land at northern end of site; exposures indicate probable ice contact origin.

Upper till—3 to 25 feet (generally 20 feet) of silty clay till, thinner below the landfill.

Lower tills—several silty, sandy tills present to a depth of at least 225 feet at LW 1.

Interbedded sands and gravels—sand and gravel deposits commonly 5 feet or more thick, interbedded with silty sandy tills. A few of these deposits can be correlated between borings, but most cannot and are probably of limited areal extent.

Soil—3 to 5 feet soil zone encountered in two borings at a depth of 165 to 167 feet.

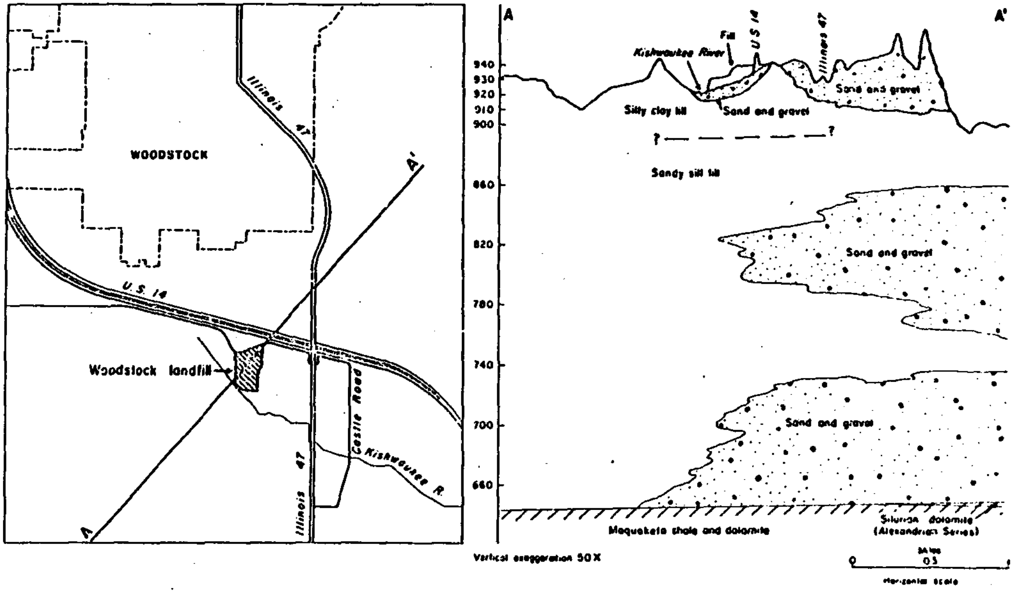

Figure 18. Map (left) shows the general area surrounding the Woodstock landfill. Cross section (right) shows the topography and general geologic sequence of the area between A and A′ on the map.

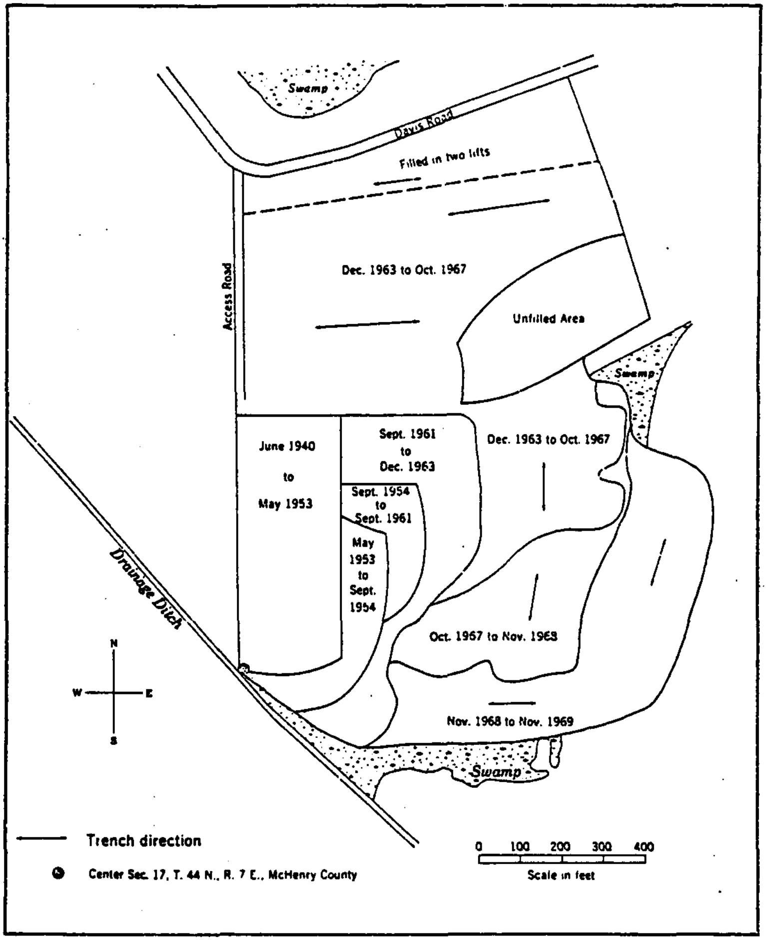

Figure 19. History of filling at the Woodstock landfill. The site was first operated as an open burning dump, from 1940 to 1965. In 1965 it was converted to sanitary landfill, and operations are continuing.

Bedrock–not encountered, but from nearby well information, it is probably at a depth of more than 225 feet and consists of shales and dolomites of the Maquoketa Group.

HYDROGEOLOGIC ENVIRONMENT. Figure 20 is a plan view of the landfill and surrounding area, showing the location of the borings and contours of the top of the zone of saturation. Gradients are away from the upland in the northern part of the landfill in all directions. In the older part of the filled area, the gradient is southward to swampy areas bordering the landfill or to the drainage ditch west and southwest of the landfill. Some influence of the landfill is shown by a steepening of gradients on the southern edge; this indicates that a small ground water mound lies below the landfill.

Figure 21 shows vertical sections across the filled area. A strong component of lateral flow in the shallow materials above the silty clay till is evident, as is a vertical gradient in the silty clay till.

A number of interbedded sands and gravels have not been shown on the Woodstock cross sections. These deposits are generally more permeable and thicker at Woodstock than at Winnetka and would tend to magnify any horizontal component of flow.

The drainage ditch west of the landfill area acts in much the same manner as the deep sewer at Winnetka, distorting the flow system and "collecting" the ground water moving from the western side of the landfill.

QUANTITATIVE EVALUATION. Infiltration into the Woodstock landfill was calculated to be 22,500 gpd. Of the 24.07 inches of rain that fell from October 1, 1968, to September 30, 1969, approximately 12 inches infiltrated.

No quantitative evaluation of flow from the Woodstock site was made, because of the complex geology and lack of data on the hydrologic properties of the materials.

The flow in the drainage ditch was estimated to 1 x 10^6 gpd, which allows dilution by about 45 times. This calculation does not include the water moving downward below the landfill area or dilution of the ground water leaving the landfill between the landfill and the ditch; it therefore minimizes the figure for dilution.

WATER QUALITY. Water quality data plotted in figure 22 show the expected inverse relationship between total dissolved solids and distance from the fill, with the exception of data from LW 2E, which is shallow, very close to the fill, and apparently unaffected. MM 6 does not show large dissolved solid content; however, the landfill upgradient from this point is relatively new and there may not have been adequate time for the leachate to move this distance.

There is no evidence of downward movement through the silty clay till at LW 3 or LW 5. Whether this is because the till has acted as a barrier to the migration of dissolved solids or whether inadequate time has elapsed is not known.

Analyses of water in the drainage ditch on January 18, 1968, and February 24, 1969 (table 6) show larger contents of chlorides opposite MM 9 than opposite MM 10. This could well be a result of ground water's containing dissolved solids from the landfill moving into the ditch, but in view of the larger concentrations of chlorides both upstream and downstream in this same ditch, the evidence is inconclusive.

Table 18 lists the wells that best show downward movement of contaminants. It is not known why LW 1B is not contaminated and LW 6A is. LW 3D is separated from the landfill by 20.5 feet of till, and data from other sites would not lead us to expect leachate in this well.

The data shown in figure 22 were gathered on November 21, 1967. Analyses of samples taken on February 25, 1969, showed the following changes:

(1) In MM 7, large increases in alkalinity, chloride, and sodium (by difference).

(2) In LW 1D large increases in alkalinity, calcium, and sodium (by difference) and decreases in magnesium.

These variations could reflect seasonal changes or long-term trends.

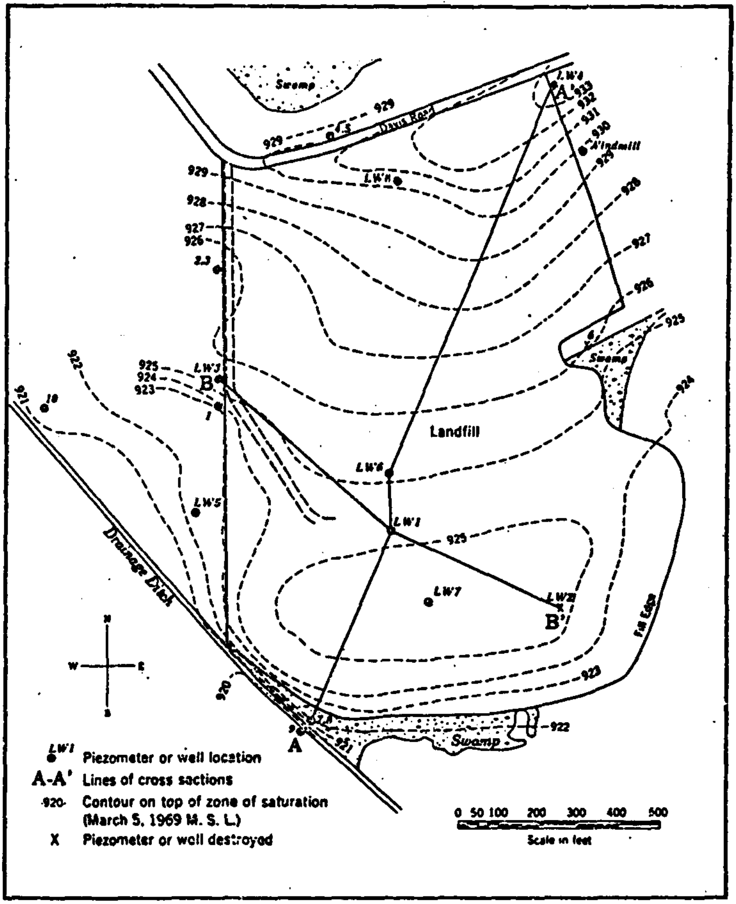

Figure 20. Plan view of the Woodstock landfill and surrounding area, showing locations of borings and the contours of the top of the zone of saturation. Gradients are away from the upland of the northern part of the landfill in all directions. In the older part of the filled area, the gradient is southward to swampy areas bordering the landfill or to the drainage ditch west and southwest of the landfill. Some influence of the landfill is shown by a steepening of gradients on the southern edge. This steepening suggests that a small ground water mound lies beneath the landfill.

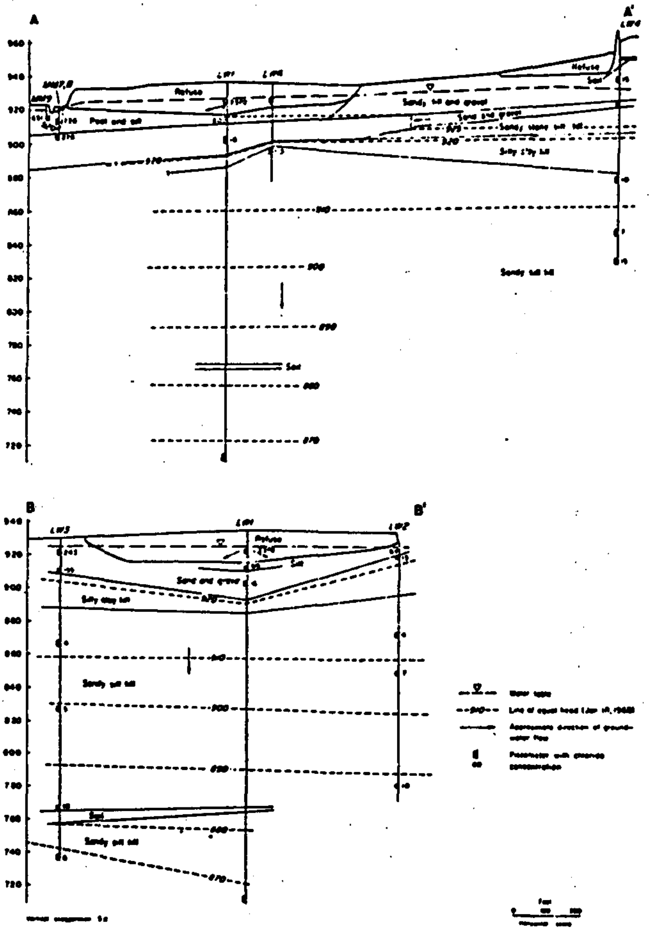

Figure 21. Cross section A-A' (top) and B-B' (bottom) of the Woodstock landfill with selected chloride concentrations. A vertical gradient in the silty clay till and a strong lateral flow of ground water in the shallow materials above the till are evident. Ground water discharges into the drainage ditch near MM 7 and MM 8, cross section A-A'.

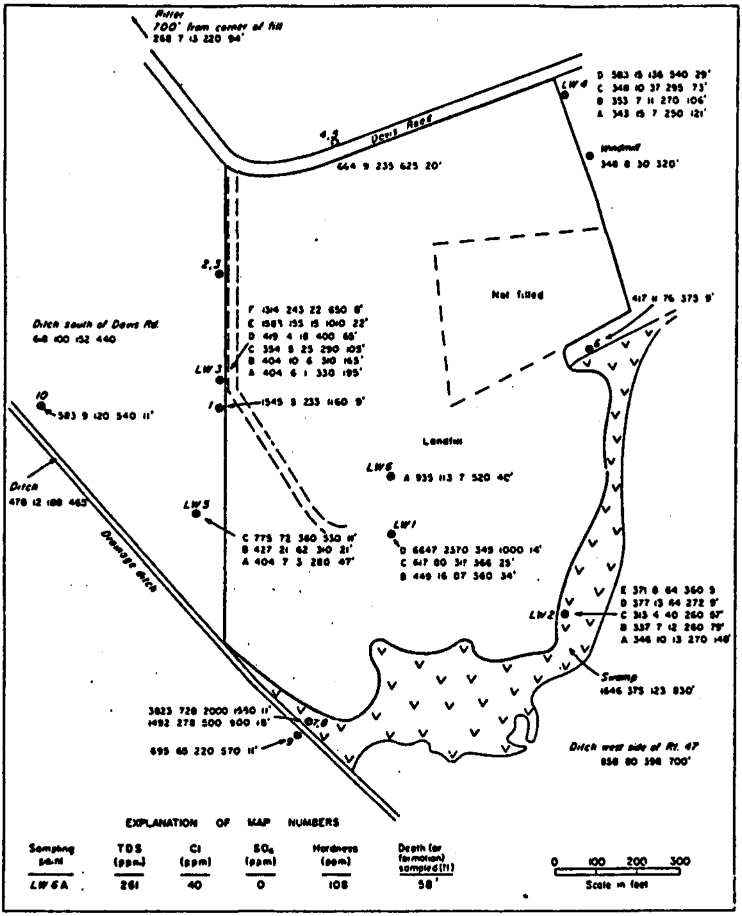

Figure 22. Water quality data for the Woodstock landfill that were gathered on November 21, 1967. The data show the expected inverse relationship between total dissolved solids and distance from the till, with the exception of data for LW 2E, which is shallow, very close to the fill, and apparently unaffected. For unknown reasons there is no evidence of downward movement of ground water through the silty clay till at LW 3 or LW 5.

BLACKWELL FOREST PRESERVE LANDFILL

Studies of the Blackwell Forest Preserve landfill (fig. 2), located about 5 miles southeast of the old DuPage County landfill, are based on data collected at a single well. This landfill was begun in October 1965 and is to be made into a winter sports hill that will eventually be approximately 150 feet high and cover an area of 30 acres. At the time the sample was collected, the refuse had been in place for approximately 39 months.

The base of the landfill is lined with 10 feet of silty clay till, and 15-foot berms are being constructed along the sides that will completely enclose the refuse. The sampling well is constructed of 5- and 6-inch slotted casing and when sampled penetrated approximately 38 feet of refuse to bottom about 3 feet above the basal liner.

At the time of sampling there was about 5 feet of water in this well. This water rises or falls in response to rainfall and is probably at least partly derived from infiltration. Inasmuch as the well was constructed as part of the investigation of water quality, the results are discussed in that section of this report.

RESULTS AND INTERPRETATION OF SPECIFIC YIELD AND INFILTRATION CALCULATIONS

It was necessary to obtain a value for the specific yield of refuse before the amount of infiltration into the landfills could be calculated. This is discussed in detail in appendix E. Infiltration and specific yield data from the four major sites are presented in table 19. The wells involved had continuous or weekly hydrographs over the period from October 1, 1968, to September 30, 1969, and the data apply to this period. Because of the short time involved, conclusions based on these data are preliminary.

The cumulative hydrograph rise is the sum of all of the water level rises in a particular well that have resulted from recharge. The specific yield values calculated from the hydrographs apply to the materials through which the water level rose.

The total recharge was calculated by multiplying the cumulative rise in hydrograph by the specific yield. There is considerable variation in the total recharge values. These variations reflect differences in the surface drainage near the particular well, and moisture conditions in the refuse above the top of the zone of saturation.

According to Remson and coworkers (1968, p. 312) in Pennsylvania, it should require approximately 3 inches of rain to raise the initial moisture content of 1 foot of refuse to field capacity. With the assumption that the recharge figures in table 19 are correct, about 12 to 16 inches of rain infiltrates the landfills in northeastern Illinois each year, and from Remson's data this is sufficient to bring 4 to 5 feet of refuse to field capacity each year. The hydrographs show that recharge has occurred at Winnetka LW 17, Woodstock LW 8, and at the Blackwell well, and, since the refuse at these locations should not as yet have been brought to field capacity, this is evidence of precipitation channelling through the refuse.

The year the refuse was emplaced is probably correct to within 6 months for the old DuPage County and Winnetka sites. Errors in landfill age of as much as 5 years are, however, possible in parts of the Elgin and Woodstock landfills.

The barometric efficiency "can be interpreted as a measure of the competence of the overlying confining beds to resist pressure changes" (Todd, 1959, p. 161). There does not appear to be any relationship between the grain size analysis of the cover materials (table 4) and the barometric efficiency.

The last two columns of table 19 bring out the following: (1) The hydrographs of wells DuPage LW 13, Woodstock LW 8 in young (1963 or younger) unburned refuse are less sensitive and show lower recharge. Full field capacity may not have been reached in the refuse associated with these borings. (2) The specific yield of wells in ash and burned refuse is variable. This may reflect erratic deposition in open burning dumps.

Figure 23 is a plot of specific yield versus refuse age. The close relation of wells completed in refuse is not surprising if we consider that the refuse at the old DuPage County and Winnetka landfills is buried in very similar environments. The specific yield of materials other than refuse (Elgin LW 7B, Elgin LW 4D, Woodstock LW 7) is not related as closely to age.

Specific yield is a measure of the part of the porosity that is subject to gravity drainage. It does not include specific retention, which is the part of the porosity containing water that will not drain by gravity. Specific retention is equivalent to field capacity, which according to Remson (1968, p. 309), is about 29 percent for refuse in Pennsylvania. Our work (appendix E) indicates that the field capacity is approximately 35 percent.

We interpret the curve in figure 23 in the following manner. The steeper, poorly defined part of the curve represents decomposition of the younger refuse containing easily degraged organics. The well-defined flat part of the curve for refuse more than 5 to 9 years old represents the more nearly uniform decomposition of the less easily reduced components of the refuse. The older refuse appears to lose about 1.2 to 1.3 percent of its specific yield each year.

This curve and the foregoing explanation are presented with some reservations, because the data on which they are based need substantiation by further investigation.

GROUND WATER MOUNDING

Ground water mounds formed beneath the old DuPage County, Winnetka, and Woodstock landfills. We believe that these mounds develop for the following reasons: Consider only water moving out of the landfill area. The quantity, Q, of water moving is, according to Darcy's law: Q = PIA (appendix H). If a mound has formed, I, the gradient has increased, and according to Darcy's law if I increases, either P, the permeability of the materials the water moves through, must decrease, or Q, the amount of water moving out of the fill, must increase, or both must change. We consider that the increase in A, the area through which the water moves, caused by the ground water mound is neglibible.

The most likely explanation for the decrease in P (permeability) would be that it is caused by scarification, reworking, and compaction of the materials around the sides and bottom of the landfill during its construction.

The necessary increase in Q may be caused by the following: (1) the fill cover's being more permeable than the surface materials adjacent to the fill, allowing increased infiltration and therefore discharge or (2) less evapotranspiration's occurring over the landfill because the top of the zone of saturation is deeper there than in the adjacent areas.

We believe that at the sites we studied the decrease in permeability around the fill margins is the major cause of the ground water mound. At the Elgin site no mound is apparent, despite the fact that infiltration is similar to that at the other sites. We believe that this is because the permeability of the materials around the site was initially very high and was not appreciably lowered during construction at the landfill. It would appear, therefore, that infiltration would have to be exceptionally large or small to affect the formation of a mound.

The presence of a ground water mound is conclusive evidence that (1) there is infiltration through the landfill surface and leachate is being produced and (2) there is a vertical component of ground water flow.

SUMMARY
HYDROGEOLOGIC INVESTIGATION

Hydrogeologic studies of four sites showed that approximately one-half of the annual precipitation had infiltrated landfills in this area to produce refuse leachate. This water moved away from the disposal site through glacial till materials with very low permeability at a velocity of 1 foot per year or less. The study also demonstrated that ground water levels below disposal sites could rise to form a ground water mound and that, at the intersection of this

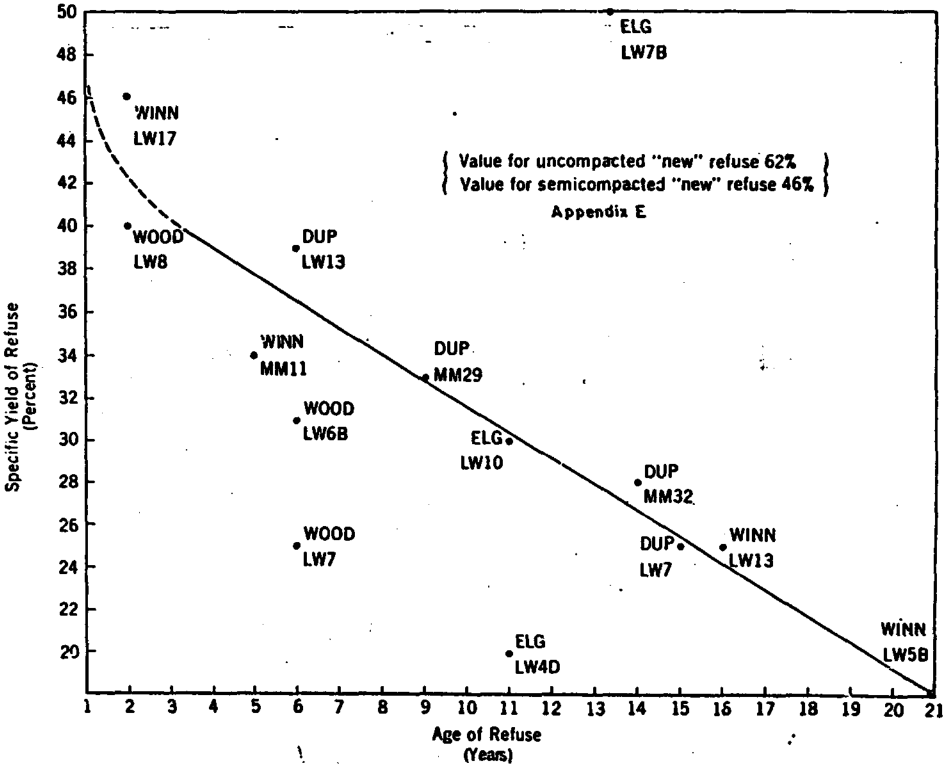

Figure 23. Relationship between age of landfill at the four major sites studied and specific yield of refuse (a measure of the part of the porosity that is subject to gravity drainage).

mound and the ground surface, springs and seeps of leachate would form.

Measurements of the specific yield of refuse showed an inverse relationship between specific yield and age of refuse. This appears to reflect "compaction" of the refuse with time (approximately 1.2 to 1.3 percent per year in the older refuse), which we attribute to decomposition of, first, the easily degradable organics, and later, of the more stable components of the refuse.

GEOCHEMICAL STUDIES OF LEACHATE, GASES, AND EARTH MATERIALS

COMPOSITION OF LEACHATE FROM THE REFUSE

One of the conclusions we have reached in this investigation is that leachate analyses are extremely variable and that interpretations based on a single analysis may be seriously misleading. Time and funds were not available for running duplicate analyses of all the minor elements, and this should be kept in mind when specific water quality data presented in this report are used. Major conclusions are, however, based on confirmed results.

Table 20 compares refuse leachate with industrial wastes and sewage and with the drinking water standards published by the Public Health Service of the U.S. Department of Health, Education, and Welfare in 1962. Raw refuse leachate sometimes contains larger than acceptable concentrations of barium, chromium, selenium, and possibly arsenic. It compares in dissolved inorganics with chemical plant wastes and in organic content with food-processing plant effluent.

Although the quality of refuse leachate is objectionable, it is fortunate that the amount produced is relatively small.

Table 9 presents the detailed chemical analyses of the leachate at the various sites. Most of the analyses on this table were run by Tenco Hydro/Aerosciences, Inc.; however, some data by the State Geological Survey and the Department of Public Health are also included. With the exception of the analyses for bromine, these additional analyses were run to confirm earlier results.

Samples obtained for trace element analyses by Tenco Hydro/Aerosciences, Inc., were digested in acid and may, therefore include elements from the "soil" as well as the refuse leachate. Calcium and magnesium were run as described and on the liquid portion of the sample only. Since there was little difference in the results obtained by the two procedures, we would not expect a large effect on the trace elements. A discussion of the analytical methods and problems encountered in these analyses is included in appendix C.

The wells shown on Table 9 and listed here were chosen to illustrate changes in the composition of ground water originating in the landfills caused by changes in the following factors:

(1) The distance moved from the landfill through the surficial sand
    DUP MM 48, 59, 44
(2) The distance moved from the landfill through glacial till
    DUP LW 6A, 14, 15, 16, 6B
    DUP LW 12A, 11A, 5B
    WIN LW 12, 13
(3) The age of landfill
    DUP LW 6B, MM 61, MM 63, LW 5B
    WIN LW 5B, LW 13, LW 17
(4) The need to describe leachate from fills other than DuPage County and Winnetka
    ELG LW 6B, WOOD LW 1C, Blackwell

VARIATIONS IN COMPOSITION OF LEACHATE WITH MIGRATION THROUGH SAND

Figures 7 and 12 show chloride values from shallow wells around the old DuPage County and Winnetka landfills, respectively. These values are high in the landfill and decrease with increasing distance from the landfill.

It was anticipated that the dissolved solids moving with the ground water away from these landfills would form a pattern of concentration at the landfill and a regular decrease in concentration with distance from the landfill. The erratic values for chlorides obtained from the groups of closely spaced sampling points (MM 46, 47, 57, 58, 59, and 60; MM 42 and 45; MM 48 and 39; and MM 36, and 37) south of the DuPage County landfill and at MM 50, 51, 52, 53, and 54 at Winnetka, show that a regular pattern does not exist, although there is a general decrease in concentration away from the landfill. Some of the variations at the old DuPage County site are probably caused by field tiles and construction operations. Other variations at this fill and at the Winnetka fill are caused by factors that will be discussed later.

Bromine and chlorine show a substantial decrease in concentration with distance from both of these landfills. If this decrease were caused by precipitation's infiltrating and diluting the leachate, it would be more pronounced in the shallower of paired wells. This is not the case in paired wells DUP MM 46 and 47; 48 and 39; WINN MM 25 and 45; 24, 44, 26, 46. This indicates that dilution is probably not a significant factor in attenuation of these components. We conclude, therefore, that chlorine and bromine are retained on earth materials and that the concentration of these components is reduced by travel through earth materials.

Similar results were obtained in Great Britain (Ministry of Housing and Local Government 1961, p. 131). In this study chlorides from refuse leachate were retained in filter beds and subsequently removed by washing. The effects of this are to reduce the concentration of the elements in the ground water but to extend the "polluting" life of the landfill.

Other components of the leachate are also attenuated with migration away from the landfill. As shown in table 9, in travelling from MM 44 to MM 48 approximately 600 feet south of the old DuPage County landfill, BOD, COD, potassium, and iron values were reduced by approximately two orders of magnitude or more, and hardness, sodium, calcium, and bromine by approximately one order of magnitude. Other components were also reduced to varying degrees. Sulfate, phosphate, and nitrate are the only components showing a definite increase in concentration. This is attributed to the fact that they cannot exist in the reducing environment caused by the large organic content of the leachate. As the organics are attenuated, however, reducing conditions become less intense, and the nitrate, sulfate, and phosphate radicals can exist.

Results obtained in the British study (Ministry of Housing and Local Government, 1961, p. 120), where in leachate was passed through gravel filters, are similar to those obtained in this study. Sulfate content rose with migration, and the drops in chloride and BOD per foot of travel were comparable.

Generally the most permeable unit in a geologic sequence will control the quantity and the velocity of leachate movement. As discussed in appendix H, ground water velocity and volume of flow are also influenced by the specific yield and the gradient; however these factors vary within relatively small limits compared with permeability. Figure 24 shows the range in permeability of different soil classes.

The shallow deposits at the Elgin landfill have permeabilities of approximately 100 or more gpd per square foot, those at the old DuPage County landfill are approximately 25 gpd per square foot, while permeabilities in the shallow deposits at Winnetka are approximately 5 gpd per square foot. Water quality data at these sites reflect the general influence of permeability. Direct comparisons are, however, difficult.

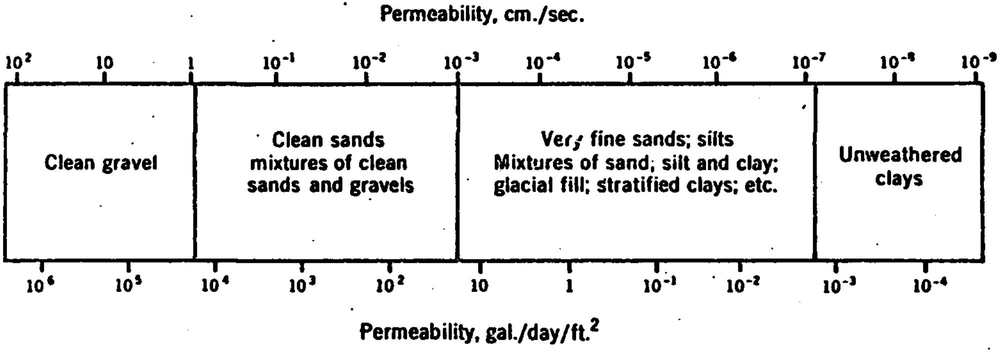

Figure 24. Range in permeability of different soil classes (modified from Todd, 1959, p. 53).

VARIATIONS IN COMPOSITION OF LEACHATE WITH MIGRATION THROUGH GLACIAL TILL

The hydrogeology at all of these sites except at Elgin is such that some of the water from the landfill migrates almost vertically downward through the underlying glacial till. Four nests of piezometers, (tables 16, 17, and 9) were constructed at the old DuPage County and Winnetka landfills to determine the changes in the dissolved solids in the water as it moved downward through this very tight material. Analyses from the series of wells at the old DuPage County landfill (LW 6A, 14, 15, 16, and 6B, table 9) appear best to illustrate the changes in dissolved solids with migration through till. There are a number of obvious exceptions to the pattern of decreasing concentration with migration shown in table 9. We believe these are sampling errors, natural variations in water quality, or laboratory errors. The landfill at this point is nearly 18 years old, and the leachate that initially moved into the till probably had a composition more like that at the Blackwell landfill, Winn LW 17 or DUP LW 5B, than that at DUP LW 6B. There is no appreciable decrease in the dissolved solids in the leachate as it migrates downward to the top of the till through the surficial sands below the landfill at DUP LW 6.

Chlorides are a good indicator of leachate movement. According to the analyses presented in table 9, chlorides have not reached DUP LW 14 after traveling through about 15 feet of silty clay till permeability approximately 10^{-7} centimeters per second. There is evidence, however, that dissolved solids from the landfill have affected LW 15, 4.31 feet below the top of the till, and little doubt that it has affected LW 16, 2.57 feet below the top of the till. If we assume that the leachate was initially similar to that of DUP LW 5B or the Blackwell well, a very short migration (4.31 feet) through this till has effected a decrease of more than one order of magnitude in chlorides and total dissolved solids and a decrease of about two orders of magnitude in organics. A similar pattern is presented by analyses from DUP LW 12A, LW 11A, and LW 12B (table 9) and by the data presented in tables 16 and 17.

