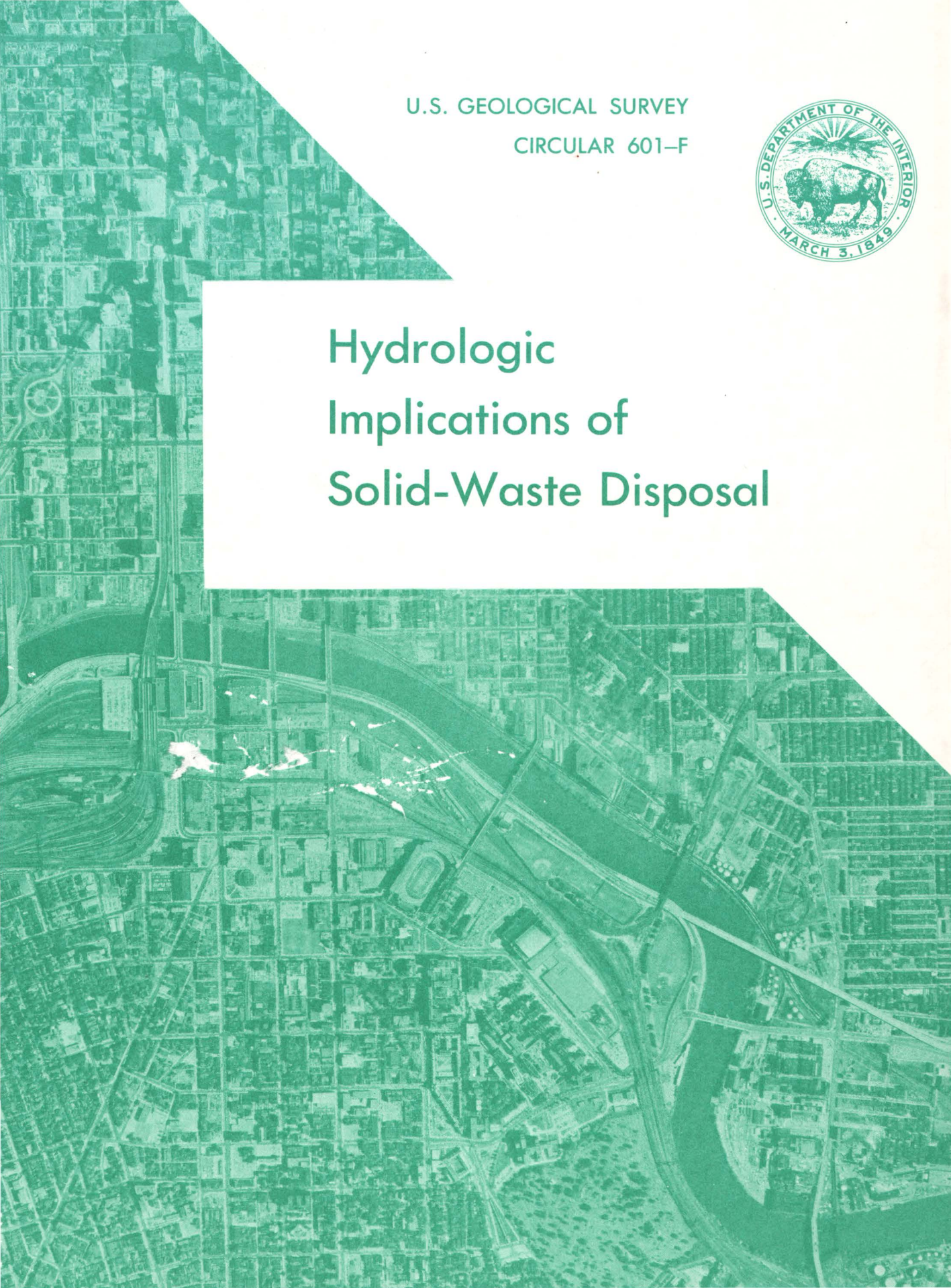


U.S. GEOLOGICAL SURVEY  
CIRCULAR 601-F



# Hydrologic Implications of Solid-Waste Disposal





**HYDROLOGIC IMPLICATIONS OF  
SOLID-WASTE DISPOSAL**





Solid wastes, the byproduct of an affluent society, accumulate at a rate of more than 1,400 million pounds per day.

# Hydrologic Implications of Solid-Waste Disposal

By William J. Schneider

WATER IN THE URBAN ENVIRONMENT

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## FOREWORD

Urbanization—the concentration of people in urban areas and the consequent expansion of these areas—is a characteristic of our time. It has brought with it a host of new or aggravated problems that often make new demands on our natural resources and our physical environment. Problems involving water as a vital resource and a powerful environmental agent are among the most critical. These problems include the maintenance of both the quantity and quality of our water supply for consumption, for recreation, and general welfare and the alleviation of hazards caused by floods, drainage, erosion, and sedimentation.

A prerequisite to anticipating, recognizing, and coping intelligently with these problems is an adequate base of information. This series of reports is intended to show the relevance of water facts to water problems of urban areas and to examine the adequacy of the existing base of water information.

