Hydrogeologic considerations in hazardous-waste disposal in Illinois

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Preface

This report was originally prepared for the Office of the Governor in response to a request for information relative to the potential geologic suitability of sites in Illinois for the disposal of toxic wastes. Increasing environmental awareness by the public and the increased production of wastes have caused concern over the disposal of all wastes, especially hazardous wastes.

The report was reviewed by knowledgeable scientists and has been revised, taking note of the comments provided. However, the report reflects the views of the authors and is based on their research and reading of the scientific literature. A bibliography is included to provide background information to the reader.

We wish to acknowledge those persons who reviewed the manuscript and provided us with comments: Harry E. LeGrand, U.S. Geological Survey, retired, Raleigh, North Carolina; Mike H. Roulier, U.S. Environmental Protection Agency, Cincinnati, Ohio; George M. Hughes, Ontario Ministry of the Environment, Toronto, Ontario; and John A. Cherry, University of Waterloo, Waterloo, Ontario, Canada.

Hydrogeologic considerations in hazardous-waste disposal in Illinois

ABSTRACT

Present regulations assume that long-term isolation of hazardous wastes—including toxic chemical, biological, radioactive, flammable, and explosive wastes—may be effected by disposal in landfills that have liners of very low hydraulic conductivity. In reality, total isolation of wastes in humid areas is not possible; some migration of leachate from wastes buried in the ground will always occur.

Regulations should provide performance standards applicable on a site-by-site basis rather than rigid criteria for site selection and design. The performance standards should take into account several factors: (1) the categories, segregation, degradation, and toxicity of the wastes; (2) the site hydrogeology, which governs the direction and rate of contaminant transport; (3) the attenuation of contaminants by geochemical interactions with geologic materials; and (4) the release rate of unattenuated pollutants to surface or ground water. An adequate monitoring system is essential. The system should both test the extent to which the operation of the site meets performance standards and provide sufficient warning of pollution problems to allow implementation of remedial measures.

In recent years there has been a trend away from numerous, small disposal sites toward fewer and larger sites. The size of a disposal site should be based on the attenuation capacity of the geologic material, which has a finite, though generally not well defined, limit. For slowly degradable wastes, engineered sites with leachate-collection systems appear to be only a temporary solution since the leachate collected will also require final disposal.

Fine-grained geologic materials are present at the surface over large areas of Illinois and have attenuating characteristics considered favorable for waste disposal. Based on geological considerations, a map was prepared that indicates five areas in Illinois with geologic conditions generally suitable for disposal of hazardous wastes. These areas have very good potential for locating landfill sites that will meet regulatory criteria and that will also meet the application of the performance standards proposed here. The areas considered suitable are underlain by a substantial thickness of fine-grained material of low hydraulic conductivity overlying bedrock that is generally not an aquifer. Careful geologic and hydrogeologic investigations must be conducted to determine the suitability of each potential disposal site.

INTRODUCTION

The term "hazardous wastes" includes the general categories of toxic chemical, biological, radioactive, flammable, and explosive wastes. Such wastes, if improperly managed, obviously threaten public health and welfare. There are many sources of hazardous wastes; as a general rule, 10 percent of all non-radioactive wastes generated by industry are considered hazardous wastes. The 5-state north-central region, which includes Illinois, reportedly generates more hazardous wastes than any other region of the United States—approximately one-quarter of the nation's total. Approximately 90 percent of the hazardous wastes are in liquid form, of which about 40 percent are inorganic and 60 percent are organic. The quantity of hazardous wastes has been growing at the rate of 5 to 10 percent annually. The volume of solid wastes, sludges, and liquid concentrates of pollutants from industry that will be disposed of in landfill is expected to double during the next ten years.

The problems of disposal of wastes into geologic materials are a relatively recent subject of research. At the Illinois State Geological Survey and elsewhere, the research has until recently concentrated on the disposal of municipal refuse. Although criteria for disposal of hazardous wastes may differ in some details from those for disposal of general refuse, the principles developed from research are applicable to both. Research shows that current methods of landfill disposal of wastes, particularly in humid climates, usually generate a liquid leachate. The leachate may be noxious and may have a high concentration of dissolved matter.

Studies of the hydrologic systems in fine-grained geologic materials, into which current practices direct most wastes, were almost nonexistent 20 years ago; however, during the past two decades, procedures for study of fine-grained materials have been developed to provide the data required to study waste disposal sites. Many disposal sites have been studied to document the chemical and physical changes that may occur as a result of the burial of waste.

Investigation of the attenuation characteristics of geologic materials began only a few years ago and is now one of the major areas of research in the United States and elsewhere. Attenuation capacity is the material's ability to remove contaminants from the percolating fluids. Approximations of the attenuation capacities of some geologic materials are known for some contaminants in leachate. These approximations provide the general relationships and principles on which judgments can be made. Further research is necessary to adequately understand the mechanisms of attenuation and the attenuation characteristics of geologic materials for most contaminants and combinations of contaminants.

PRESENT CRITERIA USED BY REGULATORY AGENCIES

The Illinois Environmental Protection Agency (IEPA), which has responsibility for regulation of nonradioactive-waste disposal in Illinois, informally distinguishes classes of landfill sites on the basis of geologic and ground-water conditions. Hazardous wastes may only be accepted at sites that have the strictest requirements. Disposal of wastes is required in trenches having at least 10 feet of geologic materials (all materials deposited by geologic processes below the land surface, such as soil, glacial drift, and bedrock) of very low hydraulic conductivity at the bottom and sides.

