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HYDROGEOLOGIC CONSIDERATIONS IN SOLID WASTE STORAGE IN IOWA

PART I. SANITARY LANDFILL SITE SELECTION

PART II. A METHOD OF HAZARDOUS AND TOXIC WASTE DISPOSAL

BY

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IOWA CITY

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The Honorable Robert D. Ray
Governor of Iowa
Chairman, Geological Board of Iowa

Dear Governor Ray,

Herewith is transmitted a copy of Public Information Circular No. 4 of the Iowa Geological Survey. It is entitled Hydrogeologic Considerations in Solid Waste Storage In Iowa and was written by Donivan L. Gordon, Fred H. Dorheim and me.

We present it to the public of the State of Iowa with the hope that it will provide a better and more scientific basis for understanding the interface between our need to manage the waste products of our society and our desire to maintain a high quality of environment for this and future generations of Iowans.

Respectfully yours,

S. J. Tuthill

Samuel J. Tuthill

SJT:wg

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ACKNOWLEDGEMENTS

During the time that the Iowa State Department of Health was formulating the rules and regulations that were to govern the establishment and operation of solid-waste disposal facilities, the Iowa Geological Survey proposed three fundamental geologic criteria to be considered in selecting sites for such facilities. These criteria were eventually incorporated in the rules, but not before definite limits and modifications were established through discussion and consultation with many engineers, soil scientists, and geologists. The following is a listing of those who took an active part in establishing the geologic criteria as they are now stated in the rules: Iowa State Department of Health; A. Reeve, K. Karch, J. Clemens, J. Charnetski, L. Becker, P. Houser, U.S. Soil Conservation Service; W. Moon, L. Harmon, W. Brune, Iowa State University Department of Civil Engineering; R. Handy, R. Lohnes, J. Hoover, J. Young, M. Dougal, Iowa State University Department of Agronomy; T. Fenton, M. Amemiya, Iowa State University Department of Earth Science; L. Sendlein, R. Palmquist, Iowa Engineering Community; W. Davidson, J. Shive, W. Reed, C. Hall, R. Wallace, P. Pietsch, H. Berry, M. Randolph, D. Fox, M. Thornton, R. Porter, U.S. Geological Survey; W. Steinhilber, K. Wahl.

The writers are indebted to these men for their contributed time and effort. Special acknowledgement is given to Senator Charles O. Laverty for his continuing effort and support in the development of sound environmental protection regulations.

PART I. SANITARY LANDFILL SITE SELECTION

INTRODUCTION

Iowa citizens are concerned about the disposal of solid waste and recognize that this is a complex problem for their public officials, engineers, and others who have responsibility for planning and carrying out a logical and feasible design that will be suitable for the local communities. Few natural environments are available in which solid wastes can be stored without causing some degree of environmental degradation. The problem is to dispose of wastes in such a way as to minimize and localize their degrading influence while at the same time reducing the capacity of solutes or gases from the wastes to lower the quality of air and water.

In regions of low-density population, such as Iowa, a sanitary landfill that is precisely engineered and properly managed appears to be the most satisfactory solution for disposing of solid waste and protecting the environment from air and water pollution. Incineration and recycling, which are alternatives to landfill storage, deserve consideration, but both methods have disadvantages that make them less desirable at the present time for our communities.

Incineration is essentially a volume-reduction technique that requires the expenditure of energy. Moreover, solid waste reduced through this method becomes a potential air and water pollutant and the substances processed are largely unrecoverable for possible reuse. All reclaimable organic materials, for example, are lost to reuse by incineration.

Recycling, which is, of course, the ultimate disposal method, awaits a conviction upon the part of our society as a whole to firmly commit community economic resources and individual energies to its accomplishment. Recycling, like all man's activities, has some environmental impact and must be carefully worked out as to procedures and feasibility. The recycling of paper, for example, has a definite effect on water resources in the vicinity of the recycling plant. To recycle glass and metals demands an expenditure of energy, and in our present technology the extraction and refinement of fuels that produce the energy have an effect on the quality of land, air and water.

Although recycling in all likelihood will be the solution of choice in time, we believe that landfilling as an interim solution is the most practical method in the light of both environmental and basic economic considerations. Experience has shown also that public acceptance and cooperation is good when a landfilling operation is properly designed and managed. We further believe that the materials we now store in landfills will be mined eventually as natural ores and resources become exhausted and therefore more expensive.

Site selection is a question of first importance to the initial and long-range success of any landfilling operation. The wide diversity of types of material that are delivered to waste-disposal sites makes it necessary to regard them as potentially harmful to natural eco-systems and to the physical environment with which these wastes come in contact. A great deal of the waste material is soluble to some degree and, therefore, poses a serious threat to our water resources which must be protected from contamination. In the sections that follow we discuss first the requirements of the Iowa Code with respect to landfill site selection and we then explain the geologic criteria that pertain to these rules. Guidelines are discussed that indicate types of earth and rock conditions in Iowa that would tend to safeguard vital water resources. Where a less favorable site has to be used because of other constraints, suggestions are made that may assist the responsible community agency to make necessary modifications to protect the regional water supplies. In such a situation, making provision in advance to prevent contamination and figuring the cost of such construction in the initial economic evaluation of a proposed site will reduce the ultimate cost to the taxpayers of the community.

SALIENTS OF IOWA CODE 406.5, 1971, PERTAINING TO THE HYDROLOGY AND GEOLOGY OF LANDFILL SITE SELECTION

In 1971, legislation was enacted in Iowa which set forth the regulations governing sanitary landfilling. To establish a base for the development of further discussion of landfill site selection, the following portion of the regulations pertaining to geological parameters is quoted below. The Iowa State Department of Health is the regulatory agency that governs the establishment and management of solid-waste disposal sites and systems.

> 3.1 (4) * A report shall accompany the drawings. It shall include data of the following types:
>
> a A stratigraphic section beneath the proposed site from the surface to and including at least five feet of the uppermost bedrock unit or to a depth of at least fifty feet of penetration into a homogeneous till unit. The lithologies shall be described in terms of grain-size distribution including gravel, sand, silt, and clay classes and Atterburg limits shall be determined.
>
> Samples of sediments and rock units shall be collected at five-foot intervals or when different lithologies are encountered, whichever is most frequent. Samples shall be identified by location and depth. The name of the

* Numerical notations refer to Title XXV, Sanitary Disposal Projects, Iowa State Department of Health Regulations, 1971.

person classifying the sediments shall be indicated. One complete set of unaltered sack samples shall be submitted with the application.

A drilling location plan and drilling log shall be submitted for each series of samples.

c Area of site in acres.

f [The report shall demonstrate that the site is:]

(1) So situated as to obviate any significant, predictable lateral leakage of leachates from the landfill to shallow unconsolidated aquifers that are in actual use or are deemed to be of potential use as a local water resource.

(2) So situated that the base of the proposed landfill is at least five feet above the high water-table.

(3) Not in significant hydrologic subsurface or surface connection with standing or flowing surface-water.

(4) Not situated in an unconsolidated sequence that will permit more than 0.04 cubic foot of liquid per day per square foot of area downward leakage into a subcropping bedrock or alluvial aquifer if such an aquifer is present beneath or adjacent to the proposed site. The potential downward leakage will be evaluated by means of the generalized Darcy's Law: $Q = PIA$ where:

Q = feet^3 of liquid/day/foot^2 of area of the interface,

P = coefficient of permeability of the unconsolidated confining unit,

I = the hydrologic gradient derived by the function: piezometric head in the unconsolidated sediments minus the piezometric head in the bedrock aquifer divided by the thickness of the confining unit of lowest permeability nominated to retard downward migration of liquids or derived by other acceptable engineering practices, and

A = one square foot of area at the base of the landfill.

(5) Outside a floodplain or shoreland, unless proper engineering and sealing of the site will render it acceptable and prior approval of the Iowa Natural Resources Council and, where necessary, the U. S. Corps of Engineers is obtained.

(6) At least one thousand feet from any existing well that draws water for human or livestock consumption from an aquifer that underlies and is in hydrologic connection with the landfill. This is meant to include any bedrock aquifer that is the uppermost subcropping bedrock unit beneath the unconsolidated sequence in which the landfill is to be developed.

(7) At least one mile from a municipal well or a municipal water intake from a body of static water or one mile upstream or one thousand feet downstream from a riverine intake, unless hydrologic conditions are such that a greater distance is required or a lesser distance can be permitted without an adverse effect on the water supply.

g Should conditions in violations of subparagraphs 3.1 (4) f (1), (2), (3), (4), or (5) exist, the original plan must be engineered to effect equal protection to the water resources.

HYDROGEOLOGIC CRITERIA FOR LANDFILL DEVELOPMENT

Realizing the higher pollution potential of the liquid fractions or leachates that derive from solid waste and being concerned for the protection of our water resources, the Iowa Geological Survey has advanced several geologic criteria for consideration in the selection of sites for sanitary landfilling. These criteria, designed to protect water resources in three geological contexts, have been incorporated in the regulations concerning sanitary landfilling, as quoted in the previous section. These three water resource types are as follows:

1. The water in streams, lakes, and ponds; that is, surfacewater or surface runoff.

2. The water in shallow (near surface) unconsolidated sediments; i.e., groundwater.

3. The water in the various bedrock units. (A water-bearing body of unconsolidated sediments or bedrock is called an aquifer.)

In the subsequent discussion the rationales for the geologic criteria are paired with the water resources they are intended to protect.

Criterion 1. That there be no significant topographic or hydrologic connection between the landfill and surfacewater (see Rule 3.1 (4) f (3). The direct mixing of leachates from a landfill with surfacewater must be prevented. There is little doubt that leachates will find their way eventually into all the water resources that exist in the immediate region, but the attenuation or dilution of leachate flow, especially in the zone of oxidation, is essential for a well managed landfill operation. The processes of chemical stabilization along with absorption (in sediments having a significant capacity to exchange ions) and dilution become more effective with the lengthening of the time of travel of leachates in an unsaturated zone of earth materials and/or in the upper oxygenated portion of the zone of saturation below a local water-table. In our opinion, a landfill developed in loess on the flank of an inter-fluve or upland best satisfies this condition (see figure 1). Research in Illinois (Hughes and others, 1969) plus the mineralogical nature of most loess prompts this conclusion. Loess is a moderately permeable sediment that has a relatively high cation exchange capacity. By selecting a site for a landfill in loess at a distance of at least 1,000 feet from surface drainages, the objective of providing a context for leachates that keeps them in the zone of oxidation for the longest possible time of travel will be best satisfied. Placing the site on the

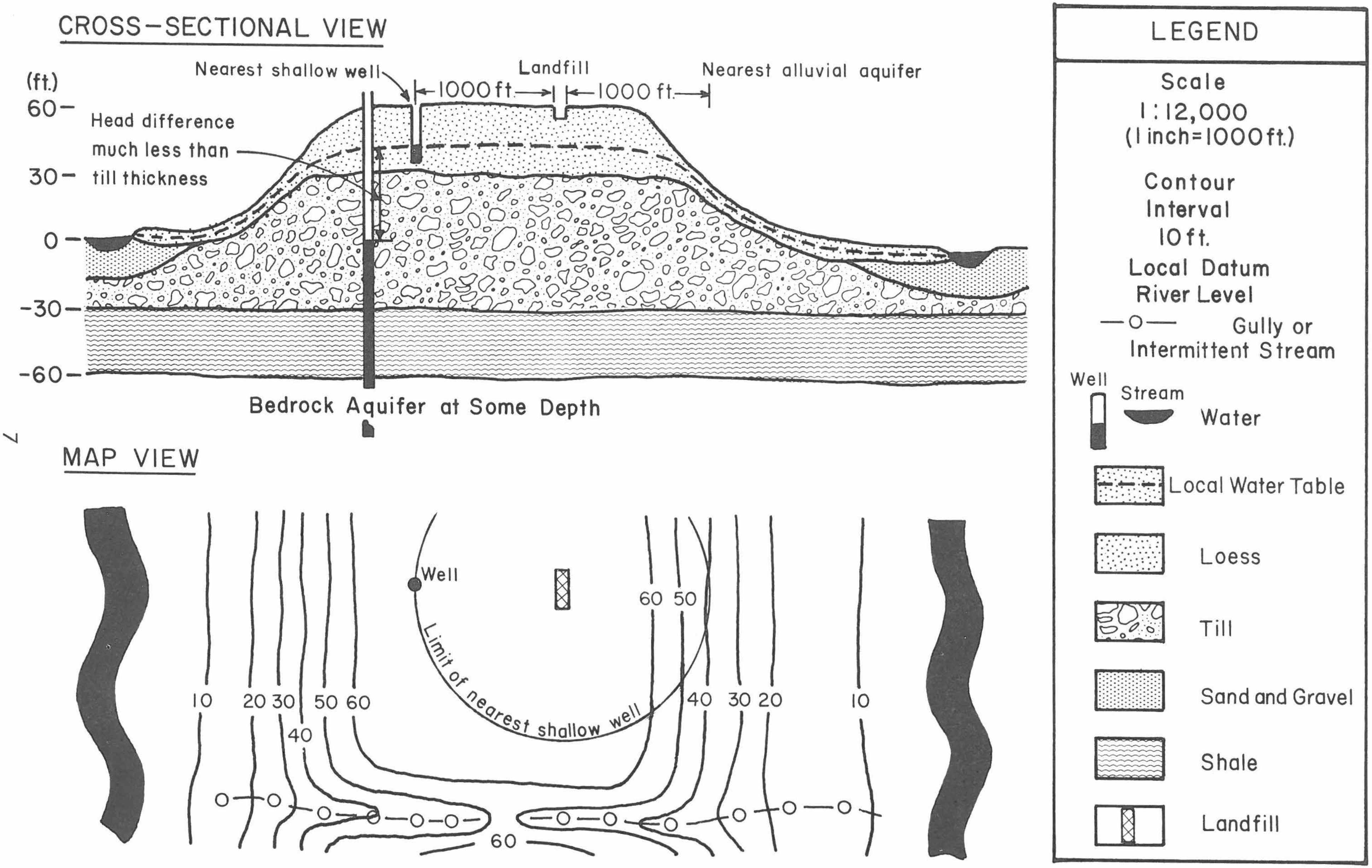


Figure 1. Hypothetical Optimum Geologic Situation for a Landfill in Iowa

flank of a loess-capped interfluve ensures that leachates are least likely to mix with the lower flow system of a perched, water-saturated zone and will influence only a sector of that zone. If a site is located in the center of an interfluve, the leachates have a greater chance to disseminate in a radial configuration.