This water is moving downwards under a hydraulic gradient of approximately 0.5 foot per foot through material with a texture of approximately 11 percent sand, 55 percent silt, and 34 percent clay. The till has cation exchange capacity of about 4.2 milliequivalents per 100 grams and is composed of about 2 percent montmorillonite, 79 percent illite, and 19 percent chlorite and kaolinite. All these factors are likely to influence the movement of dissolved solids in this water and should be considered if these data are to be applied elsewhere.

The principal exchangeable cation on the clay minerals in this till is calcium (table 13), and since all the exchange positions are probably filled, it was believed that retention of components in the leachate was likely to be low. If retention did take place, we felt it should result in an increase in ground water hardness. This increase has not been detected, possibly because it has been masked by the hardness in the leachate and the natural hardness of the water itself.

Calculations based on these water quality data indicate that the chloride ion moves downward through the tills at the old DuPage County site at a velocity of between 0.25 and 0.4 foot per year. Tracer studies indicate that the velocity of the chloride ion in ground water is only slightly less than that of the ground water itself. These data can therefore, be applied to studies of ground water movement through fine-textured materials, as discussed in appendix H to estimates of the velocity of leachate movement.

Movement of leachate through the surficial deposits is also discussed in appendix H.

VARIATIONS IN COMPOSITION OF LEACHATE WITH AGE OF REFUSE

Chloride and COD values are plotted against age of refuse in figures 25A and 25B. Even though concentrations are plotted on a logarithmic scale there is a poor correlation between age of refuse and the amount of chlorides and COD in the leachate associated with the refuse and an even poorer correlation with other dissolved solids (not shown). Most of this scatter could be attributed to the factors discussed on the following pages.

OTHER VARIATIONS IN COMPOSITION OF LEACHATE

The quality of refuse leachate varies in response to factors other than its age and the distance travelled.

Analyses of the water quality (values in ppm) from three closely spaced wells on the north side of the old DuPage County landfill are as follows:

Well	pH	Cl	Ca	Mg	Fe	M alkal as $CaCO_3$	SO_4	Total hardness as $CaCO_3$
LW 5C	7.2	2,060	400	583	40	7,300	108	3,400
LW 12B	6.0	2,270	2,420	972	750	11,000	1,300	10,100
LW 13	6.5	71	1,080	413	590	4,500	430	4,400

These wells sample the base of the refuse at approximately the same depth within a 10-foot circle in a section of the landfill emplaced in 1963. Samples were obtained on February 20, 1969, in essentially the same manner at each point, except that different amounts of water were removed from each well before it was sampled. Although well LW 12B has consistently larger concentrations of dissolved solids than LW 5C and LW 13, these latter two wells are not consistent with each other, and the variation among the three wells is large.

We believe that each sample reflects composition of the refuse that has been reached by the cone developed while the sample is pumped and is therefore dependent on the composition of the refuse in the immediate vicinity of the sampling point, its permeability, and the amount of water withdrawn before sampling. If this explanation is correct, concentrations of the various dissolved solids in samples obtained from the three wells should converge as pumping continues. This has not been verified. In view of the variations apparent in these data it is not surprising that a very poor correlation between age of refuse and quality of leachate was obtained (figures 25A and 25B).

Similar, though not so extreme, results are obtained from conductivity and chloride analyses of samples from wells outside the landfill (DUP MM 47, 57, 58, 59, and 60, MM 16A and 16B, and WINN MM 50, 51, 52, 53, and 54). These wells were completed in essentially the same manner at the same depths.

Figure 26 illustrates how the hydrogeology of a landfill affects the quality of the ground water at a particular sampling point. A well drilled to the top of the silt bed at point A samples leachate that originated in the landfill in 1967. If this well had penetrated below the silt bed it would sample water that passed through the refuse in 1965.

We should also consider the following:

(1) Each flowline passes through a different amount of fill material and surficial sand.

(2) The quality of leachate in fill of the same age at the same relative poisition in the system is not constant.

(3) There is evidence (Sawinski, 1966, p. 52) that significant seasonal changes in quality of leachate are caused by variations in the

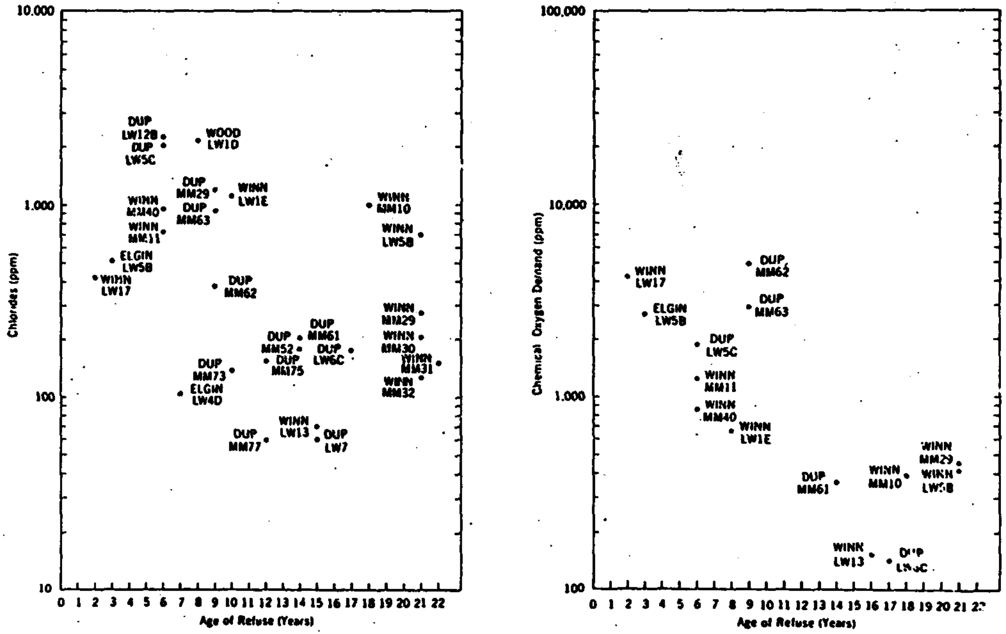

Figure 26. A (left): Relationship between age of refuse and chloride concentration in the leachate. B (right): Relationship between age of refuse and the chemical oxygen demand of the leachate. The chemical quality of the leachate does not appear to be closely related to the age of the adjacent refuse.

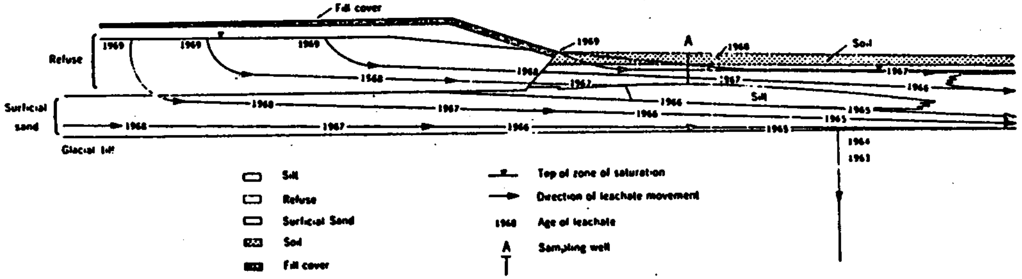

Figure 26. Diagram of leachate movement. The hydrogeology of a landfill affects the quality of leachate at a particular sampling point since a sampling well obtains water from more than one flow path.

amount of infiltrating water.

These factors can easily explain changes in quality over short vertical distances such as found in DUP MM 42 and 45, MM 48 and 39, and MM 46 and 47, as well as the rather erratic decrease in the amount of the various dissolved solids with migration away from the landfill.

It was noticed early in this investigation that the chloride concentration of water in a sampling point was not the same before and after pumping or bailing. To see how significant these changes were, chloride and conductivity were measured on successive days over a 4-day period in a series of 10 shallow wells south of the old DuPage County landfill. Each well contained about 8 feet of water. Five of these wells were measured, top and bottom, before and after the water was exchanged. The other five wells were measured daily, but the water was not exchanged. The following results were obtained:

(1) Conductivity can be as much as 20 percent lower near the top of the fluid column than near the base.

(2) Variations of 10 to 20 percent are common in conductivity and chloride measurements taken on successive days with and without an intervening period of pumping to exchange the fluid. These variations reflect changes in the composition of the ground water over short periods of time, possibly related to individual precipitation events.

CHEMICAL ANALYSES OF EARTH MATERIALS AND SOLUBLE SALTS

Water quality data from sampling wells indicate that dissolved solids are moving downwards through the glacial tills underlying the old DuPage County and Winnetka landfills. The soluble salts in the tills and the tills themselves were analyzed to see if the dissolved solids could be detected.

Table 10 shows the results of analyses of soluble salts in split-spoon samples from the sand below the landfill and in the till below this sand at DUP LW 4B as compared with a sample from DUP LW 3C from below the uncontaminated interbedded sand. Table 11 shows the results of analyses of soluble salts from samples taken at very close intervals over the upper boundary of the till at DUP LW 8 and DUP LW9.

Table 13 presents the results of analyses of exchangeable cations in samples of the upper aprt of the tills at the old DuPage County, Winnetka, and Elgin landfills, and appendix D describes a fluorometric investigation of the upper part of the till at the old DuPage County and Winnetka landfills. These data do not show the presence of dissolved solids from the landfills in these tills.

Table 12 presents the results of analysis of till samples from the old DuPage County landfill at depths corresponding to water samples from LW 14, 15, and 16. According to analysis of the water samples (table 9), dissolved solids from the landfill have reached samples 1, 2, and 3 but not samples 4 and 5.

The data in table 12 show a definite increase in the amount of most of the components in the till below sample number 3, except CaO, which decreases. This could reflect downward movement of dissolved solids or a basic difference in till composition. Further analysis will be necessary for a proper interpretation.

LEACHATE FROM BLACKWELL FOREST PRESERVE LANDFILL

One sample of leachate was collected from a well in a disposal site on the Blackwell Forest Preserve, located about 5 miles southeast of the old DuPage County landfill (figure 2).

Analysis of this leachate (table 9) shows it to be extremely high in dissolved solids and similar in BOD and COD to the leachate Steiner and Fungaroli (1968, p. 309) collected from their lysimeter before it reached field capacity. They believed that this leachate was derived primarily from compaction of the refuse with channelling, and we believe that this is a reasonable explanation for the leachate in the Blackwell observation well.

Figure 27 shows the hydrograph and pre-

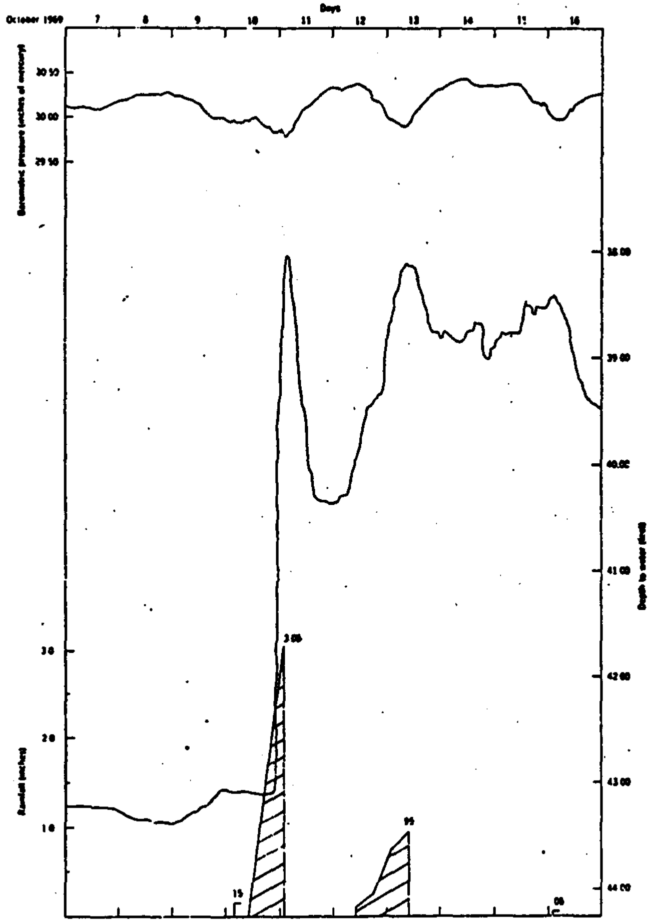

Figure 27. Continuous hydrograph from a well in a disposal site on the Blackwell Forest Preserve landfill, and the precipitation record from October 7 through October 16, 1969. The rapid hydrographic rise may indicate recharge along fissures in the refuse.

cipitation record for the Blackwell well from October 7, 1969, to October 16, 1969. The water level rise was in response to the rain on October 10. For the following reasons it probably represented channelled water moving through the refuse: (1) The response was very large and occurred within a few hours after the rain commenced. (2) Water levels declined more rapidly than in other wells after the precipitation ceased.

It appears that the well acts as a collector for the water moving along more or less horizontal channels in the landfill and that therefore the initial response to the rain was abnormally high. The rapid decline represents the movement of water out of the well into adjacent refuse. The static water level in this well has risen over the past 11 months; however we do not have enough records to know the amount of rise.

EFFECTS OF LEACHATE ON GLACIAL TILL

A brief study was undertaken to determine the effects of refuse leachate on till. Samples of till, similar to that at the old DuPage County landfill, were treated with distilled water and with leachate from the Blackwell well, DUP LW 5C, and DUP LW 6C, and the liquid limit, plastic limit, and plasticity index were determined. No significant difference was present in the results of these tests on the four samples.

Four samples of this till were dispersed in distilled water and in leachate from the Blackwell well, DUP LW 5C and DUP LW 6C. Solution densities were measured by a hydrometer. These readings, taken 118 minutes after dispersion, were 25.0 for distilled water, 27 for leachate from DUP LW 6, 29 for leachate from DUP LW 5C, and 16 for leachate from the Blackwell well. This indicates that the very concentrated "young" leachate from the Blackwell well is capable of partially flocculating this type of till, whereas leachate from older refuse has no effect.

The tills beneath of old DuPage County, Winnetka, and Elgin landfills were analyzed for exchangeable cations and cation exchange capacity (table 13). The cation exchange capacity is between 4 and 6.2 milliequivalents per 100 grams, the major exchangeable cation being calcium. These data do not indicate the leachate has had any effect on the clays below these landfills.

TREATMENT OF LEACHATE FROM REFUSE

A sample of leachate from WINN LW 17 was aerated for six days at ambient temperatures to determine whether it could be readily treated. This procedure reduced the 5-day BOD from 1,840 to 440 ppm and produced a clear fluid.

According to Professor B. B. Ewing (personal communication) of the civil engineering department, University of Illinois, the analyses in table 9 indicate that leachate should be biologically treatable without special procedures. Treatment of leachate is discussed further in the last section of this report.

ANALYSIS OF LANDFILL GASES

During this study 20 samples of landfill gas were collected and analyzed for carbon dioxide, oxygen, nitrogen, and methane (table 14). They show a maximum of 84 percent methane recovered from refuse buried in 1955 near MM 52 at the old DuPage County landfill.

In order to check the reliability of our sampling methods and see whether or not a relationship between landfill age and methane could be established, parts of the old DuPage County and Winnetka landfills were resurveyed in December 1969 with a portable explosimeter. This showed methane present near WINN LW 13 where it was not detected in the early analyses. The explosimeter also indicated that methane is being produced in the oldest part of the Winnetka landfill (1947) but not in refuse buried before approximately 1954 on the south side of the old DuPage County landfill. In this area there appeared to be a boundary between areas of younger and older refuse where methane was and was not detected. It was noted that where the grass was dead or brown, methane was present and that where it was green, no methane could be detected with the explosimeter. On August 7, 1969, analyses showed 17 percent methane present beside DUP LW 6 in this general area. On September 7, 1969, methane was not present in a sample collected beside DUP LW6 and it was not detected two weeks later with the explosimeter.

The foregoing suggests that our sampling procedures should be improved and that methane production from landfills is erratic. A *relationship between refuse age and methane content is* suggested by the fact that older landfill at Winnetka has less methane than younger landfill; however data relating methane to landfill age at the old DuPage County landfill do not confirm this.

Throughout 1966, 1967, and 1968, methane was present in an open abandoned boring about 20 feet south of the old DuPage County landfill near DUP MM 44. Samples taken from this area and the field to the south on September 7, 1969, did not contain methane. The abandoned boring itself could not be checked at this time.

Methane was not detected in samples taken near Elgin at LW 7 and Woodstock LW 7. The landfill near both of these borings is composed of inorganic and burned materials. Methane was detected with the explosimeter in the Blackwell well.

Unfortunately, this preliminary work on landfill gases appears to have raised more questions than it has answered.

SELECTION OF SITES, DESIGN, AND OPERATION OF SANITARY LANDFILLS

If we consider only ground and surface water pollution, at least 80 percent of northeastern Illinois would probably be suitable for sanitary *landfilling without site modification*, because the surficial materials are fine textured, have low permeability, and would restrict the movement of refuse leachate. Of the 20 percent remaining, 10 percent would be suitable because of favorable location within the hydrogeologic flow system. Sites in the remaining 10 percent of the area *would require some modification*. Unfortunately a disporportionately large percentage of those sites proposed as sanitary landfills fall into this latter category. These include the mined-out quarries and gravel pits. These sites are most easily filled and when filled increase substantially in value. To many, sanitary landfilling is synonymous with land reclamation.

We believe that nearly all sites are or can be designed so that they are suitable for solid waste disposal. If this is so, then the critical factors in site selection are not hydrogeologic ones but are the cost of refuse transport, site acquisition, site modification, and operation balanced against the value of the reclaimed land. Knowledge of the hydrogeology of the site is, however, essential for determining whether or not modification is necessary to meet water quality standards, and, if so, how it can best be accomplished. It will be the cost of this modification considered with the *other costs and benefits that will determine* whether or not a particular site is suitable at a particular time.

In metropolitan areas, land and transportation costs are high and "close in" sites are seldom available. In these areas, large sums can be spent on site modification, and the initial site selection will seldom be concerned with the hydrogeology.

Early in our project we have hoped to be able to present a hydrogeologic map of northeastern Illinois that would aid in locating future landfill sites. It soon became apparent, however, that landfill hydrogeology is an individual site problem and that such a map, to be of value, would have to be on an extremely large scale with a correspondingly high degree of accuracy. Hydrogeologic control is not available for such maps. Another reason for avoiding this type of map is that even at the 1 site in 10 where the natural environment is not protective, the cost of site modification, discussed in the following pages, may not be a significant part of the total costs. Such a map could actually perform a disservice if it were to lead to relocating a landfill to an area where geologic conditions are naturally more favorable but where the total operation, including site modification, would be less economical.

Our investigation has shown that unless specific preventive measures are taken almost all refuse disposal sites in humid climates, where precipitation infiltrates through the refuse, will introduce some dissolved solids into the environment. A good landfill site is, therefore, one which is designed so that the amount of dissolved solids released is acceptable in that particular environment. The evaluation of how much will be acceptable is usually the responsibility of a local or state regulatory agency and is based on factors such as the following: (1) surface and ground water use in the vicinity, (2) the amount of contamination already present, and (3) the need for a disposal site. It is a more complex decision than those dealing with the discharge of sewage into a surface stream because it involves a type of pollution that is difficult to monitor and once initiated cannot be easily rectified.

It is probably not possible to establish a reasonable set of rules or regulations that would control all the environmental factors affecting the production and migration of leachate from landfills. For example, a rule requiring the presence of a certain number of feet of material below a landfill should include specifications on the exchange capacity of the material, its permeability, and the direction of ground water movement, and rules requiring refuse to be a certain distance above the top of the zone of saturation should also have provisions for eliminating infiltration through the completed surface of the landfill. A more realistic procedure would be to require the landfill operator to design his operation to meet standards set by the regulatory agency and to submit his design to the regulatory agency for approval in much the same manner as for other types of waste disposal operations.

OBJECTIVES IN DESIGN

The four design objectives discussed in the following pages are directed at control of ground and surface water pollution by management of the leachates derived from landfills. The use of a particular design is dependent upon the hydrogeology of the site, standards imposed by the regulatory agency, the use to be made of the site after filling is complete, and the cost. Following are four design objectives:

(1) Elimination of production of leachate
(2) Migration of leachate under acceptable conditions
(3) Recovery of leachate after migration
(4) Retention and recovery of leachate

These designs can be accomplished by standard engineering techniques and procedures. It is necessary, however, to determine the type of earth materials present and to understand the ground water flow system if the capacity of the environment for self-purification is to be used advantageously.

ELIMINATION OF PRODUCTION OF LEACHATE. This objective should be the first considered in arid areas. It consists of burying the refuse above the top of the zone of saturation and preventing surface water from entering the landfill. It is the least expensive design to accomplish, and according to the results of studies (University of Southern California, 1954, p. 13), it is the safest from the standpoint of avoiding ground water pollution.

Two and possibly three types of leachate are produced from landfills. One type results from compression and compaction of the refuse. Although this type of leachate will probably be present in all landfill operations we would expect only relatively small quantities to be produced. Water is also used and produced during decomposition of the refuse (table 2). We assume that this type of water is not present in significant amounts. Leachate is also produced when refuse comes in contact with and is leached by water after burial.

In humid areas leachate will almost always be produced from landfills because precipitation is usually great enough to infilatrate the refuse and because the top of the zone of saturation is generally shallow and the refuse is buried below the water table.

In arid areas precipitation is not sufficient to satisfy the soil moisture deficiency and to infiltrate the refuse, and the top of the zone of saturation is usually deep enough so that refuse will not be buried below the water table.

In semiarid and possibly in humid climates, this objective might also be considered if the top of the zone of saturation is below the base of the disposal site and if the fill can be covered and graded so as to reduce infiltration to a negligible value.

The position of the water table is not always reflected by the elevation of the water in nearby wells or the presence or absence of water in an excavation. Water levels in wells reflect the ground water potential (or head) across the open part of the well and are, therefore, dependent on well depth. Unless a well bottoms at, or close to, the top of the zone of saturation its water level is not likely to reflect the elevation of the top of the zone of saturation. For example, a well completed at a depth of 100 feet near Winnetka, Illinois, will have a static water level at about 50 feet below the surface. A well completed at a depth of 10 feet will have a water level at a depth of about 7 feet below the surface.

Movement of water into open excavations is partly dependent on the permeability of the surrounding materials. Free water may not be present in an excavation that extends below the top of the zone of saturation in fine-textured materials of low permeability. This is because the water evaporates as fast as it reaches the sides of the excavation. After the excavation has been filled, evaporation ceases, the water table rises, and the fill materials are saturated.

If it can be determined that the base of a landfill is above the top of the zone of saturation, the amount of leachate produced will be controlled by the amount of infiltration through the fill surface. This in turn is affected by precipitation, evapotranspiration, and runoff. Seasonal precipitation and evapotranspiration data are generally available locally from State and Federal agencies. Runoff will be determined by the final surface on the fill, its grade, composition, and vegetation.

Gas production may be a problem in environments amenable to this type of design if permeable materials surround refuse emplaced above the top of the zone of saturation. These problems should be considered in the early stages of planning.

MIGRATION OF LEACHATE UNDER ACCEPTABLE CONDITIONS. This design, like the designs for migration and recovery and retention and recovery, assumes that leachate will be produced from the refuse. It applies, therefore, mainly to sites in humid areas unless the final use of the site involves irrigation or liquid waste disposal. A design for acceptable migration is the least expensive of the three methods and since very few operating landfills have constructed facilities for recovery of leachate, it is by default the most common design currently used in humid areas.

A design for acceptable migration relies on the hydrogeologic environment to reduce the amount of dissolved solids leaving a landfill to an acceptable level. The fact that so few landfills cause serious pollution problems is an indication of the effectiveness of the environment in this respect.

There are a range of hydrogeologic environments for which a design for acceptable migration can be made. We shall discuss the two extremes as follows: environments associated with relatively impermeable materials, such as clays and some glacial tills, and those associated with relatively permeable materials, such as gravels and fractured rocks.

Sites in environments of relatively impermeable materials rely on the following: (1) the earth materials to reduce the dissolved solid content of the leachate to an acceptable level over a short travel path before it reaches a point of water use or before it reaches more permeable materials (2) a longer retention time for the leachate to allow more on-site decomposition and purification.

The mechanisms involved in the attenuation of dissolved solids by earth materials have been discussed in some detail and data have been presented showing the distance the various elements originating in the landfill had travelled.

With these data we can estimate the relative amounts of attenuation leachates will undergo during migration through various materials. Silty and clayey tills, unfractured shales, and clays should reduce the total dissolved solid content of leachate by one or two orders of magnitude in travelling a distance of 5 feet. Sands and silts will reduce the total dissolved solids in leachate by about one order of magnitude in travelling 500 feet, and gravels and fractured rocks will be considerably less efficient.

These data apply specifically to the landfill sites studied in this report and generally to conditions in northeastern Illinois. When extrapolating them to other areas one should consider, among other things, the ground water gradients involved and the mineralogy of the materials through which the leachate moves – two factors that would affect contaminant attenuation. These data should, therefore, be used with some discretion.

Sites located in materials with low permeability may develop ground water mounds, and springs and seeps may form around their margins. If these surface seeps of leachate are not acceptable they can be reduced or eliminated by reducing infiltration or by collecting all or part of the leachate.

The Winnetka landfill is in a hydrogeologic environment for which a design for acceptable migration is appropriate. Here the leachate is allowed to migrate downward through the underlying clay tills and laterally through silts, sands, and clay with relatively low permeability. Our studies have shown that the dissolved solids in this leachate have been reduced to negligible values long before reaching a point of possible ground water use. Springs of leachate have developed along the margins of this landfill, but as yet they are no more than a local nuisance.

A design for acceptable migration may also be accomplished in hydrogeologic environments in which the materials are very permeable, and attenuation of contaminants during a short migration will not be significant. Such environments, which would include sites in clean gravels or those in fractured rocks, rely on the ground water flow system to dispose of the contaminants in a satisfactory manner. Such disposal would include the following: (1) transport of contaminants into, or through, a large regional flow system where attenuation could take place over a very long travel path, (2) transport into a ground water reservoir already containing poor quality water, and (3) transport of contaminants to a surface water body where they would be diluted to an acceptable level. Of these three, the last is the most common.

Transport into or through a large regional flow system was suggested by Maxey and Farvolden (1965) for the basin and range area of the Western United States. In this particular environment, dissolved solids generated in landfill located in the mountains would migrate over an extremely long path to discharge in the intermontane valleys. It is assumed that the contaminants moving in this manner would be attenuated to an acceptable level before reaching a point of water use. This design requires complete understanding the flow system in a particular area and assumes little or no water use in the recharge areas where the refuse is buried.

The second design for acceptable migration *through permeable materials is to locate the* landfill so that dissolved solids from the landfill will migrate into an aquifer containing water that cannot be used, because it is either highly mineralized or polluted. A good understanding of the flow system is also necessary in this case before the design is accepted.

The third design for acceptable migration through permeable materials involves allowing the contaminants to migrate to a body of surface water where they will be diluted to an acceptable level. This design assumes that solid wastes and liquid wastes such as domestic sewage have similar rights to surface water for dilution purposes and that dilution water is available.

This design objective can most easily be accomplished with landfills located in or near ground water discharge areas where surface water is available and the ground water is moving upward. These conditions are common in humid areas, where the valleys of the perennial streams are usually ground water discharge zones, as well as in the areas around most of the permanent swamps and lakes.

Use of this design involves estimating the volume and concentration of the leachate that is to be diluted, and, inasmuch as the volumes of leachate will often be very small compared with the amount of dilution water available, estimates will usually be adequate. Methods of estimating outflow from landfills are discussed in appendices H and G.

There are a number of drawbacks to the use of this type of design in permeable materials as follows:

(1). There will be contamination of the shallow materials between the landfill and the receiving water.

(2) Flooding may be a problem in discharge areas. .

(3) Ground water is often well developed in permeable stream valley materials. The effect of diverting the leachate into a pumping cone must, therefore, be considered. It is conceivable, however, that dilution in the pumping cone itself would reduce the concentration of dissolved solids entering any one well to an acceptable level.

The Elgin site is typical of the type of environment that could be used for this design. Leachate produced in the landfill migrates laterally down gradient to the Fox River, where it is diluted. Although some attenuation occurs during this migration, dissolved solids are at a large concentration in the water that has reached the river after passing through the landfill. Dissolved solids cannot move down into the underlying aquifers, because the ground water gradient is directed upward toward the river.

The Elgin site can be considered satisfactory if (1) pollution of the shallow sands and gravels between the landfill and the river is acceptable and (2) the landfill can be permitted to raise the total dissolved solids in the Fox River by an average of approximately 0.30 ppm.

The extreme cases associated with high and with low permeability will be far less common than intermediate environments associated with materials having moderate permeability as well as some capacity for attenuating contaminants moving with the ground water. Each environment evaluated individually would determine whether or not a design for acceptable migration can be accomplished or whether or not some sort of permanent or temporary collection facilities must be constructed.

MIGRATION AND RECOVERY OF LEACHATE. Fills designed for migration and recovery of leachate depend on the ground water flow system to concentrate the leachate at a point where it can be readily collected in the surface or subsurface. In this type of environment we assume that attenuation during migration will not be adequate to reduce the contaminants to acceptable levels and that at least some of the leachate must be collected.

To achieve this objective the landfill must be located so that the ground water flow lines that pass through the refuse converge farther on at a place where the fluid can be conveniently collected. A favorable location would be near a natural ground water discharge zone where the dissolved solids from the landfill will reappear at the surface. Examples include a slope near a stream valley or a closed depression such as a kettle hole.

If flow lines do not converge naturally they can be made to do so by creating an artificial discharge zone using ditches, tile drains, or pumping wells.

In most cases, the volume of fluid that must be dealt with will be an important consideration. Sites in saturated, permeable deposits will handle larger volumes of water than those in fine-textured materials.

This design could be used at the Elgin site to collect contaminants moving out of the fill if it were necessary to reduce the amount of dissolved solids moving into the Fox River or to protect the shallow aquifer between the landfill and the Fox River. A row of wells or a deep tile system could be installed between the fill and the river to intercept dissolved solids moving from the landfill. In this case large quantities of water would be involved inasmuch as the materials are rather permeable.

RETENTION AND RECOVERY OF LEACHATE. This design is more complicated and expensive, and its use would probably be restricted to sites in humid climates that will benefit greatly from land reclamation or short refuse haulage. It consists of isolating the refuse in the disposal site and collecting all the leachate produced. This may be accomplished with the various types of liners, covers and collection and treatment facilities discussed in the following section. Each of these techniques and procedures is dependent, to some extent, on the others. The final use of the site will determine the type of cover and surface grade, which will in turn determine how much infiltration will take place. The amount of infiltration and the amount of leakage through the liner will determine the collection and treatment facilities.

In a design such as this the amount and potency of the leachate could be regulated to fit the method of treatment or disposal over the life of the landfill.

TECHNIQUES AND PROCEDURES

CONTAINMENT. Two techniques can be used to prevent the migration of leachate from a disposal site. One is to line the site with material having low permeability; the other is to create a hydraulic gradient toward the site.

Liners can be constructed of compacted or uncompacted earth in its natural state or mixed with a variety of soil dispersants, lime, pozzolana, or other soil cements. They can also be constructed of asphalt or plastic. The type of liner to be used will depend on the amount of leakage that will be allowed, the hydrogeology of the site, the overall site design, and the economics. Because liner construction is likely to be an expensive and technical procedure, qualified personnel must be retained.

Movement out of a site across a liner will obey Darcy's law, Q = PIA (appendix D), where:

Q = amount of water
P = permeability of the liner
I = hydraulic gradient
A = area of liner in contact with fluid.

It can be seen from this that:

(1) There will be movement across the liner as long as there is a gradient across the liner. If the gradient is out of the site, leachate will migrate out of the site; if the gradient is into the site, ground water will migrate into the site.

(2) Movement across the liner, in sites that extend below the top of the zone of saturation, can be controlled by controlling the gradient or the respective water levels inside and outside the liner.

(3) In sites located above the top of the zone of saturation some leakage out of the site cannot be avoided if the permeability is greater than zero. This leakage can be minimized, however, by minimizing infiltration and by removing the leachate from the site (by tiles and drains) as rapidly as possible.

(4) The major factor controlling movement across the liner will be the permeability of the liner.

(5) The thickness of the liner is not a factor in this equation and does not affect the amount of water moving across the liner. It would, depending on the type of liner, affect the attenuation of contaminants. The thickness of the liner is important from the standpoint of practical construction procedures. Thin or fragile liners must be carefully constructed and protected from damage during emplacement and settlement of refuse.

