EXAMPLE EVALUATION OF A PERMIT APPLICATION FOR A PROPOSED HAZARDOUS-WASTE LANDFILL IN EASTERN ADAMS COUNTY, COLORADO

By Edward R. Banta

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CONVERSION FACTORS

The inch-pound units used in this report may be converted to SI (International System of Units) by use of the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain SI unit*
foot (ft)	0.3048	meter
foot per day	0.0003528	centimeter per second
inch (in.)	2.540	centimeter
mile (mi)	1.609	kilometer
acre	0.4047	square hectometer

EXAMPLE EVALUATION OF A PERMIT APPLICATION FOR A PROPOSED HAZARDOUS-WASTE LANDFILL IN EASTERN ADAMS COUNTY, COLORADO

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ABSTRACT

This report is a result of a project undertaken by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency for a series of reports demonstrating methods by which Part B permit applications required in the Resource Conservation and Recovery Act of 1976 might be evaluated. The purpose of the project was to prepare a report that would supplement a series of case studies to be made available to permit writers in the U.S. Environmental Protection Agency. Four sites in the United States were chosen for their potential applicability to geologically similar sites. The Adams County site was chosen to be representative of sites in the Upper Cretaceous Pierre Shale. The intent of a case study is to provide a permit writer with a review of an application for a site that has some similarity to the site being considered. The intent of this report is to provide an example of how available earth-science information might be used in evaluating an application and not to evaluate the acceptability of the site. Because this study is an evaluation of a permit application, the data used are limited to the data supplied in the application and in published reports. Of the five criteria required by the U.S. Environmental Protection Agency to be addressed in the permit application considered in the case study, the application was evaluated to be inadequate in addressing three criteria: (1) Site characterization, (2) ability to monitor the location, and (3) flow paths and 100-foot time of travel.

Earth materials at the proposed site near Last Chance, Colorado, are a thin layer of Pleistocene Peoria Loess underlain by Pierre Shale. Hydraulic conductivity of the materials generally is small (0.12 foot per day or less); however, sandy zones found at the site have a hydraulic conductivity of about 1.2 feet per day. The potentiometric surface for the uppermost regionally continuous aquifer is at a depth of more than 100 feet below land surface. However, perched water occurs above the regional aquifer in the sandy zones and in the weathered part of the Pierre Shale. The probable flow path for contaminants leaching from the site would be along the sandy zones. During saturated conditions, the 100-foot time of travel along this flow path probably would be about 3.5 years; because of uncertainty in hydraulic characteristics of the saturated zone, the 100-foot time of travel may range from 9 weeks to 59 years. More detailed site characterization and flow-path analysis are necessary to determine if the applicant is able to monitor the location.

INTRODUCTION

This report is a result of a project undertaken by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency for a series of reports demonstrating methods by which RCRA (Resource Conservation and Recovery Act of 1976) Part B permit applications might be evaluated. The purpose of the project was to prepare a report that would supplement a series of case studies (Office of Solid Waste, 1984b, appendix) to be made available to permit writers in the U.S. Environmental Protection Agency. Four sites in the United States were chosen for their potential applicability to geologically similar sites. The Adams County site was chosen to be representative of sites in the Upper Cretaceous Pierre Shale. The intent of a case study is to provide a permit writer with a review of an application for a site that has some similarity to the site being considered. The intent of this report is to provide an example of how available earth-science information might be used in evaluating an application and not to evaluate the acceptability of the site. Because this study is an evaluation of a permit application, the data used are limited to the data supplied in the application (U.S. Environmental Protection Agency, written commun., 1984) and in published reports. This report does not consider any application materials submitted to the U.S. Environmental Protection Agency subsequent to the application dated May 22, 1984.

The method of evaluation was specified in the "Location Evaluation Methodology" (Office of Solid Waste, 1984b, chapter 2). Hereafter, only the phrase "Location Evaluation Methodology" is used to denote this document. It describes a decision network to be used by a permit writer when determining the acceptability of a site as to the potential for the release of hazardous constituents from the containment area. One of the permit writer's responsibilities is to assess the adequacy and reliability of geohydrological data and interpretations provided in the application. This report focuses on aspects of the application that were inadequate or unreliable; where the information in the application was adequate, little or no elaboration is given.