Locating a landfill near a surfacewater drainage or in coarse grain-sized sediments in close proximity to surfacewater, reduces the time of travel of leachates in the zone of oxidation and increases the likelihood that surfacewater will be polluted. Gullies and abandoned sand and gravel pits are often thought of as desirable sites for landfills because they have few productive uses. They are <u>not</u> good sites because they permit rapid leakage of leachates out of the landfill and are often in hydrologic connection with surface- and/or groundwater resources. If for other compelling reasons such a site must be used, it can be engineered by site development to reduce the hazard of water pollution. For instance, a gully head can be isolated from a surface drainage by trenching and/or diking and the construction of lateral ditches that divert leachates from surface drainage. In a sand and gravel pit, similar techniques could be employed, or the leachates could be directed away from surfacewater by building clay barriers in the downslope region so as to divert the leachates into surrounding sedimentary bodies. It is not our purpose to compile an exhaustive list of the corrective methods available. The imagination and experience of the engineering community can be counted upon to fulfill this need. Corrective measures must of necessity be closely fitted to the conditions that exist at a specific proposed site.

Criterion 2. The base of the landfill should be at least five feet above the watertable (see Rule 3.1 (4) f (1) and (2). Groundwater in contact with organic material quickly becomes deoxygenated and a chemically reducing environment thus results. Many organic and inorganic materials are maintained in an essentially unaltered chemical state when they remain beneath the watertable. Organic material may be preserved in such a situation for several thousand years. As discussed above, oxidation of leachates before they become a part of any significant water resource reduces the pollution hazard they pose.

The position of a watertable is difficult to establish because it fluctuates as a function of the water balance of the region. It is impractical to require the establishment of the data necessary to define in detail the shallow regional groundwater flow system through a significant period of time. But it is this regional flow system that this rule is designed to protect. Inasmuch as applicants (and often their consulting engineers) use the water resources in the region being considered, they can readily recognize the fact that the rules of the Iowa State Department of Health are set up to protect the water supply where they live. Groundwater in the shallow, unconsolidated sediments across the state is a vital resource of Iowa communities, homes and farmsteads, a resource that must not be willfully degraded. This conclusion derives from any set of values, be they economic, logistic, or aesthetic.

Shallow upland aquifers should be regarded as worthy of protection if their areal extent and thickness is sufficient to make them significant as an actual or potential water resource of a region. In western and southern Iowa shallow upland aquifers are frequently of significance because of their greater thickness and areal extent, as compared to those of eastern Iowa, and because of the lack of alternative groundwater sources in the west and south. Locally, however, shallow upland aquifers may be topographically isolated and of such small areal extent that they do not constitute a significant water resource. Critical evaluation of shallow aquifers in the region of each proposed landfill site will have to be made.

If in siting a landfill this second geologic criterion cannot be met, two kinds of engineering remedies are readily apparent. A proposed site can be artificially dewatered, or it can be constructed to elevate the base of the fill adequately. We believe it will be to the engineer's advantage to acquire the hydrologic data related to a site over the longest possible span of time before designing a remedial plan. These data will permit the development of a plan that is attuned to the natural fluctuations of the watertable and will obviate the need to operate continuously for maximum stress conditions. A dewatering program, for instance, can be modified to match seasonal fluctuations, if these fluctuations are known.

Criterion 3. If the unconsolidated sediments in which a landfill is to be developed are underlain by an uppermost subcropping bedrock aquifer, the site must naturally or by artificial means be made to inhibit downward percolation of liquids to a maximum percolation of 0.04 $ft^3/day/ft^2$ (see Rule 3.1 (4) f (4). The generalized Darcy's law is to be employed to evaluate this flow rate.

The protection of bedrock aquifers is a matter of very great concern and the design of a plan to effect their protection is by no means a simple problem. Where a site can be found that has a sufficient thickness of material of low permeability between an underlying bedrock aquifer and the base of the landfill, the best and the least expensive operation becomes possible. The relationship that actually controls the amount of fluids that will enter a bedrock aquifer is the ratio of the difference in hydrostatic head between the bedrock aquifer and the surficial watertable to the thickness of the low permeability unit of sediments (the confining unit). Figure 2 shows the shape of the curve for Darcy's law when only the ratio of thickness of confining unit to difference in hydrostatic head is allowed to vary. When the head difference gets higher than the thickness of the confining unit, the amount of fluid that can pass into the bedrock aquifer increases very rapidly. However, when the one-to-one ratio is greatly exceeded, the reduction in amount of fluid passing downward is changed very little as can be seen in the flattening of the curve.

No earth material is truly impermeable; however, fine grain-sized sediments under normal hydrostatic pressures have low enough permeabilities so that they are not <u>significantly</u> permeable. In Linn County it has been demonstrated (Hansen, 1970) that recharge of bedrock aquifers occurs at a very slow rate [(.00028 $ft^3/day/ft^2$) through 90 feet of till, a sediment type characterized by a lack of sorting and a clay grain-sized matrix (median diameter of 1/256 mm)]. In general, the rate of flow depends upon the hydraulic gradients through a sedimentary unit of low permeability and the area of the interface between the confining unit and the bedrock aquifer.

The hydrologic relationships alluded to above are summarized for the general case by Darcy's law. If the entire sedimentary sequence is saturated and <u>if permeability is uniform</u> throughout the confining unit, the thickness of low permeability sediment affects the gradient factor in the following manner:

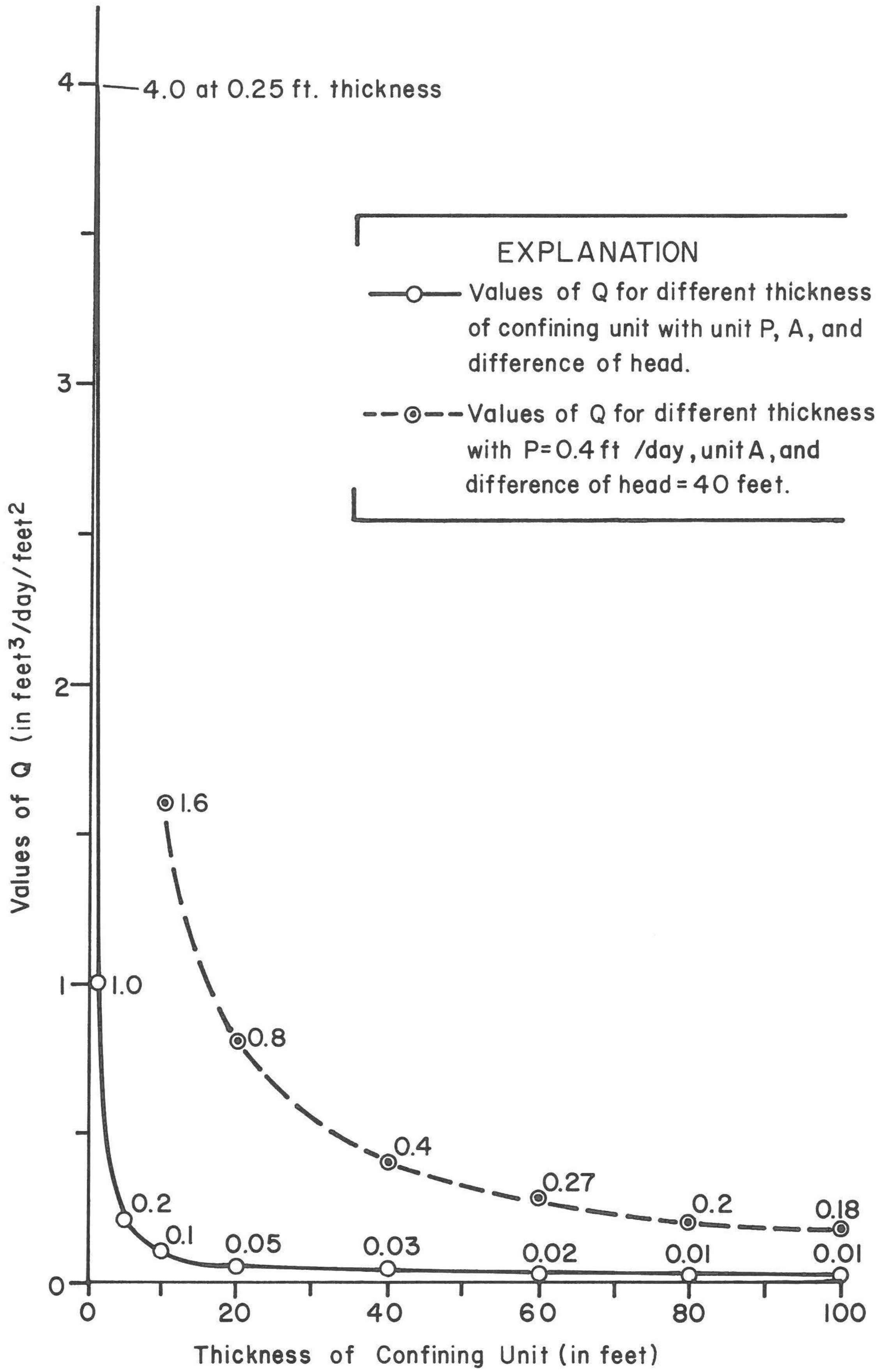


FIGURE 2. Values of Q for different thicknesses of P and A.

$$Q = PIA \text{ (Darcy's law)}$$

Where: Q = the amount of volume of water that passes an interface during some period of time (ft^3/day).

P = the coefficient of permeability (ft/day).

A = the cross-sectional area of the interface (ft^2).

I = the difference in hydrostatic head divided by thickness of confining unit (ft/ft).

Hughes (1969) found that a significant vertical passage of leachates from landfills occurred through 30 feet of low permeability till. Hansen (1970) found that insignificant amounts (for a small area) of water passed through 90 feet of the same general type of sediments. Data from these investigations can be related to the 50-foot requirement specified in Rule 3.1 (4) a of the Iowa Code.

The condition that best protects the water in a bedrock aquifer is one that includes a sedimentary sequence having sediments of moderate permeability and thickness in which the landfill cells are sited over a unit of the lowest possible permeability. This situation offers the best chance that lateral migratory velocities will be significantly higher than vertical velocities. The amount of fluid that migrates vertically for any given ratio between difference in head and thickness of confining unit does not change, but the difference in head is rapidly reduced by lateral flow in sediments of higher permeability near the surface. Thus the length of time that high differences in head persist is reduced and the amount of fluid delivered to the bedrock aquifer is less over a period of time.

If protection of the bedrock aquifer were our only concern, a gravel unit over till would be the best possible location for a landfill, but we must also consider the shallow groundwater and surfacewater resources; thus a surficial sedimentary unit of moderate permeability is preferable to one of high permeability. The thickness of the surficial sedimentary unit of moderate permeability will be a major factor in determining the amount of head that might result above the confining unit. As discussed above, the amount of head difference that develops will be the critical factor in determining the quantity of leachates that will be delivered to the bedrock aquifer. If the moderately permeable material in which the landfill is constructed is thin, the difference in head in a completely saturated sequence of sediments will be minimized. Figure 3 shows the hydrologic effect upon the amount of fluids that will pass the sediment-bedrock interface in two hypothetical examples where thicknesses of the low permeability confining unit are different. Table 1 demonstrates the areal effect of size of landfill and the effect of differences in permeability of confining unit.

ENGINEERING OF SITES THAT DO NOT NATURALLY SATISFY THE REQUIREMENTS

Chapter 3.1 (9) g of Title XXV: Rules Governing Sanitary Disposal Projects states, "Should conditions in violation of subparagraphs 3.1 (4) f (1), (2), (3), (4), or (5) exist, the original plan must be engineered to effect equal protection to water resources."

The significance of this rule is to make it possible for an agency charged with the responsibility of disposing of wastes to draw up a plan that satisfies economic, social, and aesthetic constraints as well as the natural hydrologic and geologic conditions that prevail in the region. If for reasons other than geological ones a site is highly desirable, the agency can modify the plan in order to fulfill the goal of protecting water resources. Proper site development

TABLE 1

Table of Values of Q for Different Values of P and A

Values of P (ft/day)	Values of A	Values of Q	
	ft^2	ft^3/day	gal/day
0.04	10,000	400	2,990
0.04	40,000	1,600	11,970
0.04	250,000	10,000	74,800
0.4	10,000	4,000	29,900
0.4	40,000	16,000	119,680
0.4	250,000	100,000	748,000
4.0	10,000	40,000	299,000
4.0	40,000	160,000	1,196,800
4.0	250,000	1,000,000	7,480,000

P coefficient of permeability
A area (ft^2) of the interface between the confining unit and the subcropping unit
"I" is defined as constant at 50 ft/50 ft

Discussion of Figure 3

By applying Darcy's law to the two examples shown on figure 3, we can determine the amount of fluid that will pass through one square foot of the interface between the confining unit and the bedrock aquifer each day. The difference in head is the same (40 ft.) in both examples. The coefficient of permeability is defined for the confining unit as 0.4 ft/day.