Leakage through a liner can be easily estimated. A liner with a permeability of 10^{-2} gpd per square foot and a gradient of 1 foot per foot across it under a 50-acre landfill would allow passage of approximately 22,000 gallons of water per day. If the permeability of the liner were reduced to 10^{-6} gpd per square foot, leakage would be reduced to 2.2 gpd. The liner that would be used at a given site will probably be determined by the materials available, their cost and the amount of leakage that will be allowed in that particular environment.

If there is more infiltration than loss by leakage through the liner, then the surplus water must appear as "overflow," which is merely changing the spatial distribution of the contamination.

The same principles apply if the site is located in natural materials with low permeability. Both permeability and gradient can be estimated or if necessary, measured.

Earth liners have been used to retain contaminants in refuse disposal sites in Illinois; however, there has not been, to our knowledge, any investigation of leachate movement through these liners or of the attenuation of contaminants moving through a liner. There have been investigations of earth liners in lagoons (Lee, 1941, Lambe and Anderson, 1955), and in these cases satisfactory results were obtained. We assume, therefore, that earth liners could also be used for lining solid waste disposal sites.

The physical properties of clay minerals and, therefore, of earth liners containing clay minerals are affected by contact with solutions containing large concentrations of dissolved solids, such as refuse leachate. Our preliminary investigation of the effect of leachate on the silty clay till at the old DuPage County landfill indicated that very concentrated leachate partially flocculated the till. Hence, reactions between the leachate and the earth materials to be used for a liner should be checked.

There has not been, to our knowledge, any use of other types of liners for solid waste disposal sites; however, as with earth liners, they have been used successfully for lining lagoons and should be suitable for lining refuse disposal sites, provided, of course, they could be emplaced and maintained without breaking.

In landfills that intersect the top of the zone of saturation, leachate can be completely confined to the site by maintaining ground water gradients towards the landfill. This can be accomplished by a suitable arrangement of pumping wells or drains (figure 28).

Above the top of the zone of saturation, excess soil water must move downward through the soil under the influence of gravity. For this reason leachate cannot be hydrologically confined in landfills that do not intersect the top of the zone of saturation.

REDUCTION OF INFILTRATION. Of the three sources of leachate-producing water – refuse, the ground water, and infiltration – the third is probably the most subject to control. Infiltrating water can originate from a number of sources: (1) precipitation, (2) surface water from outside the fill area, and (3) irrigation sludge or liquid waste disposal. All of these add to the water content of the landfill, and when enough has been added to exceed field capacity of the refuse and cover materials, all of this water will move downward through the refuse and become refuse leachate. As discussed earlier in this report some infiltration through channels in the refuse will probably occur before the refuse has reached field capacity.

Constructing the final fill surface for maximum runoff is probably the least expensive way of decreasing infiltration. Mr. Julius Dawes (personal communication) of the Illinois State Water Survey, Urbana, Illinois, estimates that of the approximately 33 inches of precipitation falling in northeastern Illinois, all but 2 inches could be diverted to runoff fairly readily, and infiltration could be reduced still further but probably not completely eliminated by installing a system of drains and terraces.

As with liners, a proper cover should be installed by competent personnel. Slopes must be compatible with the type of soil and the vegetation to prevent erosion, and the amount of water that does infiltrate must be compatible with the overall landfill design.

In many instances, the landfill cannot be designed for maximum runoff, because this would interfere with plans for the ultimate use of the site. In these cases infiltration will depend on that particular use and climatic conditions. Specific information on the amount of evaporation and transpiration in a given area can usually be obtained from Federal or State agencies.

COLLECTION OF LEACHATE. Two of the design objectives require collection of the leachate, either after it has migrated away from the site or at the site itself.

Collection systems using tiles, French drains, or ditches should be suitable for most sites. Hydrologic confinement that is also a collection method could also be employed.

Collection systems for lined landfills or landfills situated in materials with low permeability fall into two categories: those designed to reduce a ground water mound and prevent seepage to the land surface along the fill margins and those designed to minimize leachate infiltration downward through the base of the landfill.

Collection systems designed only to control surface seepage from the landfill or to control water levels within the landfill should be relatively simple and may involve only gravity drains

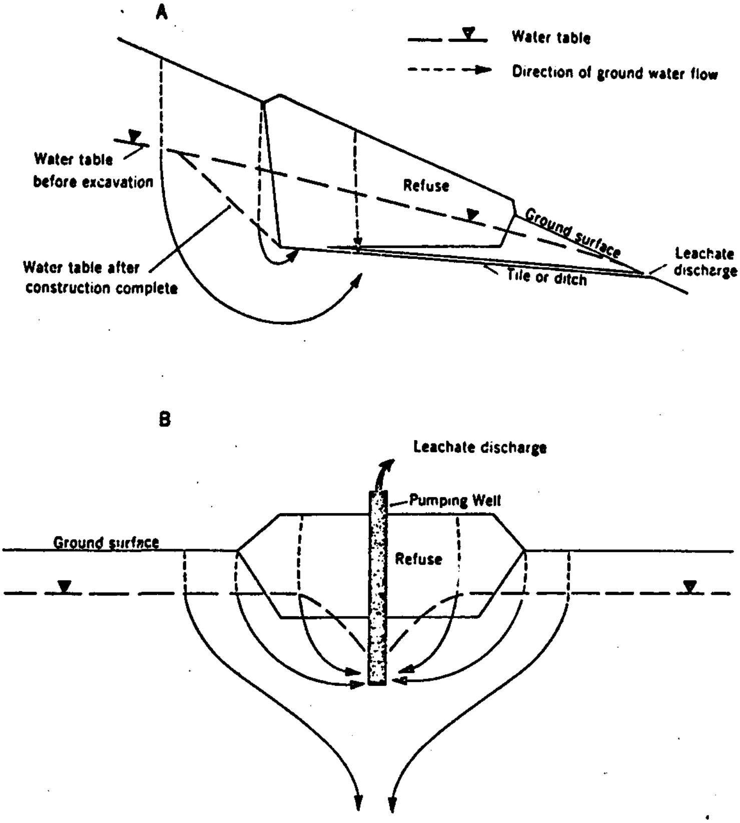

Figure 28. In landfills that intersect the top of the zone of saturation, leachate can be completely confined to the site by maintaining ground water gradients towards the landfill by (A-top) gravity drainage or by (B-bottom) a pumping well.

to keep the top of the zone of saturation within the fill below the ground surface adjacent to the fill. The permeability of refuse fills, although variable (appendix F), is approximately that of a sand, and so tiles or French drains may not be necessary.

If the base of the landfill is above the top of the zone of saturation, and collection is designed to minimize leachate contact with a liner and, hence, leakage through the liner, a more refined system must be used that would probably include tile drains, with the base of the fill graded to a single collection point. The design of this system would depend on the amount of leakage allowable at the site.

MONITORING OF WATER QUALITY. There are three reasons for including a water-quality-monitoring program in any landfill design, as follows: (1) to protect the operator against false claims that he is causing ground water pollution, (2) to give an early indication that something is wrong with the design of the landfill so that remedial measures can be taken, and (3) to provide a means of evaluating the effectiveness of the design used on the landfill.

Monitoring points should be installed in accord with the hydrogeology both up and down the hydraulic gradient from the disposal site, and if possible in materials permeable enough to yield a sample within a 24-hour period. This will reduce the possibility of water quality changes occurring in the sampling well. Silts will generally have permeability adequate for this purpose. Monitoring should begin before disposal operations have started and continue until the fill has stabilized or until the dissolved solids output of the landfill reaches an acceptable level. Sampling intervals will be determined by the hydrogeology but after base levels have been established these intervals might be annual or semi-annual. Out work has indicated that total dissolved solids and chlorides are good tracers for this purpose.

CONTROL OF LANDFILL GASES. The main problem-producing gases are methane, carbon dioxide, and odors. These gases can migrate through permeable, unsaturated materials for considerable distances. Although there have been few (Engineering-Science Inc., 1963-1966) studies on migration of gases in the subsurface, problems should be anticipated in environments where the refuse is emplaced in permeable materials above the top of the zone of saturation. This would include landfills in thick, unsaturated gravels or landfills high above ground. The installation of a thick, impermeable cover to reduce infiltration may impede the movement of gases out through the landfill surface and force them to move laterally. Methane is the most hazardous of landfill gases, since it forms a flammable mixture (5 to 15 percent methane in air) with air. An explosion in a warming house on a landfill in the city of Elmhurst in northeastern Illinois has been attributed to methane's migrating into heating ducts and being ignited.

In northeastern Illinois, odors from one fill high above ground are dealt with by venting it with perforated pipes and burning the odors with the methane, which is also present. Workers at this fill have noticed that gas production generally began about 2 years after the fill had been completed and is higher in those parts of the fill containing grass and leaves.

Venting (Eliassen, et al. 1957, p. 115) and burning (Engineering News Record, 1948, p. 86; Dunn, 1960, p. 68) are the most common procedures for dealing with landfill gases to prevent odors and explosions. To date, however, there is little documentation of the effectiveness of various venting methods under different conditions. Design of gas-tight structures for sanitary landfills is discussed by Sowers (1968, p. 115) and First *et al.* (1966).

TREATMENT. In two of the landfill designs, collection of the leachate is necessary, and, if it is not possible to dispose of this leachate into a sewerage system, on-site treatment is necessary. Unfortunately very little information is available on leachate treatment; however, the data collected in this study indicate that treatment should be possible. In Britain (Ministry of Housing and Local Government, 1961) a considerable reduction in dissolved solids, particularly organics, was accomplished by passing leachate through horizontal sand and gravel filters. In Bristol, England, treatment by ballast filters and holding ponds were also effective

(Bevan, 1967, p. 146).

In Pennsylvania simple natural aeration lagoons with a flow-through time of about 1 or 2 weeks decreased the iron and the BOD of leachate moving from a landfill by 90 percent.

It appears that because the quantities of leachate are relatively small compared with those of domestic sewage, relatively simple treatment facilities will be possible.

Design of treatment facilities will depend to a certain extent on the concentration and quantity of the leachate to be treated. These factors are, in turn, dependent on factors such as the fill cover, the liner, and final use of the land. Treatment should therefore be considered early in planning the disposal site.

OTHER CONSIDERATIONS

OPERATIONAL PROBLEMS. The operational problems concerned with the geology and the hydrology of landfills are those connected with excavation, with handling surface water, and with ensuring a supply of cover materials. Excavations should be planned to provide cover material for the fill, if other sources of cover are not available, and their depth should be related to the final height of the fill. This is primarily a matter of planning and of material balance; however, the design procedures adopted may be the controlling factor.

Most states discourage disposal of refuse into open water to avoid the production of hydrogen sulfide. Procedures have been developed (Furness 1954, 1956) to control the generation of gases in this manner. These entail the construction of dikes and rapid filling of relatively small area. Aeration and other methods of controlling the production of hydrogen sulfide were also investigated in the study by Furness.

In excavation below the top of the zone of saturation in materials with appreciable permeability, serious problems may be encountered in removing ground water from the site, and the deeper the excavation extends below the top of the zone of saturation the more water will have to be removed. In fine-textured, less permeabl. materials influent ground water should be easily controlled,

REUSE STABILIZATION OF LAND. In areas where land values are high, it is usually planned to use the landfilled areas for some other purpose after filling has been completed. In some areas, the presentation of a plan for final land use is a requirement of local regulatory agency, but in any event, final use should be considered when the landfill design is being determined since the two must be compatible.

Four major problems are associated with reuse of this land, as follows: (1) settlement of the fill materials, (2) gas production, (3) surface seepage, and (4) final cover.

Settlement will continue for a considerable period, and any construction on the fill must take this into consideration. According to the American Public Works Association (1966, p. 126), settlement ranges from 10 to 25 percent within 6 months to 2 years of emplacement, depending on compaction techniques, and in New York (American Public Works Association, 1966, p. 128) 90 percent of the total settlement occurred in the first 2 to 5 years. The data presented in figure 23 imply a more regular decrease in volume (specific yield). According to Eliassen (1947, p. 757) landfills continue to decompose for 30 or more years. Data from this study show methane production at Winnetka in refuse 23 years old, indicating that the decomposition is still underway.

A fairly comprehensive discussion of foundation and construction problems in landfills has been given by Sowers (1968). He raises the following points:

(1) "If there is any thing consistent about the sanitary landfills, it is their erratic composition and extremely erratic but low densities" 50 to 75 pounds per cubic foot."

(2) . . . the ability of a sanitary landfill to resist foundation loads without failure is seldom greater than 500 lb to 800 lb per sq ft." Surface inspection and load tests may be misleading and yield higher results.

(3) Differential settlement will probably occur. This will affect buildings and sewer lines.

(4) Steel and concrete may be affected by corrosive action of the refuse leachate.

(5) Excavations are irregular, need heavy equipment, may produce odors, and may contain dangerous gases.

(6) "Many of these construction hazards can be minimized by proper planning of the fill before installation."

Settlement in landfills is also discussed by Merz and Stone (1963a, 1963b, 1964, 1965, 1966), Fungarole and Steiner (1968).

The control of surface seepage will probably involve tiles or other subsurface drainage to reduce the ground water mound within the landfill. This is likely to become more of a problem as larger fills are constructed. These remedial measures will be easier to install during construction of the landrill rather than after it is completed and should, therefore, be considered early in the fill design.

The final cover on the fill surface will depend to a large extent on the amount of infiltration acceptable by the regulatory agency. Vegetation, grading, and drainage will all affect infiltration.

If fine-textured earth, asphalt, or some other material that is subject to cracking is used as a cover, enough methane may be concentrated at these cracks to burn if ignited. This would not be acceptable in most instances.

Land values and needs in the particular community will determine the final use of the completed landfill. It can be used for many purposes, however, if final use is considered in the design.

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Table I

REFUSE COMPOSITION[1]

Composition of refuse Percent[2]		Component	Gms. pollutant/gm. dry refuse or wt. Percent[3]
23.38	Corrugated paper boxes	Crude fiber	38.3%
9.40	Newspapers	Moisture content	18.2%
6.80	Magazine paper	Ash	20.2%
5.57	Brown paper	Free carbon	0.57%
2.75	Mail	Nitrogen	
2.06	Paper food cartons	(a) free	0.02 mg/gram
1.98	Tissue paper	(b) organic	1.23 mg/gram
0.76	Plastic coated paper	Water solubles:	
0.76	Wax cartons	(a) sodium	2.33 mg/gram
2.29	Vegetable food wastes	(b) chloride	0.97 mg/gram
1.53	Citrus rinds and seeds	(c) sulfate	2.19 mg/gram
2.29	Meat scraps, cooked	COD	42.29 mg/gram
2.29	Fried Fats	Phosphate	0.15 mg/gram
2.29	Wood	Hardness	10.12 mg/$CaCO_3$/gram
2.29	Ripe tree leaves	Major metals:	
1.53	Flower garden plants	aluminum, iron, silicon	> 5.00% (by spectrographic analysis)[4]
1.53	Lawn grass, green	Minor Metals:	
1.53	Evergreens	calcium, magnesium, potassium	1.0-5.0% (by spectrographic analysis)[4]
0.76	Plastics		
0.76	Rags		
0.38	Leather goods		
0.38	Rubber composition		
0.73	Paints and oils		
0.76	Vacuum cleaner catch		
1.53	Dirt		
6.86	Metals		
7.73	Glass, ceramics, ash		
9.05	Adjusted moisture		
100.00			

[1] Fungaroli *et al.* (1968 p. 11)

[2] Kaiser (1966) as presented in Fungaroli et al. (1968, b p. 11)

[3] Preliminary results.

[4] Of nonvolatile portion.

TABLES

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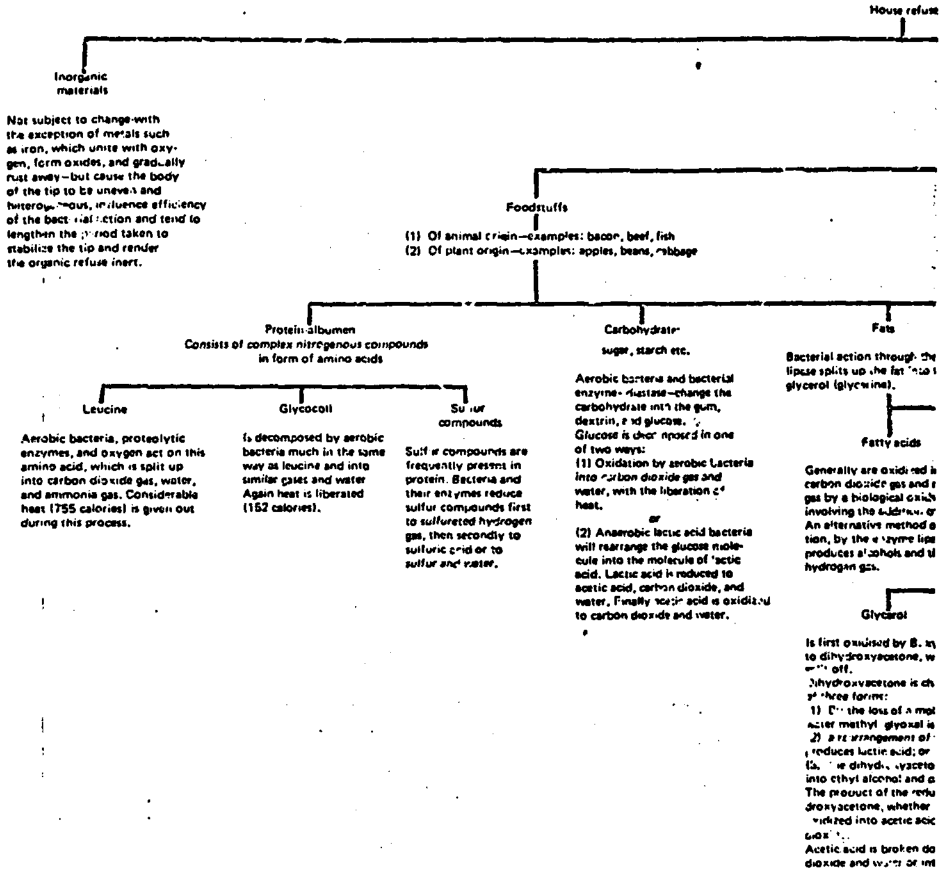
A

PROCESS OF DEC



House refuse

Inorganic materials

Not subject to change with the exception of metals such as iron, which unite with oxygen, form oxides, and gradually rust away—but cause the body of the tip to be uneven and heterogeneous, influence efficiency of the bacterial action and tend to lengthen the period taken to stabilize the tip and render the organic refuse inert.

Foodstuffs

(1) Of animal origin—examples: bacon, beef, fish
(2) Of plant origin—examples: apples, beans, cabbage

Protein-albumen
Consists of *complex nitrogenous compounds* in form of amino acids

Leucine

Aerobic bacteria, proteolytic enzymes, and oxygen act on this amino acid, which is split up into carbon dioxide gas, water, and ammonia gas. Considerable heat (755 calories) is given out during this process.

Glycocoll

Is decomposed by aerobic bacteria much in the same way as leucine and into similar gases and water Again heat is liberated (152 calories).

Sulfur compounds

Sulfur compounds are frequently present in protein. Bacteria and their enzymes reduce sulfur compounds first to *sulfureted hydrogen* gas, then secondly to sulfuric acid or to *sulfur and water*.

Carbohydrate
sugar, starch etc.

Aerobic bacteria and bacterial enzymes diastase—change the carbohydrate into the gum, dextrin, and glucose.
Glucose is decomposed in one of two ways:
(1) Oxidation by aerobic bacteria *into carbon dioxide gas and* water, with the liberation of heat.

or

(2) Anaerobic lactic acid bacteria will rearrange the glucose molecule into the molecule of lactic acid. Lactic acid is reduced to acetic acid, carbon dioxide, and water. Finally acetic acid is oxidized to carbon dioxide and water.

Fats

Bacterial action through the
lipase splits up the fat into
glycerol (glycerine).

Fatty acids

Generally are oxidized i
carbon dioxide gas and
gas by a biological oxida
involving the addition o
An alternative method o
tion, by the enzyme lipa
produces alcohols and t
hydrogen gas.

Glycerol

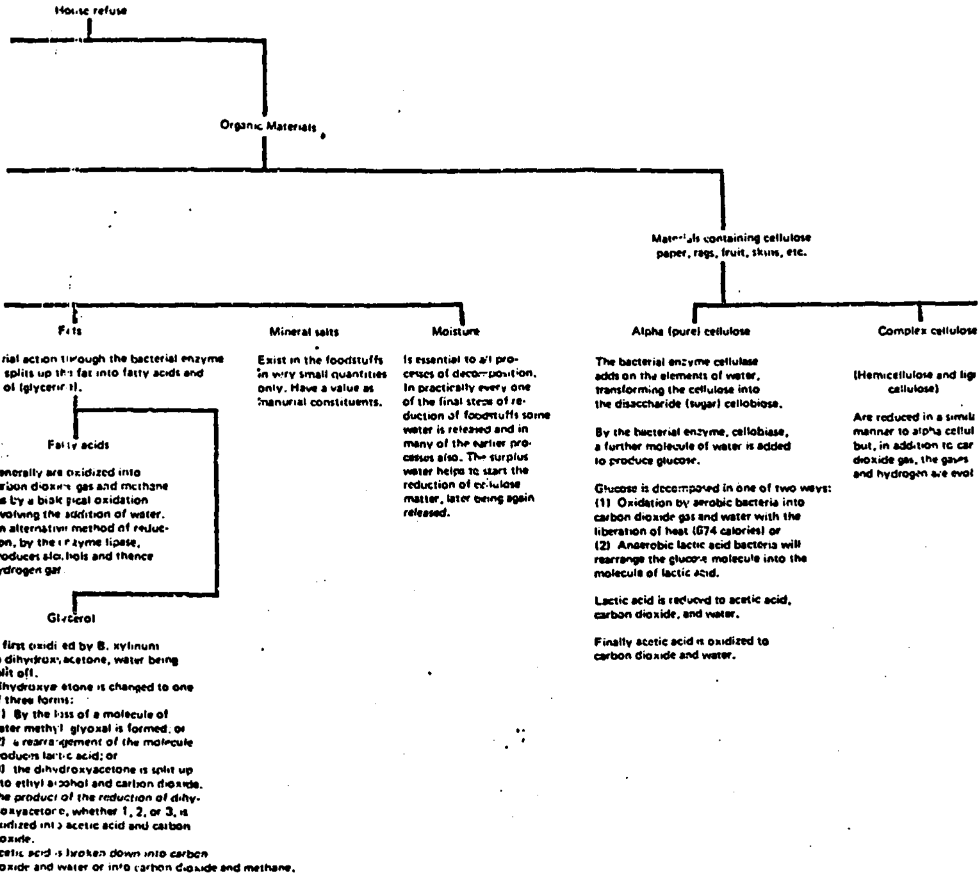
Is first oxidised by B. m
to dihydroxyacetone, w
[illegible] off.
Dihydroxyacetone is ch
of three forms:
1) By the loss of a mol
water methyl glyoxal is
2) a rearrangement of
produces lactic acid; or
(3) the dihydroxyaceto
into ethyl alcohol and c
The product of the redu
droxyacetone, whether
oxidized into acetic aci
diox[illegible]
Acetic acid is broken do
dioxide and water or int

Modified from Bevan (1967 p. 24-25)

B

Table 2

ICESS OF DECOMPOSITION OF HOUSE REFUSE



House refuse

Organic Materials

Materials containing cellulose
paper, rags, fruit, skins, etc.

Fats

rial action through the bacterial enzyme splits up the fat into fatty acids and ol (glycerol).

Fatty acids

enerally are oxidized into rbon dioxide gas and methane s by a biological oxidation volving the addition of water. n alternative method of reduction, by the enzyme lipase, roduces alcohols and thence ydrogen gas.

Glycerol

s first oxidized by B. xylinum o dihydroxyacetone, water being plit off.
lihydroxyacetone is changed to one f three forms:
1) By the loss of a molecule of ater methyl glyoxal is formed; or
2) a rearrangement of the molecule roduces lactic acid; or
3) the dihydroxyacetone is split up nto ethyl alcohol and carbon dioxide.
The product of the reduction of dihydroxyacetone, whether 1, 2, or 3, is oxidized into acetic acid and carbon lioxide.
Acetic acid is broken down into carbon lioxide and water or into carbon dioxide and methane.

Mineral salts

Exist in the foodstuffs in very small quantities only. Have a value as manurial constituents.

Moisture

Is essential to all processes of decomposition. In practically every one of the final steps of reduction of foodstuffs some water is released and in many of the earlier processes also. The surplus water helps to start the reduction of cellulose matter, later being again released.

Alpha (pure) cellulose

The bacterial enzyme cellulase adds on the elements of water, transforming the cellulose into the disaccharide (sugar) cellobiose.

By the bacterial enzyme, cellobiase, a further molecule of water is added to produce glucose.

Glucose is decomposed in one of two ways:
(1) Oxidation by aerobic bacteria into carbon dioxide gas and water with the liberation of heat (674 calories) or
(2) Anaerobic lactic acid bacteria will rearrange the glucose molecule into the molecule of lactic acid.

Lactic acid is reduced to acetic acid, carbon dioxide, and water.

Finally acetic acid is oxidized to carbon dioxide and water.

Complex cellulose

(Hemicellulose and lig
cellulose)

Are reduced in a simil
manner to alpha cellul
but, in addition to car
dioxide gas, the gases
and hydrogen are evol

C

Materials containing cellulose
paper, rags, fruit, skins, etc.

Moisture

sential to all pro-
es of decomposition.
ractically every one
e final stages of re-
:ion of foodstuffs some
r is released and in
y of the earlier pro-
s also. The surplus
r helps to start the
ction of cellulose
ter, later being again
sed.

Alpha (pure) cellulose

The bacterial enzyme cellulase adds on the elements of water, transforming the cellulose into the disaccharide (sugar) cellobiose.

By the bacterial enzyme, cellobiase, a further molecule of water is added to produce glucose.

Glucose is decomposed in one of two ways:
(1) Oxidation by aerobic bacteria into carbon dioxide gas and water with the liberation of heat (674 calories) or
(2) Anaerobic lactic acid bacteria will rearrange the glucose molecule into the molecule of lactic acid.

Lactic acid is reduced to acetic acid, carbon dioxide, and water.

Finally acetic acid is oxidized to carbon dioxide and water.

Complex celluloses

(Hemicellulose and ligno-cellulose)

Are reduced in a similar manner to alpha cellulose but, in addition to carbon dioxide gas, the gases methane and hydrogen are evolved.

Pectin

Two actions are possible in the decomposition of pectin:

(1) The aerobic organism Pectinobacter amilophilum can produce carbon dioxide and hydrogen gases with small portions of formic acid and alcohol; and
(2) the anaerobic Granulobacter pectinovorum can yield butyric acid and alcohol with small amounts of carbon dioxide and hydrogen.

Table 3

PIEZOMETER AND SAMPLING POINT DATA
OLD DUPAGE COUNTY LANDFILL

Well No.	Screened interval (ft.)	Sand Pack interval (ft.)	Well rating[1]	Principle unit measured or sampled	Sealed	Comments
MM 1	10.40-13.40	?	3	*Base of upper sand*	*Partially*	*Steel pipe used*
2	9-9.5	0-9.5	3	About middle upper sand	No	Replaced by MM 49 6/68
3	8.3-8.8	?	3	Same	No	Destroyed 4/69
4	8.4-8.9	?	Dry	Same	No	Destroyed 4/69
5	9.5-10.0	?	2	Same	No	Destroyed 4/69
6	9.0-9.5	?	3	Same	No	
7	18.6-19.1	?-19.1	4	4 ft. below top of upper till	Partially	Reduced 1967
8	9.4-9.9	?-9.9	2	About middle of upper sand	No	Reset and wirescreen replaced with 6 in. PVC plastic screen 6/68
9	19.9-20.4	?	4	8 ft. below top of upper till	Possibly	
10	9.1-9.6	?	4	About middle of upper sand	No	
11	14.6-15.1	?	3	Near base of upper sand	No	
12	12.1-12.6	?	2	Same	No	
13	11.68-12.18	?		Same	No	Destroyed late 1966
14	11.5-12.0	0-12.0	3	Same	No	Reset with new wire screen 9/66
15	6.4-6.9	?	3	About middle of upper sand	No	
16A	9.5-10.0	?	3	Same Same	No	Separated from fill by ditch and railroad embankment.
16B	18.8-19.3	?	3	Base of upper sand	No	Separated from fill by ditch and railroad embankment.
17	8.1-8.6	?	3	Middle of upper sand	No	Separated from fill by ditch and railroad embankment.
18	14.0-14.5	?	3	Near base of upper sand	No	Destroyed 1/69
19	15.5-16.0	?	3	Base of upper sand	No	
20	12.5-13.0	?-13.0	2	Same	No	
21	8.1-8.6	?	3	Same	No	
22	9.1-9.6	?	2	Near base of upper sand	No	Probably affected by septic field-destroyed
23	7.0-7.5	?	3	About middle of upper sand	No	
24	5.5-6.0	?	3	Same	No	
25	18.0-18.5	?	4	*5 ft. below top of upper till*	*Possibly*	*Reduced*
26	18.3-18.8	?	4	Same	No	
27	18.2-18.7	?	4	Same	No	Reduced
28	7.8-8.2	?	3	Near base of upper sand	No	Destroyed 5/68
29	19.0-19.5	17.0-21.0	2	10 ft. above upper till in upper sand	No	

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[1] Well ratings as follows:
1 + Pumping rate > 5 gpm.
1 Pumping rate 1-5 gpm.

[2] Can be bailed at 1/5 gt/min. to 1 gpm.

[3] Will recover in 1 to 2 hours when bailed dry.

[4] Requires more than one day to recover after being bailed dry.