The data and interpretations in this report were supplied in the application or in other publications where so referenced. The following exceptions are the author's interpretations: (1) The presence of perched water, (2) the continuity of sand lenses, (3) stratigraphic discussion of sand lenses, (4) discussion of uppermost-aquifer hydraulic gradient, (5) discussion of flow paths, (6) discussion of effective porosity, and (7) time-of-travel estimates.

DESCRIPTION OF THE STUDY AREA

A land development company has applied for a RCRA Part B permit for a hazardous-waste landfill on a 325-acre site in the extreme southeastern corner of Adams County. The site is about 68 mi due east of downtown Denver, near Last Chance, in SW1/4, sec. 25 and NW1/4, sec. 36, T. 3 S., R. 57 W., (Sixth Principal Meridian) (fig. 1). The site is within a larger tract of land owned by the applicant that is in the same township and consists of sections 21-23, 25-27, and 34-36. Topography is characterized by gently rolling hills and ephemeral-stream channels. The land surrounding the site is used predominantly for agriculture, mostly nonirrigated wheat farming and grazing; a small

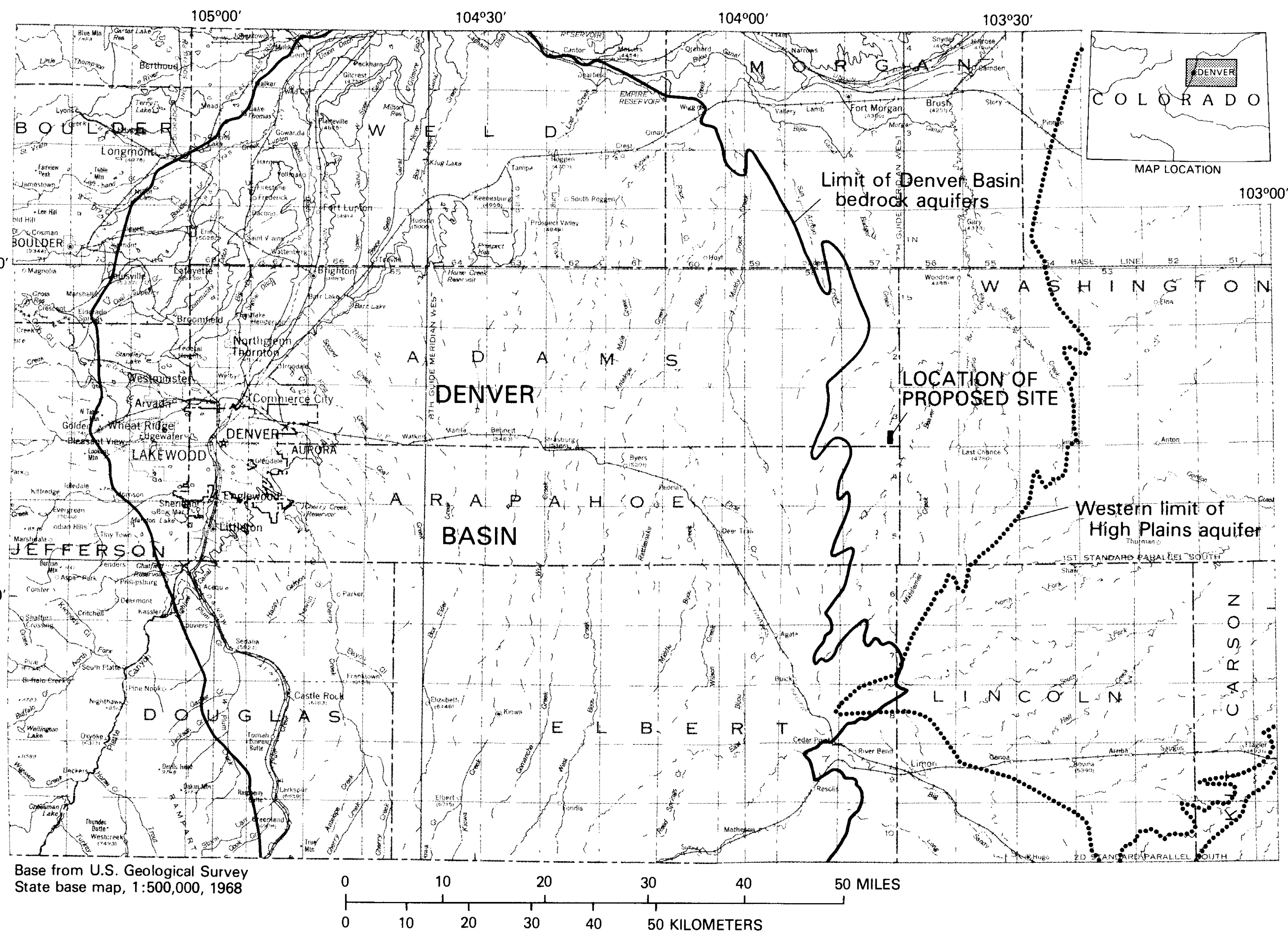


Figure 1.--Location of proposed hazardous-waste landfill.

part is used for irrigated crops. To the present (1984), the site itself has been used primarily for wheat farming and grazing, although several oil wells and an associated brine pond have been constructed there. The climate is semiarid continental steppe; the average annual precipitation is about 14 in.

Geology

The site is in an area in which Upper Cretaceous Pierre Shale crops out or is covered by a thin layer of Quaternary loess or alluvium. The Pierre Shale, about 4,300 ft thick at the site, is underlain by the Upper Cretaceous Niobrara Formation, which consists predominantly of chalk, limestone, and shale. The Pierre is mostly silty and sandy shale, although the upper part contains interbeds of soft sandstone (Sharps, 1980). In the Denver Basin to the west, the Pierre is overlain by a series of Upper Cretaceous and Tertiary formations (table 1), which contain bedrock aquifers. The nearest outcrop of the lowermost of these rocks, the Upper Cretaceous Fox Hills Sandstone, is about 6 mi to the west. About 16 mi to the east, the Pierre is overlain by the Tertiary Ogallala Formation and Quaternary deposits, which form the High Plains aquifer. Geologic materials of interest at the site itself are, or are derived from, one of two units: Upper Cretaceous Pierre Shale and overlying Quaternary eolian deposits. Pleistocene Peoria Loess and loess-derived soils entirely cover the Pierre Shale at the site and are about 5 to 30 ft thick. Additional details of the site geology are presented in the "Site Characterization" section.