Example A - (thicker confining unit)

$$
\begin{aligned}
Q &= PIA \\
&\quad 0.4 \text{ ft/day} \times 40/50 \times 1 \text{ ft}^2 \\
&\quad 0.3 \text{ ft}^3\text{/day/ft}^2 \text{ (about 2.4 gal/day/ft}^2\text{)}
\end{aligned}
$$

Example B - (thinner confining unit)

$$
\begin{aligned}
Q &= PIA \\
&\quad 0.4 \text{ ft/day} \times 40/10 \times 1 \text{ ft}^2 \\
&\quad 1.6 \text{ ft}^3\text{/day/ft}^2 \text{ (about 11.9 gal/day/ft}^2\text{)}
\end{aligned}
$$

It is obvious that five times the amount of fluid will pass the interface if only a 10-foot confining unit is present as compared to the amount that will pass through a 50-foot confining unit. The close relationship between Q and the ratio of head difference to thickness of confining unit is made clear by an examination of these two examples and figure 2. The very great impact of higher values of A and P is seen in table 1.

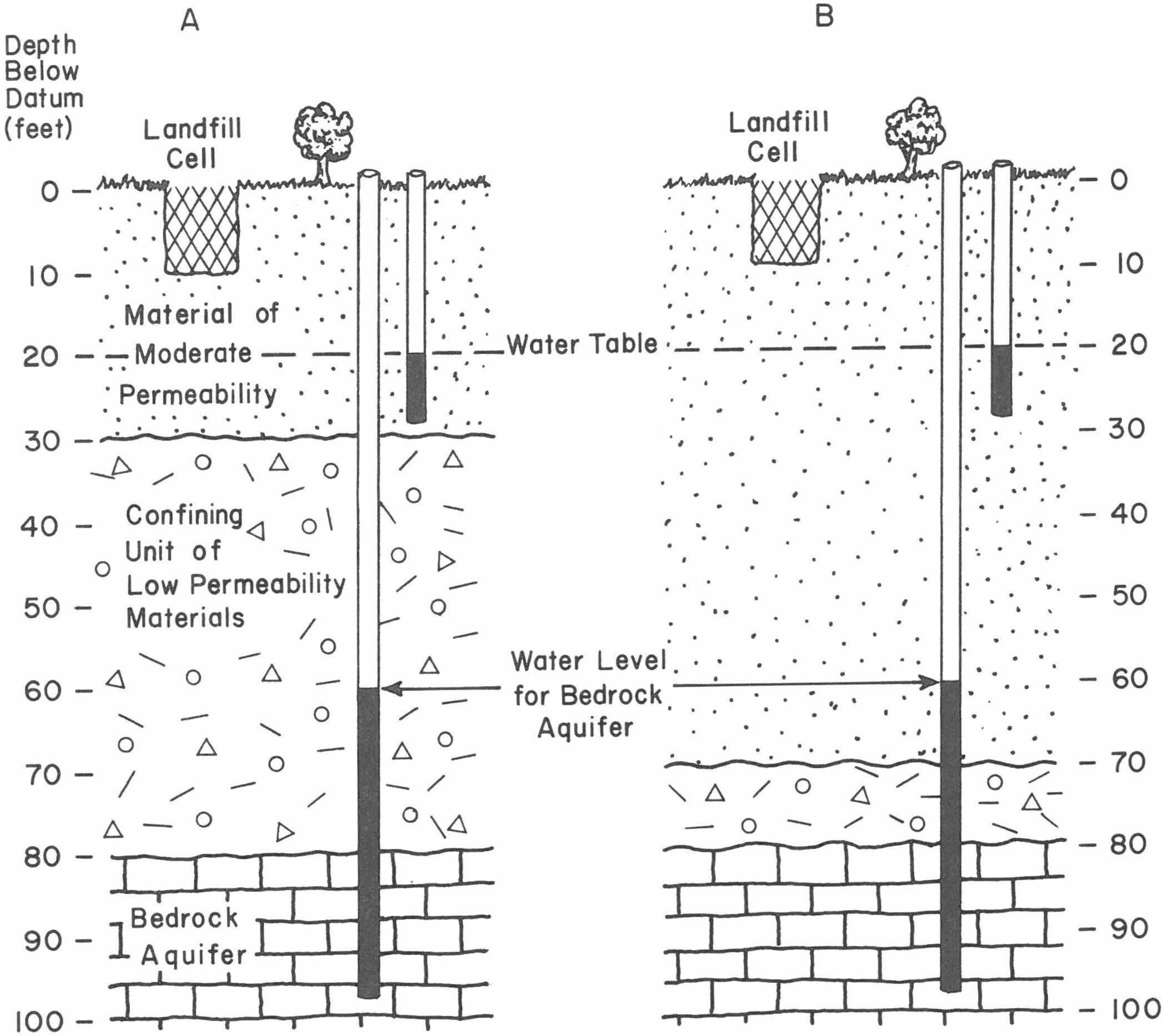


FIGURE 3. Cross-sectional diagrams showing the effect of different thicknesses of confining unit.

and careful management can usually correct the natural deficiencies of a particular location.

There is another result of this rule that will, in the long run, make a great deal of sense to the citizens of a community, who not only have to fund a sanitary waste-disposal site, but will have to live with it long after the last handful of grass seed is scattered on the completed facility. The procedure recommended places the long-term economics of site impact into the planning phase of development. Too often the economic constraints of transporation and primary land acquisition have been the overriding consideration in site selection. The cost of capturing leachates before they contaminate a vital water supply has been an after-the-fact consideration. It should be an element of the initial economic evaluation. If contamination is a potential threat, designing a site to avoid this will reduce the ultimate cost to the taxpayer.

IOWA GROUNDWATER DISTRICTS AND THEIR GEOLOGY AS RELATED TO RULE 3.1 (4) f (4) FOR LANDFILL SITE SELECTION

Three regions of the state can be defined by similarities in their groundwater resources. These are the Eastern Iowa Groundwater District, the Southern Iowa Groundwater District, and the Western Iowa Groundwater District. Figure 4 shows the approximate boundaries of these districts. Figure 5 is a generalized map of the bedrock geology of Iowa indicating zones of varying degrees of hazard for bedrock aquifers with respect to landfill sites. Some overlapping of zones of hazard and the boundaries of the groundwater districts becomes evident when the two map figures are compared. This reflects the natural irregularities of surficial and bedrock geology of the region.

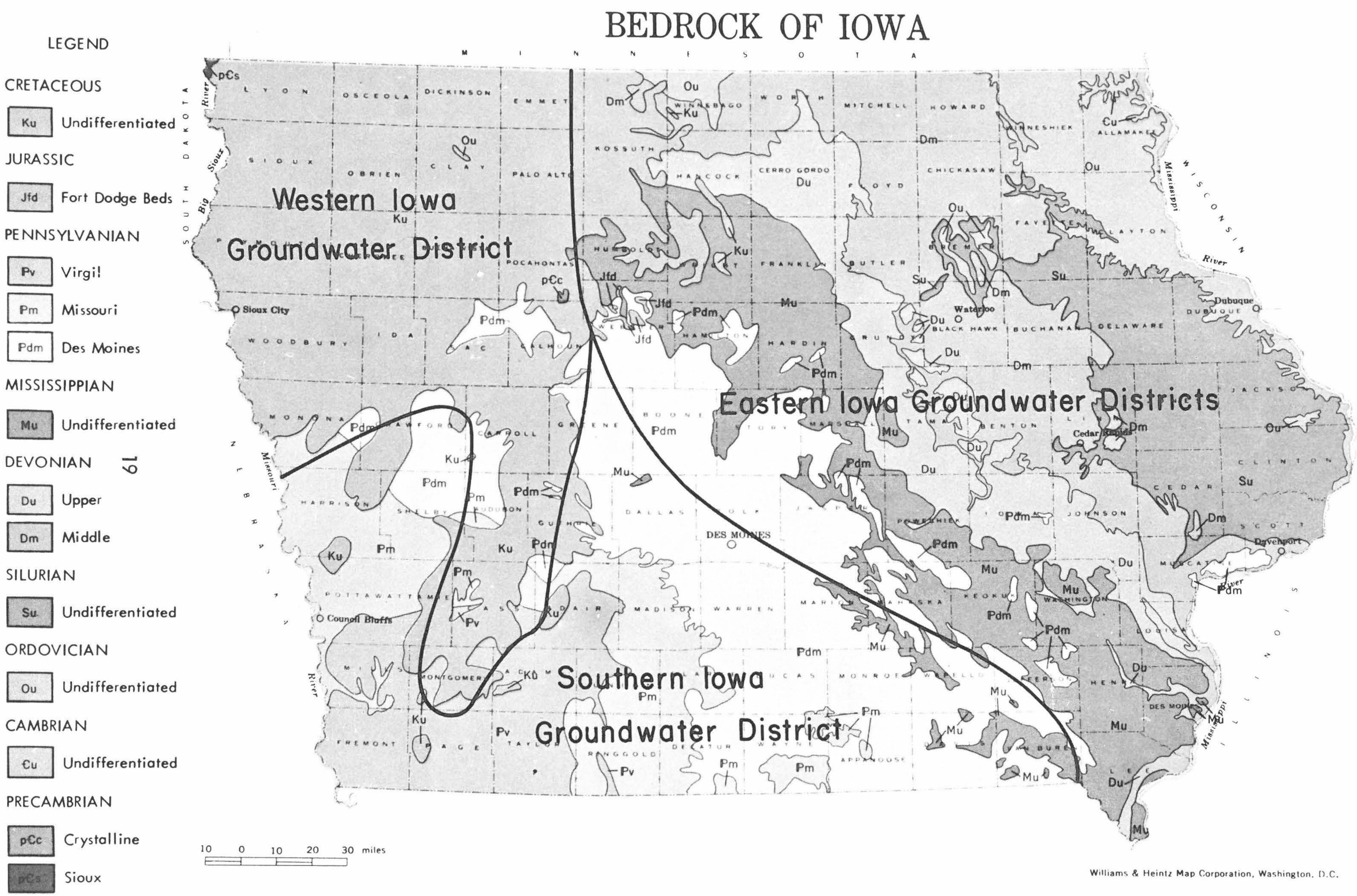


FIGURE 4. Groundwater Districts of Iowa

Figure 5--Map showing generalized bedrock geology of Iowa and zones of hazard for aquifers with respect to landfill site location:

A. High hazard zone--This zone is underlain by uppermost subcropping rock units that are regional aquifers. Caverns and solution zones in the bedrock are common. Fine grain-sized unconsolidated sedimentary units are highly variable in thickness or absent. Complete subsurface site evaluation will be vital.

B. Moderate hazard zone--This zone is underlain by rock units having a variety of lithologies. Local bedrock aquifers exist. Fine grain-sized sedimentary units are usually present. Exploratory subsurface site evaluation will be important.

C. Low hazard zone--This zone is usually underlain by rock units having a shale lithology, but locally some water-bearing sandstone units subcrop under unconsolidated sedimentary units of thick loess and/or till of variable thickness. Locally valuable loess aquifers occur. A regional evaluation of geologic conditions will be required to determine if extensive exploratory subsurface site evaluations are necessary.

D. No hazard zone-- This zone is underlain by fine grain-sized bedrock units. Where groundwater occurs, it is usually of poor quality. In the limestone of the region small amounts of water are produced for home and farm use. Inquiry from Iowa Geological Survey plus an inventory of local wells in at least a two-mile radius of a proposed site may provide enough data to eliminate the need for exploratory subsurface site evaluation.

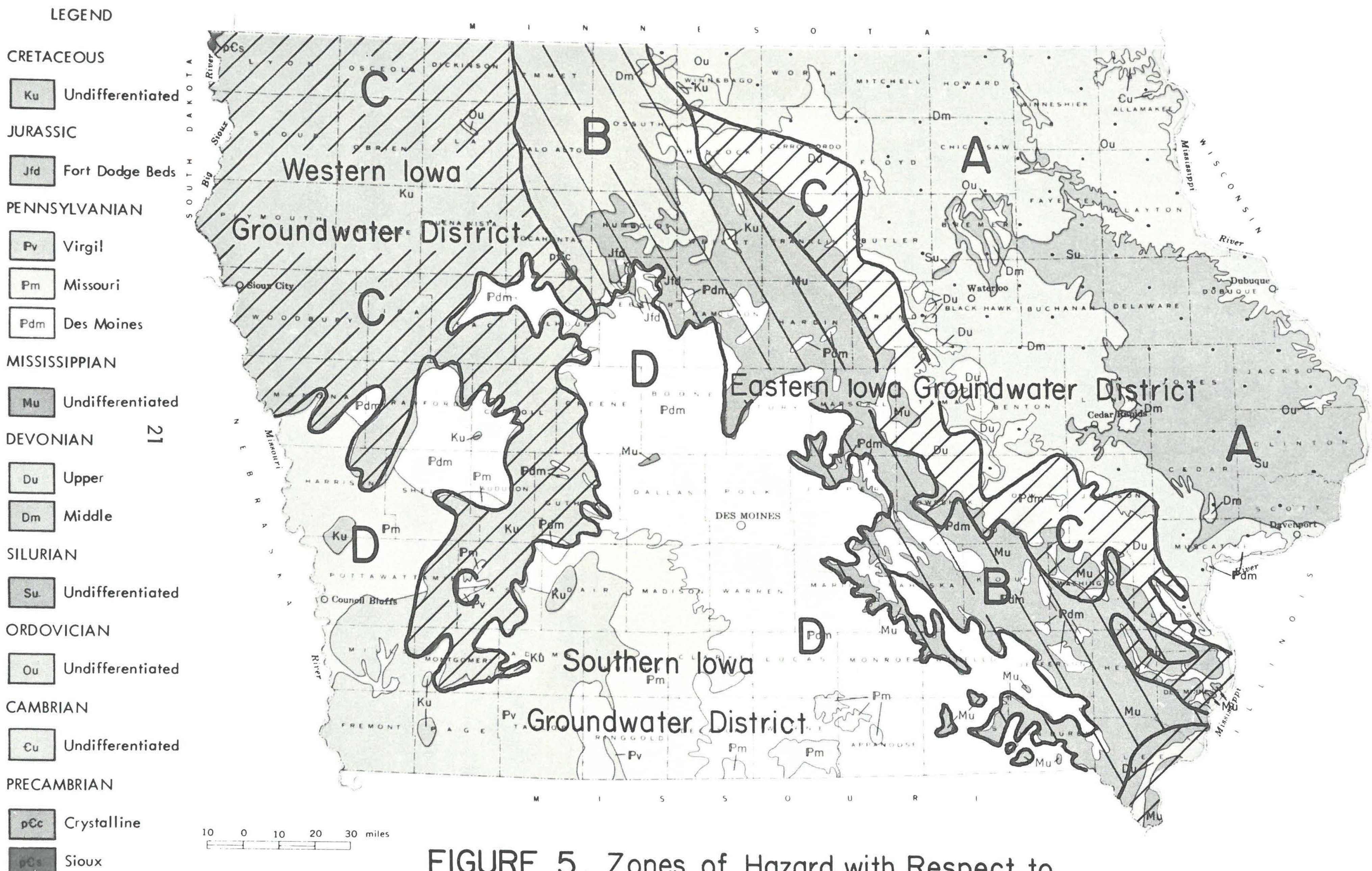


FIGURE 5. Zones of Hazard with Respect to Landfill Site Selection.