The hydraulic conductivity (also referred to as the permeability) of geologic materials is a measure of the ability of the material to transmit water. The IEPA requires an extremely low hydraulic conductivity for Class I and Class II sites and distinguishes between them on this basis: Class I sites require a hydraulic conductivity of 1×10^{-8} cm/sec or less; Class II sites require 5×10^{-8} cm/sec or less. [*Author's comment: There are no standard specifications for making this measurement, although ASTM does have a suggested laboratory method. Laboratory measurement of such low values is difficult; the error in measurement may be quite large, possibly greater than the difference which distinguishes the sites. Field measurement is also difficult, time consuming, and costly.*]

The current IEPA guidelines require, in addition to a permeability barrier at the bottom and sides of trenches, a minimum of 500 feet from the nearest water well. To protect surface water, siting on a floodplain is prohibited, surface runoff must be controlled, and the site must be at least 500 feet from a body of surface water. If a site does not meet these criteria, engineered modifications in accordance with the IEPA guidelines may be implemented to enhance site conditions. Such modifications frequently involve an artificial liner and a leachate collection system.

The United States Environmental Protection Agency (U.S. EPA) recently issued regulations for disposal of hazardous wastes in "Hazardous Waste and Consolidated Permit Regulations." The regulations provide two alternatives for landfill design, either natural geologic containment or artificial containment using engineered features. Conditions in Illinois will not allow natural geologic containment of hazardous wastes in accordance with U.S. EPA for two reasons: the mean annual precipitation in the state is too great; and the water table in geologic materials with low hydraulic conductivity is too shallow. Therefore, the federal regulations require an artificial liner and a leachate collection system for such a facility in Illinois. Natural containment and attenuation of leachates would be preferable to artificial containment in Illinois (explained in section "Consideration of site").

Additional U.S. EPA requirements for all disposal sites include low hydraulic conductivity (1×10^{-7} cm/sec), a minimum of 5 feet between the base of the artificial liner and the water table, and a separation of 500 feet from any functioning public or private water supply. The regulations also prohibit direct contact between the landfill and surface water and location on a wetland, on a floodplain, in a fault zone, or in the recharge zone of a sole-source aquifer.

In Illinois, the IEPA and U.S. EPA criteria for the disposal of hazardous wastes do not apply to the disposal of radioactive wastes. The disposal of radioactive wastes is subject to technical review and licensing by the United States Nuclear Regulatory Commission and the Illinois Department of Nuclear Safety. At present, regulations of these agencies allow landfill disposal of only low-level, solid radioactive wastes (less than 1 curie per cubic foot); landfill disposal of liquid radioactive wastes is not permitted. Disposal sites are evaluated on a site-by-site basis using hydrogeologic principles. To date only one site (Sheffield) has been licensed for landfill disposal of radioactive wastes; this site is now closed with permanent decommission being planned.

Regulations covering hazardous-waste disposal in other states also commonly stipulate specific requirements with regard to depth to the water table, natural recharge areas, location on floodplains, hydraulic conductivity of surrounding materials, engineered modifications such as liners and leachate collectors, and proximity to public or private water supplies. As discussed later in this report, some of the stipulated requirements are subjective or are based upon common misconceptions rather than on scientific principles. Present disposal regulations assume that long-term total isolation of hazardous wastes from the environment is possible through disposal of these wastes in "secure chemical waste landfills" that have liners of very low hydraulic conductivity. In reality, very long periods of isolation cannot be achieved because some leachate from the wastes buried in the ground will migrate to some extent. The assumption of complete isolation by this disposal practice is especially inappropriate for highly toxic nondegradable wastes.

PERFORMANCE STANDARDS FOR DISPOSAL

The objective of regulations governing the disposal of all wastes, including hazardous wastes, is the protection of human health and surface- and groundwater resources. Regulations with rigid specifications of geologic and hydrologic criteria for sites, such as to specify a minimum distance above the water table, are conceptually incorrect and cannot be applied to the entire United States, or even to an entire state in most cases. Strict application of some criteria, such as the depth to water table, can actually lead to the selection of less suitable sites. Rather, regulations should provide performance standards that the disposal site must meet to be acceptable and should be applied on a site-by-site basis. In the evaluation of a site, it is the possible effect upon the environment that must be considered. The specific character of the wastes, the geologic materials at the proposed site, and the interaction between the two, must be carefully examined.

A performance standard should stipulate the maximum effects that disposal can have on surrounding land uses. For example, a standard should be written to limit the amount (volume and concentration) of contaminant allowed to be discharged and should specify the water quality criteria related to a specific water use and/or the degree to which ambient water quality can be altered. The performance standard can be a general statement specifying drinking water standards or designating specific ion concentrations, or a combination of both. The standard should clearly specify where the criteria for water quality are to be applied, such as the property line or nearest aquifer or body of surface water. If a mixing zone (as in the case of point source discharges into surface water) is acceptable, then the performance standard should specify the size of that zone. These specifications must be realistic. "Zero discharge" measured at the boundary of the disposal area would not be realistic.