A handwritten signature in cursive script, reading "E. L. Hendricks".

E. L. Hendricks,  
*Chief Hydrologist*





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## Water in the Urban Environment

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# Hydrologic Implications of Solid-Waste Disposal

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By William J. Schneider

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### ABSTRACT

The disposal of more than 1,400 million pounds of solid wastes in the United States each day is a major problem. This disposal in turn often leads to serious health, esthetic, and environmental problems. Among these is the pollution of vital ground-water resources.

Of the six principal methods of solid-waste disposal in general use today, four methods—open dumps, sanitary landfill, incineration, and onsite disposal—carry an inherent potential for pollution of water resources. Seepage of rainwater through the wastes leaches undesirable constituents which reach the ground water in the area. This leachate is generally both biologically and chemically contaminated.

The extent of the pollution from this leachate is largely dependent upon the geologic environment in which the solid wastes are deposited. Pollution potential is highest in permeable areas with a shallow water table where the wastes are in direct contact with the ground water. In a relatively impermeable area, the pollution is generally confined locally to the vicinity of the waste-disposal site.

Site selection for disposal of solid wastes must be based on adequate water-resources information if pollutional potential is to be minimized. This will require regional as well as localized data on the water resources of the area. Only through such an approach can adequate protection be afforded to the environment in general and the water resources in particular.

### INTRODUCTION

The disposal of solid-waste material—principally garbage and rubbish—is primarily an urban problem. However, unlike liquid waste disposal of sewage and industrial effluents, the problem has received only limited recognition. It is common practice in many metropolitan areas to overlook or ignore the consequences of waste-disposal programs. The full scope of the problem, though, cannot be ignored.

The urban population of the United States is now

producing an estimated 1,400 million pounds of solid wastes each day. Disposal of these wastes is a major problem of all cities. In many instances, seemingly endless streams of trucks and railroad cars haul these wastes long distances—as much as hundreds of miles—to disposal sites. Based on a volume estimate of 5.7 cubic yards per ton of waste, this refuse is sufficient to cover more than 400 acres of land per day to a depth of 10 feet. Local governments spend an estimated \$3 billion each year on collection and disposal, a sum exceeded in local budgets only by expenditures for schools and roads.

The disposal of these solid wastes poses many problems to local government agencies. Unfortunately, the problem is handled by many governments on the basis of expediency without due regard to environmental considerations. Garbage and rubbish are collected, hauled minimum distances commensurate with public acceptance, and dumped. Occasionally, the waste is either burned or mixed with soil to provide landfill. As long as the procedure removes the refuse and as long as the disposal site is not a health hazard and does not offend esthetic values too greatly, the operation is considered successful. Overlooked or even ignored is the effect of the disposal on the total environment, including the water resources of the area. Although the disposal of solid wastes can create many serious health, esthetic, and environmental problems, only the hydrologic implications—the effect upon water resources—are considered in this report.

### TYPES OF SOLID WASTES

Our urban society generates many types of solid wastes. Each may exert a different influence on the

TABLE 1.—*Classification of refuse materials*  
[Adapted from American Public Works Association (1966)]

Kind of refuse	Composition	Source
Garbage -----	Wastes from preparation, cooking, and serving of food; market wastes; wastes from handling, storage, and sale of produce.	Household, restaurants, institutions, stores, and markets.
Rubbish -----	Combustible: paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, wood furniture, bedding, and dunnage. Noncombustible: metals, tin cans, metal furniture, dirt, glass, crockery, and minerals.	Do.
Ashes -----	Residue from fires used for cooking and heating and from onsite incineration.	Do.
Trash from streets -----	Sweepings, dirt, leaves, catch-basin dirt, and contents of litter receptacles.	Streets, sidewalks, alleys, vacant lots.
Dead animals -----	Cats, dogs, horses, and cows -----	Do.
Abandoned vehicles -----	Unwanted cars and trucks left on public property -----	Do.
Demolition wastes -----	Lumber, pipes, brick, masonry, and other construction materials from razed buildings and other structures.	Demolition sites to be used for new buildings, renewal projects, and expressways.
Construction wastes -----	Scrap lumber, pipe, and other construction materials -----	New construction and remodeling.

water resources of an area. In order to understand the effect of each type, it is necessary to identify the various types as to the principal constituents. Table 1 lists the various categories and sources of refuse material primarily generated by urban activities. Not included are wastes from industries and processing plants; hazardous, pathological, or radioactive wastes from institutions and industries; solids and sludge from sewage-treatment plants; and other special types of solid wastes. These items usually pose special handling problems and are usually not a part of normal municipal solid-waste-disposal programs. The following descriptions of the categories of solid wastes are abbreviated from descriptions by the American Public Works Association (1966).

*Waste* refers to useless, unused, unwanted, or discarded materials including solids, liquids, and gases.