The satisfaction of the rules cited above will be more or less difficult in the three districts depending on the nature of the water resources that exist. Each district is discussed below with respect to the types of conditions most likely to be encountered in seeking landfill sites.

Eastern Iowa Groundwater District

This district, comprising roughly the eastern half of the state, is characterized in the eastern two-thirds of its area (Zone A) by the occurrence of fractured and sometimes cavernous limestone and dolostone bedrock aquifers that are the uppermost geologic unit. The rocks of this region are Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian in age (see Appendix I). In Winneshiek, Allamakee, Clayton, northeastern Fayette, and Dubuque Counties the amounts of unconsolidated sediments (loess and glacial drift) are thin-to-absent. Elsewhere in the district drift thickness is highly variable, ranging between 50 and 300 feet in the upland areas. Thicknesses of loess range between 0 and 32 feet, according to Ruhe (1969). Many of the rivers flow directly upon bedrock and have banks developed in glacial drift. Generalized geologic cross sections typifying the relationship between the bedrock aquifers and the overlying unconsolidated materials in Winneshiek, Clayton, Allamakee, and northern Fayette Counties are shown in figures 6 and 7. Similar relationships for much of Dubuque, Delaware, Jones, Jackson, Cedar, Clinton, and Scott Counties are illustrated in figure 8.

All three basic types of water resources (see page 5) are present throughout the district. Because of the relative abundance of good quality bedrock aquifer water and the general thinness of the loess, the shallow upland aquifers are rarely used as a water resource, even for individual family units. The fractured

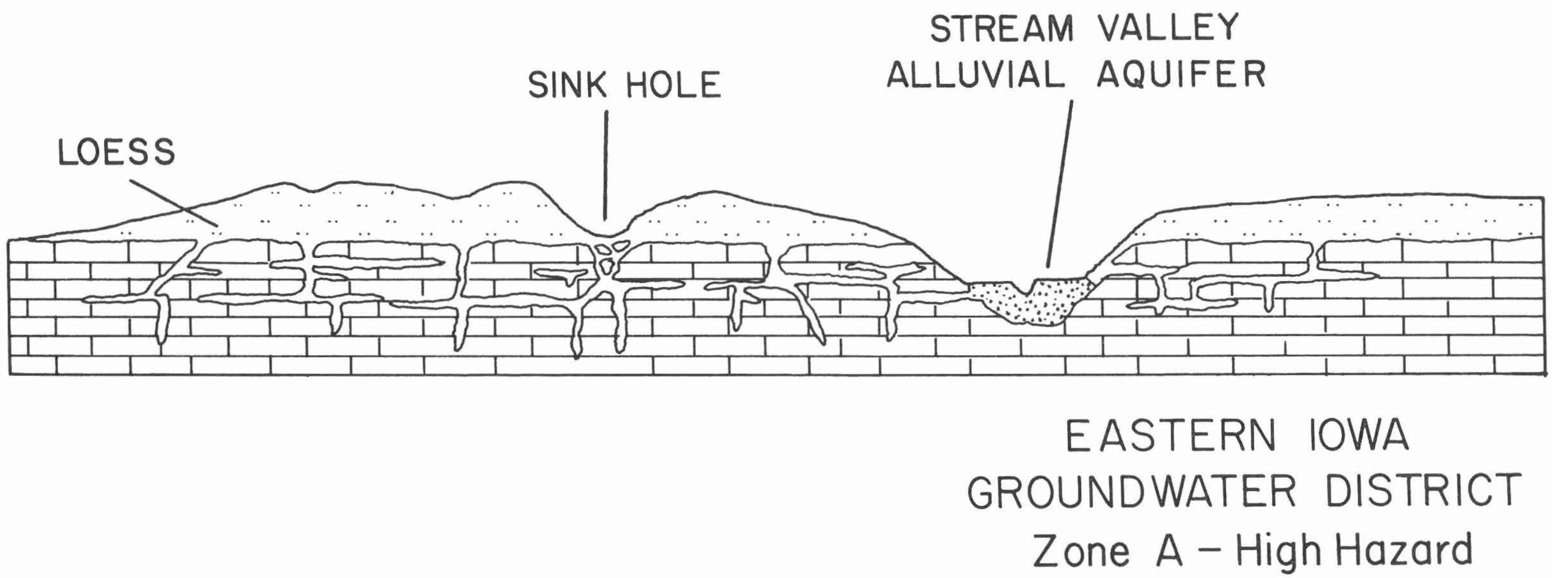


FIGURE 6. Northeast Iowa Loess-Mantled Karst Area.

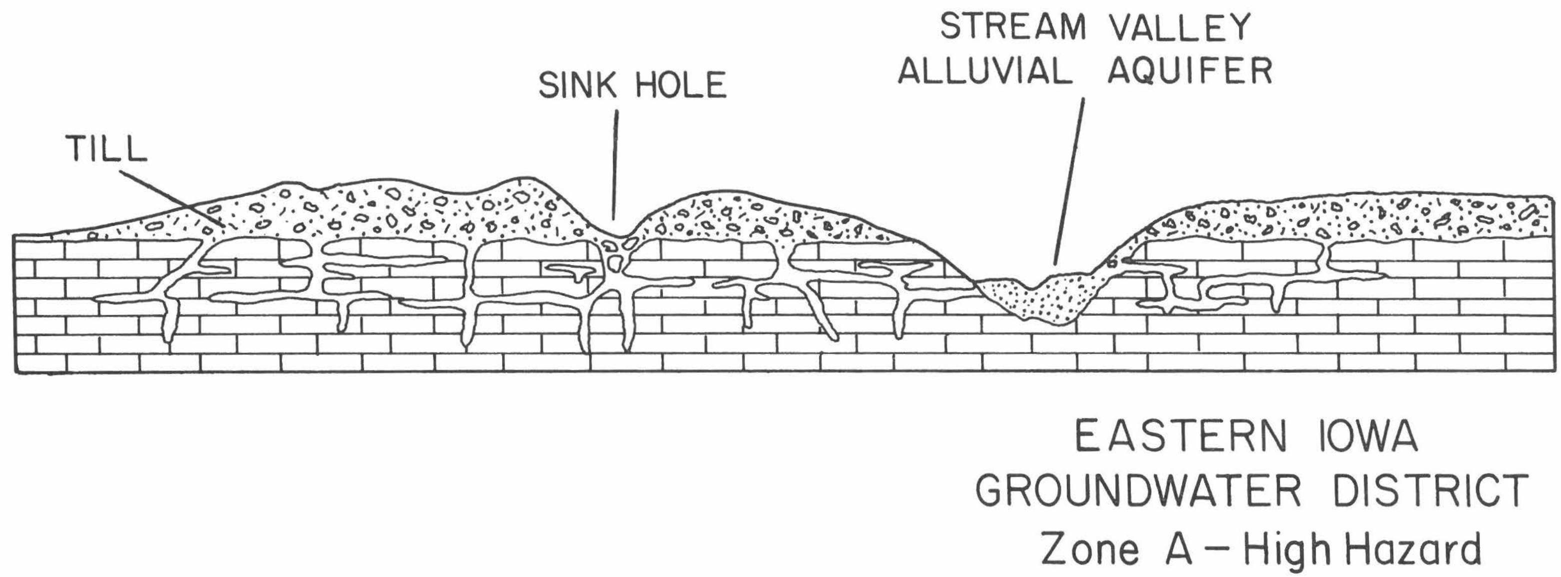


FIGURE 7. Northeast Iowa Drift – Mantled Karst Area.

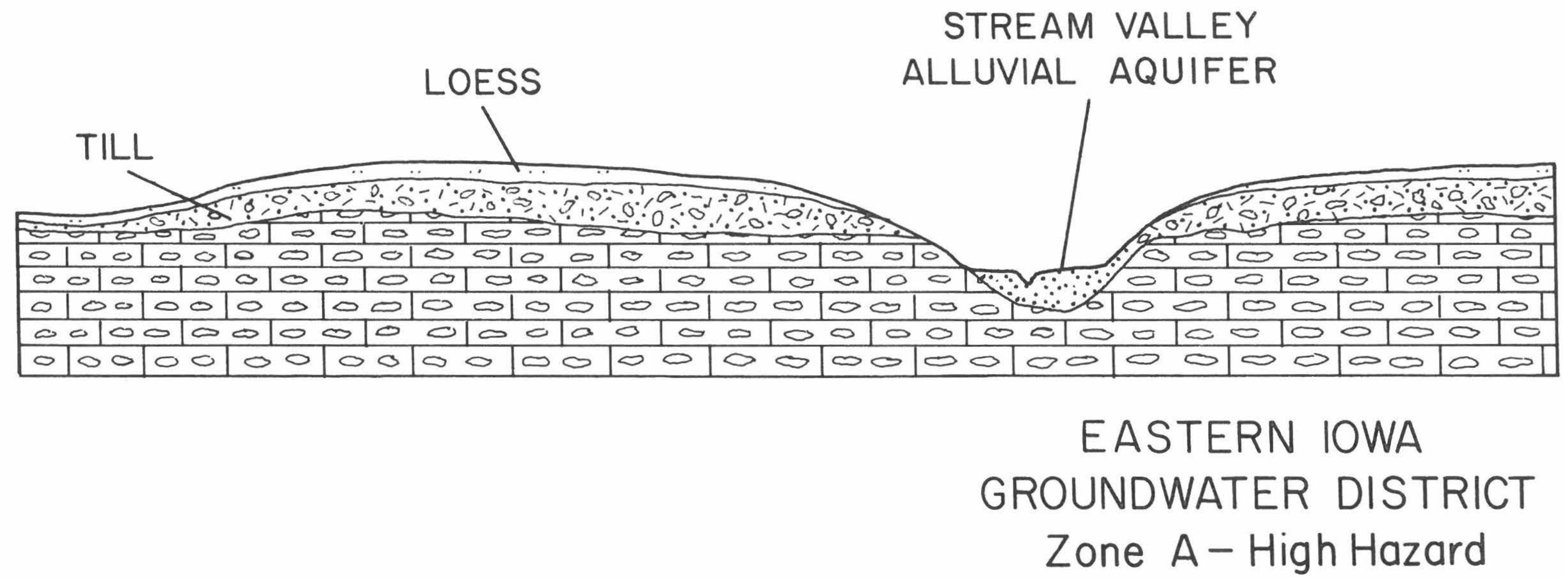


FIGURE 8. East Central Iowa Porous Dolostone Mantled by Thin Loess and Till.

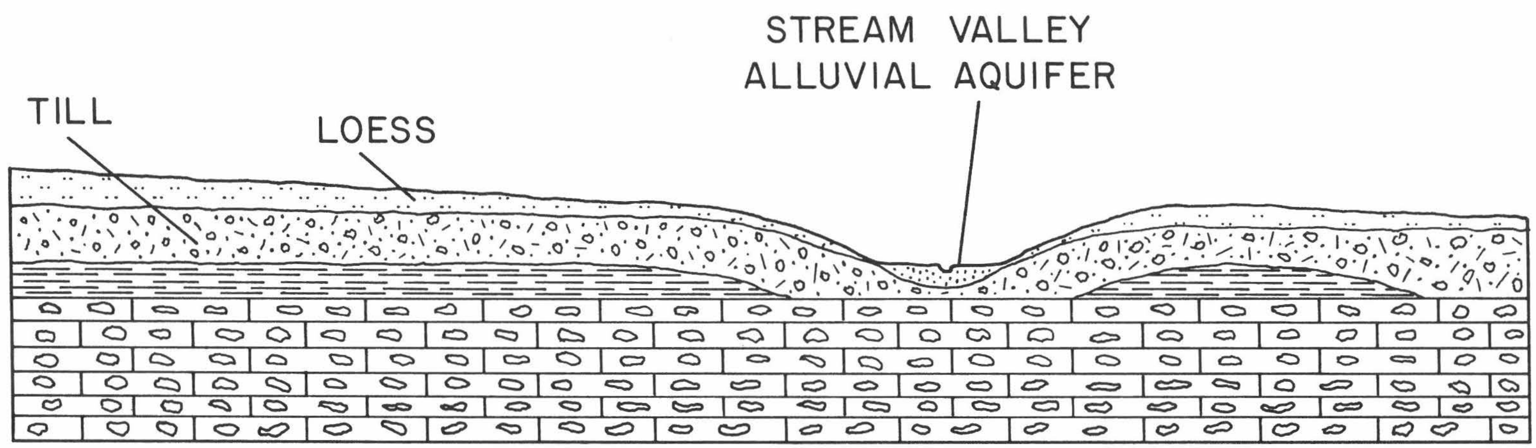
nature of the limestone and dolostone bedrock aquifers, in conjunction with the existence of many rapid-recharge points where drift is thin or absent, causes water from the surface to migrate into the bedrock aquifer at a speed that makes the assimilation of any contaminants into the water of the aquifer readily possible. The use of floodplain areas of thin drift, or land where sinkholes are prevalent for landfill purposes, does present a serious threat to the quality of water in the bedrock aquifer in this district.