Performance standards would be an alternative approach to the use of liners and the "total" containment approach; they would permit the selection of disposal sites that would provide for attenuation of the toxic constituents from the leachate by interaction with geologic materials at the site. The sites must be carefully designed and engineered to minimize differential compaction which may occur; trench covers must be constructed to control infiltration so that it is equal to or less than the possible migration rate from the site. This approach requires a thorough understanding of both unsaturated and saturated ground-water flow by those involved with both the design and the review of sites. Advantages of this approach include the prevention of the "bathtub" effect (see section on site hydrogeology) and the shortening of the required monitoring time because the waste of the landfill may leach and compact (stabilize) at a faster rate. Landfills designed to meet performance standards should take into account six factors: (1) the type of waste to be disposed; (2) the site hydrogeology that governs the direction and rate of contaminant travel; (3) the attenuation of contaminants by geochemical interactions with the geologic materials; (4) the release rate of unattenuated pollutants to surface or ground water; (5) character of the receiving waters; and (6) construction problems which may be encountered.

CONSIDERATION OF TYPES OF WASTES

Regulatory agencies commonly classify wastes as hazardous and nonhazardous, a categorization that is not easily made and often must be arbitrary. Mixed wastes, such as building debris and general municipal refuse, may contain some hazardous materials. The hazardous wastes in building debris may present a problem because current regulations regarding the disposal of building debris are lenient. The hazardous materials that are frequently present in general municipal refuse pose problems resulting from a lack of knowledge of either the composition or volume. Also, general municipal refuse is a mixture of different types of wastes that may promote reactions that may either enhance or reduce the mobility of certain toxic constituents. Presently, Illinois regulations permit the disposal of industrial wastes and sewage sludges in sanitary landfills constructed to receive general municipal refuse.

Segregation of wastes

We believe that hazardous wastes should be segregated by type where possible; this may be possible to accomplish by designating sites for particular types of waste disposal. Segregation of wastes allows for prediction of attenuation characteristics of the geologic material for geochemically similar waste materials in an aqueous solution. This is a simpler procedure than for mixed wastes, and it also prevents interaction among incompatible wastes. Chemical reactions between some mixed wastes enhance the mobility of certain toxic constituents. For example, the mobility of most heavy metals is directly related to the pH of the solution (generally, the more acid, the more mobile), and organic toxicants such as PCBs, which are nearly immobile in aqueous solution, become highly mobile in organic solvents (such as carbontetrachloride).

In some instances, an immobile ion may complex with a more mobile ion and migrate with it. Presently, the kinds of complex species that can form and their types of mobility are not very well understood for many hazardous wastes.

Degradation of wastes

The nature of degradation of wastes must be considered, i.e., whether by some natural process the waste may change from its present form to some less complex chemical compound and less noxious form. Categorization into degradable and nondegradable wastes is desirable for all types of wastes; it allows the addition of a time factor to geologic and geochemical considerations. The decay/decomposition rate governs the duration of time that the waste must be isolated from the environment; the time can range from a few days to thousands of years. The decay/decomposition process may result from radioactive decay, organic decomposition, or other processes. Wastes that require a long decay/decomposition period (thousands of years) probably should, from a practical hydrogeologic point of view, be considered nondegradable. Obviously this distinction is arbitrary and perhaps should differ from site to site and should depend upon the site characteristics.

Some geologic materials provide both containment time and attenuation of the wastes; however, the by-products of wastes buried in landfills ultimately will return to the environment in some form and concentration.

Toxicity of wastes

Because of the ultimate return of waste by-products from landfills to the environment, consideration of the toxicity of the wastes and the level at which toxicity occurs, i.e., as parts per million, billion, is essential. The toxicity of many wastes is not well known and the assigned values are often arbitrary. In evaluating waste for disposal by landfill, the toxicity of the waste must be related to its decomposition/decay rate. Geologic conditions in Illinois may be unsuitable for landfill disposal of some wastes that have slow decomposition/decay rates and for certain constituents that are extremely toxic. Destructive treatment, deep well disposal, or unique geologic conditions present at sites outside of Illinois may be suitable for landfill disposal of these wastes.

CONSIDERATION OF SITE

Hydrogeology

The objective of existing regulations, which require burial of hazardous wastes in trenches in natural clay materials or with artificial clay liners of very low hydraulic conductivity, is to contain the wastes and thereby protect ground-water resources. This approach is valid; however, it can create problems in humid climates where natural infiltration of water from the surface exceeds the hydraulic conductivity of the surrounding natural material or liner. When this excess infiltration occurs the disposal trench fills with leachate and overflows, a phenomenon known as the "bathtub" effect. These factors may cause the water table (the depth below the land's surface at which geologic materials are saturated with water) to rise into the trench area, even if the original water table was located well below the trench bottom, and eventually to fill the trenches and sometimes to "spill" out the sides as springs. Thus a site that, on the basis of standards designed for ground-water protection, was suitable for disposal of hazardous wastes may become a hazard to surface water if the leachate is not collected and treated. Because most leachate does not percolate through adjacent geologic materials, little or no attenuation takes place.

The "bathtub" effect occurs in part because most wastes have much higher hydraulic conductivities than the natural material into which they are placed; they also have very different unsaturated soil-moisture characteristics. The hydraulic conductivity of some wastes can be reduced by compaction. Municipal landfill wastes are crushed by heavy equipment or are processed and compacted with soils from the site to achieve greater density and lesser hydraulic conductivity. If a similar procedure could be followed with toxic wastes, a higher degree of the performance of the site might be achieved. Many wastes may be too dangerous to handle in this manner and may require different engineering techniques to achieve similar results.