*Refuse* refers to solid wastes which can be classified in several different ways. One of the most useful classifications is based on the kinds of material: garbage, rubbish, ashes, street refuse, dead animals, abandoned automobiles, industrial wastes, demolition wastes, construction wastes, sewage solids, and hazardous and special wastes.

*Garbage* is the animal and vegetable waste result-

ing from the handling, preparation, and cooking of foods. It is composed largely of putrescible organic matter and its natural moisture. It originates primarily in home kitchens, stores, markets, restaurants, and other places where food is stored, prepared, or served.

*Rubbish* consists of both combustible and noncombustible solid wastes from homes, stores, and institutions. Combustible rubbish is the organic component of refuse and consists of a wide variety of matter that includes paper, rags, cartons, boxes, wood, furniture, bedding, rubber, plastics, leather, tree branches, and lawn trimmings. Noncombustible rubbish is the inorganic component of refuse and consists of tin cans, heavy metal, mineral matter, glass, crockery, metal furniture, and similar materials.

*Ashes* are the residue from wood, coke, coal, and other combustible materials burned in homes, stores, institutions, and other establishments for heating, cooking, and disposing of other combustible materials.

*Street refuse* is material picked up by manual and mechanical sweeping of streets and sidewalks and is the debris from public litter receptacles. It includes paper, dirt, leaves, and other similar materials.

*Dead animals* are those that die naturally or from disease or are accidentally killed. Not included in this

category are condemned animals or parts of animals from slaughterhouses which are normally considered as industrial waste matter.

*Abandoned vehicles* include passenger automobiles, trucks, and trailers that are no longer useful and have been left on city streets and in other public places.

## METHODS OF SOLID-WASTE DISPOSAL

The disposal of these solid wastes generated by our urban environment is generally accomplished by one or more of six methods. All are currently in use to one degree or another in various parts of the United States. To a large extent, the method of waste disposal in any particular area depends upon local conditions and, to some extent, upon public attitude. In many areas several methods are employed. Each has its unique relation to the water resources of the area. The six general methods of solid waste disposal are:

1. Open dumps.
2. Sanitary landfill.
3. Incineration.
4. Onsite disposal.
5. Feeding of garbage to swine.
6. Composting.

*Open dumps.*—Open dumps are by far the oldest and most prevalent method of disposing of solid wastes. In a recent survey, 371 cities out of 1,118 surveyed stated that this method was emphasized within their jurisdictions. In many cases, the dump sites are located indiscriminately wherever land can be obtained for this purpose. Practices at open dumps differ. In some dumps, the refuse is periodically leveled and compacted; in other dumps the refuse is piled as high as equipment will permit. At some sites, the solid wastes are ignited and allowed to burn to reduce volume. In general, though, little effort is expended to prevent the nuisance and health hazards that frequently accompany open dumps.

*Sanitary landfill.*—As early as 1904, garbage was buried to provide landfill. Although in subsequent years, the practice was used by many cities, the technique of sanitary landfill as we know it today did not emerge until the late 1930's. By 1945, almost 100 cities were using the practice, and by 1960 more than 1,400 cities were disposing of their solid wastes by this method.

Sanitary landfill consists of alternate layers of compacted refuse and soil. Each day the refuse is deposited, compacted, and covered with a layer of soil. Two types of sanitary landfill are common: area land-

fill on essentially flat land sites, and depression landfill in natural or manmade ravines, gulleys, or pits. Depth of the landfill depends largely on local conditions, types of equipment, availability of land, and other such factors, but it commonly ranges from about 7 feet to as much as 40 feet as practiced by New York City.

In normal operation, the refuse is deposited and compacted and covered with a minimum of 6 inches of compacted soil at the end of each working period or more frequently, depending upon the depth of refuse compacted. Normally about a 1:4 cover ratio is satisfactory; that is, 1 foot of soil cover for each 4-foot layer of compacted refuse. Ratios as high as 1:8, however, have been used. The final cover is at least 2 feet of compacted soil to prevent the problems associated with open dumps.

*Incineration.*—Incineration is the process of reducing combustible wastes to inert residue by burning at high temperatures of about 1,700° to 1,800°F. At these temperatures all combustible materials are consumed, leaving a residue of ash and noncombustibles having a volume of 5 to 25 percent of the original volume.

Although incineration greatly reduces the volume and changes the material to inorganic matter, the problem of disposal is still present. Much of the residue is hauled to disposal sites or is used for landfill, although the land required for disposal of the residue is about one-third to one-half of that required for sanitary landfill. Some cities require that combustible materials be separated from noncombustibles prior to collection, while others use magnetic devices to extract ferrous metal for salvage.

The combination of urban growth, increasing per-capita output of refuse, and the rising costs of land for sanitary landfills has stimulated the use of incineration for solid-waste disposal. Today, there are an estimated 600 central-incinerator plants in the United States with a total capacity of about 150,000 tons per day.

*Onsite disposal.*—With the increasing rate of production of solid wastes in the urban environment, there is a growing trend toward handling this waste in the home, apartment, and institution. Onsite disposal has become increasingly popular during the past decade as a way of minimizing the waste problem at its source. Most widely used devices for onsite disposal are incinerators and garbage grinders.