Zone A is the region where the third geologic criterion will be most critical in evaluating a proposed site. Rule 3.1 (4) f (1) and (2) (see page 4) are less applicable in this district, because of the great variation in bedrock topography and drift thickness. It is likely that on-site exploratory drilling programs will have to be more comprehensive in Zone A than elsewhere in the state.

Zone B is underlain by bedrock units that in some places are aquifers and elsewhere are aquicludes. This relationship is demonstrated by the generalized geologic cross section in figure 9. Careful exploration of sites will be required, but such exploration, if it demonstrates clearly the nature of the bedrock beneath the site, may lead to overall economic benefits for the project. If an acquiclude exists, additional exploration to satisfy Rule 3.4 f (4) (see page 4) may not be necessary.

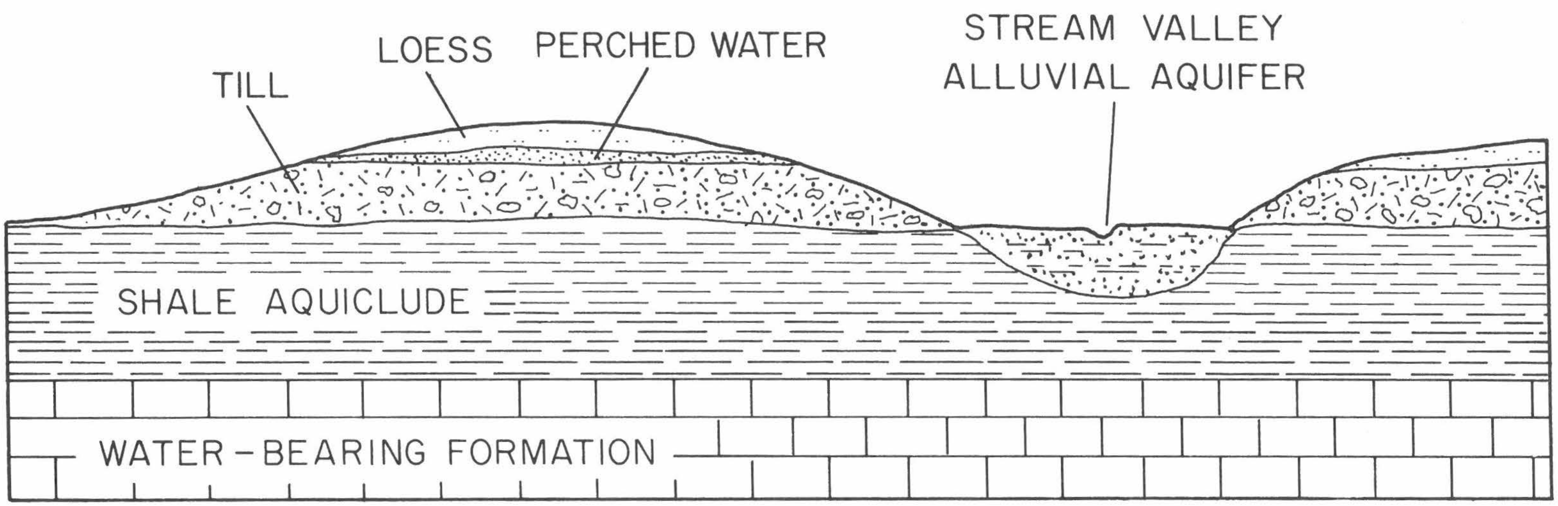
Zone C in the Eastern Iowa Groundwater District is a region underlain by aquicludes, as diagrammed in a generalized geologic cross section in figure 10. Little emphasis on Rule 3.1 (4) f (4) (see page 4) will be required.

Zone D is essentially without hazard to bedrock aquifers. However, sites proposed in these regions should be checked with the Iowa Geological Survey



EASTERN IOWA
GROUNDWATER DISTRICT
Zone B– Moderate Hazard

FIGURE 9. Central Iowa Porous Limestone or Dolomite Mantled by Shale, Till, and Loess.



EASTERN IOWA
GROUNDWATER DISTRICT
Zone C, Low Hazard

FIGURE 10. Central Iowa Drift Mantled Shale Terrane

before site exploration is commenced. Water-bearing channel sands in the Pennsylvanian-age rocks occur, especially in the western portion of this district, and their location and use are rather well known.

Southern Iowa Groundwater District

Most of this district is in Zone D. In general, bedrock sources of water are of very poor quality. Heaviest reliance for sources of potable water is placed on surfacewater, runoff, and shallow river valley alluvium. Drift thickness in this district ranges from 0 to 400 feet and generally ranges between 50 and 400 feet. Loess thicknesses in the Southern Iowa Groundwater District range from 0 to more than 64 feet (Ruhe, 1969). Well records in the files of Iowa Geological Survey indicate that in the uplands east of the Missouri River loess thickness as great as 150 feet occurs. In the thick loess portions of this district (western portion) the loess aquifer is locally important as a water resource. Rule 3.1 (4) f (1) and (2) (see page 4) is thus of greater importance in this district than in the Eastern Iowa Groundwater District.

The paucity of water sources in the district emphasizes the importance of Rule 3.1 (4) f (3) (see page 4).

Except for the southeastern portion of this district where Mississippian-age rocks subcrop as the uppermost bedrock unit and in the west where Cretaceous rocks are uppermost, this district is underlain by aquicludes as shown in figures 11 and 12. Thus Rule 3.1 (4) f (4) will not be as significant there.

Western Iowa Groundwater District

Almost all of this district within Zone C is underlain by Cretaceous Dakota Formation. This rock unit is of variable lithology and is shown in the generalized

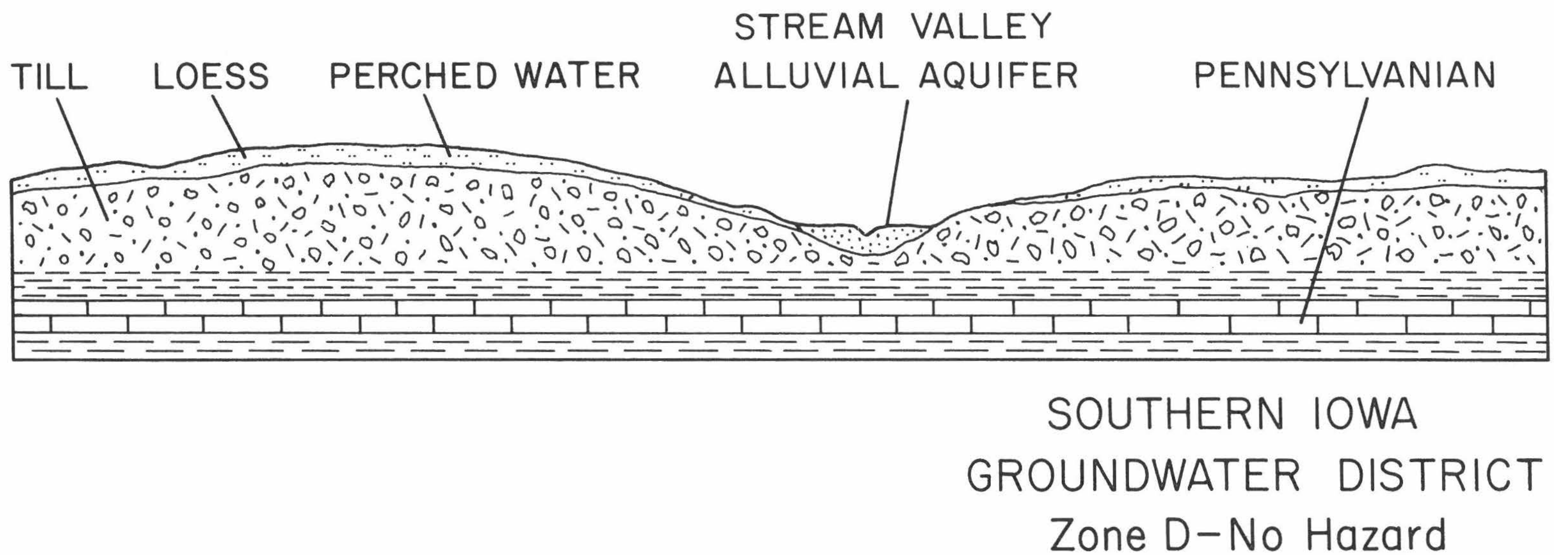


FIGURE 11. South Central Iowa Thick Till Area.