The "bathtub" effect also occurs because more moisture enters the landfill area than would infiltrate under normal undisturbed conditions. Trench covers may be constructed to achieve a desired low hydraulic conductivity and to limit infiltration for the required period of containment or until stabilization of the wastes; however, it is difficult to maintain trench covers in Illinois. The covers must withstand attack by vegetation, weather (freeze/thaw, wet/dry), erosion, and strain caused by consolidation within the trench. Most trench covers are not capable of meeting these attacks without costly, long-term maintenance programs. In addition to designing the cover to allow for expected consolidation, the cover design should utilize hydrogeologic concepts of saturated and unsaturated flow systems. Research is now underway to design and construct a cover that will control and divert infiltration and will not lose its integrity under moderate compaction of the wastes. Properly buried, the system would be unaffected by surface effects and could meet the containment requirements with minimal monitoring and maintenance. The importance of the water table is exaggerated in most regulations. With the goal of protecting ground water, the U.S. EPA (and many states) requires that the base of landfill trenches must be situated a specified distance above the water table; therefore a relatively deep water table is required. However, as pointed out earlier in this report, the water table may rise as a result of disposal operations.

In Illinois, deeper water tables usually occur in coarse-grained deposits having relatively high hydraulic conductivities. These materials may be a potential ground-water resource, and the location of the landfill trench above the water table does not ensure protection for ground water from leachate contamination. Research has shown that infiltration through refuse buried in these materials rapidly moves contaminants down to the water table. Shallow water tables generally occur in fine-grained geologic materials having low hydraulic conductivity; however, water in fine-grained materials is not a ground-water resource, that is, it does not flow readily into wells. In the proper hydrogeologic setting, these fine-grained materials are well suited for the disposal of hazardous wastes because they are more effective than coarse-grained materials in containing and attenuating wastes and isolating them from aquifers.

[*Reviewer's comment: Coarser-textured materials have been shown to be acceptable under certain circumstances. An example is disposal in large, permanent government or private reserves where migration of contaminants over moderate distances may be acceptable. Attenuation and dilution, diffusion and dispersion, and limited ion exchange can occur in the controlled area. Other circumstances that may provide significant attenuation before the public could come in contact with the contaminants may also be possible. Such sites may also be practical for wastes with low solubility.*]

Geology

The geologic setting at the disposal site determines whether the leachate will discharge near the trench or flow for great distances through the surrounding geologic materials. Fine-grained materials of low hydraulic conductivity have been found to be more effective in slowing the movement of the leachate and removing contaminants than coarse-grained or fractured materials. Water wells in fine-grained materials are usually unsuccessful because the materials, though saturated, do not transmit water fast enough to supply the pump. Where substantial deposits of these materials are present and water-yielding deposits (aquifers) are absent or isolated, conditions are most suitable for attenuation of wastes by physio-chemical processes. In Illinois, the suitable geologic materials are fine-grained deposits in the glacial drift and the shales of the bedrock. These materials protect aquifers, a primary objective when establishing criteria for disposal facilities.

The geology of the site should be studied only in the detail necessary to provide the information required for the site design and to predict the fate of the waste by-products. For some sites, areal geologic mapping may be sufficient; other sites may require considerable drilling, field and laboratory testing, geophysics, and instrumentation using piezometers, pressure-vacuum lysimeters, and tensiometers and such. Although some drilling will generally be necessary at most hazardous-waste disposal sites, we believe drilling should be held to a reasonable minimum because each boring represents a possible conduit for the waste by-products to follow. (Strict plugging requirements must be outlined in the regulations.) As was mentioned earlier in the discussion of the "bathtub" effect, the hydrology of the site may be altered by disposal trenches. Such consequences should be considered in the proposed site design and operation plan.

Attenuation capacity

Individual constituents in waste leachate may have markedly different mobilities. In addition, geologic materials provide many geochemical mechanisms for the attenuation of waste leachate; however, a mechanism that strongly inhibits the migration of one constituent in a leachate may have little or no effect on the attenuation of other constituents. Although the chemical composition of waste leachates varies widely and the interactions with geologic materials are complicated, the leachates can be considered in terms of their basic constituents. This permits the evaluation of factors affecting attenuation in landfills with regard to their impact on the environment and the effects on public health. It should be recognized that the particular combination of leachate and site is unique, mostly in the magnitude of their interactions and not in the mechanisms involved in the attenuation.

Fine-grained geologic materials are present at the surface over large areas of Illinois and include loess, clayey glacial till, and shale bedrock. The attenuation characteristics of these materials are generally considered favorable for waste disposal. The properties of geologic materials that are considered most important for attenuation are texture (grain size and structure), pore size and distribution, clay composition, and chemical composition. The high clay content and distribution of small pores in fine-grained materials provide a low flux of solutions and gases, large contact area, and long contact time between the earth materials and contaminants. However, there may be some wastes (generally organic) for which a clay-rich environment may not be suitable.

There are several types of clay minerals in the surficial materials of Illinois. The attenuation properties of the dominant types have been discussed specifically in Illinois State Geological Survey Environmental Geology Notes 78 and 79, "Attenuation of Pollutants in Municipal Landfill Leachate by Clay Minerals: Part I - Column Leaching and Field Verification" and "Part 2 - Heavy Metal Adsorption."