Onsite incineration is used widely in apartment houses and institutions. The incinerators do, however, require constant attention to insure proper operation

and complete combustion. Domestic incinerators for use in individual homes are not a major factor in solid-waste disposal, nor are they likely to be a major factor in the near future. Maintenance and operating problems are usually considerable.

Garbage grinders, on the other hand, are becoming increasingly prevalent in homes for disposal of kitchen food wastes. It is estimated that more than a million grinders are now in home use. The grinders are installed in the waste pipe from the kitchen sink; food wastes are simply scraped into the grinder, the grinder is started, and the water turned on. The garbage is ground and flushed into the sanitary-sewer system. In some local communities, garbage grinders have been installed in every residence as required by local ordinance.

*Swine feed.*—The feeding of garbage to swine has been an accepted way of disposing of the garbage part of solid wastes from urban areas for quite some time. Even as late as 1960, this method was employed in 110 American cities out of 1,118 cities surveyed on their solid-waste-disposal practices. In addition to the municipal practices of using garbage for swine feed, many cities and municipalities permit private haulers to service restaurants and institutions to collect garbage for swine feed. The feeding of raw garbage led to a wide-spread virus disease in the middle 1950's, which affected more than 400,000 swine. As a result, all States now require that garbage be cooked before feeding to destroy contaminating bacteria and viruses. However, according to the American Public Works Association (1966), more than 10,000 tons of food wastes—about 25 percent of the total quantity of garbage produced—is still used daily in the United States as swine feed.

*Composting.*—Composting is the biochemical decomposition of organic materials to a humuslike material. As practiced for solid-waste disposal, it is the rapid but partial decomposition of the moist, solid-organic matter by aerobic organisms under controlled conditions. The end product is useful as a soil conditioner and fertilizer. The process is normally carried out in mechanical digesters.

Although popular in Europe and Asia where intensive farming creates a demand for the compost, the method is not used widely in the United States at this time. Composting of solid-organic wastes is not practiced on a full-scale basis in any large city today. Although there are several pilot plants in operation, it does not seem likely that composting will be a major method of solid-waste disposal.

The selection of one or more of these methods of solid-waste disposal by a municipality depends largely on the character of the municipality. Geographic location, climate, standard of living, population distribution, and public attitudes play important roles in the selection. In general, the natural resources and environmental factors have been given only small recognition in this selection. Only recently has there been a considerable upsurge of scientific interest in the effects of solid-waste disposal on our water resources.

## HYDROLOGIC IMPLICATIONS

### TYPES OF POLLUTION

The disposition of solid wastes in open areas carries with it an inherent potential for pollution of water resources, regardless of the manner of disposal or the composition of the waste material. Of the six principal methods of solid-waste disposal, only swine feeding and composting offer no direct possibility of pollution of water resources from the waste material itself. Quite the contrary: properly composted garbage is a soil conditioner that improves the permeability of the soil and may actually assist in improving the quality of water that percolates through it. Although the cooked garbage that is fed to swine does not directly contribute to pollution of water resources, the manure from the feedlots may cause serious problems if not managed properly.

The type of pollution that may arise is directly related to the type of refuse and the manner of disposal. Leachates from open dumps and sanitary landfill usually contain both biological and chemical constituents. Organic matter, decomposing under aerobic conditions, produces carbon dioxide which combines with the leaching water to form carbonic acid. This, in turn, acts upon metals in the refuse and upon calcareous materials in the soil and rocks, resulting in increasing hardness of the water. Under aerobic conditions, bacterial action decomposes organic refuse, releasing ammonia, which is ultimately oxidized to form nitrate. In both landfills and open dumps, where decomposition is accomplished by bacterial action, the leachate has a high biochemical oxygen demand (BOD).

Table 2 indicates the magnitude of the constituents leached from solid wastes under various conditions. These data were compiled by Hughes (1967) from various sources.



TABLE 2.—Percentages of materials leached from refuse and ash, based on weight of refuse as received

[Adapted from Hughes (1967)]

Material leached	Percentage leached under given conditions *					
	1	2	3	4	5	6
Permanganate value.....30 min .....	0.039	-----	-----	-----	-----	-----
Do.....4 hr .....	.060	0.037	-----	-----	-----	-----
Chloride .....	.105	.127	-----	0.11	0.087	-----
Ammonia nitrogen .....	.055	.037	-----	.036	-----	-----
Biochemical oxygen demand .....	.515	.249	-----	1.27	-----	-----
Organic carbon .....	.285	.163	-----	-----	-----	-----
Sulfate .....	.130	.084	-----	.011	.22	0.30
Sulfide .....	.011	-----	-----	-----	-----	-----
Albumin nitrogen .....	.005	-----	-----	-----	-----	-----
Alkalinity (as CaCO <sub>3</sub> ) .....	-----	-----	-----	0.39	0.042	-----
Calcium .....	-----	-----	-----	.08	.021	2.57
Magnesium .....	-----	-----	-----	.015	.014	.24
Sodium .....	-----	-----	0.260	.075	.078	.29
Potassium .....	-----	-----	.135	.09	.049	.38
Total iron .....	-----	-----	-----	.01	-----	-----
Inorganic phosphate .....	-----	-----	-----	.0007	-----	-----
Nitrate .....	-----	-----	-----	-----	.0025	-----
Organic nitrogen .....	.0075	.0072	-----	.016	-----	-----

\* Conditions of leaching:

1. Analyses of leachate from domestic refuse deposited in standing water.
2. Analyses of leachate from domestic refuse deposited in unsaturated environment and leached only by natural precipitation.