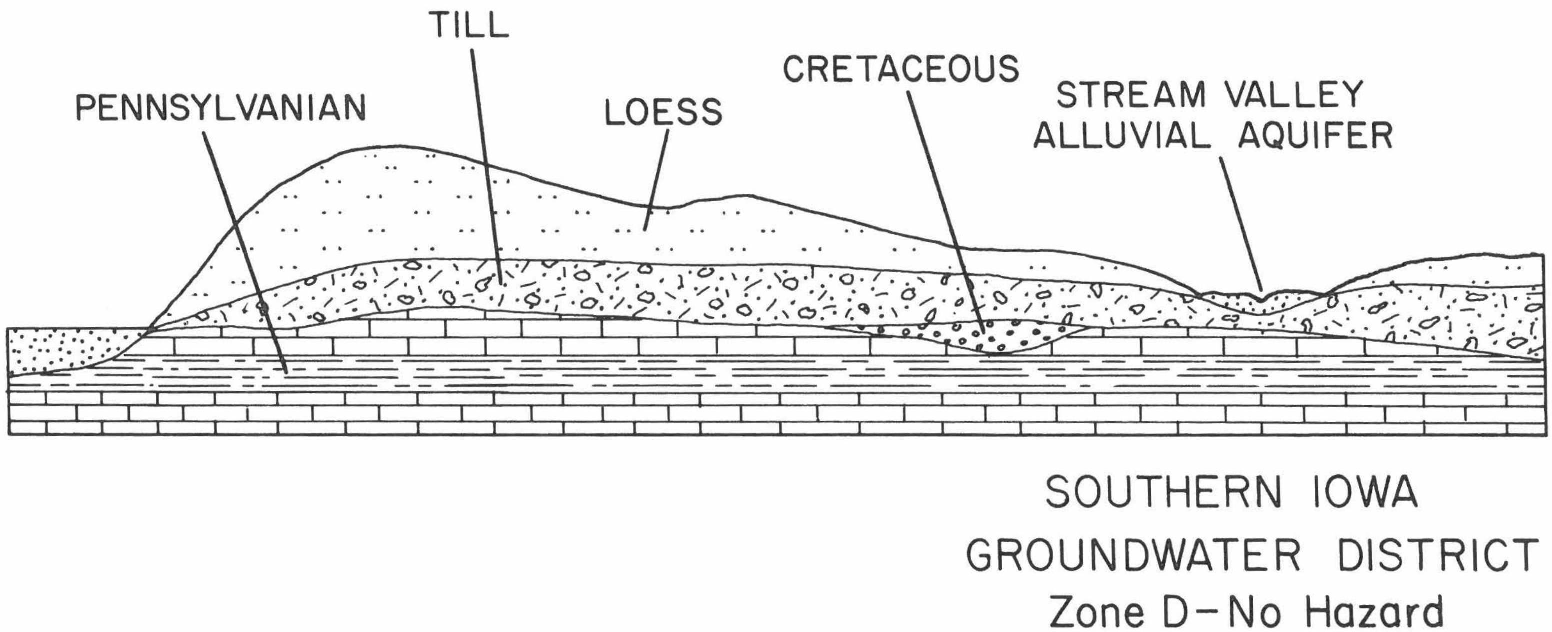


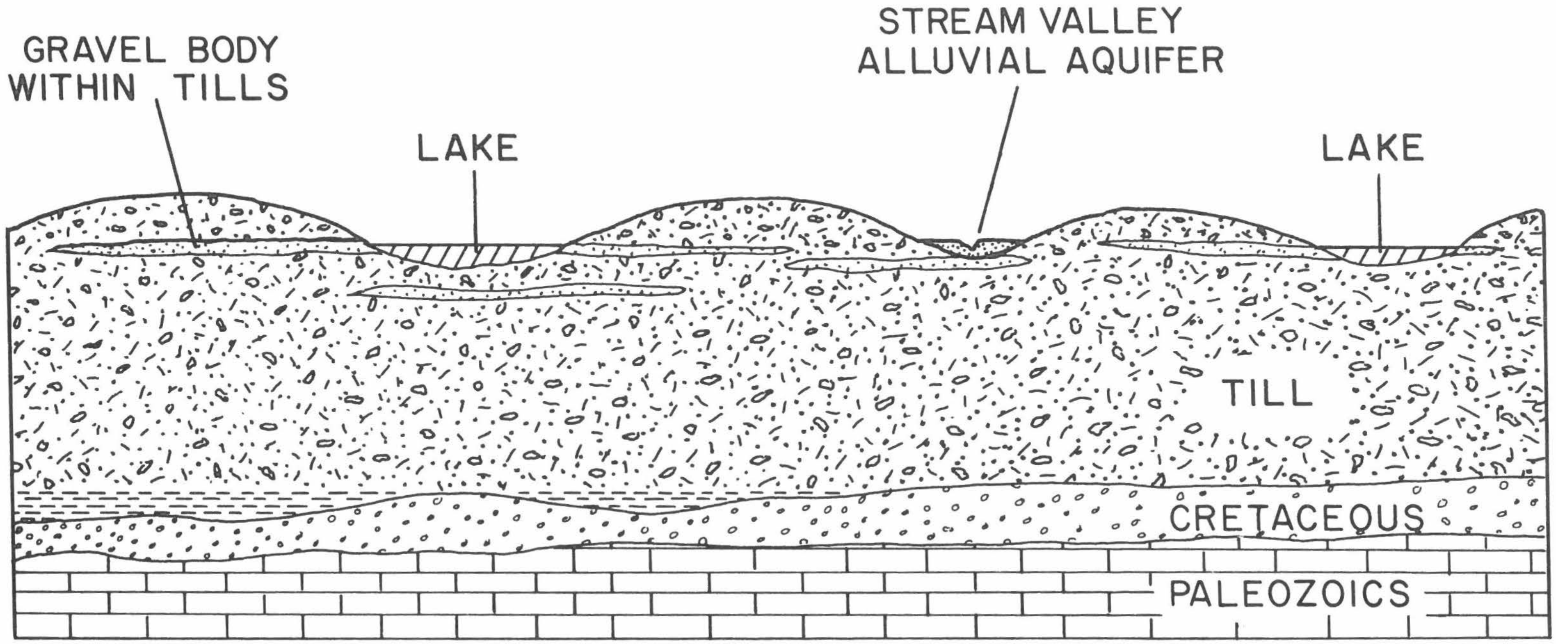
FIGURE 12. Missouri River Area.

geologic cross section in figures 13 and 14. The sandstone in the formation contains water that is of good quality in some places and of a very poor quality in others. Surfacewater, river valley alluvium, upland sandbodies (where saturated) and the loess serve as aquifers. While somewhat more plentifully endowed with usable water sources than the Southern Iowa Groundwater District, this district has few assured water resources distant from stream valleys. In almost all localities, save for the floodplain of the Missouri River, the quantity of water in an aquifer is usually a limiting factor in landfill site selection; and protection of available water resources is of critical importance.

Drift thickness in this district ranges from 250 to 600 feet. Rarely does bedrock crop out. Loess thickness ranges between 0 and more than 64 feet (Ruhe, 1969), and significantly greater thicknesses can be expected. The rather widespread, thick drift cover of the district makes the discovery of suitable landfill sites simple. In general, upland sites will be easier to qualify than gullies, ravines, and floodplains.

THE FUNCTION OF THE IOWA GEOLOGICAL SURVEY IN LANDFILL SITE SELECTION

The function of the Iowa Geological Survey is not that of a regulatory agency for approving or disapproving sanitary landfill sites. Rather, it is one of analysis and dissemination of information pertaining to landfill site investigations. The Survey can, if called upon by the officials of a state agency or legal subdivision of the state, assist communities, counties, or groups of counties in identifying and evaluating sites that have a greater natural probability of meeting the geological and hydrological criteria established in the



WESTERN IOWA
GROUNDWATER DISTRICT
Zone C-Low Hazard

FIGURE 13. Lakes Area Wisconsin Drift—Youthful Drainage.

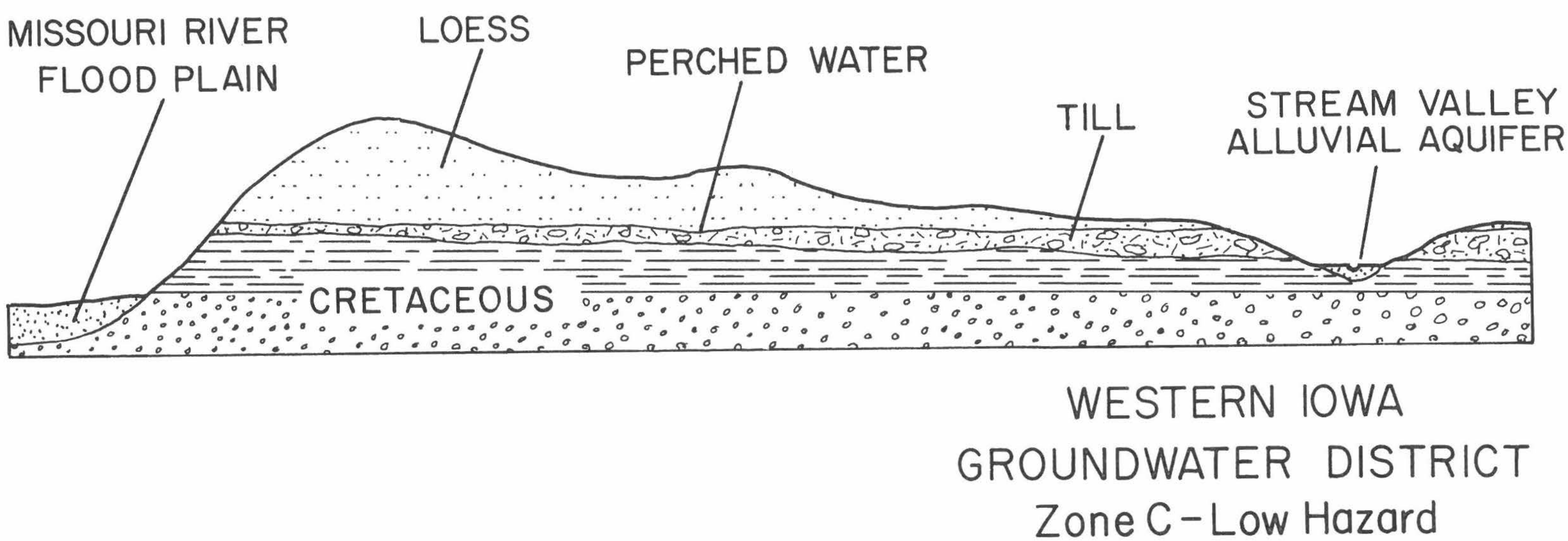


FIGURE 14. Missouri River Area Thickly Loess Mantled Terrane.

regulations of the Iowa State Department of Health. We are not permitted to consult for private firms or individuals retained by such agencies, but there is no impediment to our working in concert with them and reporting directly to the political subdivision. Our data are public information and any citizen of Iowa may have free access at our offices in Iowa City to data he needs.

The Geological Survey believes that progress in the acquisition and development of a site can be accomplished most economically if the procedures outlined below are followed:

1. Organize a legal framework. This means that the communities and/or counties wishing to establish a cooperative waste-disposal agency should select a committee with authority to consider and act on the program. In the subsequent discussion this group will be referred to as "the local authority." It would be advisable for this committee to invite a representative of the Department of Environmental Quality, Lucas State Office Building, Des Moines, Iowa 50319, and a representative of the Iowa Geological Survey, 16 West Jefferson Street, Iowa City, Iowa 52240, to meet with them at their earliest mutual convenience.

2. Initiate planning for site selection. The local authority should examine the county zoning laws applicable to those areas that are under consideration as possible locations for landfills and should so inform the Geological Survey as well as providing a description of the proposed plan. We will tabulate the pertinent data from our files and inform the local authority of those areas that appear favorable for the exploration of landfill sites. After receiving these data, prospective sites can be chosen by the local authority and on-site inspections may be requested. The Geological Survey would prefer to conduct this type

of investigation in conjunction with a member of the Iowa State Department of Health.

After the field inspection the local authority should obtain options on those sites that are considered most acceptable. If two or more sites appear to satisfy the local authority's needs equally and it is desired that some subsurface information be generated in order to facilitate the selection of a site, the Survey may be requested to conduct earth resistivity tests. The Iowa Geological Survey will conduct such earth resistivity surveys at the sites as the State Geologist deems warranted and the pressure of other assignments permits. Earth resistivity work will not obviate the need for test drilling of the site, but will give an indication of the vertical sequence of lithologies and depth to bedrock. This service is provided to duly authorized governmental agencies at no cost. However, it is requested that two workmen be furnished by the local authority to assist with the resistivity survey. The reliability of earth resistivity measurements are markedly affected by the presence of thick frost in the ground; therefore, such surveys cannot be conducted during winter months.

The results of these preliminary field studies will be evaluated by the Iowa Geological Survey and the findings forwarded to the local authority and to the Iowa State Department of Health. Thereupon it will become the responsibility of the local authority to select the site or sites that best suit all requirements for further testing. An engineering consultant should be retained to carry out the required testing for permit applications as required by the Iowa State Department of Health regulations, which include:

1. Test drilling
2. Soil sampling

3. Laboratory analysis of the sediments

   a. Permeability tests

   b. Atterberg limits

4. Topographic mapping of the site (including such cultural features as roads, homes, farmsteads, etc.)

5. Engineering design and plans for:

   a. Supportive data pertaining to remedial measures, monitoring, fencing, etc.

   b. Inventory of existing water supply in vicinity of the site.

Situations may exist in which the location of a site that meets the geologic criteria will be exceedingly difficult. If this is the case, it may be advisable to retain the services of a consulting geologist to assist in site location Presently, the budget of the Iowa Geological Survey does not provide for extensive field investigations to be made by Survey personnel for landfills designed to serve the various political subdivisions of the state.

After completion of site engineering, the required application and the supporting data should be forwarded to the Iowa State Department of Health. Samples of the sediments collected during the investigation of the site may be delivered directly to the Iowa Geological Survey office in Iowa City. A receipt will be furnished as proof of compliance with paragraph 3.1 (4) a section 406.5, Code of Iowa, 1971.

The Iowa State Department of Health will submit a copy of the site engineering study to the Iowa Geological Survey for evaluation. A copy of the evaluation will be furnished the applicant if he indicates such a desire and designates the person to whom it should be sent.

The Iowa Geological Survey evaluation is merely advisory to the Iowa State Department of Health and as such does not constitute approval or disapproval of the application.

PART II A METHOD OF HAZARDOUS AND TOXIC WASTE DISPOSAL

BORED STORAGE SHAFTS IN SHALE TERRANES

The method of toxic waste disposal described here is designed for the disposal of fluid toxic wastes. Throughout the manufacturing industry, many kinds of fluid wastes are generated as unusable by-products. The diversity of chemical compounds involved reflects a wide range of industrial processes and may include solutions of dissolved acids, caustics, insecticides, herbicides, and petroleum products. The one common denominator is the fluid nature of these wastes.

The Problem

What method is the most practical, economical, and offers the safest storage and/or disposal for this material? It may be economical and physically feasible to incinerate some toxic wastes but not all can be treated this way. Burial is an alternate storage or disposal method but fluids are very difficult to bury, particularly in highly impermeable earth materials. The Iowa Geological Survey has adopted the position that toxic materials that are to be stored should be placed in claystone or mudstone rock units and not within any unconsolidated sediment. It is reasoned that total confinement of toxic wastes within a shale unit that does not permit the passage of liquids represents the optimum natural storage site with respect to the protection of present and future water resources. The term "shale" is used here in a broad sense. Claystone and mudstone are more precise terms in geologic usage.

Disposal of fluid toxic wastes that cannot be physically or chemically reduced to a solid is a difficult task. Natural evaporation techniques are not practical in humid regions. Air pollution and its attendant probable secondary result of water pollution is also a clear possibility. Area or trench landfills require the addition of significantly large amounts of bulk materials to absorb or create increased density so that the liquid can eventually be earth covered. Also, natural materials do not readily mix with aqueous and other liquid wastes without some mechanical blending taking place. Most probably the liquid would merely be displaced upward and outward around the margins of the landfill cell. In addition, the characteristics of argillaceous rocks that have been excavated and replaced will have been drastically altered. They tend to dry and form hard disaggregated flakes and chips. When this material is replaced as fill, the original characteristics of density and low permeability are lost. Shale manipulated in this way is not effective as a seal for migrating fluids.