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA
OLD DUPAGE COUNTY LANDFILL – CONTINUED

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	Well rating	Principle unit measured or sampled	Sealed	Comments
MM 30	7.6-8.1	2.0-10.2	Dry	Refuse	No	Generally above zone of saturation – gas
31	18.8-19.3	17.3-22.0		7 ft. below refuse in upper sand	No	
32	11.7-12.2	?-13.2	3	Near base of refuse	No	
33	11.4-11.9	0-13.0	3	Near base of upper sand	No	
34	11.2-11.7	0-11.7	1	About middle of upper sand	No	
35	10.0-10.5	0-10.5	2	Same	No	Destroyed 9/69
36	12.5-13.0	12.0-13.0	3	Near base of upper sand	No	Destroyed 9/69
37	7.0-7.5	0-7.5	2	About middle of upper sand	No	Destroyed 9/69
38	3.5-4.0	0-4.0	2	Near top of upper sand	No	Pipe raised
39	10.8-11.3	0-14.0	3	Near base of upper sand	No	Destroyed
40	11.0-11.5	0-12.0	3	Base of upper sand	No	Destroyed 6/68
41	11.0-11.5	0-12.0	3	Same	No	Destroyed 6/68
42	11.8-12.3	0-12.30	3	Base of upper sand	No	
43				Same	No	Destroyed 8/68
44	13.8-14.3	0-13.27	2	Same	No	Replaces MM 2
45	6.7-7.2	0-7.15	2	Middle of upper sand	No	
46	6.6-7.1	0-7.12	1	Same	No	
47	14.8-15.3	0-15.31	1	Base of upper sand	No	
48	5.0-5.5	0-5.5	2	Middle of upper sand	No	
49	16.0-16.5	0-16.66	2	Base of upper sand	No	
50	6.8-7.25	0-7.25	1	Near base of upper sand	No	
51	4.9-5.4	0-5.42	2	Near top of upper sand	No	
52	1.4-1.9	0-1.92	2	In landfill	No	
53	8.1-8.6	0-7.56	2	Near base of upper sand	No	Destroyed 4/69
54	8.3-8.8	6.78-8.8	2	Near middle of upper sand	No	
55	6.8-7.3	0-7.30	2	Same	No	
56	6.3-6.8	0-6.80	2	Same	No	
57	12.5-13.0	0-13.08	1	Near base of upper sand	No	
58	12.3-12.8	0-12.83	1	Same	No	
59	14.2-14.7	0-14.7	1	Same	No	
60	12.3-12.8	0-12.74	1	Same	No	
61	6.2-7.2	0-7.20	1	In refuse	No	Destroyed 4/69
62	10.8-11.8	0-11.80	1	In refuse, near base	No	
63	15.8-16.8	0-16.85	1	4 ft. below refuse in upper sand	No	
64	19.0-20.0	18.57-20.07	4	6 ft. below top of upper till	Yes	Sealed in till, reduced ½ in. pipe 8/69
65	8.85-9.85	0-9.85	2-3	Near middle of upper sand	No	
66	15.9-16.9	14.0-16.9	4?	In upper till near top	Possibly	Sealed in till ?
67	15.5-16.5	0-16.5	2-3	5 ft. below refuse in upper sand	Yes	Destroyed 8/69

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

OLD DUPAGE COUNTY LANDFILL – CONTINUED

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	Well rating	Principle unit measured or sampled	Sealed	Comments
68	10.1-10.64	9.64-10.64	1	Near base of upper sand	Yes	
68A	4.5-5.0	0-5.00		Near middle of upper sand	No	
69	9.3-10.3	9.17-10.30	1	Near base of upper sand	Yes	
70	8.8-9.8	8.80-9.80	1	Same	Yes	
71	7.0-10.0	9.00-10.00	1	Same	No	
71A	5.47-5.87	0-5.87		Near middle of upper sand	No	
72	7.3-10.30	9.30-10.30	1	Near top of upper sand	No	
73	7.68-8.18	1-8.18	1	In refuse	No	
74	7.60-8.10	1-8.10	1	Same	No	
75	8.64-9.14	8.14-9.14	1	Same	No	
76	12.14-12.64	0-12.64	1	In middle sand	No	
77	13.50-14.00	1.0-14.00	1	In refuse	No	
78	13.83-14.33	1-14.33	1	In refuse	No	
79	10.90-11.40	1-11.40	1	Middle of upper sand	No	
80	6.01-6.51	3-6.51	1	Same	No	
81	11.70-12.20	0-12.20	1	Same	No	
LW 1A	72.0-75.0	70.0-75.0	2	Top of silurian	Yes	Crack in piezometer near surface
1B	29.5-31.0	-33.0	4	16 ft. below top of till	Yes	
2A	71.0-75.0	-75.5	3	Top of silurian	Yes	Partially plugged
2B	38.0-41.0	-41.0	1	24 ft. below top of till in interbedded sand	Yes	
3A	68.5-71.5	-73.0	3	Top of dolomite	Yes	
3B	17.5-20.5	-20.0	4	3.5 ft. below top of till	Partially	Reduced
3C	39.5-42.5	-45.0	1	20.5 ft. below top of till in interbedded sand	Yes	
3D	47.5-49.0	47.5-50.0	4	Top of lower till	Yes	
4A	90.0-93.0	85.0-93.0	2	Top of dolomite	Yes	
4B	48.0-51.0	45.5-51.0	3	13 ft. below top of till	Yes	
4C	28.5-31.5	-32.0	3	Base of upper sand	Yes	
5A	47.0-50.0	47.0-50.0	1	21 ft. below top of till in interbedded sand	Yes	
5B	20.0-23.0	18.0-23.0	2	Base of upper sand	Yes	
5C	13.0-13.5	12.0-13.5	2	1 ft. below refuse	Possibly	

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

OLD DUPAGE COUNTY LANDFILL–CONTINUED

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	*Well rating	Principle unit measured or sampled	Sealed	Comments
6A	45.5-48.5	41.0-48.5	1	17.33 ft. below top of till in interbedded sand	Yes	
6B	18.0-21.0	15.0-21.0	2	Lower part of upper sand	Yes	
6C	7.5-8.0	5.0-11.0	2	Upper part of upper sand	Possibly	
7	5.2-9.2	0-9.17	1-2	Refuse	No	4 in. observation well
8						Caved and abandoned–samples only
9						Caved and abandoned–samples only
10	39.1-39.6	38.12-39.62	4	12.22 ft. below top of upper till	Partly	
LW 11A	29.0-30.0	28.20-30.03	4	2.30 ft. below top of till	Yes	2 in. sampling well, sealed in clay, reduced 8/69
11B	23.8-24.8		3	*Base of upper sand*	*Possibly*	
12A	33.6-34.6	33.37-34.57	4	7.47 ft. below top of upper till	Yes	2 in. sampling well, sealed in clay, reduced 8/69
12B	14.8-15.3		3	*Near base of refuse*	*Possibly*	*Possibly sealed in refuse*
13	9.7-13.7			*In refuse*	No	4 in. observation well
14	39.2-39.8	38.26-39.26	4	15.19 ft. below top of till	Yes	Sealed in till, reduced
15	29.2-30.2	29.14-30.31	4	4.31 ft. below top of till	Yes	2 in. sampling well, sealed in clay, reduced
16	26.2-27.2	25.92-27.00	4	2.8 ft. below top of till	Yes	2 in. sampling well, sealed in clay, reduced

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

WINNETKA LANDFILL

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	Well rating	Principle unit measured or sampled	Sealed	Comments
MM 1	13.5-14.0	12.0-14.0	3	Upper part of till	Partly	
2	4.5-5.0	0.5-5.0	3	Upper part of alluvium	No	
3	10.5-11.5	9.0-11.0	3	Upper part of till	Partly	
4	16.5-17.5	15.0-17.0	4	Upper part of till	Partly	Buried by fill
5	4.0-4.5	0.5-4.5	3	Upper part of alluvium	No	
6	5.5-6.0	0.5-6.0	2	Alluvium	No	Buried by fill
7	17.5-18.0	16.0-18.0	4	Upper part of till	Partly	Reduced with 8 ft. of ½ in. tubing
8	5.0-5.5	0.5-5.5	2	Alluvium	No	
9	4.5-5.0	0.5-5.0	3	Alluvium	No	
10	4.5-5.0	0.5-5.0	2	Refuse	No	
11	8.5-9.0	0.5-9.0	3	Refuse	No	
12	8.5-9.0	0.5-9.0	2	Alluvium	No	
13	17.0-17.5	16.0-18.0	4	Upper part of till	Partly	Reduced with 12 ft. of ½ in. tubing
14	7.5-8.0	0.5-8.0	4	Alluvium	No	Reduced with 8 ft. of ½ in. tubing
15	10.5-12.0	9.8-12.0				Plugged with Bentonite at 5 ft.
16	10.5-12.0	10.0-12.0	4	Base of alluvium	Yes	
17	10.5-12.0	10.0-12.0	4	Base of alluvium	Yes	
18	10.5-12.0	10.0-12.0				Pulled piezometer off while back filling
19	10.5-12.0	10.0-12.0	4	Base of alluvium	Yes	
20	10.5-12.0	10.0-12.0				Plugged dry at 8 ft.
21	10.5-12.0	10.0-12.0	4	Base of alluvium	Yes	
22	10.5-12.0	9.7-12.0				Tubing pulled off
23	10.5-12.0	10.0-12.0	4	Base of alluvium		
24	8.56-9.06	0.5-9.06	3	Alluvium	No	
25	5.71-6.21	1.0-6.21	3	Alluvium	No	
26	8.83-9.13	1.0-9.13	2-3	Alluvium	No	
27	10.62-11.12	1.0-11.12	3-4	Alluvium	No	
28	8.77-9.27	1.0-9.27	3	Alluvium	No	
29	0.48-3.48	0-3.48	1-2	Refuse	No	

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

WINNETKA LANDFILL – CONTINUED

Well No.	Screened interval (ft.)	Sand Pack interval (ft.)	Well rating	Principle unit measured or sampled	Sealed	Comments
MM 30	2.64-5.64	0-5.64	1-2	Refuse		Flowing at ground level
31	6.00-9.00	1.0-9.0	1-2	Refuse		
32	3.44-6.44	1.0-6.44	1-2	Refuse		
33	0.30-3.30	0.0-3.30	3	Alluvium	No	Some surface leakage
34	8.45-8.95	1.0-8.95	3	Alluvium	No	
35	8.29-8.78	1.0-8.78	2	Alluvium	No	Over sewer
36	8.46-8.96	1.0-8.96	3	Alluvium	No	
37	5.38-8.38	1.0-8.38	3	Alluvium	No	
38	8.14-11.14	1.0-11.14	3	Alluvium	No	
39	6.31-9.31	1.0-9.31	2	Alluvium	No	
40	13.13-16.13	1.0-16.13	2	Refuse	No	Slotted for gas sample
41	5.62-6.12	1.0-6.12	2-3	Alluvium	No	In ditch surface leakage
42	8.86-9.36	1.0-9.36	3	Alluvium	No	
43	9.30-12.30	1.0-12.30	2-3	Alluvium	No	Destroyed
44	19.81-20.11	17.11-20.11	4	Upper part of till	Yes	
45	17.11-18.11	15.11-18.11	4	Upper part of till	Yes	
46	19.79-20.79	17.79-20.79	4	Upper part of till	Yes	
47	19.99-20.99	19.49-20.99	4	Upper part of till	Yes	
48	29.82-30.32	27.32-30.32	4	Upper part of till	Probably	
49	29.82-30.36	27.86-30.36	4	Upper part of till	Probably	Reduced
50	6.87-7.37	0.00-7.37	3	Alluvium	No	Injection testarray
51	6.39-6.89	0.00-6.89	3	Alluvium	No	Injection testarray
52	6.61-7.11	0.00-7.11	3	Alluvium	No	Injection testarray
53	6.55-7.05	0.00-7.05	3	Alluvium	No	Injection testarray
54	6.60-7.10	0.00-7.10	3	Alluvium	No	Injection testarray
55	8.0-8.5	7.0-8.5	?	Alluvium	Probably	
56	8.0-8.5	7.0-8.5	?	Alluvium	Probably	
LW 1A	120.5-123.5	110.0-124.0	2	Upper part of silurion	Partially	
1B	95.5-98.5	92.0-99.0	3	Near base of till	Partially	
1C	83.0-86.0	79.0-99.0	3	Near middle of till	Partially	
1D	54.5-57.5	55.0-57.5	3	Upper part of till	Partially	
1E	12.0-15.0	1.0-15.0	2	Base of refuse	No	
2A	121.5-124.5	112.0-124.5	1	Upper part of silurion	Yes	
2B	67.5-70.5	65.0-70.5	2	Near middle of till	Yes	
2C	34.0-37.0	30.0-37.0	2	Near top of till	Partly	
2D	7.5-10.5	1.0-10.5	3	Base of alluvium	No	
3A	116.0-118.0	112.0-118.0	1	Upper part of silurion	Yes	
3B	63.5-66.5	54.0-66.5	2	Near middle of till	Partially	
3C	27.5-30.5	24.0-30.5	3	Upper part of till	Partially	
3D	11.0-13.0	8.5-13.5	2	Base of alluvium	Partially	
3E	[illegible].0-4.5	2.0-4.5	Dry	Top of alluvium	No	
4A	123.5-126.5	118.0-126.5	1	Top of silurion	Yes	

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

WINNETKA LANDFILL – CONTINUED

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	Well rating	Principle unit measured or sampled	Sealed	Comments
4B	82.0-85.0	77.0-85.0	3	Near base of till	Yes	
4C	55.0-58.0	44.5-58.5	2	Near middle of till	Partly	
4D	32.0-35.0	30.0-35.0	3	Upper part of till	Partly	
4E	13.0-16.0	11.0-16.0	2	Base of alluvium	No	
5A	32.0-35.0	30.5-36.0	4	19.5 ft. below top of till	Probably	
5B	9.5-12.5	0.0-12.5	2	Base of refuse	No	
6A	55.5-58.5	52.0-58.5	2	Near middle of till	Yes	
6B	27.5-30.5	24.5-31.5	4	Near top of till	Yes	
7A	92.0-95.0	88.0-95.0	3	Lower part of till	Partially	
7B	42.0-45.0	38.0-45.0	3	Near middle of till	Partially	
7C	9.5-12.5	6.0-12.5	3	Base of alluvium	No	
8A	60.0-63.0	55.0-66.0	2	Near middle of till	Yes	
8B	26.0-29.0	23.0-30.0	3	Upper part of till	Probably	
8C	11.5-12.00	0.5-12.0	3	Base of alluvium	No	
9A	64.0-66.0	57.5-66.0	2	Lower part of till	Questionable	
9B	10.0-10.5	0.5-10.5	3	Base of alluvium	No	
10A	35.30-35.80	34.80-35.80	4	Till, 23.3 ft. below refuse	Yes	Reduced
10B	11.31-11.81	?-11.81	2-3	Base of refuse	No	
11	14.91-15.91	14.91-15.91	4	Till, 0.41 ft. below refuse	Yes	
12	19.89-20.89	19.89-20.89	4	Till, 9.4 ft. below refuse	Yes	Reduced
13	3.75-8.00	0.00-8.00	1	Base of refuse	No	
14	33.49-33.99	33.32-33.99	4	Till, 19.5 ft. below refuse	Yes	Reduced
15	24.46-25.46	24.45-25.46	4	Till, 11.13 ft. below refuse	Yes	Reduced
16	19.38-20.38	19.20-20.38	4	Till, 5.93 ft. below refuse	Yes	
17	14.58-19.38	0.00-19.38	2	Base of refuse	No.	

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

ELGIN LANDFILL

Well No.		Screened interval (ft.)	Sand pack interval (ft.)	Material set in	Well rating	Sealed	Comments
LW	1A	41.0-44.0	37.0-44.0	Dolomite	1	Yes	Buried, 8/68
	1B	23.0-26.0	20.0-26.0	Gravel	2	Yes	Buried, 8/68
	1C	7.5-10.5	3.0-10.5	Sand and gravel	1	No	Buried, 8/68
	2A	60.0-63.0	53.0-63.0	Dolomite	1	Yes	
	2B	46.0-49.0	39.5-49.5	Sand and gravel	1	Yes	
	2C	8.0-11.0	7.0-11.0	Sand and gravel	?	No	Foot valve removed
	3A	55.0-58.0	51.0-58.0	Dolomite	2	Yes	
	3B	31.5-34.5	27.0-34.5	Sand and gravel	1	Yes	
	3C	8.0-11.0	-11.0	Sand and gravel	3	No	Foot valve removed
	4A	46.5-49.5	-52.0	Dolomite	1	Partly	
	4B	34.5-37.5	-37.5	Sand & pea gravel	1	Partly	
	4C	20.5-23.5	19.0-23.5	Sand & pea gravel	1	Partly	
	4D	8.5-11.5	0.0-11.5	Sand & pea gravel	3	No	
	5A	18.5-21.5	17.5-21.5	Silty sand	2	Partly	
	5B	10.5-13.5	6.0-13.5	Sand and gravel	1	No	
	6A	38.0-41.0	35.0-41.0	Silty sand	1	Yes	
	6B	18.5-21.5	-21.5	Sand and gravel	2	No	
	7A	30.0-33.0	28.0-33.0	Silty sand	2	Partly	
	7B	22.0-25.0	18.0-25.0	Sand and gravel	3	No	
	8A	33.5-36.5	31.0-36.5	Sand	1	Yes	
	8B	15.0-18.0	10.0-18.0	Sand and gravel	1	No	
	9A	28.0-31.0	25.0-31.5	Sand and gravel	1	Yes	
	9B	12.0-15.0	11.0-15.0	Sand and gravel	1	No	
	10	15.97-16.47	11-16.47	Sand and gravel	?	Partly	
	11	9.86-10.36	0-10.36	Sand and gravel	?	No	
Well	1	4.90-7.90	0-7.90	Sand and gravel	2	No	Foot valve removed
Well	2	17.8-19.8	0-19.8	Sand and gravel	1	No	Lost

Table 3 (Continued)

PIEZOMETER AND SAMPLING POINT DATA

WOODSTOCK LANDFILL

Well No.	Screened interval (ft.)	Sand pack interval (ft.)	Material set in	Well rating	Sealed	Comments
MM 1	7.5-8.0	0.0-8.0	Sand	1	No	
2	17.0-17.5	11.0-18.0	Gravelly sand	3	Partly	
3	6.5-7.0	0.5-7.0	Silt	3	No	
4	18.5-19.0	12.0-21.0	Gravel	1	Partly	
5	10.5-11.0	8.5-11.0	Silty sand	3	Partly	
6	6.0-6.5	0.5-6.5	Sand and gravel	1	No	Buried, 1968
7	8.5-9.0	0.5-9.0	Organic silt	2	No	
8	15.0-15.5	14.0-15.5	Organic silt	3	Partly	
9	8.5-9.0	0.5-9.0	Organic silt	2	No	
10	8.0-8.5	0.5-8.5	Organic silt	3	No	
LW 1A	220.5-223.5	209.0-223.5	Sand and gravel	4	Yes	Reduced
1B	31.0-34.0	30.0-34.0	Sand and gravel	2	Partly	
1C	22.0-25.0	-25.0	Silt	2	Partly	
1D	11.5-14.5	-14.5	Refuse	3	No	
2A	145.0-148.0	-148.0	Sand and gravel	2	Yes	Destroyed, 10/69
2B	76.0-79.0	-79.0	Sand and gravel	2	No	Destroyed, 10/69
2C	63.5-66.5	-66.5	Sand and gravel	2	No	Destroyed, 10/69
2D	8.5-9.0	-9.0	Till	2	Probably	Destroyed, 10/69
2E	4.5-5.0	-5.0	Sand and gravel	1+	No	Destroyed, 10/69
3A	192.0-195.0	180.0-195.0	Sand and gravel	2	Partly	
3B	162.0-165.0	158.0-169.0	Clay over sand and gravel	3	Partly	
3C	101.5-104.5	98.0-104.5	Sandy till	3	Partly	
3D	62.0-65.0	55.0-65.0	Sand and gravel	1+	Partly	
3E	19.0-22.0	-22.0	Sand and gravel	1	Probably	
3F	7.0-7.5	-7.5	Sand and gravel	2	No	
4A	118.0-121.0	113.0-121.0	Sand	2	Probably	
4B	102.0-105.0	98.0-105.0	Silty sand	1+	Probably	
4C	70.0-73.0	65.0-73.0	Sand	1	Yes	
4D	26.5-29.5	-29.5	Sand and gravel	1	Yes	
4E	13.0-13.5	11.0-13.5	Sandy silty till	Dry	No	
5A	44.0-47.0	43.0-51.0	Sand	1	Yes	
5B	18.5-21.5	18.0-21.5	Sandy silt	1	Yes	
5C	9.5-10.0	8.0-10.0	Sandy silt	2	No	
6A	31.0-34.0	22.0-34.0	Sand and gravel	1+	Yes	
6B	8.0-11.0	6.0-11.0	Refuse	3	No	
7	9.79-13.79	0-13.79	Refuse	?	No	
8	13.08-17.08	0-17.08	Refuse	?	No	

Table 4

TEXTURAL ANALYSES[1, 2]

Well No.	Depth (ft.)	Stratigraphic position	Total sample Gravel (%)	Sample <2 mm diameter Sand (%)	Silt (%)	Clay (%)	Classification[3]
			DuPAGE COUNTY LANDFILL				
Near LW 4	0-1	Cover on fill	3	14	60	26	Silt loam
5	0-1	Cover on fill	8	12	53	35	Silty clay loam
1	0-1	Cover on fill	3	13	55	32	Silty clay loam
6	0-1	Cover on fill	8	11	51	38	Silty clay loam
3	1.5	Topsoil adjacent to fill	9	20	43	37	Silty clay loam
1	1.5	Topsoil adjacent to fill	16	36	36	28	Clay loam
7	0.5	Cover on fill	18	14	48	38	Silty clay loam
7	1.5	Cover on fill	1	6	62	32	Silty clay loam
13	0.5	Cover on fill	5	20	47	33	Clay
13	1.5	Cover on fill	24	25	45	30	Clay loam
1B	3-4.5	Surficial sand	38	45	37	18	
1B	10.5-12	Surficial sand	0	25	64	11	
2B	12-13.5	Surficial sand	14	20	61	19	
4B	18-19.5	Surficial sand (below fill)	1	46	41	13	
4B	27.5-29	Surficial sand (below fill)	1	16	84		Mostly silt
1B	17-18.5	Upper till	5	11	55	34	
2B	17-18.5	Upper till	6	10	53	37	
3B	17-18.5	Upper till	10	7	71	22	
4B	48-49.5	Middle till	23	35	44	21	
5	42-43.5	Middle till	21	35	45	20	
2B	40-41.5	Interbedded sand	29	76	16	8	
Near LW 2B	41.5-43	Interbedded sand	30	86		14	
3C	42-43.5	Interbedded sand	36	86		14	
5	50-51.5	Interbedded sand	14	87		13	
6	44.5-46	Interbedded sand	3	95		5	
			WINNETKA LANDFILL				
Near LW 7	0-1	Cover on fill	1	32	40	28	Loam
NE corner	1.5	Adjacent to fill	5	11	66	23	Silt loam
South side of fill	1.5	Adjacent to fill	0	8	64	28	Silt loam

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[1] Analyses performed under the supervision of W. Arthur White.

[2] Gravel > 2mm sand 2-0.062 mm silt 0.062-0.0039 mm clay < 0.0039 mm.

[3] U.S. Department of Agriculture.

WINNETKA LANDFILL (Continued)

Well No.	Depth (ft.)	Stratigraphic position	Total sample Gravel (%)	Sample <2 mm diameter Sand (%)	Silt (%)	Clay (%)	Classification
Near LW 6	1.5	Adjacent to fill	0	26	46	28	Loam
6	9.5-11	Upper till	9	19	53	28	
6	24.5-26	Upper till	3	17	49	34	
6	34.5-36	Upper till	5	10	41	49	
6	47-48.5	Lower till	1	42	45	13	
13	0.5	Cover on fill	3	48	29	23	Loam
13	1.5	Cover on fill	2	65	20	15	Sand loam
17	0.5	Cover on fill	2	40	31	29	Clay loam
17	1.5	Cover on fill	0	40	26	34	Clay loam
6	4.5-6	Surficial silt	1	21	51	22	
5	13.5-15	Upper till		bad reading			
5	26-27.5	Upper till	3	13	48	39	
5	31.5-33	Upper till	4	10	46	44	

ELGIN LANDFILL

Well No.	Depth (ft.)	Stratigraphic position	Total sample Gravel (%)	Sample <2 mm diameter Sand (%)	Silt (%)	Clay (%)	Classification
Near LW 7	0-1	Cover on fill	40	40	27	33	Clay loam
7	0.5	Cover on fill	15	33	36	31	Clay loam
7	1.5	Cover on fill	18	39	37	24	Loam
8	15-16.5	Surficial sand	3	10	84	6	
8	17.5-19	Surficial sand	14	96	4		
6	19.5-21	Surficial sand	65	79	21		
6	24.5-26	Upper till	13	27	41	32	
6	32-33.5	Upper till	7	33	42	25	
6	38-39.5	Basal sand	55	76	24		

WOODSTOCK LANDFILL

Well No.	Depth (ft.)	Stratigraphic position	Total sample Gravel (%)	Sample <2 mm diameter Sand (%)	Silt (%)	Clay (%)	Classification
Near LW 6	0-1	Cover on fill	33	53	31	16	Sandy loam
SW corner	0-1	Cover on fill	16	26	61	13	Silt loam
Near LW 2	0-1	Cover on fill	9	15	49	36	Silty clay loam
4	1.5	Topsoil adjacent to fill	1	50	34	16	Loam
NW corner	1.5	Topsoil adjacent to fill	0	94	6		Sand
Near LW 7	0.5	Cover on fill	29	48	39	13	Loam
7	1.5	Cover on fill	29	55	31	14	Sandy loam
8	0.5	Cover on fill	2	72	14	14	Sandy loam
8	1.5	Cover on fill	14	58	25	17	Sandy loam
5	24.5-26	Upper till	3	14	44	42	
5	42-43.5	Upper till	3	11	51	38	
6	35-36.5	Upper till	4	10	48	42	
5	49.5-51	Lower till	11	39	36	25	
6	39.5-41	Lower till	12	44	38	18	
6	54.5-56	Lower till	22	41	36	23	

TABLE 5

CLAY MINERAL ANALYSES[1, 2]

Landfill	Well No.	Depth (ft)	Percent <2 μ fraction Mont-morillonite	 Illite	 Chlorite and kaolinite	Unit sampled
DuPage County	LW 6	26-27.5	2	79	19	Upper till
	LW 6	39.5-41	2.5	71.5	26	Upper till
Winnetka	LW 5	12-13.5	3	80	17	Alluvium?
	LW 5	17-18.5	2.5	81	16.5	Upper till
Elgin	LW 5	16.5-17	15	67.5	17.5	Upper till
	LW 6	21-22.5	11	65	24	Lower till

[1] Analyses performed under the supervision of Herbert D. Glass.

[2] Percentages obtained by x-ray diffraction of the <2-micron-size fraction.

TABLE 6

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well no.		Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	? Comments
							DUPAGE COUNTY						
LW	1A	10-3-67	382	7.5	32	40	290	8	42	18	126	0	
	1A	11-29-67	314	8.0	24	neg	265	4	23	6	55	0	
	2B	10-3-67	426	7.7	44	20	320	29	49	26	139	0	
	3C	10-3-67	378	7.6	20	56	340	23	17	16	97	0	
	3C	11-29-67	388	8.0	22	neg	330	21	27	9	18	0	
	4A	10-3-67	382	7.5	91	neg	340	17	19	23	70	0.1	
	4C	11-13-67	374	8.4	4	neg	338	63	17	11	27	0.4	
	5A	8-8-67	348	7.7	36	70	310	18	18	8	2.3	0	
	5B	8-8-67	6,712	6.7	1,813	1,840	4,620	295	962		33	0	
	5B	8-31-67	11,254	6.4	35,700	7,050	8,700	940	1,200	1,100	206		Detergents, 2.
	5B	9-6-67	11,875	6.4	51,400	4,500	9,000	1,600	1,323	2,250	403.6	0	
	5B	9-21-67	12,589	6.5	44,800	3,960	9,000	820	1,651	1,900	400		
	5B	10-3-67	13,409	6.2	45,643	9,200	10,600	1,200	1,202	2,030	774	0	
	5B	10-24-67	11,465	7.6	20,700	6,550	8,000	461	1,180	1,750	762	0	
	5B	11-7-67	8,047	6.5	17,083	9,150	6,200	190	1,310	1,075	461	0	
	5C	8-8-67	6,712	6.7	1,883	6,700	4,060	350	906		40	0	
	6A	8-9-67	353	7.9	8	0	350	16.8	2	10	6.8	0	
	6A	11-28-67	391	7.9	22	neg	320	30	28	10	38	0	
	6B	8-9-67	1,703	7.3	167	60	620	7.6	512		6	0	
	6B	9-6-67	1,715	7.1	180	neg	590	6.4	518	186	25.6	0	
	6B	11-28-67	2,075	7.6	238	neg	600	24	726	220	110	0	
	6C	8-9-67	1,372	7.3	143	80	690	8.4	360		16.2	0.2	
MM	2	9-21-67	1,970	7.0	232	neg	840		523	240	49.6	neg	
	2	10-3-67	1,928	7.2	206	neg	740	16	914	400	416	0	
	3	9-6-67	4,980	7.4	873	20	840	26	1,904	800	192	0	

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (as) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
DUPAGE COUNTY												
5	8-9-67	1,084	7.4	68	100	720	146	167	120	4.2	Tr 0.1	
5	11-28-67	1,012	7.3	100	neg	470	66	249	1,500	400	0.2	
12	10-3-67	9,604	6.7	19,038?	6,000	6,100	58	1,338	250	454	0	
15	10-25-67	908	7.4	40	neg	520	34	178	300	238	0.2	
17	10-25-67	1,468	6.9	58	neg	1,040	27	206	2	400	0.7	
18	8-9-67	3,250	7.5	430	40	1,450	82	828	450	27.7	0	
18	11-29-67	3,031	7.5	260	neg	700	31	1,003	925	440	0	
19	10-3-67	2,866	7.2	210	neg	1,000	4	582	325	142	0	
20	10-3-67	2,334	7.2	249	80	760	9	715	300	67	0	
20	11-29-67	2,812	7.5	290	neg	740	26	367	157	300	0	
21	10-3-67	788	7.4	91	neg	520	22	120	48	403	0.1	
22	10-25-67	618	6.3	20	neg	460	18	73	175	333	0	
23	9-6-67	632	7.1	51	neg	570	9	107	58	24	0.3	
24	9-6-67	424	7.3	63	neg	400	76	43	248	22.8	0.3	
34	9-2-67	1,506	7.3	71	neg	820	10	316	220	144	0	
34	11-29-67	1,291	7.8	68	neg	480	43	302	63	440	0	
39	10-25-67	590	7.3	18	neg	400	339	56	18	22	0	
40	10-25-67	636	7.2	20	56	570	230	30	23	70	0.5	
41	10-24-67	604	7.4	246	neg	460	648	62	385	30	0.2	
62	2-19-69	3,001	6.7	4,900	1,960				5			
Asphalt							10	35	5	1	0	Dolomite well
plant	9-6-67	317	7.7	14	neg	240	11	32		1	0	Dolomite well
	11-1-67	319	7.5	6	neg	250			8			
Farm well	8-9-67	321	7.9	0	40	270	20	23		0.55	0	Dolomite well
Aluminum									6			
plant	8-9-67	392	7.7	4	40	320	68	33		0.2	0	Dolomite well

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
DU PAGE COUNTY—continued												
Aluminum plant	11-1-67	407	7.3	6	neg	310	88	44	8	0.2	0	Dolomite well
Electronics plant	9-6-67	358	7.8	16	20	330	64	13	6	0.6	0	Dolomite well
Spring on S. side of road near MM 3	1-24-68	2,695	7.0	230.	80	800	150	1,010	290	78	0	
	2-19-69	2,682	7.1	476	70				275			
Kress Creek 200 ft N MM 9	1-24-68	551	7.8	2	neg	330	162	102	48	0.4	0	
	2-19-69	506	7.8	2	40				33			
Kress Creek near MM 12	1-24-68	554	7.9	4	36	330	160	103	51	0.4	0	
Kress Creek near MM 53	1-24-68	559	7.3	3	neg	350	164	96	37	0.6	0	
Kress Creek near MM 53	2-19-69	562	7.6	5	30				39			
Kress Creek at bend, middle of field	1-24-68	563	7.3	8	60	370	196	80	34	0.7	0	Old channel—equivalent to stream near MM 56

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)
DU PAGE COUNTY—continued											
Kress Creek near MM 56	2-19-69	561	7.8	3	20				39		
WINNETKA											
1A	10-18-67	332	7.7	24	neg	140	6	88	60	128	0
1A	12- 5-67	439	7.5	43	20	160	20	119	65	8	0.2
1E	8-17-67	5,146	7.4	737	20	930	0	1912	115	27	0
1E	11-15-67	4,750	7.6	603	110	1,000	48	1688	1040	68	0
2A	8-16-67	247	8.0	18	0	98	24	69	48	30	0.2
2B	8-18-67	1,060	7.3	57	0	630	114	218	249	34	0.2
2B	10-28-67	548	7.5	38	neg	200	36	119	113	304	0.3
2B	12- 4-67	463	7.5	28	neg	230	28	107	88	160	0.2
2C	9-20-67	2,548	6.9	163	neg	1,480	227	491	770	170	0.1
2C	10-18-67	2,471	7.1	113	neg	1,340	210	620	695	83	0.3
3A	8-21-67	223	7.5	18	0	190	8	15	51	30	0.2
3A	8-23-67	442	7.3	22	20	260	18	84	61	27	0.2
3A	10-18-67	365	7.5	20	neg	170	4	90	90	50	0.2
3A	12- 5-67	339	7.9	18	15	172	7	99	62	3	0.1
3B	8-30-67	1,286	7.0	129	neg	810	38	219	200	150.4	0.2
3B	10-18-67	1,827	7.0	190	neg	1,110	14	330	475	342	0.1
3C	8-30-67	1,715	7.1	186	neg	1,200	6.8	237	360	45.2	0
3C	10-18-67	1,802	6.8	145	neg	1,270	14	282	440	80	0
3D	8-21-67	1,501	7.0	119	0	800	32	322	275	36	0
3D	10-17-67	1,939	6.9	157	neg	1,170	15	354	440	362	0

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

	Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
							WINNETKA – Continued						
LW	4A	9-10-67	224	8.0	121	40	80	6	66	31	9.8	0.7	
	4C	9-18-67	631	7.7	20	neg	370	66	120	118	20.4	0.5	
	4C	10-16-67	450	7.4	28	neg	240	26	97	110	262	0.4	
	4E	9-19-67	1,330	7.4	52	neg	890	157	202	323	14.8	0.2	
	4E	10-17-67	1,341	7.1	48	neg	1,020	274	148	295	108	1.2	
	5B	8-17-67	2,918	7.0	229	0	760	18	993	600	22	0	
	5B	11-15-67	2,941	8.0	200	40	720	11	1,012	610	260	0	
	6A	9-20-67	218	8.1	8	neg	92	16	68	34	4.8	neg	
	6A	9-28-67	261	7.5	6	neg	108	0	70	40	28	0	
	6A	2-26-69	221	7.5	162	20				33			
	7A	12-5-67	593	7.3	18	neg	370	116	103	39	15	0.2	
	7D	11-6-67	376	7.5	23	neg	90	67	132	33	29	0	
	7B	12-5-67	436	7.5	39	20	230	66	95	31	5	0.2	
	7C	12-5-67	1,022	7.1	22	neg	830	340	65	80	30	0.2	
	8A	11-10-67	268	7.8	0	neg	172	28	44	39	330	0	
	8A	11-14-67	238	8.3	4	neg	100	20	63	37	25	0	
	8B	11-15-67	435	8.2	31	30	152	130	130	33	26	0	
	8B	2-26-69	2,378	7.2	189	30				850			
	8C	2-26-69	676	7.5	189	120				188			
	9A	11-10-67	301	7.6	19	30	124	22	81	45	78	0	
MM	5	12-5-67	2,624	7.0	681	40	1,320	140	654	360	150	0	
	6	8-16-67	1,236	7.5	31	0	920	600	145	190	7	0.1	
	6	10-16-67	1,466	7.3	20	neg	1,390	730	36	209	110	0.8	
	6	12-5-67	1,625	7.3	102	30	840	38	331	390	300	0.5	
	8	1-25-68	1,421	7.1	60	neg	710	103	327	356	162	0.2	
	9	12-5-67	4,235	7.2	102	neg	1,600	216	1,258	1,960	140	0	
	9	1-25-68	4,060	7.3	33	35	1,480	208	1,187	2,000	68	0	
	9	2-26-69	3,244	7.3	171	neg				1,625			