3. Material leached in laboratory before and after ignition.
4. Domestic refuse leached by water in a test bin.
5. Leaching of incinerator ash in a test bin by water.
6. Leaching of incinerator ash in a test bin by acid.

### RELATION TO HYDROLOGIC REGIMEN

That part of the hydrologic regimen associated with pollution from solid-waste disposal begins with precipitation reaching the land surface and ends with the water reaching streams from either overland or subsurface flow. The manner in which this precipitation moves through this part of the cycle determines whether or not the water resource will become polluted.

Precipitation on the refuse-disposal site will either infiltrate the refuse or run off as overland flow. In open dumps, there is little likelihood of direct runoff unless the refuse is highly compacted. In sanitary landfills, the rate of infiltration is governed by the permeability and infiltration capacity of the soil used as cover for the refuse. A part of the water entering the refuse percolates downward to the soil zone and eventually to the water table. If the water table is above the bottom of the refuse deposit, the percolating water travels only vertically through the refuse to the water table. During the vertical-percolation process the water leaches both organic and inorganic constituents from the refuse.

Upon reaching the water table, the leachate becomes part of and moves with the ground-water flow

system. As part of this flow system, the leachate may move laterally in the direction of the water-table slope to a point of discharge at the land surface. In general, the slope of the water table is in the same direction as the slope of the land. The generalized movement of leachate in this part of the hydrologic cycle is shown in figure 1.

There are several well-documented cases of pollution caused by leachates from solid-waste-disposal sites, especially those compiled by the California Water Pollution Control Board (1961). Most of these studies, however, were able to determine only that the pollution originated from solid-waste-disposal sites; few, if any, data on the gross magnitude of the pollution and its fate in the hydrologic cycle are available.

One well-documented case is that of pollution from about 650,000 cubic yards of refuse deposited in a garbage dump near Krefeld, Germany, over a 15-year period in the early 1900's. High salt concentrations and hardness were detected in ground water about a mile downgradient from the site within 10 years of operation. Concentrations up to 260 mg/l (milligrams per liter) of chloride and a hardness of 900 mg/l were measured—an increase of more



FIGURE 1.—Generalized movement of leachate through the land phase of the hydrologic cycle.

than sixfold in chloride concentration and fourfold in hardness. The pattern of pumping of wells in the area precludes detailed understanding of the course of the pollution in the ground water, but wells near the dumping site were still contaminated 18 years later.

In Schirrhof, Germany, ashes and refuse dumped into an empty pit extending below the water table resulted in contamination of wells about 2,000 feet downstream. The contamination occurred 15 years after the dump was covered; measures of hardness up to 1,150 mg/l were recorded as compared with 200 mg/l prior to the contamination.

In Surrey County, England, household refuse dumped into gravel pits polluted the ground water in the vicinity. Refuse was dumped directly into the 20-foot-deep pits where water depth averaged about 12 feet. Maximum rate of dumping was about 100,000 tons per year over a 6-year period, and this occurred during the latter part of the period of use (1954–60). Limited observations on water quality extending less than a year after the closing of the pits showed chloride concentrations ranging from 800 mg/l at the dump site, through 290 mg/l in downgradient adjacent gravel pits, to 70 mg/l in pits 3,500 feet away. Organic and bacterial pollution were detected within half a mile of the dumping sites, but not beyond. Because of the limited study period and the

slow travel of the pollutants, the maximum extent of pollution was not determined.

More recently, a study was made of the ground-water quality associated with four sanitary landfill sites in northeastern Illinois (Hughes and others, 1969). At the DuPage County site, total solids of more than 12,500 mg/l and chloride contents of more than 2,250 mg/l were measured in samples collected about 20 feet below land surface under the fill. These were by far the highest concentrations measured at any of the four sites. In general, total solids ranged from 2,000–3,000 mg/l under the fill to as low as 223 mg/l adjacent to the fill.

#### HYDROLOGIC CONTROLS

The movement of leachate from a waste-disposal site is governed by the physical environment. Where the wastes are above the water table, both chemical and biological contaminants in the leachate move vertically through the zone of aeration at a rate dependent in part upon the properties of the soils. The chemical contaminants, being in solution, generally tend to travel faster than biological contaminants. Sandy or silty soils especially retard particulate biological contaminants and often filter them from the percolating leachate. The chemical contaminants, however, may be carried by the leachate water to the

water table where they enter the ground-water flow system and move according to the hydraulics of that system. Thus, the potential for pollution in the hydrologic system depends upon the mobility of the contaminant, its accessibility to the ground-water reservoir, and the hydraulic characteristics of that reservoir.