The chemical composition of the geologic material includes its soluble, adsorbed, and matrix composition. The surficial materials in Illinois are generally low in soluble species that could contribute to the pollutant load. This condition differs from that of arid regions where, in some instances, the natural salt content of surficial materials is sufficient to degrade the ground water below waste disposal sites. Surficial geologic materials in Illinois contain moderate to high amounts of hydrous oxides and carbonate minerals which, along with clay minerals, provide good adsorption properties for a wide range of chemical species.

Some important geochemical mechanisms that attenuate leachate constituents are exchange processes in which contaminants are selectively removed from the leachate and are replaced by nontoxic constituents from the enclosing geologic materials. Because these are exchange processes, the total concentration of dissolved solids in the leachate does not change greatly. The capacity of the geochemical mechanisms in the geologic materials to renovate leachate is finite and, if exceeded, will allow the leachate to pass with little change. Therefore, the attenuation capacity of the site's geologic materials must be the limiting factor for the volume of wastes to be disposed at a site.

Release rate of unattenuated contaminants

Determining the release rate of unattenuated or poorly attenuated contaminants from fine-grained geologic materials to surface water or ground water (aquifers) is a necessary step in evaluating a waste disposal site. A decision must be made as to which ions must be attenuated totally and which eventually could be released to the environment. A properly designed and operated landfill promotes the dilution of contaminants by severely restricting to an acceptable level the rate of their release into the environment; thus the release rate of specific constituents is slow enough to keep their concentrations in the receiving waters below an acceptable maximum. As stated earlier, landfill disposal may not be suitable for poorly attenuated, slowly degradable or nondegradable wastes that are extremely toxic.

The calculation of the release rate of leachate from the bottom and sides of a landfill and of its flow path presents a complex problem. The use of a high-speed digital computer to predict the rate and path of fluids may be required; however, preliminary estimates of leakage can be made by using Darcy's equation. Even though the present hydrogeologic system can be defined, changes in the hydraulic gradient of the system, caused by the presence of the landfill, must be considered. The leakage calculated for the landfill must then be compared in volume to the receiving waters.

The rate of contaminant travel is determined by the time required for a contaminant leached from the wastes to arrive at some point away from the source. The exact rate of contaminant travel considering both dispersion and attenuation is very difficult to predict. However, the rate of water movement provides an estimate of the rate of contaminant travel, except in cases of extremely slow water movement; the rate may be calculated using a modified form of the Darcy equation. The modified equation takes into account the pore volume and structure of the geologic materials which may increase the rates of travel by a factor from about 5 more than 100 times greater than rates calculated by use of the unmodified Darcy equation. The attenuation characteristics of the geologic materials will retard this rate for a specific contaminant by an amount related to its retardation factor.

Geochemical mechanisms that attenuate waste by-products as they migrate through fine-grained geologic materials have been discussed earlier. Recent research has determined retardation factors for certain waste constituents by certain geologic materials; however, there is insufficient information on the attenuation of many waste constituents. If the composition of the leachate is known, an approximation of the retardation factor can be made in the laboratory. The distribution coefficient or the less complicated retardation factor are measured for the samples of geologic materials from the disposal site and leachate from the waste. The values measured in the laboratory for both factors, in practice, present some difficulty because they are not constant but vary as the concentration of waste by-products changes in the leachate; nevertheless, these factors do provide data upon which a sound judgment can be made. However, the composition of the leachate is rarely known prior to burial. (Research efforts are in progress to provide methods of predicting the leachate composition.) Although laboratory measurements are preferred, an adequate approximation of the retardation factor for the by-products of some wastes can be calculated from known general relationships and principles. More research will be necessary before the mechanisms of attenuation can be well understood and the attenuation characteristics for various contaminants by most geologic materials are known; however, present knowledge is sufficient to implement this approach in the disposal of hazardous wastes.

COMMENTARY

In recent years the trend has been from numerous, widely dispersed, small disposal sites to fewer and larger sites. This strategy should be used with extreme caution, especially since both large and small sites are judged by the same design standards. We believe that the use of performance standards rather than design standards is essential under these circumstances. The attenuation capacity of any geologic material has a limit which, if exceeded by the volume of leachate that enters the material, will allow contaminants to pass almost unretarded. Unfortunately, there are insufficient data on the attenuation capacities of geologic materials for most leachate constituents to clearly define this limit. Larger landfills are more likely than smaller sites to exceed this limit; therefore, the smaller, more widely dispersed sites may provide less environmental danger.

For slowly degradable or nondegradable wastes, we view the trend to engineered sites with leachate collection systems as a temporary measure because the leachate collected will have to be redisposed of at a final disposal site, perhaps at great expense. Such engineered sites may be suitable for the disposal of degradable wastes where isolation of wastes from the environment is not necessary for long periods of time. Engineered sites may reduce the volume of wastes that need to be transferred for final disposal; such a site may be appropriate in densely populated regions (although it is becoming difficult to gain acceptance of disposal sites in urban and suburban settings). The leachate collected from these sites eventually presents a disposal problem. Destructive treatment may be difficult and processing the leachate in a standard waste treatment plant may only dilute hazardous substances, possibly causing the sludge from the treatment plant to become hazardous.

This discussion has considered hazardous waste in general. Radioactive materials, mentioned several times in the report, represent a special type of hazardous waste that is often given special consideration. In our opinion, such special consideration is not necessary; the discussion in this report also applies to low-level radioactive-waste disposal.