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
						WINNETKA—continued						
MM 10	8-15-67	3,379	7.1	617	0	890	0	1,145	650	23	0	
10	11-15-67	3,250	7.7	324	70	920	17	1,072	600	211	0	
11	9-20-67	5,560	6.7	5,828	3,400	3,280	26	1,049	1,130	323	neg	
11	11-15-67	5,938	7.3ᵃ	10,800	3,000	3,440	192	1,149	620	589	0	
11	2-26-69	3,304	6.9	1,240	160				725			
12	11-15-67	1,328	7.8	0	neg	1,300	1,900	13	80	10	0.3	
12	12-5-67	1,119	7.2	32	neg	930	480	87	205	83	0.8	
25	2-26-69	927	7.4	433	0				60			
26	2-26-69	1,427	7.3	128	20				73			
28	2-26-69	2,403	7.1	470	0				1,100			
29	2-26-69	1,735	6.7	443	0				280			
33	2-26-69	5,263	7.1	830	40				2,650			
36	2-26-69	479	7.5	65	0				13			
37	2-26-69	1,052	7.1	600	30				58			
38	2-26-69	1,828	7.0	104	40				800			
39	2-26-69	4,459	6.9	947	70				1,050			
40	2-26-69	4,280	6.9	848	70				975			
41	2-26-69	844	7.1	610	0				100			
42	2-26-69	1,107	7.1	98	40				10			
43	2-26-69	931	7.4	164	70				27			
47	2-26-69	683	7.6	377	0				14			
48	2-26-69	401	7.6	62	20				95			
49	2-26-69	279	7.7	86	0				22			
52	2-26-69	595	7.3	1,374	0				61			
2061	10-6-67	220	7.8	6	neg	76	2	63	38	0.2	0	Dolomite wells ¼ to ½ miles north of LW 3
2062	10-6-67	260	7.6	8	neg	84	1	76	36	0.2	0	

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chlorides (ppm)	Iron (ppm)	Manganese (ppm)
						ELGIN					
LW 1A	7-27-67	498	7.2	50	0	380	76	est. 54	28		0.2
1A	8-2-67	412	7.0	20	0	328	6	est. 39	9		0
1A	9-27-67	401	7.3	16	30	308	2	43	6	7.2	0.1
1B	7-27-67	416	7.1	30	35	348	14	est. 31	9		0.7
1B	8-30-67	428	7.1	26	neg	350	6.4	36	8	3.2	0.8
1C	7-27-67	523	7.2	70	35	408	40	est. 53	29		1.7
1C	8-30-67	1,946	7.0	44	40	1,010	650	431	600	4.2	1.6
2A	7-27-67	412	7.5	23	0	344	44	est. 31	9		0.3
2A	8-2-67	393	7.4	12	20	332	34	est. 28	10		0
2A	9-26-67	376	7.6	4	neg	324	20	24	6	4	0.1
2B	7-27-67	391	7.7	20	0	332	28	est. 27	9		0.5
23	9-26-67	383	7.6	8	30	332	20	23	6	4.8	0.4
3A	7-27-67	349	8.0	110	35	272	10	est. 35	16		0.3
3A	8-2-67	371	7.3	22	0	340	8	est. 14	7		0.3
3A	9-26-67	376	7.6	8	neg	320	0.4	26	6	19.2	0.2
3B	7-27-67	374	7.7	236	0	248	30	est. 58	7		0.3
3B	9-26-67	383	7.7	10	neg	308	6	35	6	4.4	0.2
4A	7-26-67	374	7.2	290	75	328	3	est. 21	7		0.9
4A	8-2-67	383	7.0	8	20	324	5	est. 27	7		0.2
4A	9-26-67	389	7.4	8	100	332	0.4	26	5	3.2	0.6
4B	7-26-67	398	7.2	60	0	348	4	est. 23	11		0
4B	8-30-67	388	7.3	12	20	310	2	35	5	2.6	0.2
4C	7-26-67	368	7.4	60	35	348	6	est. 9	7		0
4C	8-30-67	390	7.3	neg	neg	350	14	22	6	4.8	0.2
5A	7-26-67	2,470	7.7	1,000	3,360	812	16	est. 763			0
5A	7-27-67	2,246	7.3	1,500	330	844	10	est. 645			0
5A	8-2-67	2,237	7.3	800	220	860	5	est. 645			0

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)
ELGIN – Continued											
LW 5B	7-26-67	2,570	7.4	1,400	270	1,140	60	est 658			0
5B	7-27-67	2,287	6.9	1,700	160	912	51	est 633			0
5B	8-30-67	2,470	6.8	992	260	1,100	28	630	510	75	0
6A	7-26-67	379	7.2	23	76	352	4	est 12	7		0
6A	8-2-67	396	7.4	160	0	340	10	est 25	7		0
6A	9-27-67	365	7.4	4	neg	332	5	29	5	8.8	0
6B	7-26-67	1,647	7.8	170	40	1,420	1,000	est 104	165		0.2
6B	8-30-67	1,383	7.2	10	neg	1,000	810	136	138	4	0.3
7A	7-27-67	374	7.5	230	0	316	8.2	est 27	9		0
7A	8-2-67	371	7.4	40	0	332	9	est 18	7		0.1
7A	9-27-67	365	7.6	12	neg	316	0.4	23	5	10.4	0
7B	7-27-67	710	7.7	2,600	0	680	343	est 60	28		0
8A	7-27-67	386	7.5	30	20	348	13	est 17	7		0
8A	7-27-67	359	7.4	16	0	348	3	est 5	7		0
8A	9-27-67	365	7.4	8	neg	324	0	33	5	6.4	0
8B	7-27-67	1,123	7.3	70	0	856	480	est 123	145		0.7
8B	8-30-67	1,605	7.2	20	neg	1,260	910	169	198	3	1.2
9A	8-2-67	371	7.6	468	0	360	44	est 5	15		0
9A	9-27-67	359	7.7	12	65	280	33	36	7	12	0
9B	8-2-67	1,262	7.7	472	0	708	487	est 218	198		0.4
9B	8-29-67	2,272	7.3	34	20	1,300	1,360	314	435	27.2	0.5
9B	11-28-67	1,529	7.7	50	neg	670	542	395	290	95	0.3
Well 1	9-15-67	2,129	7.9	417	90	700	trace	657	655	12.8	neg
1	10-24-67	1,659	7.2	238	60	640	20	487	595	54	0
1	2-24-69	2,471	8.0	178	20				1,600		
2	9-15-67	437	7.5	42	neg	330	7	35	69	0.8	0
2	10-24-67	452	7.6	28	30	328	8	58	88	11	0

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
ELGIN—continued												
Farm	11-28-67	458	7.8	24	neg	240	2	100	7	10		800 ft west of site
Airport	11-1-67	452	6.9	21	neg	350	18	47	4	24	0.1	¼ mile west of LW 3
Fox River at LW1	10-24-67	404	8.3	30	neg	320	89	38	38	3	0	
Fox River at Marina	2-24-69	478	8.1	26	40				49			
Fox River at Well 1	2-24-69	481	8.0	38	50				44			
Marina	7-27-67	1,372	7.3	65	0	928	620	est 204	200		1.1	
Marina	8-30-67	1,284	7.3	20	neg	840	650	204	220	1.8	1.0	
Marina	11-1-67	1,284	7.2	23	neg	810	900	218	210	2.4	0.8	
WOODSTOCK												
LW1B	9-13-67	448	7.6	12	neg	340	68	60	22	137.67	0.4	
1B	11-7-67	449	7.2	0	neg	360	87	41	16	12	0	
1C	9-13-67	1,003	7.6	85	75	420	28	268	190	30.6	?	Detergents, 2.0
1C	11-7-67	806	7.5	19	neg	330	31	223	135	22.4	0	
1C	11-20-67	617	7.0			306		115	80			
1D	11-7-67	6,647	7.7	564	80	1,000	345	2,598	2,370	34.4	0	
1D	11-20-67	7,205	8.2			1,110		2,831	2,400			
2A	10-6-67	348	8.1	4	neg	270	13	35	10	24	0.2	
2B	10-6-67	337	8.1	2	neg	260	12	35	7	6.8	0.2	
2C	8-10-67	338	7.7	8	0	270	12	31	6	32	0	
2C	8-11-67	335	7.7	10	0	270	14.0	est 30	6	13.9	0.2	
2C	10-6-67	313	8.3	10	neg	260	40	24	4	13.8	0	

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)
					WOODSTOCK–continued						
LW2D	9-13-67	377	[illegible]	0	neg	272	64	48	13	19.2	0.5
2E	8-10-67	371	7.4	4	0	360	64	est. 5	8	1	0
2E	11-20-67	333	7.3			333		31	15		
3A	10-6-67	404	7.9	98	neg	330	1	34	6	1.1	0
3B	10-6-67	404	8.1	0	neg	310	6	43	10	25	0.4
3C	9-13-67	352	7.8	24	neg	303	2.4	24	15	123.2	0.6
3C	10-5-67	364	7.4	12	neg	290	25	29	6	48	0.4
3D	8-10-67	452	7.5	12	20	390	14	est. 29	2	1.4	0
3D	9-13-67	490	8.1	4	neg	420	9.6	[illegible]	6	3.4	0.2
3D	10-5-67	419	7.5	14	neg	400	16	8	4	1.3	0
3D	11-20-67	472	7.4			395		35	10		
3E	9-13-67	1,593	7.5	129	neg	1,010	14.8	234	166	24.8	0
3F	9-13-67	1,235	7.4	428	75	670	22	260	195	71.2	0
3F	11-20-67	1,314	7.1			660		306	243		
4A	10-6-67	343	8.1	8	neg	250	7	43	16	48	0.2
4B	10-6-67	353	8.0	0	neg	270	11	38	7	10	0
4C	10-6-67	353	7.9	2	neg	280	46	34	8	1.8	0.3
4C	11-20-67	348	7.7	0	neg	295	37	24	10	12	0.5
4D	11-7-67	805	7.5	31	neg	430	175	150	65	4.8	0
4D	11-20-67	583	6.3	0	neg	540	136	20	15	4	0.3
5A	8-11-67	397	7.5	8	0	350	14	est 22	4	1.2	0
5A	11-29-67	404	8.0	34	neg	280	3	67	7	20	0
5B	8-14-67	407	7.3	6	0	360	66	est 22	19	3.1	0
5B	11-29-67	427	7.7	28	neg	310	62	54	21	38	0.1
5C	8-14-67	645	7.2	8	0	500	190	est 67	80	3.7	0.4
5C	11-29-67	775	7.7	28	neg	530	360	113	72	38	1.1
6A	8-11-67	1,120	7.0	81	0	770	28	est 165		6.9	0.2
6A	11-7-67	1,133	7.2	69	20	520	13	282	120	8	0
6A	11-20-67	935	7.7	68	neg	520	7	191	113	17	0

TABLE 6 (continued)

WATER QUALITY ANALYSES BY THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

Well No.	Date sampled	Total dissolved solids (ppm)	pH	Total COD (ppm)	Organic acids (ppm)	Hardness (as $CaCO_3$) (ppm)	Sulfate (ppm)	Sodium (est) (ppm)	Chloride (ppm)	Iron (ppm)	Manganese (ppm)	Comments
						WOODSTOCK—concluded						
MM 1	8-14-67	1,545	6.8	53	0	1,160	233.3	est 177		12.2	0.2	
4	9-13-67	730	7.2	8	neg	720	290	5	16	24.8	0.4	
4	11-20-67	664	7.9	0	neg	625	235	18	9	17	0.3	
6	8-11-67	416	7.3	4	20	390	72	12	12	3.4	0.2	
6	11-20-67	417	8.1	0	neg	375	76	19	11	14	0	
7	11-7-67	3,823	7.4	108	neg	1,650	2000	1,046	728	33.6	0.1	
7	11-20-67	3,743	7.1			1,720		931	680			
8	11-7-67	1,492	7.2	61	neg	900	500	272	272	53	0	
8	11-20-67	1,342	7.9	4	neg	980	400	167	208	2.8	0.1	
8	2-24-69	1,236	7.2	1,103	0				238			
9	8-14-67	638	7.4	61	0	600	136	est 64	16	2.6	0	
9	11-7-67	695	7.1	61	neg	570	220	58	65	20	0.3	
9	11-20-67	718	6.9			590		59	60			
10	8-14-67	624	6.8	39	0	470	56	est 26	5	15.2	1.1	
10	11-20-67	583	7.3	31	neg	540	120	20	9	19	0.8	
10	2-24-69	563	7.0	68	0				18			
Stream near MM 10	1-18-68	478	7.0	29	50	465	188	6	12	2	0	
	2-24-69	450	7.5	49	0				44			
Swamp south of LW 2	1-18-68	1,646	7.2	80	36	830	123	376	375	7	0	
Stream near MM 8 and 9	1-18-68	710	7.1	25	50	560	300	69	60	1	0	
	2-24-69	595	7.5	60	20				60			
Stream south side Davis Rd.	1-18-68	618	7.5	20	neg	440	152	82	100	8	0	¼ mile upstream
Stream west side Rt. 47	1-18-68	858	7.2	33	120	700	398	73	80	13	0	¼ mile downstream
J. Ritter	11-20-67	268	8.2	4	neg	220	13	22	7	0.8	0	400 feet NE of site
Windmill	9-13-67	348	7.5	0	neg	320	30	13	8	2.8	0.2	200 feet S of LW 3

TABLE 7

WATER QUALITY ANALYSES BY ALLIED LABORATORIES[1]

Well, No.	Date in	Date out	pH	Iron (ppm)	M Alkalinity as $CaCO_3$ (ppm)	Chloride (ppm)	Sulphate (ppm)	Calcium (ppm)	Magnesium (ppm)	Total hardness (as $CaCO_3$) (ppm)	Sodium (by diff) (ppm)	Total Kjeldahl nitrogen (ppm)	Total nitrate-nitrite nitrogen (ppm)	Total dissolved solids by conductivity (as NaCl) (ppm)
Du Page														
MM 3	2/19/69		7.0	1.43	2,750	425	1.1	72	114	650	1,242			
12	2/19/69		6.4	85	8,900	9,359	10	2,000	24	5,100	7,825			
12	11/18/67	12/1/67	5.9	160	6,070	1,390	neg	732	328	3,180	2,230	302	5.5	6,840
20	2/19/69		6.9	1	2,200	376	neg	140	122	850	866			
35	2/19/69		7.0	neg	540	184	68	160	58	640	107			
36	2/19/69		7.5	3.3	420	177	280	178	83	780	92			
36	2/20/69		6.5	0.03	408	180	140	148	89	738	29			
MM 39	11/28/67	12/1/67	6.7	0.5	322	65	12	97	61	452	4[illegible]	2.2	0.7	340
42	2/19/69		6.3	61.8	3,000	335	neg	660	49	1,600	875			
45	2/19/69		6.8	3.5	1,450	199	2.8	120	107	740	457			
46	2/20/69		6.7	4.0	2,200	674	neg	220	289	1,740	649			
47	2/19/69		7.5	0.05	390	35	50	88	51	430	28			
MM 49	2/19/69		6.6	2.46	1,630	737	5	336	243	1,840	335			
50	2/19/69		7.1	0.23	400	78	140	96	97	640	5			
53	2/19/69		6.9	2.11	1,810	227	4	100	104	680	670			
54	2/19/69		6.9	0.1	780	135	140	180	110	900	97			
55	2/19/69		7.3	neg	450	71	61	88	55	448	76			
MM 56	2/19/69		7.3	0.05	340	14	53	64	68	390	14			
58	2/19/69		7.4	0.1	360	20	90	96	51	450	15			
64	2/19/69		7.1	1	490	35	22	92	56	460	43			
65	2/19/69		6.5	63.8	4,540	809	neg	1,200	610	5,100	267			
67	2/19/69		5.9	1,060	10,300	1,630	660	2,720	635	9,000	1,975			
LW 2B	11/28/67	12/1/67	6.9	0.4	305	12	26	62	40	318	57	4	1.7	325
2B	11/28/67	12/1/67	6.9	0.6	363	19	28	74	47	380	18	4.2	1	325
2B	2/20/69		6.6	0.05	310	10	24	56	41	310	18			
4A	11/26/67	12/1/67	7.3	0.8	328	24	18	53	47	328	24	0.5	1.2	210
4A	2/20/69		6.9	0.10	328	23	11	55	43	318	24			
5A	11/28/67	12/1/67	6.7	0.5	345	12	21	65	30	291	40	2	0.9	240
5A	2/20/69		6.7	0.26	340	26	6	63	38	314	32			
5B	11/28/67	12/1/67	5.9	460	6,360	1,650	neg	830	299	3,300	2,480	711	11.2	7,010
5C	11/28/67	12/1/67	6.2	330	6,810	1,710	1.8	595	257	2,550	3,070	766	14.4	8,560
5C	2/20/69		7.2	40	7,3[illegible]0	2,060	108	400	683	3,400	3,180			
LW 12B	2/20/69		6.0	750	11,000	2,270	1300	2,420	972	10,100	2,[illegible]90			
13	2/20/69		5.5	690	4,100	71	320	1,080	413	4,400	239			
Winnetka														
MM 6	12/4/67	12/8/67	6.7	1.1	353	210	492	263	85	1,010	77	4.2	0.9	1,030
10	12/4/67	12/8/67	6.6	28.5	1,970	387	3	68	169	868	958	193	1.4	2,740
10	2/26/69		6.7	25.2	2,010	1,028	4	68	199	988	1,156			

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[1] Chicago, Illinois.

TABLE 7 (Continued)

WATER QUALITY ANALYSES BY ALLIED LABORATORIES

Well No.		Date in	Date out	pH	Iron (ppm)	M Alkalinity as (CaCO$_3$) (ppm)	Chloride (ppm)	Sulphate (ppm)	Calcium (ppm)	Magnesium (ppm)	Total hardness (as CaCO$_3$) (ppm)	Sodium (by diff) (ppm)	Total Kjeldahl nitrogen (ppm)	Total nitrate-nitrite nitrogen (ppm)	Total dissolved solids by conductivity (as NaCl) (ppm)
FP	20G1[2]	12/4/67	12/8/67	7.0	0.8	198	41	7	23	7	89	72	1.1	1.4	205
FP	20G1[2]	2/26/69		6.9	0.36	156	45	4	18	9	84				
LW	1E	2/4/67	12/8/67	6.8	17.5	3,050	1,320	25	315	93	1,170	1,640	374	1.0	4,280
	1E	2/26/69		6.7	14.3	3,050	1,156	4.6	116	243	1,290	1,561			
	2A	12/4/67	12/8/67	7.8	2.2	171	39	23	20	13	106	66	2.5	0.6	205
	2A	2/25/69		7.5	1.2	200	42	neg	32	14	140	55			
	8A	12/4/67	12/8/67	7.7	1.6	161	36	18	41	10	144	40	2.8	1.0	205
	8A	12/4/67	12/8/67	7.7	1.2	178	35	20	26	7	92	72	4.3	1.2	205
	8A	2/26/69		7.1	0.29	124	136	140	69	33	306	74			
	9A	12/4/67	12/8/67	7.9	1.2	164	53	23	23	18	123	65		1.3	220
	9A	2/25/69		6.9	0.1	320	134	310	147	67	644	90			
	10A	2/26/69		7.0	0.4	342	60	20	47	20	200	114			
	11	2/26/69		6.8	0.46	930	560	440	316	156	1,430	372			
Elgin															
LW	1B	11/28/67	12/1/67	7.0	0.6	404	17	8	72	40	346	42	5.8	0.7	240
	1C	11/28/67	12/1/67	7.0	1.1	515	266	131	116	76	606	194	5.5	1.0	940
	3B	11/28/67	12/1/67	7.2	0.5	370	15	8	64	46	352	21	3.0	1.2	188
	3B	2/25/69		6.9	0.2	342	16	10	66	40	330	21			
	6A	11/28/67	12/1/67	6.9	0.5	359	15	15	71	36	328	31	2.3	1.4	220
	6A	11/28/67	12/1/67	6.8	0.5	363	12	8	75	32	321	31	1.5	0.5	220
	6A	2/25/69		6.7	0.26	368	23	8.5	74	39	340	32			
	6B	11/28/67	12/1/67	6.8	0.6	440	126	377	134	104	766	116	1.6	0.3	630
	8A	11/28/67	12/1/67	7.0	0.3	397	12	7	77	33	328	42	2.6	0.7	240
	8A	2/25/69		6.8	0.56	362	67	3.4	60	41	340	49			
	8B	11/28/67	12/1/67	7.1	0.6	568	182	710	167	154	1,050	213	4.6	1.0	860
	8B	2/25/69		6.7	0.35	438	126	640	141	131	892	134			
Marine		2/26/69		6.6	0.86	420	156	440	118	124	806	134			
Woodstock															
MM	7	11/21/67	11/24/67	6.8	10.3	882	648	1,250	170	287	1,610	686	1.8	1.4	3,360
	7	2/25/69		7.0	3.6	2,400	1,276	1,900	176	300	1,700	2,070			
	9	11/21/67	11/24/67	6.7	7.2	322	70	213	142	51	568	153	3.9	0.9	680
	9	2/26/69		7.0	2.59	340	57	290	141	41	520	96			
LW	1C	11/21/67	11/24/67	6.9	17	468	94	8.2	67	48	366	112	2.5	0.9	375
	1C	11/21/67	11/24/67	6.9	26	434	63	8.2	62	46	346	86	1.5	1.0	445
	1D	11/21/67	11/24/67	7.9	6	1,410	2,320	neg	62	262	1,100	1,650	3.2	1.5	6,850
	1D	2/26/69		7.6	1.62	4,110	2,198	0.6	608	22	1,510	2,627			

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[2] Dolomite well, 1/4 mile north of LW 3.

TABLE 7 (Continued)

WATER QUALITY ANALYSES BY ALLIED LABORATORIES

Well No.	Date in	Date out	pH	Iron (ppm)	M Alkalinity as $CaCO_3$ (ppm)	Chloride (ppm)	Sulphate (ppm)	Calcium (ppm)	Magnesium (ppm)	Total hardness (as $CaCO_3$) (ppm)	Sodium (by diff) (ppm)	Total Kjeldahl nitrogen (ppm)	Total nitrate-nitrite nitrogen (ppm)	Total dissolved solids by conductivity (as NaCl) (ppm)
2E	11/21/67	11/24/67	7.1	5.9	328	19	56	68	36	318	44	1.8	0.9	310
2E	2/25/69		7.0	1.43	340	11	56	74	40	348	30			
3D	11/21/67	11/24/67	7.1	1.4	422	12	8.2	48	66	393	28	3.0	0.7	275
3D	2/25/69		7.1	0.85	452	17	13	70	57	412	35			
3F	11/21/67	11/24/67	6.8	22	806	208	10	63	60	363	432	1.5	0.6	1,060
3F	2/25/69		7.0	3.3	684	303	4.6	78	111	652	214			

TABLE 8

NEUTRON ACTIVATION ANALYSES[1,2]

FEBRUARY 1967

Well No.	Bromine (ppm)	Sodium (ppm)	Chlorine (ppm)	Manganese (ppm)	Comments
Dup. LW 3C	< 0.09	7.6	2.1	0.12	Interbedded sand—not affected
Dup. LW 2B	< 0.11	16	2.4	0.04	Interbedded sand—not affected
Dup. MM 2	6.2	187	262	< 0.01	Immediately south of fill in surficial sand
Dup. MM 29	13.6	875	1,150	< 0.03	Below fill in surficial sand

DECEMBER 1967

Well No.	Bromine (ppm)	Selenium (ppm)	Sodium bromine	Comments
DuPage LW 5B	8.2[3]	< 0.2	156	Surficial sand below fill
DuPage MM 12	4		188	Surficial sand immediately east of fill
Winnetka MM10	3.6[3]	< 0.3	95	Point within refuse
Winnetka LW 1E	11		60	Point at base of refuse
Elgin LW 5B	3.6[3]	< 0.1	115	Sand and gravel below refuse
Elgin LW 1C	1.9		115	Surficial sand east of fill beside Fox River
Woodstock LW 1D	15[3]	< 0.3	128	Point in refuse
Woodstock LW 3E	0.5		340	Surficial sand immediately west of fill

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[1] Irradiated for 1 hour in Triga Reactor in January, 1967. No long-lived radioactivity detected after 2 weeks.

[2] Analyses performed by R. R. Ruch, Illinois State Geological Survey, Urbana, Illinois.

[3] Average of duplicate runs. Estimated accuracy ±25% relative value.

A

Well No.			pH 4,6	BOD—30 day	BOD recheck[5]	COD	COD recheck[5]	Total dissolved solids	TDS recheck	Pesticides[17]	Alkalinity	Alkalinity recheck[14]	Alkalinity recheck[4]	Hardness[13]	Chloride	Bromide[4]	Sulfate[10]	Cyanide[8]
DUP	LW	6A		10		7		352		BDL	530	216	252	300	7	< 0.1	16	BDL
	LW	14		230	73	284	225	372		BDL	630	256	247	260	17		16.4	BDL
	LW	15		58		52		606		BDL	750	228	337	440	94	0.4	26	BDL
	LW	16		60		96		1,334	1,581	BDL	1,110	298	1,326	880	309	1.3	14	BDL
	LW	6B		225		40		1,198		BDL	2,250	1,040	1,011	540	136	2.8	2	0.02
DUP	LW	12A		53	13	207	34	504		BDL	640	264	258	350	12	< 0.1	97.5	BDL
	LW	11A		290	11	36	19	446		BDL	550	226		280	7	< 0.1	100	BDL
	LW	5B		14,080		8,000		6,794		BDL	6,810		4,159	2,200	1330	10	2	BDL
								622		BDL	540	136		410	64	0.3	85	BDL
DUP	MM	48		36		68		1,620	1,582	BDL	2,130	728	428	900	289	3.9	21	BDL
	MM	59		180		348		1,270	7,024	BDL	5,000		1,963	3,180	287	5.4	BDL	BDL
	MM	44		6,560		8,200												
								1,104		BDL	1,630			890	205	3	1	BDL
DUP	MM	61		125		360		6,910		BDL	4,720		2,646	2,250	946	12	1	BDL
	MM	63		4,560		2,940												
								2,306		BDL	3,370		431	1,180	429	6.8	13.6	BDL
WIN	LW	17		6,400		4,280		878	708	BDL	940		422	560	99	0.7	190	BDL
	LW	12		24		48		584	894	BDL	1,450		1,424	710	70	1.1	5	BDL
	LW	13		105		153		994	2,466	BDL	3,080		1,426	970	701	8.4	1	BDL
	LW	58		250		415												
								1,410		BDL	790		302	1,080	102	2.3	680	BDL
ELG	LW	6B		14		30												
								530		BDL	690			470	91	0.3	24	BDL
WOOD	LW	1C		40		308												
								19,144		BDL	11,570		3,255	7,830	1697		680	0.024
Blackwell				54,610		39,680												

1. Questionable values underlined.
   Concentrations in parts per million. (ppm)
2. Sampled 1 August 1969 for pH and BOD and COD rechecks. All other samples Feb. 1969.
3. Analyses by Texco Hydro/Aero Sciences unless noted otherwise.
4. Analyses by the Illinois State Geological Survey.
5. Analyses by the Illinois Department of Public Health.
6. Measured within 5 minutes of sampling.
7. BDL < 0.1 milligram per liter.
8. BDL < 0.05 milligram per liter.

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B

TABLE 9

COMPREHENSIVE WATER QUALITY ANALYSES [1-3]

Total phosphate [10]	Nitrate	Total nitrogen	Fluoride	MBAS [15]	Hexane Solubles	Total magnesium	Soluble magnesium	Potassium	Potassium recheck	Sodium	Sodium recheck	Copper [8]	Cadmium [8]	Lead	Lead recheck [4,11]	Zinc	Zinc recheck [4]	Iron total	Chromium [8]
BDL	0.28		0.35	0.02	11	40	38	2		12		BDL	BDL	0.50	BDL	0.15	0.83	0.4	0.10
2.85	0.66	6.48	0.65	0.06	0	25	26	2.7		50		BDL	BDL	0.50	BDL	2.90	0.54	1.0	BDL
0.61	0.32		0.19	0.02	7	50	56	2.6		52		BDL	BDL	1.1	BDL	0.25	< 0.10	0.4	0.10
0.50	1		< .05	0.04	7	100	135	2.7	5	112	120	BDL	BDL	0.5	BDL	0.2	0.11	0.5	BDL
8.90	1.60		0.31	0.30	7	90	88	100		74		BDL	BDL	1	BDL	4.5	< 0.10	0.8	BDL
1.36	0.40	2.40	0.31	0.02	0	29	37	2.7		61		BDL	BDL	1	BDL	0.15	< 0.10	0.7	BDL
0.47	0.28	3.36	0.27	0.04	8	26	28	2.5		49		BDL	BDL	1	BDL	0.30	0.10	0.9	0.05
1.20	0.70		2	0.72	19	450	480	610		810		BDL	BDL	0.5	BDL	0.40	0.13	6.3	0.15
1.86	0.93		0.08	0.01	3	52	60	0.75		72		BDL							
6.50	0.17		0.15	0.06	5	163	150	56.5	60	188	198	BDL	BDL	0.5		1.70		0.3	BDL
0.24	0.65		0.39	0.152	3	175	177	264	138	236	246	BDL	BDL	1	BDL	1.40	< 0.10	1.2	0.10
													BDL	0.5	BDL	0.15	0.34	60	BDL
0.50	0.14		0.44	0.210	5	110	98	85		63		BDL							
0.17	0.50		0.09	0.260	6	725	440	220		615		BDL	BDL	1		0.10		100	0.05
													BDL	1		0.05		12	BDL
2.60	0.50		0.40	0.35	5	198	165	168		298		BDL							
0.87	0.06		0.34	0.012	3	70	50	4	3.7	110	118	BDL	BDL	1		1.50		96	0.05
1.30	0.20		0.23	0.15	8	75	67.5	39		34		BDL	BDL	0.5	BDL	1.25	< 0.10	.2	0.05
2.76	0.43		0.54	0.50	4	200	171	220	200	348	358	BDL	BDL	1.0		0.10		11	0.05
													BDL	0.5		0.60		13.65	0.06
3.25	0.04		0.37	0.03	7	190	159	38		96		BDL							
													BDL	0.1		0.35		0.4	BDL
5.00	0.10		0.15	0.08	6	53	59	7		46		BDL							
													BDL	1		3.85		0.6	0.05
6	1.70				350	600		790		900		BDL							
													BDL	1.3		40		5,500	0.2

9. BDL < 0.005 milligram per liter.
10. BDL < 0.02 milligram per liter.
11. Below 0.50 ppm and probably below 0.02 ppm.
12. Hcl added to all samples. No glass used.

13. Blackwell value calculated from magnes concentration.
14. Back titration.
15. Methylene blue active substances (inclus
16. Indicates refuse buried.
17. BDL < 5 micrograms per liter.