Method of Disposal for Consideration

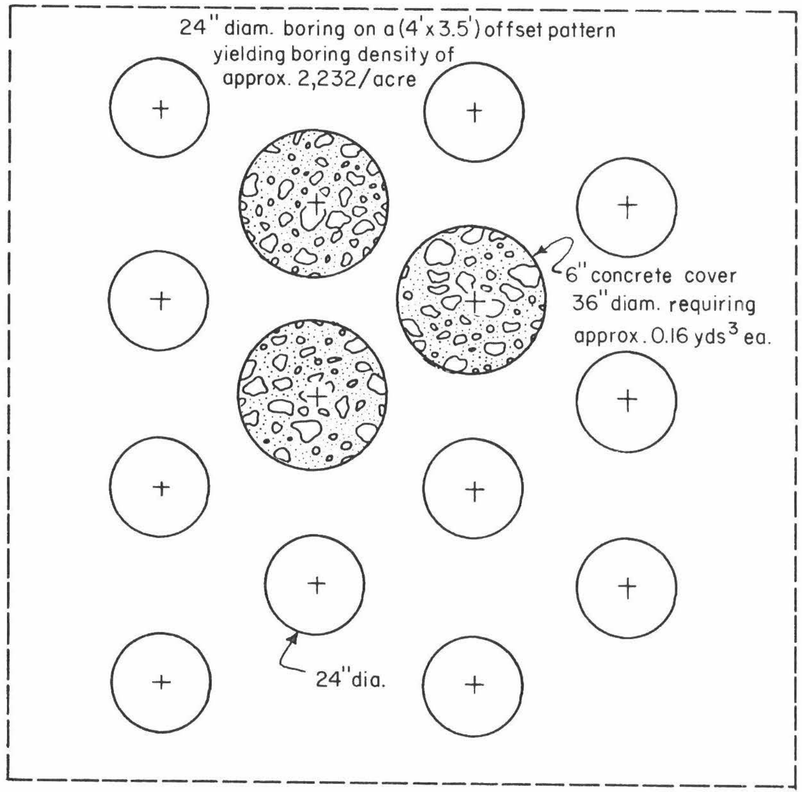
The policy of toxic-waste disposal in shale terrane generates special problems in the handling of fluids, problems that may be alleviated by storing these waste fluids in drums within vertical shale storage shafts bored in essentially impermeable rock units. The shale storage shafts would be bored to depths limited only by the thickness of the rock unit and would accomodate a series of steel drums stacked in the holes. A minimum thickness of 30 feet of the same undisturbed shale should extend below any given storage shaft. The rock unit in which the shafts are excavated should be unjointed, unfractured, unfaulted, and nonfissile. Six inches of freeboard should be maintained between the top of the last drum and the collar of the hole. Finally, a six-inch thick concrete cap 12 inches larger in diameter than the bore of the shaft would be positioned at the top of each shaft. A counter bore the diameter of the cap, extending from the top of each shaft downward one foot, would allow six inches of back-fill over each cap. This should preclude the possibility of cap tilting. The shafts, when filled would act as confined liquid columns that could easily be earth covered. Eventually, the land area involved in this disposal method could be returned to limited usefulness but the site should be preserved until some final disposal technique is applied to the toxic wastes. The rudiments of the shale shaft storage concept in plan and vertical sections are outlined in figures 15 and 16.

What are the Advantages of the Method?

Shale shaft storage does not represent the ultimate method for disposing of liquid toxic wastes, but from the standpoint of minimal environmental hazard, operational flexibility, and ease of operation this method appears feasible.

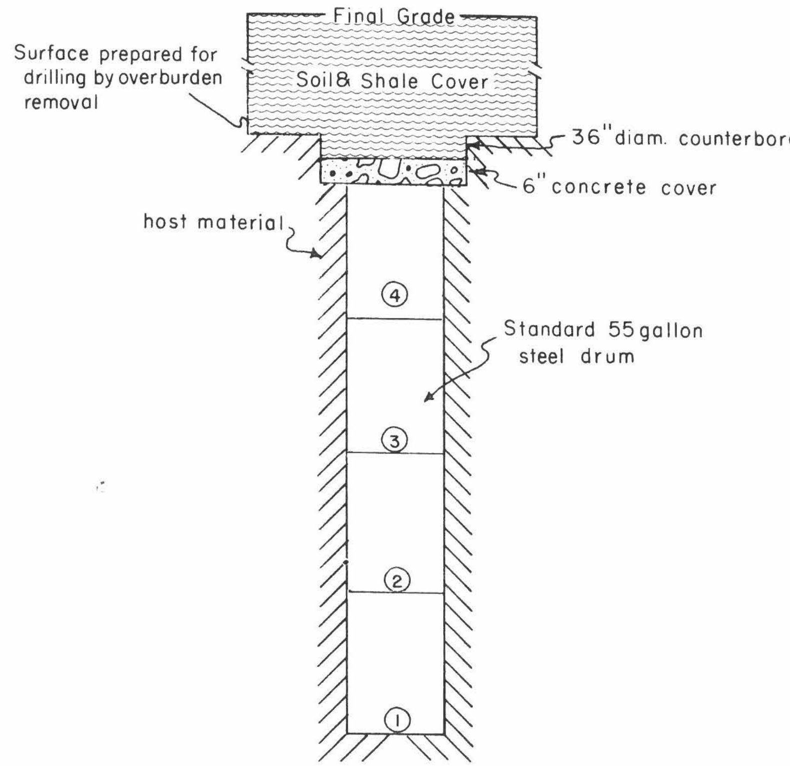
Owing to the fact that most liquid waste materials can be stored in steel drums, operating techniques can be quite flexible. Drums could be temporarily stored above ground on site until storage receptacles were bored. There would be no immediate problem created owing to equipment breakdown, inclement weather, etc. The operation would not, so to speak, be at the mercy of the elements.

Subsequent to filling, capping, and covering, should the drums deteriorate the liquid will still be confined and capped. The natural properties of the confining shale will not have been altered. In other burial techniques, such as trenching, which employ conventional earth-moving methods, blasting may be necessary to facilitate excavation. In shales, blasting may produce a fracture zone about the perimeter of the excavation as well as horizontal partings and



Plan View of Bored Storage Shaft

Figure 15



Vertical Section of a Bored Storage Shaft

Figure 16

fractures below the base of the excavation. Such disruption of the natural characteristics of the shale might critically reduce its effectiveness in preventing the migration of fluids. Infiltration of surface runoff could be kept to a minimum with devices for drainage control. Owing to the nature of the storage method, remedial measures will be simpler and less costly, should they become necessary. Post storage monitoring should be required.

Economics of the Shale Shaft Storage Concept

The figures that follow are generalized and should be considered only in terms of feasibility evaluation. Material costs are based on local economic guidelines. The following data have been projected for a 4 x 3.5-foot drilling pattern (shown in figure 15) or 2,232 shafts per acre, drilled to a depth of 13.5 feet to accommodate four drums vertically (see figure 16). The total storage capacity would be approximately 2,500 cubic yards per acre. Additional storage capacity and cost figures are given in table 2.

Storage Costs per Acre (2,232 shafts per acre)

Drilling	$2.00/foot	$ 60,264
Drums	$6.00/each	53,568
Concrete	$22.00/cubic yard	3,571
Land	$600.00/acre	600
Labor (two men) $10,000 each/annum		20,000
Handling shale cuttings $0.10/cubic yard		3,348
Earth moving & grading (average depth 6 feet) 10,000 cubic yards/acre $0.25/cubic yard		2,500
		$ 143,851

Cost per cubic yard of storage $57.00

Many items have not been included in the above figures, such as maintenance costs, insurance, etc. The costs of capitalization are not refected in the figures presented in this discussion. These costs are presumed to be of the same order of magnitude as for alternate toxic or hazardous waste storage techniques.

TABLE 2. Estimated Cost of Bored Storage Shaft Method.

Number of Drums per Shaft	Boring Depth Required (feet)	Cubic Yards Storage per Shaft	Cubic Yards Storage per Acre	* Storage Cost per Cubic Yard
3	10.5	0.84	18 75	63.00
4	13.5	1.12	25 00	57.00
5	16.5	1.40	31 25	54.00
6	19.5	1.68	37 50	52.00
7	22.5	1.96	43 75	51.00
8	25.5	2.24	50 00	50.00
9	28.5	2.52	56 25	49.00
10	31.5	2.80	62 50	48.00

* Assuming the only cost variables being that for additional drums and the additional drilling footage.

Additionally, equivalent standards are assumed with respect to regulation and operation. The intent here is to determine relative economic feasibility of several methods. At a single site, as an adjunct to liquid storage, solid materials of a hazardous or toxic nature might also be stored using more conventional landfilling techniques. If such were the case, possibly a unit price could be established to be inclusive of both solid and liquid waste materials. This might in effect improve the economics of fluid waste storage if the greater volume of material to be stored were solid.

For general comparison, according to 1970 prices, it would cost approximately \$40.00 [1] per cubic yard to transport a distance of 200 miles and deposit the same kind of materials in a hazardous waste storage site.

An Alternate to Drum Storage

With some sacrifice in operational flexibility, one might consider directly filling storage shafts with liquid. In doing so, the drilling pattern would probably have to be spread slightly. Additionally, the liquid level in the storage shafts should be held at approximately one foot below the lower surface of the concrete cap to eliminate displacement of the concrete caps caused by settlement. The concrete caps should be modified as shown in figure 17. The requirement for concrete per acre would be approximately doubled. However, this additional expense would be more than offset by the elimination of the expense for drums. Possibly some on-site tank storage would be required as a holding facility. This, however, could be constructed at minimal cost. Economically, using the same cost figures as for the drum storage method, and the same capacity figures, the cost per cubic yard could be reduced to the following:

[1] \$33.75 of this represents charge for storage

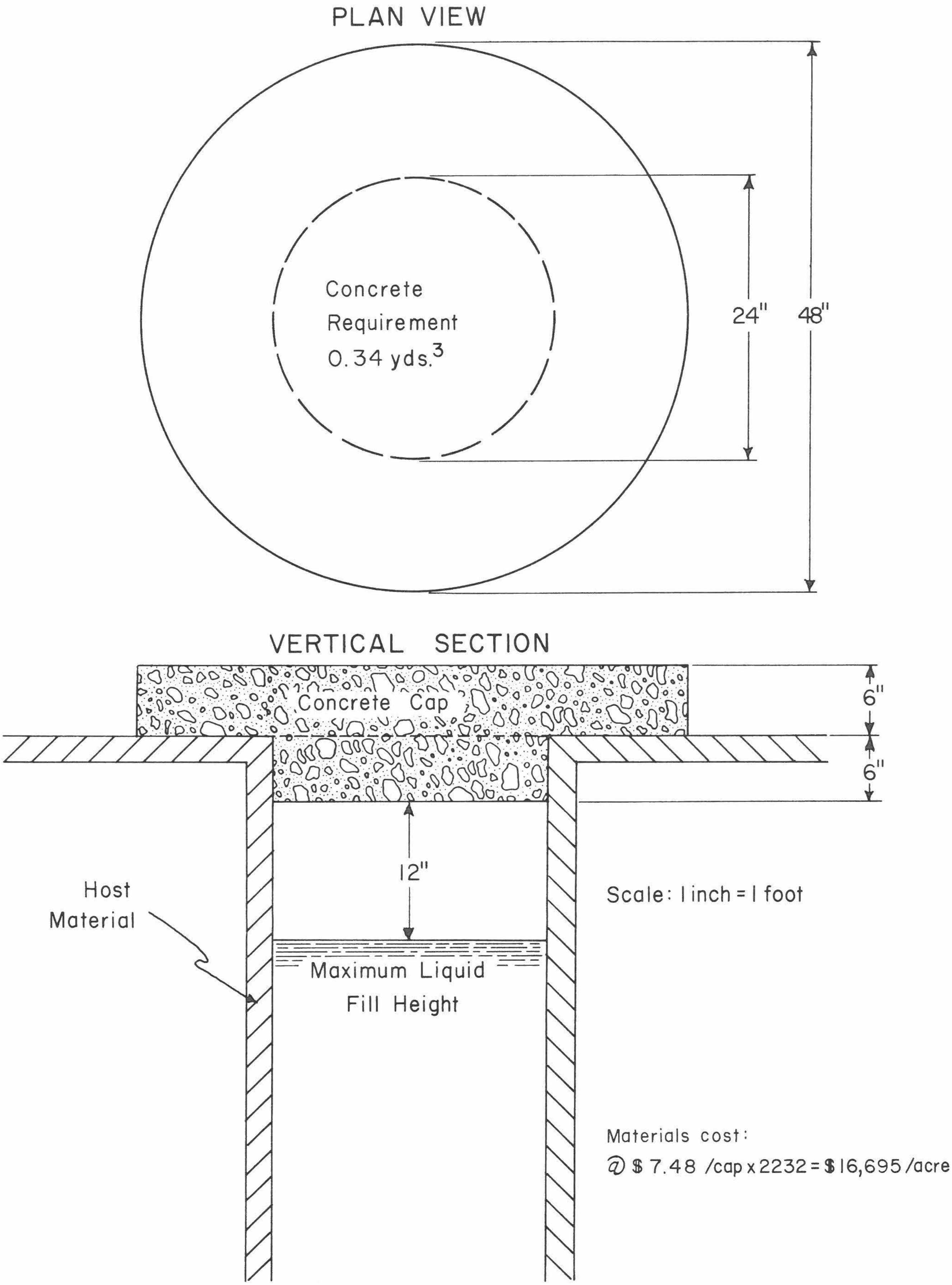


Figure 17

Alternate Bored Storage Technique
(Alternate Liquid Filling)

Storage Costs per Acre

Drilling	$2.00/foot	$ 56,246
Concrete	$22.00/cubic yard	16,695
Land	$600.00/acre	600
Labor (two men) $10,000/man/annum		20,000
Handling shale cuttings $0.10/cubic yard		3,348
Earth moving and grading (average depth 6 feet 10,000 cubic yards/acre $0.25/cubic yard		2,500
		$ 99,389