An adequate monitoring system is essential to the operation of a hazardous waste disposal site. The monitoring system should test the extent to which the operation of the site meets performance standards of the site design. Also, the monitoring system should provide sufficient warning of potential pollution problems to institute the prescribed remedial measures that should accompany all designs. These measures should be specified in the site design as a contingency plan to ensure against environmental degradation in the event that operation of the disposal site fails to meet performance standards.

U.S. EPA and IEPA regulations prohibit the burial of wastes in floodplains of rivers; however, these regulations do not recognize that often the floodplain does not occupy the entire river valley. The floodplain should be defined as the portion of the river valley that will become inundated by a flood of a certain frequency. In Illinois, where river valleys are commonly underlain by shallow, high-capacity aquifers, geologic conditions are generally not suited for the disposal of hazardous wastes. Sites that are located in the valley well out of the reach of erosion by flood waters and are not underlain by coarse sands and gravels may be suited under some circumstances for the disposal of certain types of hazardous wastes. These sites should be underlain by geologic materials that have adequate attenuation capacity and permit the release of contaminants to the environment at an acceptable rate. The migration of contaminants from disposal sites in this hydrogeologic setting will follow short, well-defined flow paths and consequently there will be a limited area of contamination that may be relatively easy to monitor. At these sites the slow release of poorly attenuated or unattenuated contaminants to the environment where there is a high volume of receiving water will provide very high dilution rates. The proper operation of a waste disposal site in this setting is very similar in concept to the current operation of sanitary waste treatment plants that discharge directly to surface water.

Deep disposal wells in bedrock were mentioned briefly in this report as a possible method for disposal of some wastes. These disposal wells are drilled into deep-bedrock formations containing saline ground water (greater than 10,000 parts per million of total dissolved solids), and the liquid wastes are pumped into these formations. Engineering aspects for the construction of deep disposal wells are well understood; however, determining the feasibility of deep disposal wells requires careful consideration of the nature and volume of wastes and the geologic and hydrologic conditions of the disposal zone. The necessary geologic considerations include the presence of appropriate permeable and porous geologic formations to receive the wastes and the presence of confining geologic formations having low hydraulic conductivity to prevent contamination of potable ground water by the wastes or by displaced saline formation waters. The wastes must be compatible with the receiving geologic formations and the saline formation water. With thorough site investigations, adequate monitoring, and careful operation, deep-well disposal has the potential to provide excellent isolation from the environment for limited quantities of highly toxic wastes. Proposed disposal wells will have to meet comprehensive underground injection-control regulations (UIC) proposed by U.S. EPA for enactment in the near future.

AREAS WITH WIDESPREAD GEOLOGIC CONDITIONS SUITABLE FOR HAZARDOUS WASTE DISPOSAL

Given the above considerations, we have used the following criteria to delineate areas in Illinois with geologic conditions generally suitable for disposal of hazardous wastes. These areas have a high potential for locating landfill sites that will meet the criteria of the IEPA for disposal of hazardous wastes and that will also meet the application of performance standards as proposed in this report. Only geologic considerations have been applied in this assessment; in the actual selection of sites, social and economic factors must also be evaluated.

(1) Geologic materials:

Surficial materials. There should be a sufficient thickness of suitable surficial geologic materials in which to construct the disposal trenches, provide attenuation capacity for released leachate from the waste, and limit the migration of leachates.

Bedrock. The bedrock beneath the site should be of low permeability to provide additional safeguards.

Aquifers. The site should be isolated from all aquifers that may be used or developed as a source of water.

(2) Surface characteristics:

Floodplains. It is generally inadvisable to locate a hazardous waste disposal site on the floodplain of a river or stream.

Topography. The slope of the land should not allow surface runoff to enter the disposal site; the site should not be located in areas of potential landslide, earth creep, or high rates of erosion.

The accompanying map (fig. 1) is modified for this report from a map prepared in 1969 at the Illinois State Geological Survey to assist in locating potential landfill sites. In the 1969 report, the map was used to indicate areas where geologic conditions may be favorable, locally favorable, and unfavorable for the disposal of general solid refuse. Although considerations at specific sites for the disposal of hazardous wastes may differ from those for general refuse, the regional geologic conditions used to develop the map apply to both.

In the 1969 study, regions where there are known shallow aquifers (at depths of less than 50 feet) were classified as least favorable. Regions classified as favorable include those where 50 feet or more of clayey or silty material having low hydraulic conductivity overlie a known aquifer and those where no extensive, near-surface aquifers are known. The map does not show the potential for pollution at individual sites, nor does it take into account the exact physical character of the surficial material or the bedrock formations in each area. Ground-water flow conditions were considered in only the most general sense.

The modified map shows five areas with widespread geologic conditions considered generally suitable for the disposal of hazardous wastes. Potential for locating suitable sites for hazardous waste disposal is good in these areas. A major consideration in delineating the five areas is the requirement of a substantial thickness of clayey or silty material with low hydraulic conductivity overlying bedrock that is generally not a ground-water source; this limits suitable areas to those underlain by shale bedrock of Pennsylvanian age. There are bedrock valleys cut into Pennsylvanian bedrock that were subsequently filled with water-bearing sand and gravel and then buried by glacial till; regions underlain by such bedrock valleys should generally be considered unsuitable for disposal of hazardous waste. Most of the valleys are not shown on the map. Thus geologic conditions at specific sites located within the five areas may be unsuitable for hazardous waste disposal. Each potential disposal site must be carefully investigated to determine its suitability by complete geologic, hydrogeologic, and hydrologic investigations.