C

Zinc recheck	Iron total	Chromium[8]	7		Soluble calcium	Boron	Boron[4,12] recheck	Aluminum[8]	Manganese[8]	Arsenic[7]	Selenium[7]	Barium	Beryllium[7]	Remarks
.83	0.4	0.10	BDL	78	91	1.00	0.15	0.3	BDL	6.6	BDL	0.30	BDL	Interbedded Sd, Well not polluted; samples
.54	1.0	BDL	BDL	78	72	BDL	0.27	1.1	0.17	6.9	BDL	0.25	BDL	Samples 15.19 ft. below top of till
.10	0.4	0.10	BDL	115	116	BDL	0.14	0.4	BDL	3.8	BDL	0.15	BDL	Samples 4.31 ft. below top of till
.11	0.5	BDL	BDL	230	224	BDL	0.31	0.1	0.10	BDL	BDL	0.40	BDL	Samples 2.57 ft. below top of till
.10	0.6	BDL	BDL	103	102	15.60	0.91	0.9	0.06	4.6	BDL	0.30	BDL	Screen 6 ft. below base of refuse (1952)
.10	0.7	BDL	BDL	110	66	28.40	0.21	0.7	0.07	6.	BDL	0.30	BDL	Samples 7.47 ft. below top of till
.10	0.9	0.06	BDL	86	98	1.16	0.48	0.3	0.06	BDL	BDL	0.20	BDL	Samples 2.30 ft. below top of till
.13	6.3	0.15	BDL	475	308	96.80	5.35	0.1	0.06	BDL	BDL	0.80	BDL	Screen 3 ft. below refuse in sand (1963)
	0.3	BDL	BDL	125	131	41.20	-	0.4	0.15	BDL	BDL	0.20	BDL	Samples top of surficial sand 650 ft. south
.10	1.2	0.10	BDL	185	111	25.40	0.13	0.7	0.09	BDL	BDL	1.2	BDL	Samples base of surficial sand 325 ft. south
.34	60	BDL	BDL	1,900	500	20.40	2.70	0.3	0.83	BDL	BDL	7.5	BDL	Samples base of surficial sand 30 ft. south
	100	0.05	BDL	170	158	20.	-	0.2	0.24	BDL	BDL	0.3	BDL	Samples refuse (1958)
	12	BDL	BDL	440	147	35.20	-	BDL	0.09	BDL	BDL	3.5	BDL	Samples near base of refuse (1960)
	96	0.05	BDL	600	100	-	-	0.3	1.14	BDL	BDL	0.15	BDL	Samples near base of refuse (7/11/67)
.10	.2	0.06	BDL	150	72	26.40	0.60	BDL	0.03	BDL	BDL	0.15	BDL	Samples transition zone, 7 ft. below refuse
	11	0.05	BDL	220	109	24.00	-	0.6	0.20	BDL	BDL	0.15	BDL	Samples refuse (1953)
	13.65	0.05	BDL	100	108	37.20	-	BDL	0.09	BDL	BDL	0.50	BDL	Samples refuse (1943)
	0.4	BDL	BDL	220	209	-	-	0.4	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1964)
	0.6	0.08	BDL	115	115	-	-	0.2	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1961)
	5,500	0.2	BDL	2,150	-	320	-	2.2	1.68	4.3	2.7	8.5	BDL	Samples refuse probably "squeezed" leacha

lue calculated from magnesium and calcium

n.

lue active substances (includes detergents).

ure buried

nicrograms per liter.

C

D

Boron	Boron[4,12] recheck	Aluminum[8]	Manganese[8]	Arsenic[7]	Selenium[7]	Barium	Beryllium[7]	Remarks
1.60	0.15	0.3	BDL	6.6	BDL	0.30	BDL	Interbedded Sd, Well not polluted; samples 17.33 feet below top of till
BDL	0.27	1.1	0.17	6.9	BDL	0.25	BDL	Samples 15.19 ft. below top of till
BDL	0.14	0.4	BDL	3.8	BDL	0.15	BDL	Samples 4.31 ft. below top of till
BDL	0.31	0.1	0.10	BDL	BDL	0.40	BDL	Samples 2.57 ft. below top of till
15.60	0.91	0.9	0.06	4.6	BDL	0.30	BDL	Screen 5 ft. below base of refuse (1952)[16]
28.40	0.21	0.7	0.07	6.	BDL	0.30	BDL	Samples 7.47 ft. below top of till
1.10	0.48	0.3	0.06	BDL	BDL	0.20	BDL	Samples 2.30 ft. below top of till
96.80	5.35	0.1	0.06	BDL	BDL	0.80	BDL	Screen 3 ft. below refuse in sand (1963)
41.20	-	0.4	0.15	BDL	BDL	0.20	BDL	Samples top of surficial sand 650 ft. south of fill
25.40	0.13	0.7	0.09	BDL	BDL	1.2	BDL	Samples base of surficial sand 325 ft. south of fill
20.40	2.70	0.3	0.83	BDL	BDL	7.5	BDL	Samples base of surficial sand 30 ft. south of fill (1957)
20.	-	0.2	0.24	BDL	BDL	0.3	BDL	Samples refuse (1955)
36.20	-	BDL	0.09	BDL	BDL	3.5	BDL	Samples near base of refuse (1960)
-	-	0.3	1.14	BDL	BDL	0.15	BDL	Samples near base of refuse (7/11/67)
26.40	0.60	BDL	0.06	BDL	BDL	0.15	BDL	Samples transition zone, 7 ft. below refuse
24.80	-	0.5	0.20	BDL	BDL	0.15	BDL	Samples refuse (1953)
37.20	-	BDL	0.09	BDL	BDL	0.50	BDL	Samples refuse (1948)
-	-	0.4	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1964)
-	-	0.2	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1961)
320	-	2.2	1.06	4.3	2.7	8.5	BDL	Samples refuse probably "squeezed" leachate in part

TABLE 9

COMPREHENSIVE WATER QUALITY ANALYSES[1,2,3] – CONTINUED

Well No.			Soluble calcium	Boron	Boron[4,12] [illegible]	Aluminum[8]	Manganese[8]	Arsenic[7]	Selenium[7]	Barium	Beryllium[7]	
DUP	LW	6A	91	1.80	0.15	0.3	BDL	6.6	BDL	0.30	BDL	Interbedded Sd. Well not polluted; samples 17.33 feet below top of till
	LW	14	72	BDL	0.27	1.1	0.17	6.9	BDL	0.25	BDL	Samples 15.19 ft. below top of till
	LW	15	116	BDL	0.14	0.4	BDL	3.8	BDL	0.15	BDL	Samples 4.31 ft. below top of till
	LW	16	224	BDL	0.31	0.1	0.10	BDL	BDL	0.40	BDL	Samples 2.57 ft. below top of till
	LW	6B	102	15.60	0.91	0.9	0.06	4.6	BDL	0.33	BDL	Screen 5 ft. below base of refuse (1952)[16]
DUP	LW	12A	66	28.40	0.21	0.7	0.07	6.	BDL	0.30	BDL	Samples 7.47 ft. below top of till
	LW	11A	98	1.16	0.48	0.3	0.03	BDL	BDL	0.20	BDL	Samples 2.30 ft. below top of till
	LW	5B	308	96.80	5.35	0.1	0.06	BDL	BDL	0.20	BDL	Screen 3 ft. below refuse in sand (1963)
DUP	MM	48	131	41.20	–	0.4	0.15	BDL	BDL	0.20	BDL	Samples top of surficial sand 650 ft. south of fill
	MM	59	111	26.40	0.13	0.7	0.09	BDL	BDL	1.2	BDL	Samples base of surficial sand 325 ft. south of fill
	MM	44	500	20.40	2.70	0.3	0.83	BDL	BDL	7.5	BDL	Samples base of surficial sand 30 ft. south of fill (1957)
DUP	MM	61	156	20.	–	0.2	0.24	BDL	BDL	0.3	BDL	Samples refuse (1935)
	MM	63	447	35.20	–	BDL	0.09	BDL	BDL	3.5	BDL	Samples near base of refuse (1960)
WIN	LW	17	100	–	–	0.3	1.14	BDL	BDL	0.15	BDL	Samples near base of refuse (7/11/67)
	LW	12	72	26.40	0.60	BDL	0.08	BDL	BDL	0.15	BDL	Samples transition zone, 7 ft. below refuse
	LW	13	109	24.80	–	0.5	0.20	BDL	BDL	0.16	BDL	Samples refuse (1953)
	LW	5B	109	37.20	–	BDL	0.09	BDL	BDL	0.50	BDL	Samples refuse (1948)
ELG	LW	6B	209	–	–	0.4	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1964)
WOOD	LW	1C	115	–	–	0.2	0.11	BDL	BDL	0.20	BDL	Samples near base of refuse (1961)
Blackwell			–	320	–	2.2	1.86	4.3	2.7	8.5	BDL	Samples refuse probably "squeezed" leachate in part

APPENDIX A

DRILLING, PIEZOMETER INSTALLATION, AND SAMPLING

INSTALLATION PROCEDURES

Much of the drilling for the landfill investigation was done under an hourly contract with Layne-Western Company, Aurora, Illinois, but a substantial number of the shallow borings were made by project personnel with a portable Mobile Minuteman auger drill loaned by the University of Illinois Water Resources Center, and a small truck-mounted rig owned by the State Geological Survey. A total of approximately 4,700 feet was bored and 274 piezometers and sampling points installed. Pertinent data regarding these borings are given in table 3.

The contract drilling program during 1966 and 1967 proceeded as follows. A rotary rig, in most cases a Franks FA 54 with bentonite or natural drilling fluid, drilling a 4-3/4-inch to 7-7/8-inch hole was used first at each site to establish the sequence of materials. Piezometers were then installed to get preliminary information on ground water elevations. Samples of drill cuttings were collected at the mud tank, and these, with information from the driller on the drilling characteristics of the materials and from a Wideo electrical resistivity drill hole log, provided data for the selection of points at which the piezometers were to be set.

The next series of contract borings used the hollow-stem auger method and generally a Mobile B61 auger rig boring a 10-inch hole. These holes were limited to a depth of approximately 55 feet. Split-spoon samples were taken inside these augers to get a more precise definition of the character of the materials by visual and laboratory methods.

Additional contract borings were made by using one of these methods, and in one case the air-drilling method was used.

Five types of piezometers* were used, as follows:

(1) 24- x 1¼-inch No. 10 brass well screen (3 ft. total length) on 1¼-inch ABS plastic pipe
(2) A 6- x 1¼-inch No. 10 brass suction strainer on 1¼-inch ABS plastic pipe
(3) A porous plastic 1½- x 18-inch piezometer tip on 3/8-inch ID (internal diameter) polyethylene tubing
(4) A 6- x 1¼-inch No. 8 or No. 10 slotted PVC plastic screen on 1¼-inch ABS plastic pipe (1968-69)
(5) A 4-ft x 4-inch No. 8 slotted PVC plastic screen on 4-inch PVC plastic pipe (float-activated recorder wells)
(6) A 2- x 12-inch No. 8 slotted PVC plastic screen on 2-inch PVC plastic pipe (1968)

During 1966 and 1967 well screens and suction strainers were set in materials considered permeable enough to produce water samples easily for chemical analyses. The porous plastic piezometer tip was used only in relatively impermeable materials. The suction strainer was used only in holes less than 20 feet deep.

The installation of screened piezometers in rotary borings proceeded in the following manner. After the boring was made, the screen attached to the 1¼-inch plastic pipe was installed in the hole at the proper depth. If the screen were to be set above the bottom of the hole, backfill was added until a solid bottom was present at the proper depth. The bore hole was then backflushed, through the plastic pipe and screen, until returns were relatively clear. An average of 200 gallons of water was necessary to flush a 100-foot hole. Sand** was then poured

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*Peizometer types 1, 2, 4, 5, and 6 can be obtained from water well suppliers. Type 3 was obtained from Terratest, Weston, Ontario, Canada.

**Commercially bagged silica sand (St. Peter Sandstone, with 60 and 30 percent retained on U. S. sieves 30 [0.589 mm] and 40 [0.417 mm] mesh, respectively) was used in most contracted borings. Local sand was used on some shallow borings.

into the boring or washed down a half-inch pipe to approximately 1 foot above the screen. The latter method was most efficient. Next, a seal was installed above the sand by one of the following methods.

(1) A bentonite slurry was pumped down a half-inch pipe in the annulus. If the slurry is too thick, backfill will not settle and subsequent piezometers will sink.

(2) Dry bentonite pellets or granules were poured down the annulus. This method was used onl'' in shallow borings, since the bentonite tended to bridge.

(3) Clay cuttings and mud returns from the rotary drilling were poured down the annulus.

The hole was then backfilled with cuttings or a fill, sand, and cuttings mixture to the approximate base of the next piezometer, and the foregoing procedure was repeated. As many as six piezometers were installed in one boring. In holes subject to caving, two piezometers were hung in the hole at the same time so that if caving occurred the hole could be flushed through both piezometers.

Installations drilled by the hollow-stem auger method, in which screened piezometer tips were used, were made in a similar manner except that the piezometer was installed inside the hollow-stem augers. The augers were raised a little at a time to allow placement of the sand around the piezometer tip and the seal. The porous plastic tips were also installed through a hollow-stem auger and dry bentonite pellets used as a seal.

In the boring made by the air-drilling method, casing was used to shut out any shallow water, and the hole was advanced dry to the first permeable zone below the casing. A screened piezometer was installed opposite this zone, sand was blown around the point, and dry bentonite blown down above the sand to form a seal. Dry bentonite coats and seals the sides of the boring, making multiple installations less practical. This type of installation can be used if no appreciable quantities of water are encountered.

During the summer of 1968 a series of borings was made to collect materials and water samples from the till below the landfill. The borings for materials samples were constructed with a hollow-stem auger rig as described previously. Samples from these borings were sealed with wax in glass jars or carefully wrapped in double polyethylyne bags. The borings for water samples were advanced into the top of the till with a 10-inch hollow-stem auger, and casing was set to prevent leachate from moving out of the landfill into the boring. Six-inch augers were then used to advance the boring inside the casing to the proper depth. The boring was washed clean and pumped dry, and a 2-inch plastic pipe with a 1-foot slotted plastic screen was installed. This was followed by a sand pack saturated with water and a dry bentonite seal. The casing was then pulled and the boring backfilled.

Four-inch plastic pipes and screens for float-activated water level recorders were also installed at the old DuPage County, Winnetka, and Woodstock landfills in 1968. Borings for this purpose were made with 6-inch solid augers and the pipe and screen washed into place. This method could not be used at Elgin, because of the presence of course, caving gravel.

Borings made with the portable Mobile Minuteman power auger and the Geological Survey rig were generally less than 15 feet deep. Screened piezometers (1- to 1¼-inch diameter) were installed in these borings with and without flushing. Seals were installed at land surface to prevent vertical leakage and occasionally emplaced at depth by dropping dry bentonite down the annulus of the bore hole or inside aluminum casing that had been pumped dry.

During the summer of 1968 and 1969 a number of shallow well points were washed into place at the old DuPage County landfill with a contractor's pump. These installations could not be sealed.

EVALUATION OF INSTALLATION PROCEDURES

Whereas the foregoing methods of installing piezometers are relatively inexpensive, it is difficult to install adequate seals between units with a bentonite slurry, and these seals leaked in a number of instances. Leakage was established by adding or removing water from a suspect piezometer and noting changes in water level in adjacent piezometers in the same boring. Those units in which appreciable leakage could be established are as follows: (1) DuPage County landfill–LW 3B to surface sand; (2) Elgin landfill–between LW 4A and B; LW 5A and B; LW 7A and B; (3) Winnetka landfill–LW 1A, B, C, and D; LW 2C and D; LW 3B, C and D; LW 4D and E; LW 7A, B, and C; LW 9A and B; (4) Woodstock landfill–LW 1B and C; LW 2B and C; LW 3A, B, and C. The leakage appears to be decreasing as the backfill in the borings compacts. The major problem arising from this leakage is in obtaining reliable water quality data.

Winn LW 9A is the only leaky piezometer installed with a dry bentonite seal, and as noted in the text, this may not be the fault of the seal.

REDUCING STANDPIPE DIAMETER

Two methods were used successfully for reducing the diameter of a piezometer standpipe to increase its sensitivity..

In the first method, a cork cut to the inside diameter of the standpipe was attached to a length of polyethylene tubing (3/8-inch ID) and placed in the annulus just above the screen. The apparatus was installed by threading it through a half-inch iron pipe and pushing the iron pipe and tubing with the cork on the end into the standpipe. The half-inch iron pipe could be removed. Dry bentonite or a bentonite slurry was poured into the annulus above the cork for a seal.

A removable reducer (fig. 29) was used in piezometers that were to be used again for water-sampling points. This consisted of a half-inch pipe to which a cork, cut to fit the standpipe, was bolted. The array was inserted into the standpipe and the annulus filled with a bentonite slurry. To reduce further the volume of the standpipe and to provide easier access for a steel measuring tape (deposits tended to build up on the inside of the iron pipe), a length of polyethylene tubing was inserted into the half-inch iron standpipe.

WATER-SAMPLING PROCEDURES

After each piezometer or sampling point was installed, it was developed and pumped with a windmill pump jack, a contractor's pump, an air compressor or a hand bailer. For wells pumped with the pump jack, a plastic seat had been installed with the well screen, into which a ball bearing could be dropped to serve as a foot valve. The pipe was used as the cylinder. The ball bearing was removed by a magnet after pumping had been completed. This initial pumping was continued until the water was clear or the chloride content became constant, as measured in the field with a Hach kit.

In wells that would recover within 1 day, samples were taken after the fluid had been exchanged at least once in the screen and standpipe. This was done with the pump jack, contractor's pump, air compressor, or a bailer. Use of the air compressor was the most efficient method of exchanging the water before sampling in borings that had water levels deeper than 25 feet. In wells that would not recover in 1 day, the water in the well was not exchanged. The samples were usually collected with a rinsed bailer, put in glass jars, and sent immediately to the laboratory for analysis. No special precautions were taken to avoid loss of gases or to impede biologic activity during transportation to the laboratory. During sampling from a well attached to a water system, the water was allowed to run for 5 to 10 minutes and the sample taken from as near the pump as possible. Samples of surface water from ditches, streams, or tiles were dipped up in 1-quart fruit sealers.

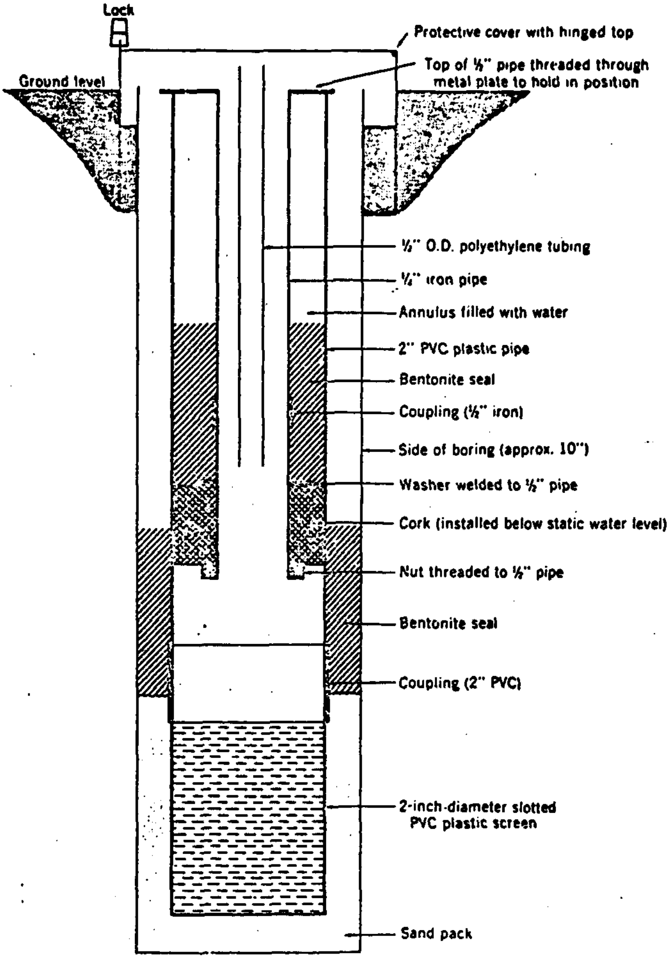

Figure 29. Diagram of piezometer installation with removable reducer. Use of this device is a relatively inexpensive method of increasing the sensitivity of a piezometer by reducing the diameter of its standpipe.

APPENDIX B
DESCRIPTION OF SAMPLES FROM CONTRACT BORINGS*

Old DuPage County landfill

Boring LW 1

	Depth (ft)
Black, clayey silt topsoil	0 - 3
Yellow-brown to black silty sand, coarse-grained grading to fine grained; black oily staining and ordor	3-14
Gray, silty clay till	14-24
Gray, sandy silt till	24-46
Gray, silt till	46-64½
Yellow-brown to light gray pebbly dolomite	64½-76

Boring LW 2

Sand and gravel grading to silty sand at base	0-15½
Gray, silty clay till	15½-40
Brown to black fine-grained sand	40-41½
Gray, silty clay till	41½-45
Gray silt till	45-70
Light gray and pinkish gray dolomite	70-77

Boring LW 3

Brown to black clayey silt topsoil, sandy at base	0 - 3½
Silty sand, fine grained, dirty at top and base	3½-14
Gray, silty clay till	14-21
Gray silt till, pebbly	21-40½
Gray, silty clay till	40½-41½
Sand gravel	41½-46½
Gray silt till, pebbly at 60-65 ft	46½-65
Yellow-brown to light gray dolomite	65-73

Boring LW 4

	Depth (ft)
Clayey silt cover material	0- 1½
Refuse—some garbage, glass, 1958 and 1964 newspapers	1½-15
Gravelly sand, silty	15-19
Silty sand, very fine grained; black staining and odor; bedded at 28-29 ft.; medium to very coarse grained at 30-36 ft.	19-36
Gray, silty clay till	36-41
Sandy silt till	41-50
Gray silt till, pebbly (poor samples at 50-80 ft.)	50-88
Light gray dolomite	88-93

Boring LW 5, 10, 11, 12, and 13

Clayey silt cover material	0- 3
Refuse—legible papers, wood, cans	3-15½
Silty sand to sand, fine grained; bedded at 17½-19 ft.	15½-25.9
Brown to gray silty clay till Arbitrary pick for base	25.9-33½
Gray, sandy silt till, pebbly	33½-45
Gray, sandy silt	45-46½
Sand and gravel, medium to coarse grained	46½-50½
Gray silt till (poor samples)	50½-51½

Boring LW 6, 14, 15 and 16

Clayey silt cover material	0-3
Refuse and gravel—cans, bottles—little if any odor	3-12
Silty sand, fine-grained grading to medium grained	12-16
Black sandy silt	16-23.67
Gray, silty clay till	23.67-43
Silty sand, medium-grained grading to very fine grained	43-48½
Gray, silty clay till (no sample)	48½-49½

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*Location of borings shown as Figures 5, 10, 15, and 20.

Boring LW 7, 8, and 9	Depth (ft)
Black clay with stones and odd bits of refuse–cans, plastic, and some cloth	0-16
Dark gray fine sand	16-21
Gray silt	21-22.5
Gray silty clay till	22.5-28

Winnetka landfill

Boring LW 1

Black, sandy, clayey silt cover material	0-1
Cinders	1-2
Refuse–paper, plastic, wood	2-14
Probably silt (poor samples)	14-20
Gray, clayey silt till	20-38
Silty sand (no samples)	38-40
Gray, sandy, clayey silt till; thin sand, some gravel at 48-48½ ft., 58-64½ ft., 83½-88 ft., 94-96 ft., 101-103 ft.	40-118
White to light gray dolomite bedrock; creviced (lost circulation)	118-124

Boring LW 2

Cinder fill	0-2
Black organic clay, soil	2-3
Brown sandy silt	3-8½
Gray, clayey silt till	8½-31
Black shale, pebble gravel	31-32
Gray, sandy, clayey silt till, pebbly; thin sand stringers at 66½-68½ ft. and 85½-86 ft.	32-108
White to light gray dolomite bedrock; some till fragments	108-125

Boring LW 3

	Depth (ft)
Fill material (not refuse)	0-4½
Brown, clayey, sandy silt	4½-8½
Gray clay	8½-11
Shale sand and gravel	11-13
Gray, clayey silt till	13-28
Gray, sandy, clayey silt till, often gravelly; sand stringers at 62-62½ ft., 78 ft., 82 ft., 92½-93 ft.	28-112½
White to light gray dolomite bedrock	112½-118

Boring LW 4

Fill (not refuse)	0-3
Black sandy silt	3-4
Brown to gray silty clay	4-13½
Black shale sand	13½-14
Gray, clayey silt till	14-32
Shale sand, medium grained	32-33
Gray, sandy, clayey silt till; gravelly till at 35½-36 ft.; shale sand at 51-52 ft.; sand at 64-65 ft.; very gravelly till at 95-110 ft.	33-110
White to light gray dolomite bedrock; some till gragments (probably cave)	110-121

Boring LW 5

Gray to black silty sand clay cover	0-3
Refuse–glass, fiber, mostly unrecognizable black material	3-11½
Probably silty alluvium (poor samples)	11½-13½
Gray, clayey silt till; more stones near base; 1 in. sand at 33 ft., 33½ ft.	13½-36

Boring LW 6

Black, clayey silt soil	0-1½
Gray, sandy silt	1½-5½
Gray, clayey silt till; borwn to brown-gray at 5½-8½ ft.; sandy till at 14½-16 ft.	5½-52½

	Depth (ft)
Gray, sandy, clayey silt till; very sandy at 52½-54 ft.	52½-57
Gray, fine to medium-grained sand	57-58½

Boring LW 7

Black, sandy silt soil	0-3½
Brown silt with sand stringers	3½-5
Gray, clayey silt	5-11
Gray, clayey silt till	11-33
Gray, sandy, clayey silt till	33-41½
Black shale sand	41½-43½
Gray, sandy, clayey silt till; silty sand at 91½-94 ft.	43½-95

Boring LW 8

Black, sandy silt soil	0-2½
Yellow-brown clayey silt, sandy at 5½-6½ ft.; possible sand at 12-13 ft.	2½-13
Gray, clayey silt till	13-26
Black shale sand	26-27
Gray, sandy, clayey silt till; black shale sand at 42½-43 ft., 60½-63 ft.	27-70

Boring LW 9 (no samples)

Soil and clay cover	0-1½
Refuse–only a few cans were distinguishable	1½-12½
Gray, clayey, silt till (?); possible fine sand at 22 ft.	12½-42½
Drilling break, possible silt	42½-43½
Gray, clayey till, softer	43½-47
Possible shale sand	47-48
Harder till	48-63½
Gray silt to fine sand	63½-69
Gray fine sand	69-73

Boring LW 10, 11, 12, and 13

	Depth (ft)
Sandy loam cover material	0-2
Refuse–glass, paper soil, black dirt and muck below 6.5 ft.	2-11.5
Gray, fine – to medium-grained sand and silt and brown silty clay alluvium	11.5-14.5
Gray and brown silts and silty clay, transition zone	14.5-20
Gray clayey silt till	20-35

Boring LW 14, 15, 16, and 17

Clay loam, cover material	0-2
Refuse–paper, bricks, bottle-caps. Not badly decomposed	2-13.75
Brown and gray sand, silt, and silty clay alluvium	13.75-17.5
Gray, fine sand, silt, and silty clay. Transition zone	17.5-23
Gray clayey silt till	23-34

Elgin landfill

Boring LW 1

Black, sandy silt soil; sand and gravel fill	0-7½
Sand and gravel	7½-11
Light pink, sandy silt till	11-16
Peat or soil horizon	16-16½
Brown-gray, sandy silt till	16½-24½
Sand and gravel	24½-26½
Gray, sandy, silty till	26½-30
Silty sand; white clay	30-32
Light gray dolomite bedrock	32-46

Boring LW 2

Clayey, silty sand cover material	0-2
Refuse–glass, cinders	2-7
Sand and gravel	7-10
Pink, sandy silt till	10-20
Yellow, light pink, sandy silt till	20-27
Brown-gray, sandy silt till	27-44½
Gravel	44½-48
Yellow-brown, sandy silt till	48-53½
Yellow-brown to light gray dolomite bedrock	53½-63

Boring LW 3

	Depth (ft)
Brown, silty clay topsoil	0-3
Sand and gravel	3-11
Pink, sandy, silty till	11-13
Brown-gray, sandy, silty till; some yellow-pink thin gravel seams at 16-18 ft.; wood at 28½ ft.	13-32½
Sand and pea gravel, very coarse grained	32½-49
Yellow-brown to light gray dolomite bedrock	49-58

Boring LW 4

Brown to black, sandy silt cover material	0-2
Refuse–wood, glass, metal	2-14
Sand and pea gravel	14-23
Light pink, sandy silt till	23-30
Brown-gray, sandy silt till	30-34½
Sand and pea gravel	34½-37½
White clay and weathered dolomite	37½-39
Yellow-brown to light gray dolomite bedrock	39-52

Boring LW 5

Brown to black sandy silt cover intermixed with refuse–cinders, ash, paper board	0-11½
Sand and gravel (no sample)	11½-16½
Pink, sandy silt till	*16½-18*
Brown-gray, sandy silt till	18-21
Silty sand, fine grained	21-21½
Brown-gray, sandy silt till	21½-28½

Boring LW 6

	Depth (ft)
Logged cover, refuse–paper, wood, glass, ashes (no samples or poor recovery)	0-14
Sand and gravel becoming silty with depth	14-22
Light pink, sandy silt till	22-27
Brown-gray, sandy silt till	27-34½
Sand and pea gravel	34½-35
Brown-gray, sandy silt till; wood fragments	35-36½
Sandy silt, silty sand and gravel	36½-39½
White clay, weathered dolomite fragments	39½-41
Refuse; probably bedrock	41

Boring LW 7

Cover, refuse–cinders, ash, glass	0-15
Silty sand, minor gravel	15-25½
Light pink, sandy silt till	25½-28
Gray to balck silty sand	28-29
Brown-gray, sandy, silty till	29-32
Silty sand, very fine to fine grained	32-32½
Brown-gray, sandy silt till	32½-33

Boring LW 8

Gravel and sand, fine grained; very coarse sand at base	0-19½
Pink, sandy silt till	19½-20
Light gray, sandy silt	20-21
Brown-gray, sandy silt till	21-31
Sand, coarse to very coarse grained	31-35½
Brown-gray, sandy silt till; white silty clay and dolomite fragments	35½-36½

Boring LW 9

Black, sandy topsoil	0-2
Sand and gravel, poorly sorted	2-20
Brown-gray, sandy silt till	20-25
Gravel and sand, fine grained	25-30½
Dolomite bedrock	30½-31½

Boring LW 10

Cover, medium -- to coarse-grained sand and gravel	0-3

	Depth (ft)
Refuse–cinders, cans, wire glass and gravel	3-16
Brown medium-grained sand and gravel	16-22

Boring LW 11

Cover, mainly fine – to coarse-grained sand	0-2
Refuse–wood, cloth, cans and paper–not badly decomposed	2-8
Gravel, coarse	8-10
Sand, no recovery	10-15.5

Woodstock landfill

Boring LW 1

Refuse–cinders, glass, metal (poor samples)	0-19½
Gray silt (poor samples)	19½-24½
Sand and gravel, very coarse grained	24½-42½
Brown-gray, silty clay till	42½-50
Pink, sandy silt till; pebbly at 67-71 ft.; wood fragments at 105-110 ft.–possibly cave; silty sand; possible stringers at 110-115 ft.	50-123
Gravel; some very coarse-grained sand	123-132
Pink, sandy silt till; pebbly at 145-150 ft., 155-160 ft.	132-160
Brown, pebbly, sandy silt, probably till; wood fragments	160-167
Black, silty clay, probably soil	167-170
Brown-gray, sandy silt till	170-180½
Fine sand (no samples)	180½-187½
Brown-gray, sandy silt till	187½-203
Sand, medium to coarse grained	203-207
Brown-gray, sandy silt till	207-213
Sand and gravel; some till–probably cave	213-225

Boring LW 2

	Depth (ft)
Black, silty clay soil	0-1½
Gravel, sandy	1½-7
Gray, silty clay till	7-32
Pink, sandy silt till; stringer of sand and gravel at 50-52 ft., 55-57 ft., 66-69 ft., 76-78 ft.	32-138
Sand and gravel	138-155

Boring LW 3

Black, silty clay soil	0-2
Brown, sandy clay	2-3
Sand and gravel, sandier at base	3-22
Gray, silty clay till	22-42½
Pink, sandy silt till; medium-grained sand at 53½-54 ft.; sand and gravel at 57-64 ft.; brown clay (not till) at 64-67 ft.; sand and gravel at 67-70 ft.; very little sand in till at 70-80 ft.	42½-122
Gray, sandy silt till; some pink	122-130
Pink, sandy silt till	130-149
Brown-gray, sandy silt till	149-161
Brown-gray, sandy silt till, pebbly; possibly a very silty sand and gravel (E-log would indicate former)	161-165
Black, silty clay soil	165-172
Brown-gray, sandy silt till	172-180
Sand and gravel	180-185
Brown-gray, sandy silt till	185-187½
Sand and gravel	187½-195

Boring LW 4

Black, silty clay soil	0-1
Brown, sandy clay, gravelly	1-4
Sand and gravel	4-7
Pink-brown, sandy silt till, gravelly; mostly gravel at 10-20 ft.–probably ice-contact	7-25½
Gray sand and gravel, very coarse grained	25½-29
Brown-gray, sandy silt till, gravelly	29-44
Gray, silty clay till	44-68
Gravel	68-72½
Pink-gray, sandy silt till, gravelly; till in chunks	72½-92½

	Depth (ft)
Sand and gravel	92½-95½
Pink, sandy, silty till	95½-100
Silty sand, medium grained; some gravel	100-106
Pink, sandy, silty till; sand at 116½-118 ft.	106-121

Boring LW 5

Black silt soil	0-4
Brown to gray sandy silt, very finely grained	4-23
Gray, silty clay till	23-44
Sand, fine to coarse grained	44-45½
Pinkish gray, sandy silt till	45½-51

Boring LW 6

	Depth (ft)
Cover, refuse—ashes, wood, and indistinguishable fill	0-15
Peat and clayey silt, spongy	15-23
Sand and gravel, coarse grained grading to fine grained	23-34½
Gray, silty clay till	34½-37½
Pinkish gray, sandy silt till; pink at 36½-37½ ft.	37½-58

Boring LW 7

Loam to sandy loam cover material—contains glass and cinders	0-2
Sand and coarse gravel, cinders, glass, and plastic	2-4
Black dirt, wood, wire, cans	4-12?
Gray organic silt	12?-16

Boring LW 8

Cover material—sandy loam	0-2
Refuse—paper, glass, etc not badly decomposed	2-13
Drilled like gravel—no returns	13-18

APPENDIX C
METHODS USED FOR WATER QUALITY ANALYSES

THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH

This section, by the Illinois Department of Public Health, lists the procedures used for the various analyses they performed and the precision of these methods. Where these procedures differ from the procedure described in *Standard Methods for the Examination of Water and Waste Water* (American Public Health Association *et al.*, 1965), they are described separately. Table 6 presents the results of these analyses.