The character and strength of the leachate are dependent in part upon the length of time that infiltrated water is in contact with the refuse and the amount of infiltrated water. Thus, in areas of high rainfall the pollution potential is greater than in less humid areas. In semiarid areas there may be little or no pollution potential because all infiltrated water is either absorbed by the refuse or is held as soil moisture and is ultimately evaporated. In areas of shallow water table, where refuse is in constant contact with the ground water, leaching is a continual process producing maximum potential for ground-water pollution.

The ability of the leachate to seep from the refuse to the ground-water reservoir is another factor in the degree of pollution of an aquifer. Permeable soils permit rapid movement; although some filtering of biological contamination may take place, the chemical contamination is generally free to move rapidly under the influence of gravity to the water table. Less permeable soils, such as clays, retard the movement of the leachate, and often restrict the leachate to the local vicinity of the refuse. Under such conditions, pollution is frequently limited to the local shallow ground-water reservoir and contamination of deeper lying aquifers is negligible.

Leachate that does reach the water table and enters an aquifer is then subject to the hydraulic characteristics of the aquifer. Because the configuration of the water table generally reflects the configuration of the land surface, the leachate flows downgradient under the influence of gravity from upland areas to stream valleys, where it discharges as base flow to the stream systems. The rate of flow is dependent upon the permeability of the rock material of the aquifer and on the slope of the water table. In flat areas or areas of gentle relief, minor local topographic variations may have no effect on the configuration of the water table, and movement of ground water may be uniform over large areas.

In some places dipping confined aquifers crop out in upland areas and thus are exposed to recharge. Contaminants entering the aquifer in these areas move downgradient into the confined parts of the aquifer. Although there is usually some minor leakage to con-

fining beds above and below the aquifer, the contaminants in general will be confined to the particular aquifer, and water-supply wells tapping that aquifer will thus be subject to contamination to the extent that the contaminants are able to move from the outcrop to the wells.

Optimum conditions for pollution of the ground-water reservoir exist where the water table is at or near land surface, subjecting the solid waste to continual direct contact with the water. Such conditions commonly exist where abandoned quarries that penetrate the ground-water reservoir are used as refuse-disposal sites. The continual contact of the water with the refuse produces a strong leachate highly contaminated both biologically and chemically. Under hydrogeologic conditions of permeable materials and steep hydraulic gradients, the leachate may move rapidly through the ground-water system and pollute extensive areas. The hydrologic effects of solid-waste disposal in four geologic environments are shown in figure 2.

Figure 2A illustrates a waste-disposal site in a permeable environment. The waste is shown in contact with the ground water in a permeable sand-and-gravel aquifer underlain by confining beds of relatively impermeable shale. In this case, the potential for pollution is high because conditions of both high infiltration and direct contact between wastes and ground water exist. Because of the permeability of the aquifer, the contaminants move downgradient with the water in the aquifer and are diffused and diluted during this movement. In areas where the water table is below the bottom of the waste material, the degree of contamination is lessened because the wastes are no longer in direct contact with the ground water. In this case, leachate from the wastes moves vertically through the zone of aeration to the water table. It then enters the ground water and moves downgradient as in the case of a shallow water table.

Figure 2B illustrates a waste-disposal site in a relatively impermeable environment. In humid areas, the water table may be near land surface, and the disposed waste may or may not be in direct contact with the ground water. In the illustration, ground water is shown confined to the underlying limestone aquifer. The relative impermeability of the overburden prevents significant infiltration of the rainfall; consequently there is only minor leaching of contaminants from the wastes. Pollution is confined locally to the vicinity of the waste-disposal site; movement in all directions is inhibited by the inability of the water to