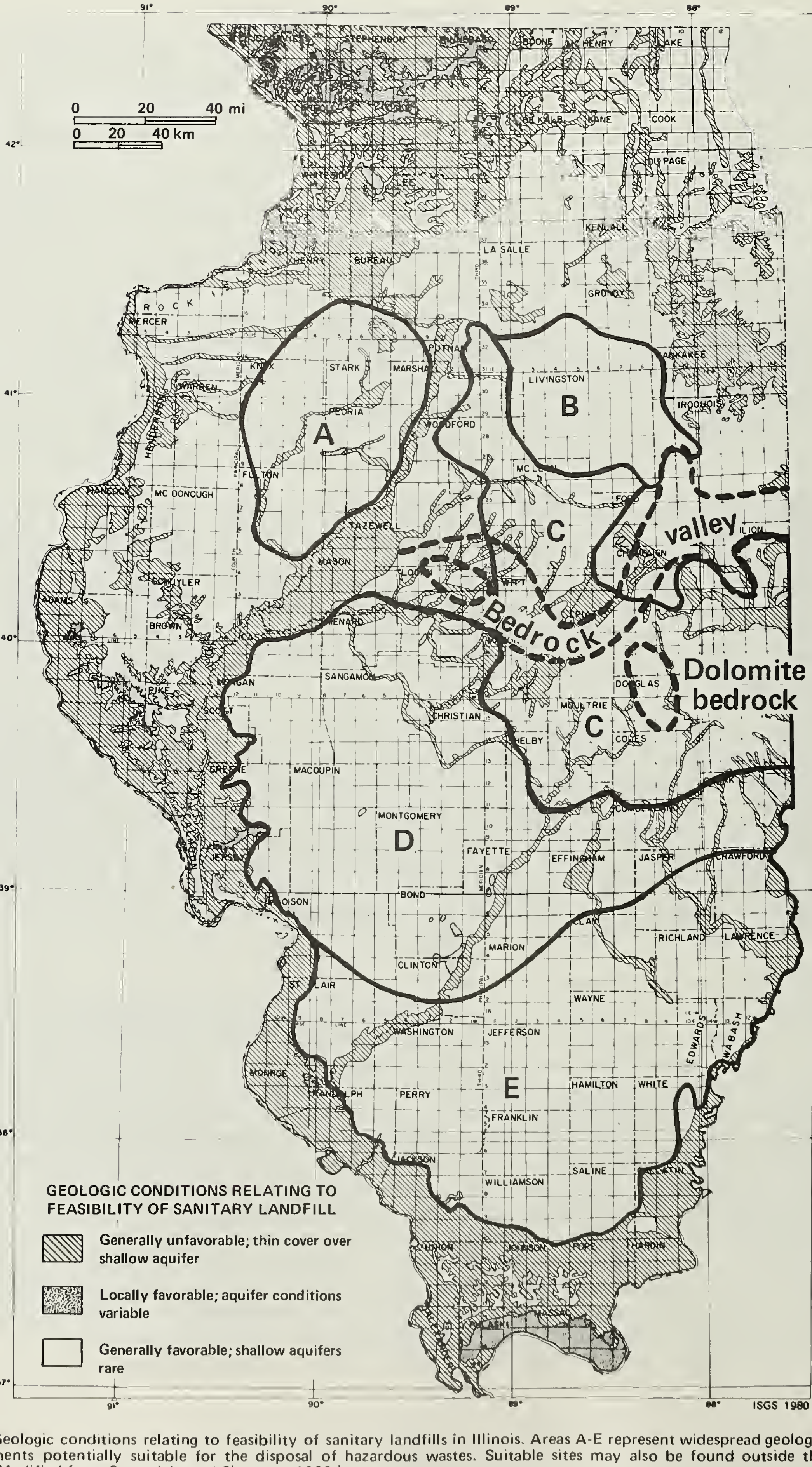
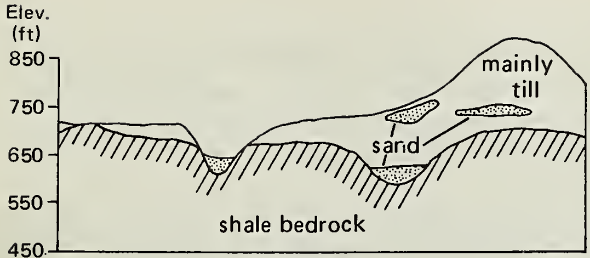
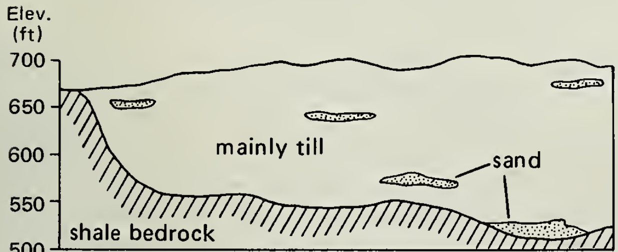


Figure 1. Geologic conditions relating to feasibility of sanitary landfills in Illinois. Areas A-E represent widespread geologic environments potentially suitable for the disposal of hazardous wastes. Suitable sites may also be found outside these areas. (Modified from Cartwright and Sherman, 1969.)