Determination	Procedure	Precision
Specific conductance	Standard Methods 12th ed.	± 5%
pH	Standard Methods 12th ed.	± 0.1 pH unit
Chemical oxygen demand	Standard Methods 12th ed.	Standard deviation with glucose is ± 6.2% of mean
Organic acids	Colorimetric Description follows	± 2%
Hardness	EDTA Titrimetric Method Standard Methods 12th ed.	± 3%
Sulfate	Turbidimetric Method Description follows	± 5%
Sodium	Estimation Description follows	
Chloride	Mercuric Nitrate Method Description follows	± 1.4%
Iron	Phenanthroline Method Standard Methods 12th ed.	± 3%
Manganese	Persulfate Method Standard Methods 12th ed.	± 3%
Nitrate	Phenoldisulfonic Acid Method. Standard Methods 12th ed.	± 2%

Organic Acids
(Colorimetric Method)

Note: This colorimetric procedure is more precise and accurate than the old distillation procedure and about equal to the column chromatographic method. The test requires less than 30 minutes and is particularly advantageous where more than one digester is to be analyzed since several tests can be run simultaneously almost as easily as one test.

Principle

This procedure converts the organic acids (called volatile acids in the past because they were vaporized and separated by distillation) to colored materials that are measured by light absorption in a suitable instrument (colorimeter).

Sample

A very small portion (0.5 ml) is used for the test; therefore, a 6-oz water bottle is sufficient for organic acids and related tests.

Equipment

(1) Colorimeter. The Bausch and Lomb Spectronic 20 with 3/4-inch-diameter test tubes is an excellent instrument for this test because the entire test can be run and measured in the test tube without a transfer.
(2) Boiling water bath or a kettle of boiling water on an electric hot plate or Bunsen burner.
(3) Test tube rack to hold 3/4-inch test tubes.

Reagents

The following reagents are necessary, either to make reagent solutions or to use directly as purchased.

(1) Sulfuric acid, H_2SO_4, concentrated, reagent grade.
(2) Ethylene glycol, reagent grade.
(3) Sodium hydroxide, Na OH, pellets, reagent grade.
(4) Hydroxylamine hydrochloride, reagent grade.
(5) Ferric chloride, $FeCL_3$ $6H_2O$, lump, reagent grade.

Solutions

(1) Sulfuric acid, diluted. Mix equal volumes of reagent grade, concentrated sulfuric acid and distilled water. CAUTION: Always add acid to water–never water to acid.
(2) Ethylene glycol, reagent grade. Use as purchased.
(3) Sodium hydroxide 4.5N. Dissolve 90 g of sodium hydroxide pellets in distilled water and dilute up to 500 ml.
(4) Hydroxylamine solution, 10 percent. Dissolve 10 g of hydroxylamine hydrochloride in distilled water and make up to 100 ml.
(5) Ferric chloride reagent. Dissolve 20 g of ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$) in distilled water, add 20 ml of concentrated sulfuric acid, and dilute to 1 liter.

Procedure

(1) Clarify a few milliliters of sample by filtration or centrifugation or both (It is desirable to have a relatively clear sample since turbidity will interfere with light transmission..)
(2) Provide test tubes in a rack–one for a blank and one for each sample.
(3) Pipet carefully and exactly 0.5 ml of distilled water into the blank tube and 0.5 ml sample into each sample tube. If the organic acids are more than 2,000 mg/liter. an aliquot diluted to 0.5 ml is used.
(4) Add 1.5 ml ethylene glycol to each tube.
(5) Add 0.2 ml of the diluted sulfuric acid (1-1) to each tube. Mix well by swirling tube.
(6) Heat in a boiling water bath exactly 3 minutes.
(7) Cool immediately in cold water.
(8) Add 0.5 ml hydorxylamine solution.
(9) Add 2.0 ml of 4.5 N sodium hydroxide. Mix well by swirling tube.
(10) Add 10.0 ml ferric chloride solution.
(11) Add 5.0 ml distilled water.
(12) Stopper and invert to mix.
(13) Let stand 5 minutes, unstoppered, for color development.
(14) Read at 500 millimicrons after 5 minutes standing but within 1 hour.
(15) Calculate mg organic acids per liter from calibration.

Note: A calibration curve car be made by using a 2,000 mg/liter standard acetic acid solution. A series of 6 tubes are used containing 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5 ml standard acetic acid made up to 0.5-ml volume with distilled water where necessary. This ste-by-step procedure is followed and percent transmission readings are plotted on semilog graph paper.

Reporting

Report as mg organic acids per liter.

Comment

This method is suitable for the determination of organic acids in sewage treatment plant digesters and in raw sludge. It is particularly advantageous where several tests can be run simultaneously.

REFERENCES

Montgomery, H. A. C., J. F. Dymock, and N. S. Thom. The rapid colorimetric determination of organic acids and their salts in sewage-sludge liquor. Analyst, p.949-955, Dec. 1962.

Mueller, H. F., T. E. Larson, and M. Ferretti. Chromatographic separation and identification of organic acids. Analytical Chemistry, 32:687-690, May 1960.

Sedlacek, M. The colorimetric determination of fatty acids in sludge and sludge waters. Chemical Abstracts, 62:8822, 1965.

SULFATE

Principle

Sulfate ion is precipitated in a hydrochloric acid medium with barium chloride in such a manner as to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate is measured by a photometer and the sulfate ion concentration and is determined by comparison of the reading with a standard curve.

Sample

At least 100 milliliters is required.

Reagents

All distilled water should be sulfate free.

(1) Hydrochloric acid--sodium chloride reagent: Dissolve 240 g NaCl in about 200 ml of distilled water. Add 20 ml of concentrated HCl and dilute to 1,000 ml with distilled water.

(2) Blank reagent: Dissolve 2.5 g acacia (gum arabic USP grade) in 250 ml of hot distilled water, adding the acacia in small amounts, and mixing well until dissolved. Cool to room temperature. Add 250 ml of propylene glycol. Add 0.5 g of Hyamine 1622 (Rohm & Haas quaternary ammonium germicide) and mix well until dissolved. Filter through a fine paper (Whatman 40). This is accomplished most easily with suction and Buchner funnel.

(3) Barium reagent: Dissolve 2.5 g of acacia in 200 ml of hot distilled water as for blank reagent above. Dissolve 10 g of $BaCl_2$ in 50 ml of hot distilled water and add to acacia solution. Cool to room temperature. Add 250 ml of propylene glycol. Add 0.5 g of Hyamine 1622, and mix to dissolve. Filter as for blank reagent.

Preparation of Standard Curve

(1) Prepare a standard sulfate solution, 1.00 ml=0.10 mg SO_4, by diluting 10.4 ml of the standard 0.020 $NH_2$4 solution specified in alkalinity to 100 ml with distilled water.

(2) Prepare a suitable series of standards from 0 to 100 mg/liter in 10 mg/liter increments by diluting 0, 2.5, 5.0, 7.5, 10.0 ml, etc. to 25.0 ml with distilled water. The standard curve does not follow Beer's law.

Significance

Sulfate is relatively abundant in hard waters. Concentrations larger than 300 mg/liter often produce a laxative effect in human beings and some animals. The 1962 U. S. Public Health

Service Drinking Water Standards specified 250 mg sulfate per liter as the maximum desirable limit.

REFERENCES

Sheen, R. T., H. L. Kahler, and E. M. Ross, Turbidimetric determination of sulfate in water. Industrial Engineering Chemistry Analytic Edition, 7: 262, 1935.

Standard methods for the examination of water and waste water. 11th ed., 1960, p. 237.

Reisch, R. F. Modification of the Sheen-Kahler and Ross procedure for turbidimetric determination of sulfate. Unpublished, 1960.

SODIUM

(Estimation in Water)

Principle

The sodium content of water can be approximated from the mineral content and the hardness.

Sample

At least 100 milliliters is required.

Equipment

None

Procedure

(1) Determine total mineral content.
(2) Determine total hardness.
(3) Estimate the sodium content as follows:

(Total mineral x 0.02 total hardness x 0.02) x 23 = Sodium (Na) in mg/liter

Reporting

Report as mg Na per liter.

Significance

Sodium content in water is important to the medical profession in some cases of heart disease and hypertension.

REFERENCE

Standard methods for the examination of water and waste water: 11th ed., 1960, p. 231.

DETERMINATION OF CHLORIDE

Modified Mercuric Nitrate Method

Reagents

(1) Standard sodium chloride solution, 0.014N: Dissolve 8.243 g NaCl, dried by fusing at 900° C for ½ hour, in 500 ml distilled water. Dilute 50.0 ml to 1,000 ml. Each ml of this solution contains 0.500 mg Cl.

(2) Mercuric nitrate solution, 0.0141N: Dissolve 2.42 g $Hg(NO_3)_2 H_2O$ in 20 ml distilled water to which 0.25 ml concentrated HNO_3 has been added and dilute to 1 liter. Determine the exact normality of this solution by standardization against 10.0 ml standard sodium chloride solution diluted to 100 ml.

(3) Diphenylcarbazone-bromphenol blue mixed indicator solution: Dissolve 0.5 g diphenylcarbazone and 0.05 g bromphenol blue in 100 ml 95 percent ethyl alcohol. Store in a brown bottle.

(4) Nitric acid solution, 0.2N: Dilute 12.9 ml concentrated nitric acid to 1 liter.

Procedure

Add 5 drops of the mixed indicator solution to the sample and then add 0.2N nitric acid dropwise until the color becomes a definite yellow (about pH 3.6). Add 5 drops more 0.2N nitric acid. Titrate with mercuric nitrate solution to the first permanent tinge of violet. A few drops before the endpoint is reached, the color becomes orange, and then the remainder of the titration should proceed slowly and with vigorous stirring.

Calculation

$$\text{ppm Cl} = \frac{\text{ml } Hg(NO_3)_2 - \text{blank} \times N \times 35.46 \times 1{,}000}{\text{ml sample}}$$

REFERENCE

DOMASK, W. C., and K. A. KOBE, Mercurimetric determination of chlorides and water-soluble chlorohydrins. Analytical Chemistry 24: 989, 1952.

ALLIED LABORATORIES

The methods to be described are those used by Allied Laboratories, Chicago, Illinois, to obtain the results shown on table 7. The samples were taken to the laboratory the day they were collected. Analytical methods used are from Standard Methods for the Examination of Water and Waste Water (American Public Health Association et al., 1965) and are listed here, with appropriate page references to that book:

pH Glass electrode method (Beckman pH meter)-p. 226
Iron–tripyridine method-p. 159
Bicarbonate ("M" alkalinity)–titration with methyl orange -p. 48
Chloride–argentometric method-p. 86
Sulfate–turbidimetric method -p. 291
Calcium-EDTA titration -p. 74
Magnesium (by difference between Ca and total hardness)
Total hardness–EDTA titration -p. 147
Sodium and potassium (by difference between total hardness and total anions)
Total Kjeldahl nitrogen -p. 404
Total nigrate-nitrite nitrogen–phenoldinsulfenic acid -p. 195

TENCO HYDRO/AEROSCIENCES, INC.

The following review of methods used and problems encountered in the analyses of leachate samples was prepared by Alfred M. Tenny of Tenco Hydro/Aerosciences, Inc., Chicago, Illinois. This discussion refers to analyses presented on table 9.

I Metal Analyses

II General Condition

All metals were measured with a Jarrell-Ash maximum versatility atomic absorption spectrophotometer. The gas mixtures and wave lengths are listed under analytical conditions. A laminar flow burner was used in all cases, and at least five standards were measured to prepare a calibration curve. Internal standards were not used in most analyses.

ANALYTIC CONDITIONS

	Wave length	Gas mixture oxidant*	Fuel	Remarks
Aluminum	3092-A	N_2O	C_2H_2	
Arsenic	1937-A	Ar	H_2	
Barium	5535-A	N_2O	C_2H_2	
Beryllium	2349-A	N_2O	C_2H_2	
Cadmium	2288-A	Air	C_2H_2	
Calcium	4227-A	Air	C_2H_2	Added lanthanum carrier
Chromium	3579-A	Air	C_2H_2	
Copper	3247-A	Air	C_2H_2	
Iron	2483-A	Air	C_2H_2	
Lead	2170-A	Air	C_2H_2	

ANALYTIC CONDITIONS

Magnesium	2852-A	Air	C_2H_2
Manganese	2795-A	Air	C_2H_2
Potassium	7665-A	Air	C_2H_2
Selenium	1961-A	Ar	H_2
Silver	3281-A	Air	C_2H_2
Sodium	5890-A	Air	C_2H_2
Zinc	2139-A	Air	C_2H_2

Chemical symbols

N_2O = nitrous oxide
C_2H_2 = acetylene
H_2 = hydrogen
Ar = argon
A = angstrom units

*Oxidant or inert gas used to aspirate sample.

Sample preparations

All samples except where noted were treated with dilute nitric acid (1% v/v of the concentrated acid) and digested for ½ hour. The samples were filtered and returned to original volume.

In the case of calcium and magnesium, both the total and soluble contents were determined. The soluble metals were measured on the filtrate of laboratory-filtered samples with medium-porosity filter paper. Arsenic and selenium samples were prepared with HCl, since HNO_3 appears to interfere with the atomic absorption procedures when the argon-hydrogen flame is used.

Special problems

For most procedures few problems were encountered. An abnormal zinc result was found in one sample (DUP LW 6B). The same sample was rechecked on two separate occasions and continued to give a high result. A recheck by the State Geological Survey gave a low result on a new sample from the same well but a high abnormal result from the next sample in analytic series (DUP LW 11A). Rechecks by the State Geological Survey on a series of samples gave lower results for both lead and zinc. The State Geological Survey analyzed for soluble materials, while Tenco Hydro/Aerosciences checked for total materials present (acid leachable).

Problems were also noted in the arsenic analysis, which gave several high readings. These samples were all rechecked with internal standards to compensate for interferences, but results still indicate the presence of arsenic. No reasonable explanation can be given either for the presence of arsenic or for the cause of the anomalous instrument readings.

The presence of barium is also very difficult to explain from a geological viewpoint, but the atomic absorption method of analysis gave definite readings.

Discussion on methods selected

In several samples a precipitate of hydrated iron had formed by the time samples were received in laboratory. Since iron hydroxide tends to scavenge most trace ions in solution, any method of testing soluble metals could not provide meaningful data. It was assumed that the source of metals was the leachate and not the clay till. Later analysis of the till in uncontaminated areas indicated a larger than expected concentration of several metals.

It appears that a dynamic system to filter samples in the field, before exposure to the atmosphere or air, may be a better method of sample collection. The presence of fine suspended material in leachate samples received to date has prevented filtration of large volumes without changing filtering medium frequently.

Boron

Procedure

Boron was measured by the carmine colorimetric method given in Standard Methods for the Examination of Water and Waste Water, 1965 Edition. No interferences are listed that should affect results, except the use of borosilicate glass. The analyst used borosilicate glass to concentrate samples. Although this procedure is not recommended, many laboratories use it since the cost of large-size platinum vessels is prohibitive. The sensitivity of the carmine colorimetric method requires the use of about a 1-liter sample for boron concentration of less than 1 ppm.

Hardness

Hardness was titrated by a standard procedure for well and boiler waters (Standard Methods). The calculated values did not compare with the titrated values. The analysts complained of trouble with end point in titration. A number of possible interferences exist in the titration method, and the calculated value is preferred in all situations. Interferences include suspended and collodial organic matter.

Cyanide

The only two results reported were at about the limit of accuracy of the test. A colorimetric method with pyridine-pyrazolone reagent was used as given in "Standard Methods." Samples were distilled before analysis.

Bod-Cod

The ratio of COD divided by BOD is usually a number greater than 1, frequently quite large. There were eight cases in which the COD-to-BOD ratio was reversed. It has been noted on other occasions that this phenomenon occurs when a volatile organic is present. The organic could volatilize and be lost before being oxidized in the COD test. The same material, if biodegradable, would be detected in the BOD test.

While the possibility of an air leak or bubble entrapment exists, this tends to give low, rather than high, BOD results. The BOD test was run according to "Standard Methods" with modifications adopted by the Chicago Program Office of the Federal Water Pollution Control Association and Metropolitan Sanitary District of Greater Chicago. Filtered raw sewage is used to seed the dilution water. Both seed and dilution water controls are included in the procedure. All dilution water is aged at 20° C for at least 5 days before being used in the test.

COD is also tested according to "Standard Methods."

Ag_2SO_4 is added to prevent problems from the chloride ions present and to serve as an oxidation catalyst.

Alkalinity

Alkalinity can be measured by several methods. The original results were determined by the potentiometric method on page 368 of *Standard Methods.* This was selected because of turbidity in samples and possible unknown interferences. From a literature review, the potentiometric procedure appears to be the most reliable. The direct titration method using sulfuric acid as titrant and either methyl orange or mixed bromcresol green-methyl red as indicator was employed by the State Geological Survey. Results showed considerable differences. A third method using a hot alkali titration and back titration of the hot solution with acid is given on page 438 of *Standard Methods.*

The alkalinity of many leachate samples varied with the method used, even within the same laboratory. It is felt that alkalinity cannot be used to determine carbonate concentration without measurement of other parameters. These can include but are not limited to pH, organic and mineral acids, ionic strength, and temperature.

Other Tests

All procedures according to 12th Edition, *Standard Methods,* except where noted.

Parameter	Sample treatment	Procedure	Problems
Chloride	Filtered	Argentometric	None
Sulfate	Filtered	Turbidimetric	None
Surfactants (MBAS)	Filtered	Methylene blue	Foaming
Hexane solubles	None	FWPA method Antimony tartrate Ascorbic acid	None
Fluoride	Filtered	SPADNS	Numerous interference
Dissolved solids	Filtered	Dried at 105° C	None
Nitrate	Filtered	Phenoldisulfonic acid	None
Total nitrogen	None	Kjeldahl digestion	Occasional foaming

Pesticides Analyses

Since the number of pesticides presently being used is very extensive, it was necessary to limit testing to a few of those more commonly used and of a residual nature. Because of the necessity of having a long residence time before degradation, chlorinated pesticides were selected. Final selection was also guided by the availability of standards.

Samples were checked for the following pesticides: Lindane, Heptachlor, Heptachlor Eposide; Aldrin, DDE, Ortho, Para DDT, Para, Para–DDT, Dieldrin, and Endrin.

One-liter samples were extracted as per procedures of the FWPCA (FWQA). The sample size was limited, owing to amount of leachate available.

An electron-capture detector on a gas chromatograph was used for actual determination. By use of standards a detection limit of at least 0.1 nanogram per microliter was verified for all nine pesticides tested.

The extract of leachate, after being concentrated to 2 milliliters, was injected in 20 lamda (microliter) aliquots. This gives an effective detection limit of approximately 5 micrograms per liter. Owing to the large number of steps in the preparation, concentration, and redilution of the samples, a large inherent error exists, which was not evaluated.

Peaks were noted in the Blackwell sample, but they did not correspond to any of the reference standards. Whether these are other pesticides or decomposition products cannot be specualted with limited information available. Extraneous peaks were also noted in several other samples but were of lesser intensity.

It is suggested that if the presence of pesticides in leachate is suspected, larger volume samples be used in the study to increase chances of positive results.

APPENDIX D

FLUOROMETRIC PROCEDURE FOR DETECTING LEACHATE IN GLACIAL MATERIALS

I. Edgar Odom
Northern Illinois University
DeKalb, Illinois

Procedure. 25 grams of fresh material (sample) is dissaggrated in 25 ml of distilled H_2O for about 15 minutes. The suspension is then transferred to a 50-ml centrifuge tube and the flask is cleaned by washing with an additional 20 ml of H_2O. This liquid is also added to the centrifuge tube (total 45 ml).

The suspension is then centrifuged for 25 minutes at 2,500 rpm. The supernate liquid is then transferred into a fluorometer curette and the fluorescence is read immediately (SM reading). A second reading is taken after sufficient HCl has been added to obtain a 5 percent solution (SM and HCl reading).

Fluorescence Background. The fluorescence characteristics of several glacial tills known not to be contaminated by landfill leachate were studied to ascertain fluorescence background characteristics. SM readings averaged 43 (σ=7), whereas SM-HCl readings averaged 26 (σ=5).

Summary of Results. Two cores from two different landfills were studied. These cores were sealed in polyethylene from the time they were collected until they were opened in the laboratory for sampling. The cores were sampled at closely spaced intervals. Two samples from each sampling position were processed simultaneously. The fluorescence values shown on the accompanying diagram (fig. 30) represent the average recorded for these two samples.

It was found that leachate and carbonate are the principal materials in tills that produce fluorescence above background. Treatment with HCl eliminates the fluorescence caused by the carbonate but does not eliminate the fluorescence due to leachate. It is assumed that the high fluorescence of the leachate is produced by organic acids in solution.

Fluorescence values out of harmony with adjacent samples were obtained in sandy materials (see DuPage 23.25 feet and Winnetka 13.8, 14.2, and 15.6 feet). This relation might be caused by the fact that the leachate has been flushed by ground water movement or that the sandy sediments contain little mineral matter such as clay minerals that absorbs organic acids.

Core LW 14 DuPage Landfill.[*] Fluorescence producing organic acids appears to have permeated to 23.5 feet.

The low fluorescence value at 23.2 feet is related to the sandy nature of the material.

The reading slightly higher than normal background at 29 feet is due to contamination of the material during sampling.

Core LW 14 Winnetka Landfill.[†] Organic acids in the leachate have penetrated to a depth of 16.5 feet. the low fluorescence value at 15.5 feet is due to the sandy nature of the materials as are those at 13.8 and 14.1 feet.

The high fluorescence value at 19.5 feet does not appear to be due to contamination that is visible although this is probably the best explanation.

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[*] Below landfill 16 years old at time of sampling. Top of till at 23.67 ft.

[†] Below landfill 1.5 years old at time of sampling. Base of refuse at 13.75 feet. Top of till at 23 feet.

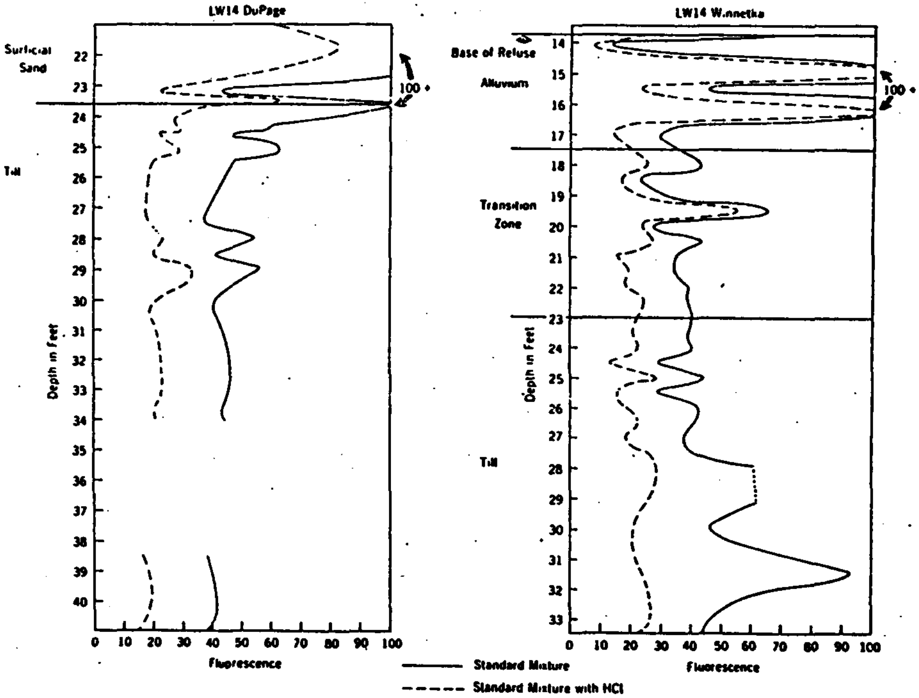

Figure 30. Fluorescence of aqueous solutions centrifuged from core samples beneath DuPage and Winnetka landfills. There is no indication that components from the refuse have moved downward into the underlying till.

APPENDIX E
HYDROGRAPHS

STABILIZATION AND INSTRUMENTATION

Hydrographs obtained from float-operated recorders studied in conjunction with microbarographs and precipitation records provide the best information for analysis of the mechanics of the flow system. The factors influencing these hydrographs must be understood before such an analysis can be made.

The water level in a piezometer finished in a permeable zone responds quickly to changes in fluid pressure in the ground. Piezometers finished in material of low permeability respond more slowly because it is necessary to move a volume of water into or out of the piezometer to change the water level in the piezometer standpipe. This water must be transmitted into the piezometer at the screened interval. The larger the diameter of the piezometer standpipe the larger the volume of water that must be moved. The lower the permeability of the materials the slower this water is able to move. Piezometers with large standpipes in materials of low permeability will, therefore, react slowly to changes in fluid pressure. Thus, a single water level measurement on a piezometer in clay is not a reliable index of the fluid pressure at the screen. The time required for stabilization is known as "time lag." In order to ensure that the piezometer reading is reliable, one must either stabilize the piezometer by adding or removing small amounts of water or else wait until the hydrograph indicates stability by reversal of a rising or declining trend.

In this study, after each piezometer had been pumped and developed, water level measurements were taken to determine whether it had been stabilized and to determine its sensitivity. Measurements for this purpose were carried out at weekly or shorter intervals, depending on rainfall and other factors, until sufficient data had been gathered. When the piezometer's response time was very slow, water was added or removed to stabilize the unit. The diameter of he standpipe of most of the piezometers with slow response time was reduced as described in Appendix A.

After each piezometer had been stabilized, routine measurements were made at monthly intervals to determine seasonal changes in water levels. Additional measurements were made at shorter intervals after rain had fallen or the units had been pumped and sampled. Rainfall at each site was also measured during 1966 and most of 1967 with nonrecording gages.

In the early fall of 1967 a recording rain gage and a recording barometer were installed at the DuPage County site, in conjunction with three water level recorders equipped with Keck water-level-sensing devices. The recorders were used to determine the relative effects of precipitation and barometric changes on water level and aided in evaluating the routine measurements. Two of the water level recorders and sensing devices were stolen in November, and this operation was abandoned for the winter.

In the fall of 1968 two float-actuated recorders were installed at the Old DuPage County, the Winnetka, and the Woodstock landfills, while one recorder equipped with a Keck device was installed at the Elgin landfill and at Blackwell. Recording rain gages and barometers were installed at all sites except the Blackwell Forest Preserve.

Water level data obtained in this investigation have been plotted on hydrographs, which are filed at the Naperville office of the Illinois State Geological Survey.

RESPONSE TO RECHARGE

Hydrographs reveal long-term trends in water levels within the saturated zone, which are related to recharge and drainage of the ground water system. During the spring months, soil moisture is at field capacity, the maximum *amount of water that the soil can retain against* gravity drainage. Under these circumstances any infiltration will result in downward movement and recharge to the ground water reservoir. During the growing season, beginning early in April, water demands by the plants reduce the soil moisture content to below field capacity by evapotranspiration, creating a soil moisture deficiency. Recharge cannot occur unless infiltration is sufficient to overcome this soil moisture deficiency, allowing drainage of the excess soil water *(during the summer this re*quires heavy, sustained rains).

In long intervals between recharge events the hydrographs show a gradual decline, indicating slow drainage of the ground water reservoir. The rise in the water table followed by a long,slow decline is a measure of the amount of recharge.

Infiltration through refuse follows the same pattern as through earth materials except that (1) *refuse may reach the landfill with a moisture* content far below field capacity, and considerable quantities of water may have to be added before normal infiltration can proceed; and (2) there is evidence of recharges through channels in the refuse occurring before the moisture content of the refuse reaches field capacity. Remson et al. (1968, p. 312) calculated that in Pennsylvania approximately 2.98 inches of rain would be required to bring 1 foot of refuse to field capacity. If moisture does move in refuse through channels, this figure cannot be used to estimate when infiltration will first penetrate a landfill to produce leachate.

OTHER FLUCTUATIONS

Wells that respond to changes in barometric *pressure indicate confined (artesian) conditions.* The ratio of water level to barometric change is the barometric efficiency. This condition is usually attributed to the presence of a confining aquiclude or relatively impermeable stratum that bears some portion of the changing load owing *to air pressure. Thus, a well in an aquifer with a* free water surface should have a barometric efficiency of zero. Most of the continuous hydrographs obtained in this study indicate a significant barometric efficiency even where there is no apparent confining stratum. Under these circumstances the apparent confinement must be attributed to a flow system in which artesian conditions exist without the requirement of the confining stratum. The barometric efficiency did not remain constant in every well *but appeared to be affected by frozen ground* surface, flooding, and changes in the moisture content of the soil.

In many instances the hydrograph shows a rapid rise after a rain begins and a decline within hours to the prerain level. These fluctuations are similar though not identical to fluctuations described by Meyboom (1967, p. 14) in Saskatchewan, where the fluctuations were related to an increase in pressure above the capillary fringe caused by light precipitation (Lisse effect). They are not related to ground water recharge, and continuous hydrographs or closely spaced measurements are necessary to separate these *effects from genuine recharge* events.

CONTINUOUS HYDROGRAPHS

Traces of the continuous hydrographs for DUP LW 7 and DUP LW 13 are presented on figure 31 with precipitation and barometric records, as well as the hydrograph traces corrected for barometric effect.

The hydrograph of LW 7 is the simpler of the two. It shows a recharge event beginning shortly after the rain of March 24 and continuing until March 29. A barometric efficiency of about 5 percent was used to correct the hydrograph. This was obtained by considering the ratio of water level change to barometric change at a time when no other effects were present. The total rise in water level caused by this rain was approximately 0.33 foot.

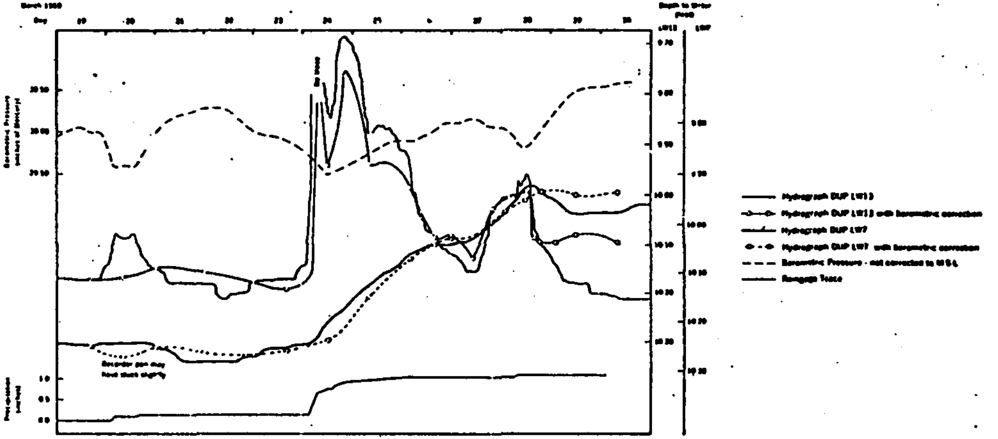

Figure 31. Traces of continuous hydrographs for DuPage LW 7 and DuPage LW 13, March 19 through 30, 1969. Precipitation and barometric records, as well as hydrograph traces corrected for barometric effect, are also presented. The rain of March 24 produced a consider amount of recharge in LW 7 but little or none in LW 13, where the refuse is younger.