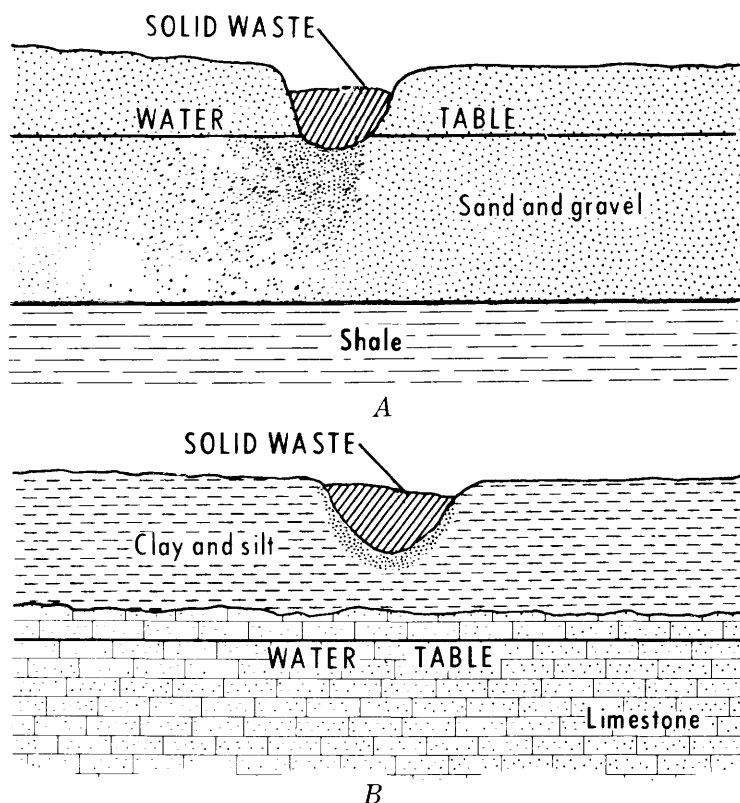


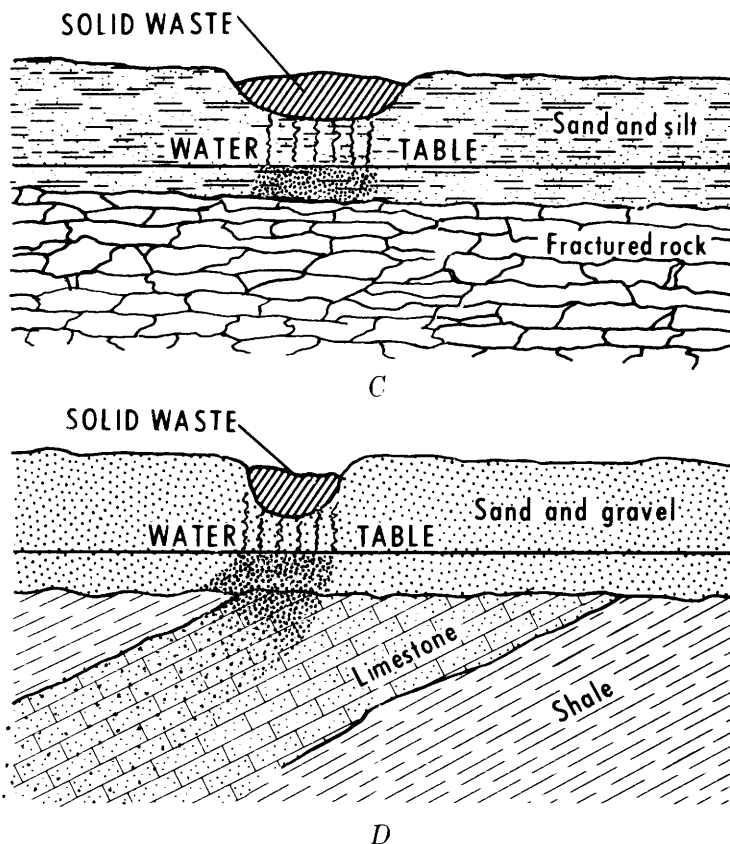
FIGURE 2 (above and right).—Effects on ground-water resources of solid-waste disposal at a site (A) in a permeable environment, (B) in a relatively impermeable environment, (C) underlain by a fractured-rock aquifer, and (D) underlain by a dipping-rock aquifer. Leachate shown in red.

move through the tight soils. If significant amounts of rainfall penetrate the wastes, a local perched water table may develop in the vicinity of the fill, and that water will likely be highly contaminated, both chemically and bacteriologically.

Figure 2C illustrates a waste-disposal site above a fractured-rock aquifer. The position of the water table in the overburden relative to the waste-disposal site is dependent upon the amount of infiltration and the geometry of the ground-water flow system. The water table shown here is below the body of waste. In this case, the potential for pollution is not high because of limited vertical movement of the leachate to the water table. However, the contaminants that reach the fractured-rock zone may move more readily in the general direction of the ground-water flow. Dispersion of the contaminants is limited because the flow is confined to the fracture zones. A thin, highly permeable overburden with a shallow water table (similar to that shown in figure 2A) overlying the fractured

rock would provide an ideal condition for widespread ground-water pollution.

Figure 2D illustrates a waste-disposal site in a geologic setting in which dipping aquifers are overlain by permeable sands and gravels. In this illustration, the waste-disposal site is shown directly above a permeable limestone aquifer. Here leachate from the landfill travels through the sand and enters the limestone aquifer as recharge. Again, the strength of the leachate depends in part upon whether the water table is in direct contact with the waste. Leachate will move downgradient with the ground-water flow in both the sands and gravels and the limestone, as shown in the illustration. If the waste-disposal site were located above the less permeable shale, most of the leachate would move downgradient through the sand and gravel, with very little penetrating the relatively impermeable shale as recharge. However, in its downgradient movement, it would enter any other permeable formations as recharge.