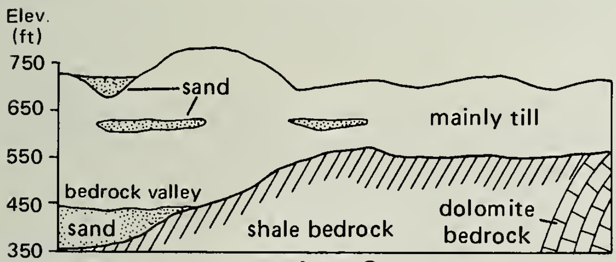
Area A

The glacial drift generally overlies shale bedrock in Area A and ranges in thickness from thin or absent to greater than 150 feet. Suitable thicknesses of fine-grained geologic materials for hazardous-waste disposal are widespread. In most of this area only limited ground-water supplies are available from isolated deposits of sand and gravel in the glacial drift. The shallow bedrock is usually not a ground-water source because it is generally too highly mineralized for most uses. Ground water from very deep bedrock formations is used for some municipal supplies, although it is somewhat undesirable because of mineralization.



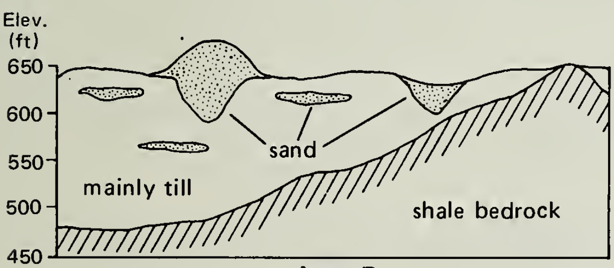
Area B

The glacial drift in Area B varies from 50 to 200 feet thick. Very locally the drift is absent, and underlying shale bedrock crops out at land surface. Suitable thicknesses of fine-grained geologic materials for hazardous-waste disposal are widespread. In most of this area, only limited ground-water supplies are available from isolated deposits of sand and gravel in the glacial drift. Ground water is usually not found in the shallow bedrock, but where found may be mineralized and unsuitable for most uses. Ground water from very deep bedrock formations is used for some municipal supplies, although it is somewhat undesirable because of mineralization.



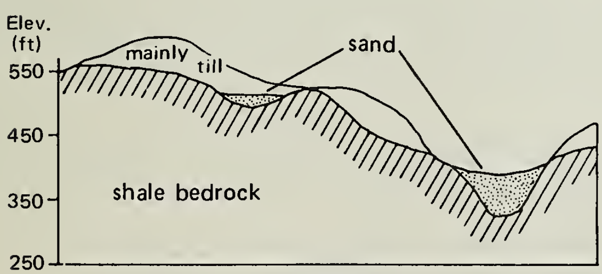
Area C

The glacial drift in Area C ranges from 100 to 300 feet thick and generally overlies shale bedrock; at one locality the bedrock is dolomite that is capable of yielding moderate supplies of ground water. Large supplies of ground water are available in a region of thick deposits of sand and gravel located mainly in a deeply buried bedrock valley filled with glacial debris. Regions that overlie the dolomite bedrock, or the bedrock valley, should be considered unsuitable for disposal of hazardous wastes. Moderate to limited supplies of ground water are available in other localities where scattered sand and gravel deposits occur in the glacial drift, but fine-grained geologic materials with thicknesses suitable for hazardous-waste disposal occur over large portions of the area. The shallow bedrock is usually not a ground-water source. In the northern part of this area, ground water from very deep bedrock formations is used for some municipal supplies, although it is somewhat undesirable because of mineralization.



Area D

The glacial drift in Area D is generally at least 50 feet thick; however, locally the drift is thin or absent and the shale bedrock crops out at the land surface. Shallow, high-capacity aquifers are present in some well known regions in the glacial drift. These regions are not suitable for waste disposal. In most of the area only limited ground-water supplies are available from thin, isolated deposits of sand and gravel in the glacial drift. The bedrock is usually not a ground-water source, although locally water supplies are obtained from shallow bedrock formations. At relatively shallow depths, the ground water that is in the bedrock is too mineralized for most uses.



Area E

The glacial drift in Area E is commonly less than 50 feet thick and overlies shale bedrock. The drift is generally thin, or locally absent; however, fine-grained geologic materials of suitable thickness for hazardous-waste disposal are widespread in the area. Shallow, high-capacity aquifers are present at some well known regions in the glacial drift. Regions underlain by these aquifers are not suitable for waste disposal. In most of the area, only limited ground-water supplies are available from thin, isolated deposits of sand and gravel in the glacial drift. The bedrock is usually not a ground-water source, although locally water supplies are obtained from shallow bedrock formations. At relatively shallow depths, the ground water that is in the bedrock is too mineralized for most uses.

Figure 2. Generalized sequence and description of geologic materials found beneath each area delineated in figure 1.

Geologic conditions suitable for the disposal of hazardous wastes are also present in Illinois at sites outside of the five areas. Waste disposal at many sites located outside these areas has had no known adverse environmental impact.

The five areas shown on figure 1 delineate regions of widespread, relatively uniform, favorable geologic conditions; no ranking of areas is intended. The generalized cross sections in figure 2 present general geologic characteristics for each area.

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