In contrast, working with the hydrograph of DUP LW 13 is much more difficult. It shows a large rise immediately after the rain commenced and a rapid decline beginning before the rain was finished. This type of fluctuation is described by Meyboom (1967) in Saskatchewan. There is another rise on the 27th and 28th that appears to be related to a decline in barometric pressure; however, the barometric efficiency based on this rise is not the same as that calculated for the 20th. If we consider water levels up to the 23rd and after the 28th, the rise in water level amounts to no more than 0.10 foot. Most of the water from this precipitation event has gone to bring the moisture content of the materials above the zone of saturation to field capacity.

Each of the seven continuous hydrographs was evaluated in this manner and the total rise in water level computed for the period October 1, 1968, to September 30, 1969.

In most cases water levels in the shallow wells begin to rise a few hours after rain begins to fall, provided precipitation is intense enough to raise the materials above the top of the zone of saturation to field capacity or to move down through cracks in the refuse. With heavy rains this rise may continue for a week after precipitation has ceased.

WEEKLY HYDROGRAPHS

Weekly hydrographs were kept on seven wells from early in 1968 to the present, and intermittently on these and other wells through 1966 and 1967. Weekly hydrographs were also compiled for wells with continuous hydrographs. An example of weekly hydrographs for DUP LW 7 and DUP LW 13 from October 1, 1968, to September 30, 1969, together with precipitation and temperature records, are shown in figure 32. Also plotted in this figure is the water level rise attributed to infiltration for DUP LW 7 as taken from the continuous (hydrograph).

The first significent recharge shown on the hydrograph of DUP LW 7 occurs after December 24, 1968, in response to rain on December 27 and 28, 1968. Rains in October and November had not been sufficient to bring the materials above the zone of saturation to field capacity, and there was only one minor recharge event near the end of November. The second major recharge event follows the warm weather on January 21, 1969. Winter recharge such as this was not anticipated, since we expected that the ground surface would be frozen and relatively impermeable. Other recharge occurs through March, April, June, and July of 1969, in response to precipitation.

The hydrograph of LW 13 shows a more subdued response. The first appreciable rise occurs early in April, and subsequent rain caused a gradual rise that continues into August. The late and sluggish response of this hydrograph is probably the result of the refuse's not having completely reached field capacity. Recharge events did occur in LW 13 prior to October 1968, but it is felt that these were caused by water's channelling through the refuse.

Both hydrographs decline through August and September. It is possible that the slower decline in LW 13 reflects the fact that the ground water mound at this location has not reached its maximum height.

Evapotranspiration from plants is effective throughout the growing season. The effect of this evapotranspiration in reducing soil moisture is shown by the relatively large rains that are necessary in June and July to produce a rise in water level and by the fact that there is no response to rains in August and September. Precipitation in June and July was abnormally high and may have caused greater infiltration than usual during these months.

Infiltration can be estimated from the weekly hydrographs in the same manner as it is from the continuous hydrographs, but because they cannot be corrected for anomalous readings such as that shown on March 24, 1969, and for barometric fluctuations, the results are less accurate.

CALCULATION OF SPECIFIC YIELD

Specific yield was calculated by selecting a recharge event at a time when the materials above the top of the zone of saturation were at

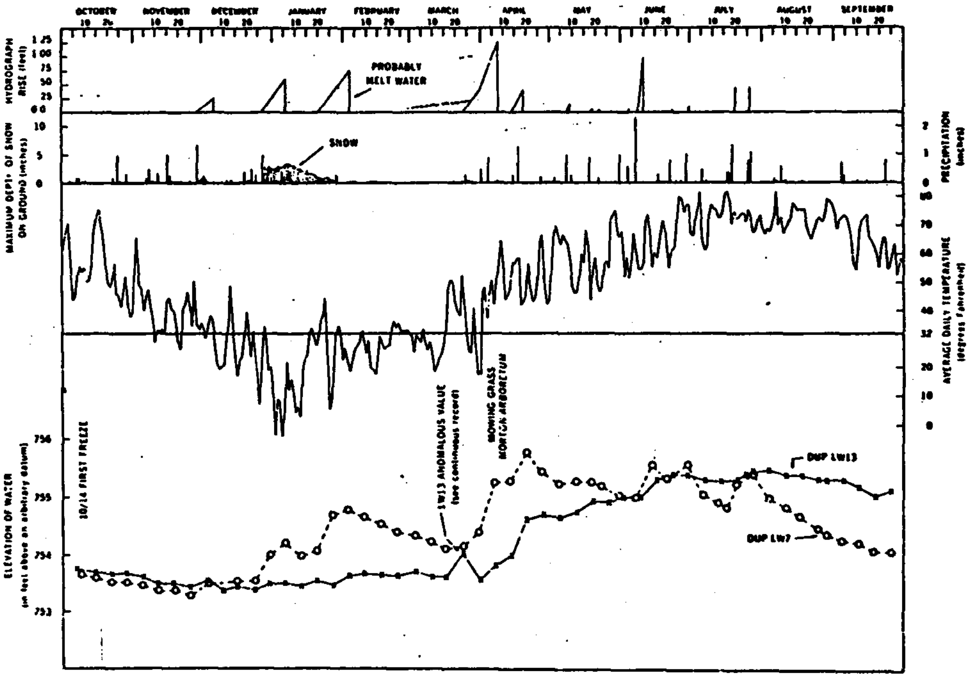

Figure 32. Weekly hydrographs for DuPage LW 7 and DuPage LW 13 for the period October 1, 1968, through September 30, 1969, together with precipitation and temperature records. Also presented is a plot of the rise in water level attributed to infiltration for DuPage LW 7 as taken from the continuous hydrograph. Individual recharge events are summed to yield the total recharge for the year.

or near to field capacity and assuming that all the precipitation falling on the landfill infiltrated and contributed to the water level rise. During this event specific yields can be calculated by using the equation $Sy = Rppt/\Delta h$ as discussed in appendix H.

This calculation assumes that (1) the field capacity of the materials above the zone of saturation has been reached and (2) there is little or no runoff or ponding and a representative amount of the precipitation enters the ground.

We assumed that the materials were at field capacity for about 1 week after a substantial recharge event and calculated field capacity for subsequent recharge events falling within this time span.

The effect of runoff and ponding was estimated from the slope of the ground in the vicinity of the recorder and considered in selecting the specific yield value to be used for calculating total infiltration (appendix G).

As can be seen, a considerable amount of personal judgment is involved in this procedure. If the material is not at field capacity or there is runoff, a high figure for specific yield will be obtained. If there is ponding, a low specific yield will be calculated.

Specific yield, total porosity, and field capacity were, on two occasions, measured directly in the field on refuse placed in two 55-gallon drums welded together. On the first occasion the two drums were filled to the top with measured amounts of uncompacted refuse and water, left overnight, and then drained for 24 hours. On the second occasion, the refuse was compacted with a tamper as the water was added. The mixture was left for 7 days before being drained. During this interval more water was added as necessary to cover the refuse.

Calculations were based on the following relationships:

$$\text{Specific yield} = \frac{\text{Volume of water drained from barrel} \times 100}{\text{Total volume of barrel}}$$

$$\text{Total porosity} = \frac{\text{Volume of water added to barrel} \times 100}{\text{Total volume of barrel}}$$

$$\text{Field capacity} = \text{Total porosity} - \text{specific yield}$$

The specific yield, porosity, and field capacity obtained on the first occasion were 63, 73, and 10 percent respectively and on the second occasion 44, 79, and 35 percent respectively.

Results from the first measurements are not realisitic, inasmuch as the refuse was not compacted sufficiently, nor was the refuse and water mixture left long enough for all of the pore space to become saturated. A field capacity of 35 percent as obtained on the second occasion can be compared with measurements of 29 percent made with an asbestos tension table by Remson et al. (1968, P.309) in Pennsylvania. The specific yield value of 44 percent compaires well with that obtained for Winn LW 17, on table 19.

APPENDIX F
RESULTS AND INTERPRETATION OF PERMEABILITY CALCULATIONS

SLUG TESTS

Table 15 shows the results of slug tests for permeability grouped according to site and materials. Permeability values obtained from sands and gravels at the old DuPage County, Elgin, and Woodstock landfills reflect the variable texture of these glacial deposits. Values for glacial tills and for the alluvium at Winnetka show more consistency. Values for refuse are also variable, as would be expected from its heterogeneous nature.

In some instances valid results could not be obtained. These are noted in the comments column in table 15. If the permeability of a unit is high and the diameter of the standpipe is small: the drop in water level is too rapid to be measured by the method used. In these cases we have given an estimated value for the permeability.

In a number of wells water levels continued rising after slugging, dropped below their original level, or remained stationary. These are noted in the comments column as a matter of interest.

A value of 25 gpd per square foot was taken to represent the permeability of the survicial sands around the edges of the old DuPage County landfill. This rather arbitrary figure is derived by averaging all the slug tests taken in this unit except those from MM 29, 59, 63, and 76. We believe that rejection of these higher (and possibly erroneous) values may compensate for the fact that most of the slug tests were run on the south side of the landfill, where the materials appear to be coarser textured.

PUMPING TESTS

Pumping tests were run on the shallow deposits at the old DuPage County and Winnetka landfills to verify the permeability values arrived at through slugtesting. The first such test was run on wells MM 46, 47, 57, 58, 59, and 60, south of the old DuPage County landfill. These wells are approximately 12 feet deep, in a line spaced at intervals of 5 and 10 feet on either side of MM 58, the pumping well. MM 58 was pumped with a peristolic pump at between 0.125 and 0.10 gpm for 16 hours. This test was repeated with a contractor's pump at a pumping rate of 0.50 gpm on MM 59. The results obtained with the unsteady-state leaky artesian mithod of analyses (Walton, 1962.p. 5) compared well with those obtained by slugtesting.

A similar test was run on DUP MM 68 to 72, inclusive, to compare results between sealed and unsealed well points. These are wells about 9 feet deep and arranged as the arms of a cross 2 and 5 feet from the center well MM 68, the pumped well.

Two tests were run on this array. In the first test, MM 68 was pumped at different rates from 0.605 gpm to 1.73 gpm with a small contractor's pump for about 4 hours and step drowdown analysis was made as described by Walton (1962, p 27) In the second test MM 68 was pumped at 1.21 gpm with the contractors pump for about 4 hours and the results analyzed by the nonsteady-state leaky artesian method (Walton, 1962, p. 5). Both of these methods gave similar results, which indicated that the materials had a permeability one to two orders of magnitude higher that given by slugtesting. There was no indication that different results would be obtained in sealed versus unsealed wells.

An input test was run on the alluvium at Winnetka MM 50-54 inclusive. These wells are about 7 feet deep in a line spaced at 2 and 4 feet from MM 52. The center well, MM 52, was injected at 0.101 gpm for 24 hours and the results analyzed by the nonsteady-state leaky artesian method (Walton, 1962, p. 5). These results compared well with those obtained through slugtesting.

LABORATORY TESTS

Vertical and horizontal values for permeability were obtained on a sample of till collected from an excavation about 4 miles south of the old DuPage County landfill. The vertical permeability obtained was 2.8 x 10^{-7}, centimeters per second, with a constant head of 5.25 pounds per square inch over an area of 37.0 square centimeters for 23.40 hours. The vertical permeability was 2.2 x 10^{-7} centimeters per second a head of 0.43 pound per square inch over a sample area of 35.6 square centimeters for 16.25 hours. These compare well with values obtained from slugtests in the till at the old DuPage County site.

OTHER WORK IN AREA

Coefficients of vertical permability based on pumping cone analyses calculated from the drift materials (Walton. 1965, p. 34) raged from 2.17 x 10^{-7} centimeters per second for a clay till with some sand and gravel and shaley dolomite to 4.8 to x 10^{-7} *centimeters per second for sand and* gravel with some clay. Other studies in this area have yielded calculations of permeability for the drift from 9.4 x 10^{-9} centimeters per second to 3.8 x 10^{-3} centimeters per second. The latter has been interpreted as a joint in clay till (Williams, 1966, p. 48).

APPENDIX G
QUANTITATIVE DATA AND CALCULATIONS

This appendix lists pertinent quantitative data and calculations of water movement. Figure 33 is a sketch of conditions similar to those found at the old DuPage County and Winnetka landfills and illustrates the components of ground water flow that were calculated. The value of " lateral movement " applies to the quantity of water moving from the fill across section A-A' at the fill margin. It is a measure of the amount of water from the fill moving outward above the first zone of very low permeability (top of the glacial till) on all four sides of the fill area. The value for "vertical movement" applies to the quantity of water from the fill moving across section A'-B below the fill. It is a measure of the amount of water from the fill moving downward beneath the fill itself. It is not a measure of total downward movement from the fill, because some downward movement also occurs outside of the margin of the fill (below area indicated by C).

The maximum distance that dissolved solids from the landfill can move laterally should be fixed hydrologically at the point where the flow line leaving the landfill at A enters the top of the till. An estimate of the distance to this point from the landfill has been made for the south side of old DuPage County landfill

The spreading effect of the sand bed within the till section is effective only if the sand extends part way below the filled area. If it underlies all the fill area, it will move the zone of vertically moving water over as a unit. The right side of figure 33 illustrates the effect of a tile on the flow system. Note the diversion of both downward and laterally moving water to this tile.

DUPAGE COUNTY LANDFILL

3.40×10^{6} ft^{2}	Surface area of fill
8.5×10^{3} ft	Length of landfill edge North, south, and west sides
1.5×10^{3} ft	East side
1.30 ft/year	Estimated yearly recharge based on table 19
	Estimated average horizontal gradient in surficial sand at
2×10^{-2} ft/ft	fill edge
	North, south, and west sides
1.7×10^{-1} ft/ft	East side
25 gal/day/ft^{2}	Estimated average permeability of surficial sand at fill edge based on table 15
30 gal/day/ft^{2}	*Estimated permeability of* surficial materials in area south of landfill
	Average saturated thickness of surficial sand at fill edge
10 ft	North, south, and west sides
7 ft	East side
8×10^{3} gal/day/ft^{2}	Estimated average permeability of till below fill based on table 15
0.5 ft/ft	Average vertical gradient at top of till unit
0.15	Estimated specific yield of surficial sand unit

Recharge by precipitation (October 1, 1968; to September 30, 1969)

Recharge is calculated by the method described by Williams and Lohman (*1949, p.* 127-129).

Total recharge = 1.30 ft/yr $\times 3.40 \times 10^{6}$ ft^{2} = 4.4×10^{6} ft^{3}/yr=90,000 gpd Discharge from fill.

Lateral movement through surficial sand North, south, and west sides of fill.

25 gpd/ft$^{2} \times 2 \times 10^{-2}$ ft/ft $\times 10$ ft $\times 8.5 \times 10^{3}$ = 4.25×10^{4} gpd.

East side of fill

25 gpd/ft$^{2} \times 1.7 \times 10^{-1}$ ft/ft $\times 7$ ft $\times 1.5 \times 10^{3}$ ft = 4.46×10^{4} gpd.

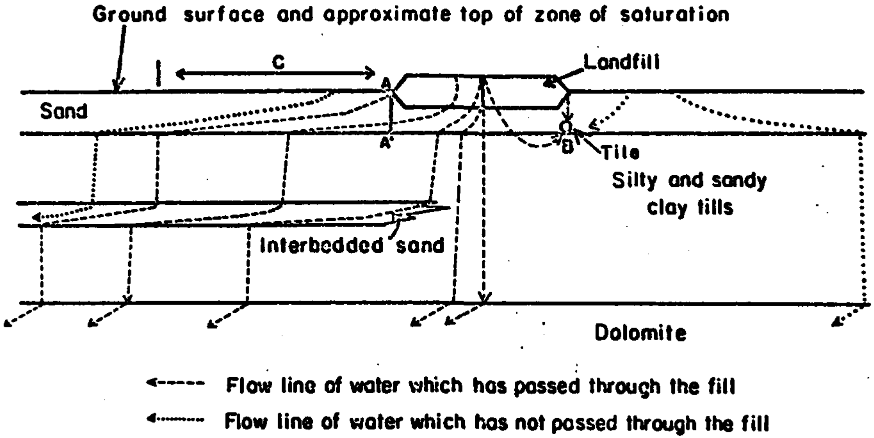

Figure 33. Illustration of conditions similar to those found at the old Du Page County and the Winnetka landfills and of the components of ground water flow calculated in Appendix G. The right side of the figure illustrates the effect of a tile on the flow system. Both downward and laterally moving water are diverted to this tile.

Total lateral discharge through surficial sand = 87,100 gpd.

Vertical movement downward through till beneath fill.

8×10^{-3} gpd/ft^2 x 0.5 ft/ft x 3.40×10^6 ft^2 = 13,600 gpd.

Total discharge = 100,700 gpd or approximately 100,000 gpd.

Estimated velocity of ground water flow.

South of landfill with a horizontal gradient of 6×10^{-3} and specific yield of 0.15

$$\frac{30 \text{ gpd/ft}^2 \times 6 \times 10^{-3} \text{ ft/ft} \times 3.65 \times 10^2}{7.48 \times 0.15}$$

$$= 60 \text{ ft/yr}$$

Dilution of leachate by Kress Creek.

Flow from east side of fill = 4.46×10^4 gpd

Flow in Kress Creek measured at 2.6 ft^3/sec or 1.7×10^6 gal/day on 7/15/69. Appeared to be slightly lower than average flow

$$\text{Dilution} = \frac{1.7 \times 10^6 \text{ gpd}}{4.46 \times 10^4 \text{ gpd}} = 38.6 \text{ times}$$

Hydrogeologic limitations on the migration of dissolved solids from the landfill, south side of the old DuPage County landfill.

Assume that the amount of water leaving through A-A, figure 32, is equal to the amount of water entering over the interval C. According to Darcy's law, Q = PIA, as discussed in appendix E, and therefore:

$$P_1I_1\,(A\text{-}A') = P_2I_2C$$

$$C = \frac{P_1I_1\,(A\text{-}A')}{P_2I_2} =$$

$$\frac{30 \text{ gal/day/Ft}^2 \times 2 \times 10^{-2} \text{ Ft/Ft} \times 10 \text{ Ft}}{8 \times 10^{-3} \text{ gal/day/Ft}^2 \times 0.5 \text{ Ft/Ft}} =$$

1,500 Ft

The calculated distance would be strongly affected by variations in vertical permeability within the surficial sands through which the dissolved solids move, and we know from our drilling that these variations in permeability are present.

WINNETKA LANDFILL

1.06×10^6 ft^2	Surface area (A) of fill
4,900 ft	Perimeter of fill
2×10^{-1} ft/ft	Estimated average horizontal gradient (I) in surficial alluvium around perimeter of fill
1.30 ft	Estimated yearly recharge based on table 19
5 gal/day/ft^2	Estimated average permeability (P) of surficial alluvium at fill edges (table 15)
6 ft	Estimated saturated thickness of surficial alluvium
3.4×10^{-3} gal/day/ft^2	Estimated permeability of till below fill, based on table 15
0.5 ft/ft	Estimated vertical gradient (I) in till below fill

Recharge by precipitation

Total recharge = 1.30 ft/yr x 1.06×10^6 ft^2 = 1.38×10^6 ft^3/yr = 2.83×10^4 gpd or 28,300 gpd

Discharge from fill

Lateral movement through surficial alluvium 5 gpd/ft^2 x 2×10^{-1} ft/ft x 4.9×10^3 ft x 6 ft = 30,000 gpd

Vertical movement through clay till below fill 3.4×10^{-3} gpd/ft^2 x 0.5 ft/ft x 1.06×10^6 ft^2 = 1,800 gpd

Total discharge from fill = 31,800 gpd

Estimated velocity of ground water flow through alluvium on north, east, and west sides of landfill with a horizontal gradient of 3.5 x

10^{-2} ft/ft and a specific yield of 0.10

$$\frac{5\ \text{gpd/ft}^2 \times 3.5 \times 10^{-2}\ \text{ft/ft} \times 365}{7.48 \times 0.10} = 85.2\ \text{ft/yr}$$

ELGIN LANDFILL

$1.45 \times 10^6\ \text{ft}^2$	Surface area (A) of fill*
1.25 ft/yr	Estimated yearly infiltration based on table 19

Total infiltration = $1.45 \times 10^6\ \text{ft}^2 \times 1.25\ \text{ft/yr} = 1.81 \times 10^6\ \text{ft}^3/\text{yr} = 6.6 \times 10^4$ gpd

Dilution in Fox River

Low flow 7.76×10^6 gpd + 6.6×10^4 gpd = 120†

Average flow 4.89×10^8 gpd + 6.6×10^4 gpd = 7,400†

This estimate assumes that all the water infiltrating into this landfill moves to the river. Since this is a discharge zone, there is no downward movement. The estimate maximizes the possible level of pollution entering the river by making no allowance for dilution by ground water infiltrating between the landfill and the river.

WOODSTOCK LANDFILL

$1.1 \times 10^6\ \text{ft}^2$	Surface area (A) of fill
1 ft/yr	Estimated yearly infiltration based on table 19

Total infiltration = $11 \times 10^5\ \text{ft}^2 \times 1\ \text{ft/yr} = 11 \times 10^5\ \text{ft}^3/\text{yr} = 22{,}500$ gpd (2.2×10^4)

Estimated flow in the drainage ditch is 10^6 gpd and on the assumption that gpd reaches this ditch, it would allow dilution of (1×10^6 gpd + 2.35×10^4 gpd) = 45 times. This does not take *into account water moving downward inside* or outside of the fill boundaries or dilution and attenuation of leachate between the fill and the drainage ditch.

**A maximum figure, since it includes old ash, which appears to have nearly stabilized, and relatively thin fill.*

†Stream flow data from Water Resources Data for Illinois, 1966 (U.S. Dept. of the Interior, Geological Survey, Water Resources Division, 1967), Part 1, p. 111.

APPENDIX H
ANALYTICAL METHODS USED IN HYDROLOGIC INVESTIGATION

There were two objectives to our hydrogeologic investigation. The first was to obtain a water balance in order to determine how much *water was entering and leaving the landfills and* by what means. The second was to describe the subsurface travel path of the water as leachate leaving the landfill. A water balance equation was developed and solved to obtain the first objective, and modified flow nets were constructed to describe the movement of the *ground water.*

WATER BALANCE STUDIES

Hydrographs of observation wells indicate that the ground water flow systems in and around the landfills are in a quasi-steady-state condition. This means that the water flowing *out of the system is replaced by water flowing* into the system, either recharged from infiltration of precipitation or by ground water inflow. A water balance equation for this situation is:

$$R_{pptn} + I_{GW} = O_{GW} + ET_{GW} \pm S_{GW}$$

where

R_{pptn} = recharge from infiltration of precipitation

I_{GW} = inflow of ground water

O_{GW} = outflow of ground water

ET_{GW} = evapotranspiration loss from the ground water reservoir

and

S_{GW} = change in volume of ground water in storage

Ground water inflow, I_{GW} is zero if a ground water mound has formed under the site so that all gradients are away from the site. This is the case in three of the studied sites. Evapotranspiration from the saturated zone (ET_{GW}) is small if the water table is low or if the plants present are not heavy users of ground water. This factor was neglected as minor in the calculations. Because we are assuming the mound to be stable or nearly so the change in volume of ground water in storage S_{GW} is considered zero. In view of this, Rpptn will equal O_{GW}.

$$R_{pptn} = \Delta h \cdot Sy$$

where

R_{pptn} = recharge by infiltration

Δh = rise in water level due to infiltration of precipitation

and Sy =

specific yield of material at the water table

Specific yield is the effective porosity of the medium and is described by the expression:

$$N = Sy + S_R$$

where

N = porosity of the medium

Sy = specific yield, the volume of water yielded by gravity drainage

and

S_R = specific retention, the volume retained by a unit volume of material after gravity drainage.

Specific yield of refuse was calculated from the continuous hydrographs by dividing the *rainfall by the corresponding rise in hydrograph,* $R_{pptn}/\Delta h$ at a time when the materials above the zone of saturation were at field capacity. It was also measured directly on refuse compacted in a barrel filled with water (appendix E).

The value for Δh is taken from continuous hydrographs where a rise due to a rainstorm indicates a recharge event. It was necessary to distinquish water level changes caused by other factors from those due to recharge and depletion. The total recharge for a year is the sum of all recharge events (Williams and Lohman, 1949, p. 127-129), and recharge to each landfill was calculated by this method (appendix E).

The remaining unsolved factor in water balance equation, O_{GW}, is obtained by Darcy's law and a flow net analysis.

DARCY'S LAW

The flow of water is governed by Darcy's law, which can be written:

Q = PIA, where Q = rate of flow
P = permeability of the medium
I = hydraulic gradient, the rate change of hydraulic head along a flow path dh/dl

and

A = cross sectional area through which flow occurs

The permeability, P, of a material refers to the ease with which a fluid will pass through it. In this study permeability was measured with slug tests, pumping tests, and laboratory tests on samples (appendix F). I, the hydraulic gradient, is a measure of ground water potential or hydraulic head and is determined from water levels in piezometers.

To calculate O_{GW}, the outflow of ground water, we applied Darcy's law to vertical sections along the sides of the landfill and to the horizontal section at the base of the landfill and, knowing P, I, and A, we calculated the amount of water leaving the landfill area. Because of the difficulties involved in arriving at an accurate value for P, the measurement of input is considered to be much more reliable than that for output based on Darcy's law.

GROUND WATER VELOCITY

The velocity of ground water movement, both lateral and vertical, can be calculated by the relationship:

$$V = \frac{P\ I}{7.48\ S_Y}$$

where V is the velocity in feet per day, P the coefficient of permeability in gallons per day per square foot, I the hydraulic gradient, and S_y the specific yield, a fraction expressing the amount of water that will drain from a saturated material.

Velocity calculations based on this relationship can be considered only as rough estimates because P, the permibility, is (appendix F) very difficult to measure accurately and we do not have reliable data on the specific yield of the till. Todd (1959, p. 25) gives a value of 3 percent for the specific yield of materials similar to glacial till, whereas Schicht and Walton (1961) arrived at values of about 10 percent in basin studies in Illinois. Specific yield values of approximately 20 percent would be necessary to explain the velocity as estimated from the resistivity data gathered in this study (Hughes et al. 1968), and values of 51 to 78 percent would fit the velocity figures indicated by the water quality data gathered in this investigation. Variations in specific yield of this magnitude could be accounted for easily by errors in the estimates of the till's permeability. Travel velocities through till were therefore based on water quality data, which is more appropriate in a study of this nature.

Specific yield for the surficial sand at the old DuPage County landfill and for the alluvium at the Winnetka landfill could be estimated fairly accurately from data given by Todd (1959, p. 25) for similar materials. At these sites calculated velocities agreed fairly well with velocities based on chloride movement through the surficial deposits.

FLOW NET ANALYSES

A flow net is a graphical solution to the LaPlace equation:

$$\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} = 0$$

where h = ground water fluid potential
x,y = cartesian coordinates

This equation relates the distribution of head or fluid potential in two dimensions, for steady -state flow.

Distribution of head in the field is found by plotting the elevation of water levels in piezometers and contouring them. A smooth pattern is some confirmation of the validity of the measurements. Anomalous values that cannot be reasonably accounted for from natural conditions are usually good clues to faulty piezometer installation.

Flow lines are drawn to intersect the equal potential contours at right angles, and if the two sets of lines are made to form a network of curvilinear squares, the analysis is simplified.

Darcy's law again provides the expression for calculating the rate of flow. Permeability is found from field tests of piezometers and laboratory tests of core samples. The gradient I and area A are derived from the flow net. Gradient is merely the difference in potential between two points on a flow line divided by the length of the flow line. Area is the product of the distance between two lines and the thickness of flow field. For flow nets in cross sections thickness is set at unity so that area is numerically equal to the distance between flow lines. For flow nets in plan view on maps, the thickness is based on geology and is taken as the thickness of the aquifer through which most flow occurs.

The true steady-state condition implied in the flow net analysis is seldom, if ever, met in the field. In this study, well hydrographs show considerable fluctuation in water levels with time, which is proof of unsteady flow. The fluctuations are not, however, so great that water levels at any one time are not reasonable representations of the average potential distribution throughout the year. Water levels for flow net analyses were chosen at times when piezometers were stable, to reduce error caused by time lag.

The materials of the subsurface have widely varying hydrogeologic properties that are usually related to the geologic origin. The materials are classified and grouped into hydrostratographic units according to their properties.

Where a flow line crosses a boundary between hydrostratographic units with different permeabilities, it is refracted so that:

$$\frac{k_1}{k_2} = \frac{\mathrm{Tan}\,\phi_1}{\mathrm{Tan}\,\phi_2}$$

where k_1 and k_2 equal the permeabilities of the two units and ϕ_1 and ϕ_2 equal the angles of incidence of the flow lines on the boundary between the two units. In practice this means that water moving downward below a ground water mound and encountering material of lower permeability is refracted into this material, increasing the downward component of flow.

Determining the distribution of the units in the subsurface and evaluating their hydrogeologic properties are important tasks to the hydrogeologist because these are the factors that control the ground water flow system.

Flow direction shown on the cross sections in this report are corrected for vertical exaggeration and permeability variations, as discussed by van Everdingen (1963). The use of vertical exaggerations in cross sections has the effect of suggesting more lateral movement than is actually taking place. The effect of permeability on flow has already been discussed.

PERMEABILITY DETERMINATIONS

Slug tests were made on selected piezometers to determine values of permeability *in situ*. These involve changing the water level in a piezometer and then plotting the hydrograph as the water level returns toward equilibrium at the static level. According to Hvorslev (1951, p.43) the permeability of the screened zone of a piezometer can be found from expression:

where $K = \frac{A}{FT}$

$K =$ cross section area of piezometer tube, cm^2

$F =$ shape factor, depending upon the area of the interface between piezometer bore and formation and

T = basic time lag, the time required for complete recovery if the initial flow rate, q, remains constant until stabilization is reached. If the total volume of flow is V then T = V/q, sec.

For most of the piezometers in this study the shape factor for a well point filter in uniform soil is most suitable (Hvorslev, fig. 18, case G).

An important consideration is the ratio of horizontal permeability to vertical permeability, k_h/k_v, and the square root of which is the transformation ratio, m.

The expresssion for K_h for this case is:

$$K_h = \frac{d^2/n\left[\frac{mL}{d} + \sqrt{1 + \frac{mL}{D}^2}\right]}{8 \cdot L \cdot T}$$

where

d = diameter of the piezometer tube, cm

L = length of the piezometer screen, cm

D = diameter of the piezometer screen, cm

and the other terms as previously stipulated

For piezometers in clay, the simplified form given by Horslev was used:

$$K_h = \frac{d^2/n\left(\frac{2\,mL}{D}\right)}{8 \cdot L \cdot T}$$

Table 15 shows the results of slug tests for permeability. The method is subject to considerable error, in part because of subjective evaluation.

Pumping tests, input tests, and laboratory tests were also run and their results compared against those obtained from slug testing.

The major source of error in applying Darcy's law to ground water flow is the value used for permeability. Earth materials are seldom homogeneous, and permeability values may vary by an order of magnitude over short distances in the same deposit. This is particularly true of the upper sand and alluvium deposits at the old DuPage County and Winnetka landfills. For this reason, calculations of the amount of water coming out of the landfill are must less reliable than calculations of input, which are not dependent on the accuracy of the permeability factor.

In order to obtain some quantitative ideas concerning the potential distribution and thus the ground water flow patterns in the old DuPage County waste disposal site, a two-dimensional digital model was constructed by Dr. Paul C. Heigold of the Illinois State Geological Survey. The model was set up to handle anisotropic, nonhomogeneous, steady-state flow with fixed hydraulic potentials at the water table surface and at the points where piezometers were located, and fixed hydraulic potential gradients at boundaries other than the water table.

Essentially the model involves the solution of the boundary value problem given by the partial differential equation for steady-state flow

$$\frac{\partial\left(H\frac{\partial\phi}{\partial x}\right)}{\partial\phi} + \frac{\partial\left(H\frac{\partial\phi}{\partial z}\right)}{\partial z} = 0$$

where

H = hydraulic conductivity at a point P (x,z) in the field of interest

ϕ = hydraulic potential at a point P (x,z) in the field of interest

and its attendant boundary conditions

ϕ = f (x) at the water table

ϕ = f (x,z) at points where piezometers were located

$\frac{\partial \phi}{\partial n}$ = constant at those boundaries other than the water table (n is the director normal to boundary)

In this study a numerical solution that involved the method of finite differences and the Gauss Seidel iteration technique was applied to the boundary value problem outlined.

Input to the finite-difference equations for the nodes of the grid superimposed on the field of interest included water table elevations, potential values obtained from piezometers located within the field of interest, vertical and horizontal hydraulic conductivities dependent on the lithology within which a node was located, and reasonable hydraulic potential gradients at boundaries other than the water table.

The iteration procedure was carried out on the IBM 360/75 at the University of Illinois. A total of 4,000 iterations were made with a resultant residue of 0.006 foot.

The ground water flow pattern obtained from this procedure is more accurate than had been previously obtained; however the procedure is relatively expensive and has the same dependence on reliable permeability measurements as the simple methods of flow analyses do that are used in appendix G.

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