Cost per cubic yard of storage $39.00

Boring Rates in Claystone

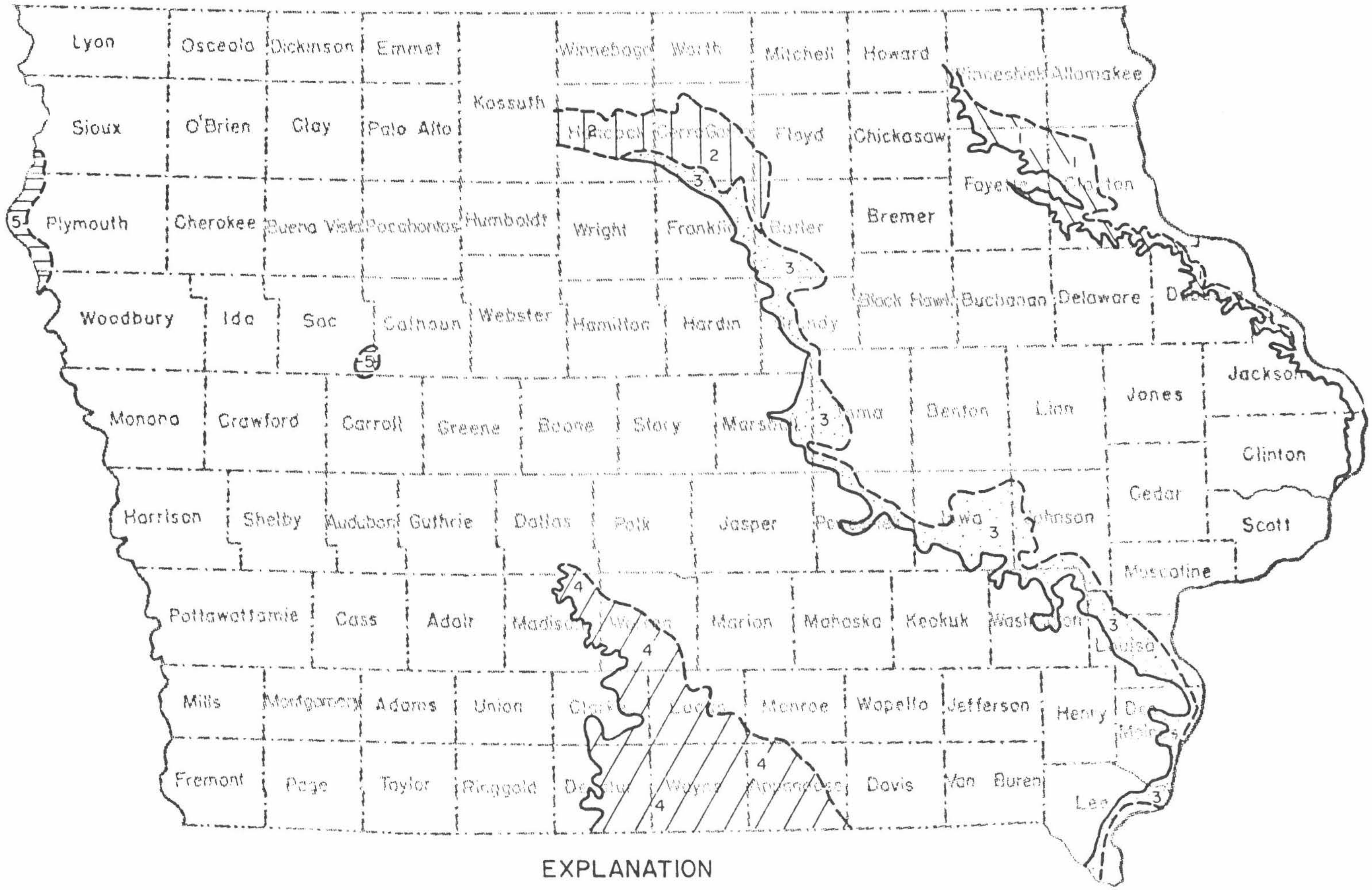
According to drillers with experience in shale augering, one might expect penetration rates as rapid as 40 feet per hour. A conservative estimate of an average rate would, therefore, be 20 feet per hour. A two-man operation could accomplish 160 feet of 24-inch hole per 8-hour day. Storage capacity so generated would be in the order of 55 cubic yards daily, 275 cubic yards weekly (40 hours), and 14,300 cubic yards annually (52 weeks) without regard for downtime or weather.

Hydrologic and Geologic Considerations in Site Planning and Selection

In the evaluation of prospective sites for bore shaft storage several hydrologic and geologic parameters must be considered. The naturally favorable site will be comprised of a unique combination of elements with respect to topography, minimal soil cover, and remoteness of the site with respect to surface- and groundwater.

Topographically, a favorable site should be located in an upland area at or near a drainage divide. In so locating, surface runoff may be controlled with greater facility and infiltration amounts would be expected to be at a

GENERALIZED MAP SHOWING DISTRIBUTION
OF
ROCK UNITS POTENTIALLY FAVORABLE FOR BORED SHAFT STORAGE



EXPLANATION

1 Brainard Shale

2 Lime Creek Shale

3 Yellow Spring Group

4 Pleasanton - Marmaton Groups

5 Cretaceous Undifferentiated

WARNING Site prospecting should not be attempted from a maps of this scale. Contact the Iowa Geological Survey for more detailed information.

Figure 18

minimum. Those areas having thin soil cover will naturally be most economically favorable. Of critical importance in the bored shaft method of storage is the lithology of the host shale, claystone or mudstone. The drilling characteristics are anticipated to be comparable to those of a clay till section that lacks significantly large erratics. The total confinement of liquid waste is dependent upon the low permeability of the host lithology. In addition to low permeability, fluid migration in rock materials is also influenced by the relations of bedding and structure. As related in an earlier section of this discussion the ideal lithology, for the proposed method of storage, would be a homogeneous, dense, nonfissile, unjointed and/or unfractured, and unfaulted claystone or mudstone. Owing to the fact that the ultimate storage potential of a site will be dictated by the thickness of the host unit, each site must be evaluated with respect to this parameter. Figure 18 presents the general distribution of stratigraphic units considered to be favorable for bore shaft storage. More specific geological information may be obtained from the Iowa Geological Survey, 16 West Jefferson Street, Iowa City, Iowa.

That hazardous and toxic waste storage areas be isolated from ground- and surfacewater environs should require no qualification. During the evaluation of prospective sites for hazardous waste storage, extreme care should be exercised to insure against the pollution of any water resources by surface runoff. A well devised program of drilling will be necessary to evaluate a prospective storage site and to preclude any possible introduction of contaminants into groundwater supplies. An acceptable plan should provide for continuous monitoring once toxic materials have been emplaced.

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APPENDIX I

Geologic Time Units

Geologic Name: Era	Period	Epoch	Approximate Durations (Millions of Years)	Approximate Years Since Beginning and End of Time Unit (Millions of Years)
Cenozoic	Quaternary	Pleistocene	1	21 to present
	Tertiary	Pliocene	10	11 to 42
		Miocene	14	25 to 11
		Oligocene	15	40 to 25
		Eocene	20	60 to 40
		Paleocene	10	70 to 60 ± 2
Mesozoic	Cretaceous		65	135 to 70 ± 5
	Jurassic		45	180 to 135 ± 5
	Triassic		45	225 to 180 ± 5
Paleozoic	Permian		45	270 to 225 ± 5
	Pennsylvanian		40	310 to 270 ± 5
	Mississippian		40	350 to 310 ± 5
	Devonian		50	400 to 350 ± 10
	Silurian		40	440 to 400 ± 10
	Ordovician		60	500 to 440 ± 15
	Cambrian		100	600 to 500 ± 20
Precambrian			(?) 4400	(?) 5000 to 600

GLOSSARY

alluvium

A general term that applies to stream deposits (sand, gravel, silt, etc.) laid down in river-beds, floodplains, lakes, estuaries, etc.; alluvial, adj.

aquiclude

A rock unit or body of sediments of low permeability that may absorb water slowly but will not transmit it in significant amounts. (see aquifer.)

aquifer

A rock unit(s) or body of sediments that is able to transmit water readily and from which useful amounts of water can be extracted. Bedrock aquifers are those occurring in rock units; unconsolidated aquifers are those found in sediments.

argillaceous

Applies to rocks or sediments composed of clay or containing a high proportion of clay.

Atterberg limits

Are comprised of the following three factors: (1) Plastic limit - the lower limit of the plastic state, expressed as the minimum water content at which a soil can be rolled into a thread 1/8 inch in diameter without crumbling. (2) Liquid limit - the upper limit of the plastic state, expressed as that moisture content at which a trapezoidal groove cut through the sample will just be closed by 25 blows in a standard liquid limit device. (3) Plasticity index - the liquid limit minus the plastic limit.

bedrock

The solid rock that everywhere, at depth, underlies surficial unconsolidated sediments or is itself exposed at the surface.

bedrock units

A term used collectively to describe a sequence of layers of solid (lithified) rock, generally with regard to only a single parameter; i.e., dominant rock type, geologic age, etc.

cavernous

Containing cavities, caves, or caverns; most frequent in limestones and dolostones. (See karst.)

clay

A natural, earthy, fine-grained material that develops plasticity when mixed with a limited amount of water. In geology clay is generally defined as material finer than four microns; in soils engineering the usual practice is to use two microns as the upper limit of clay size grade.

claystone

Sedimentary rocks in which much clay is present or which are largely composed of clay, generally nonlaminated.

confining unit

A body of low-permeability material which separates the base of the landfill from an underlying more permeable rock or sedimentary unit.

Dakota Formation

A stratigraphic unit in the upper midcontinent region consisting mainly of sandstone with minor amounts of shale; Cretaceous in age, deposited approximately 90 million years age. (See formation.)

Darcy's law

The rate of fluid flow through saturated porous media varies directly with the hydraulic pressure and inversely with the distance of flow for a unit cross-section area.

deoxygenated

Indicates that absorbed, or dissolved oxygen has been removed from a material and that the material is deprived of oxygen supply. The term does not refer to chemically combined oxygen.

dolostone

A sedimentary rock composed predominantly of the mineral dolomite (calcium magnesium carbonate).

drift

A general or inclusive term for unconsolidated deposits of glacial origin composed of clay, silt, sand, gravel, boulders, or mixtures of various kinds of rock material.

earth resistivity

The natural resistance of different earth materials to the passage of an induced electric current. Resistivity measurements help to determine the sequence of soil and rock types under investigation.

erratic

A term applied to boulders, large or small, that have been transported by ice. Erratics are different in lithologic composition from the bedrock on which they lie, either free or as part of a sedimentary unit.

floodplain

The area adjoining a river or stream, which has been or may be hereafter covered by flood water. Floodplains are nearly flat and are made up of sediments (alluvium) deposited by the river.

formation

The ordinary unit of geologic mapping consisting of a persistent stratum of sufficient thickness and geographic extent to be mapped.

Geologic Time Scale

Geologic time is divided into units of unequal length, as defined by the appearance and disappearance of the fossil remains of characteristic organisms preserved in the various sedimentary rock units. By means of a variety of scientific methods, approximate time values, in terms of solar years, have been assigned to the geologic time units. Appendix 1 gives these time values.

grain size (unconsolidated sediments)

The effective diameter of discrete particles used in describing sediments; the predominant particle size giving the sediment its name, i.e., gravel, sand, silt, clay.

groundwater

That water occurring below the surface of the earth. In a more restricted sense, that water occurring within the zone of saturation.

hydrologic

Of or pertaining to the behavior or state of water; its properties, movement, environment, spatial relations, and distribution.

hydrostatic head

The pressure of the fluid at the point measured, generally expressed in pounds per square inch or in feet of water.

infiltration

The downward movement of water through earth materials.

interface

A contact surface separating two different substances.

interfluve

A higher land that serves as a divide between two streams flowing in the same general direction.

Iowa Natural Resources Council

A state regulatory body that was created in 1949 by legislative action which assigned the council the duty and authority to establish and enforce comprehensive state-wide programs for the control of water and the protection of the surface and underground water resources of the state. Subsequently, authority was given to the council for a permit system for regulation of water use.

karst topography

Produced by solution of limestone or dolostone formations, marked by sinkholes and usually underlain by caverns and underground streams.

leachate

A highly mineralized liquid which results from the solution of materials from solid waste by percolating groundwater.

lithologies

A condensation of the term lithologic types, meaning rock or sediment types, i.e., limestone, sandstone, shale, etc.

local authority

The local landfill agency, board of supervisors, or city council.

loess

A fine-grained, unconsolidated, sediment of wind-blown origin, composed predominantly of angular silt grains and minor amounts of clay minerals.

mudstone

A nonfissile clay rock, usually consisting of an indefinite mixture of clay, silt, and sand particles.

nonfissile

Describes a sedimentary rock that does not have closely spaced bedding planes; hence, one that will not split readily along parallel planes; as, for example claystone or mudstone.

perched water

Is generally assumed to be separated from the main aquifer by impermeable (nonwater-bearing) strata.

permeability

The capacity of a substance to transmit water or other fluids.

piezometric surface

An imaginary surface that everywhere coincides with the static level of water in an aquifer.

potable water

Drinkable water.

Q values

As defined for the Darcy equation, Q is the rate of discharge (flow) expressed in gallons per day or cubic feet per day.

recharge

The process by which water is replenished to the zone of saturation.

shale

A laminated sedimentary rock, the constituent particles of which are predominantly clay. The term is used here in the broad sense to refer to any argillacous rock.

sinkhole

A topographic depression formed by the collapse of soil materials into underlying voids created by the solution and cavitation of soluble bedrock by groundwater. (See <u>karst</u>.)

stratigraphic section

A vertical sequence of unconsolidated or consolidated (bedrock) lithologic units. A typical stratigraphic section in eastern Iowa <u>might</u> be, from the surface downward, loess 15 feet, till 65 feet, sand 5 feet, Cedar Valley Formation 100 feet.

subcropping bedrock

The bedrock directly underlying unconsolidated sediments.

surfacewater

Used here in the general sense to include both free-standing (pools, lakes, etc.) and flowing (runoff) water; any water that has not passed below the surface of the land.

terrane

A geographic area characterized by landscape features that are related to the bedrock type.

unconsolidated sediments

Aggregations of earth materials in which the individual particles are not cemented.

till

A heterogeneous mixture of rock materials ranging in particle size from clay to boulders which have been tranported and deposited by glacial ice.

watertable

The undulating surface of the zone of groundwater saturation, bulging upward under hills, flattening under valleys, and rising or falling as the available water supply varies.