A high pollution potential exists also where waste-disposal sites are located on flood plains adjacent to streams. Water-table levels generally are near land surface in flood-plain areas, especially during the usual period of high water in winter and spring throughout much of the humid areas of the United States. In such environments the water may have contact with the refuse for extended periods, giving rise to concentrated leachate. The contaminated water moves through the flood-plain deposits and discharges into the stream during low-flow periods when the bulk of the streamflow is from ground-water discharge. The degree of pollution of the stream depends upon the concentration of the leachate, the amount of leachate entering the stream, and the available streamflow for dilution.

### HYDROLOGIC CONSIDERATIONS IN SITE SELECTION

It is obvious that our current national policy of pollution abatement and protection of our natural environment requires full consideration of the water resources in selection of sites for solid-waste disposal.

To date, with few exceptions, these considerations have been on a local scale, dealing primarily with the hydrological characteristics of the immediate site.

The American Society of Civil Engineers in a manual on sanitary landfill (American Society of Civil Engineers, 1959) discussed site selection from a hydrologic standpoint as follows:

In choosing a site for the location of a sanitary landfill, consideration must be given to underground and surface water supplies. The danger of polluting water supplies should not be overlooked.

The report states further that:

Sufficient surface drainage should be provided to assure minimum runoff to and into the fill. Also, surface drainage should prevent quantities of water from causing erosion or washing of the fill \* \* \*. Although some apprehension has been expressed about the underground water supply pollution of sanitary landfills, there has been little, if any, experience to indicate that a properly located sanitary landfill will give rise to underground pollution problems. It is axiomatic, of course, that when a waste material is disposed of on land, the proximity of water supplies, both underground and surface, should be considered \* \* \*. Also, special attention should be given areas having rock strata near the surface of the ground. For example, limestone strata may have solution channels or crevices through which pollution contamination

may travel. Sanitary landfills should not be located on rock strata without studying the hazards involved. In any case, refuse must not be placed in mines or similar places where resulting seepage or leachate may be carried to water-bearing strata or wells \* \* \* In summary, under certain geological conditions, there is a real potential danger of chemical and bacteriological pollution of ground water by sanitary landfills. Therefore, it is necessary that competent engineering advice be sought in determining the location of a sanitary landfill.

Consideration of hydrology in site selection is required by law in several States. Section 19-13-B24a of the Connecticut Public Health Code requires that:

No refuse shall be deposited in such manner that refuse or leaching from it shall cause or contribute to pollution or contamination of any ground or surface water on neighboring properties. No refuse shall be deposited within 50 feet of the high water mark of a watercourse or on land where it may be carried into an adjacent watercourse by surface or storm water except in accordance with Section 25-24 of the General Statutes which require approval of the Water Resources Commission.

The rules and regulations of the Illinois Department of Public Health require that:

The surface contour of the area shall be such that surface runoff will not flow into or through the operational or completed fill area. Grading, diking, terracing, diversion ditches, or tilling may be approved when practical. Areas having high ground water tables may be restricted to landfill operations which will maintain a safe vertical distance between deposited refuse and the maximum water table elevation. Any operation which proposes to deposit refuse within or near the maximum water table elevation shall include corrective or preventive measures which will prevent contamination of the ground-water stratum. Monitoring facilities may be required.

Other States have similar regulations.

A common denominator in these sets of recommendations is the general concern for the onsite pollutional aspect. This is characteristic of most current approaches, especially from the engineering and legislative viewpoints. Another characteristic is the restrictive approach to the problem. Hydrologic conditions are documented under which disposal of solid wastes is either discouraged or prohibited. In general, the pollutional problem is treated more in local than in regional context. These are, of course, important considerations and should be followed in any site selection. In fact, even stronger guidelines are desirable, to the extent of requiring detailed knowledge of the extent and movement of potential pollution at any site before the site is activated.

The water resource, however, must be considered also as a regional resource, not just a localized factor. As such, it should be considered in a regional concept in its relation to solid-waste disposal. This, of course,

requires that adequate regional information on the water resource is available. Given such information, the planner can weigh all available alternatives and insure that the final site selection is compatible with comprehensive regional planning goals and environmental protection. The Northwestern Illinois Planning Commission followed this comprehensive approach in developing its recommendations on refuse-disposal needs and practices in northeastern Illinois (Sheaffer and other, 1963).

It is, of course, quite possible that, in the comprehensive approach, some otherwise optimum sites for solid-waste disposal may be only marginally acceptable from a hydrologic viewpoint. Under such conditions detailed information on the hydrology should be obtained and detailed evaluations made of the impact of the potential waste disposal before the site is put into use; the actual impact should then be monitored during and after use. In general, although such studies are desirable for all solid-waste-disposal sites, they are essential where geologic, hydrologic, or other data indicate a possibility of undersirable pollutional effects.

The problem of solid-waste disposal is one of the most serious problems of urban areas. The ever-increasing emphasis on protection and preservation of natural resources though regional planning is evident today. The implementation of these commitments and goals can insure adequate protection of vital water resources from pollution by disposal of solid wastes.

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