Hydrology

Because of the relatively small annual precipitation, surface water at the site is scarce. Although no streams are perennial on the site, several are ephemeral. Land surface at the site is more than 50 ft higher than the 100-year flood plains of nearby perennial streams, based on the method outlined in McCain and Jarrett (1976).

Because of the scarcity of precipitation and surface water, recharge to the uppermost aquifer likely is small and probably primarily occurs during spring snowmelt. The following hydraulically connected zones comprise the uppermost aquifer: (1) Sand zones or lenses, (2) permeable claystone (weathered Pierre Shale), and (3) shale of the upper part of the unweathered Pierre Shale. According to the Location Evaluation Methodology, these three units may be considered as one aquifer, because water in the sand and claystone generally is perched and the regional water table generally is in the unweathered Pierre Shale. Several shallow domestic and stock wells within 2 mi of the site yield water from one or more of the three units that comprise the uppermost aquifer.

Table 1.--*Generalized stratigraphic correlation chart of Quaternary, Tertiary, and Cretaceous rocks of the Denver Basin*

[Modified from Tweto (1979); Sharps (1980)]

ERATHEM	SYSTEM	SERIES	STRATIGRAPHIC UNIT
CENOZOIC	QUATERNARY	Holocene	Alluvium
		Pleistocene	Peoria Loess
	TERTIARY	Pliocene	
		Miocene	Ogallala Formation
			Arikaree Formation
		Oligocene	White River Formation or Group
		Eocene	Dawson Arkose
			— — — ? — — — — — ? — —
		Paleocene	Denver Formation
MESOZOIC	CRETACEOUS	Upper	Arapahoe Formation
			Laramie Formation
			Fox Hills Sandstone
			Pierre Shale
			Niobrara Formation
			Benton Shale
		Lower	Dakota Group or Sandstone

Values of hydraulic conductivity of the uppermost-aquifer materials at the site generally are small; however, sand zones encountered in some of the holes drilled at the site have a relatively large value of hydraulic conductivity. Perched water in these sand zones and in the weathered Pierre Shale results in a complex, localized flow system. Weathering and fracturing of the Pierre Shale have produced a zone of claystone in which the hydraulic conductivity is variable but generally decreases with depth. Water levels in the claystone are indicative of additional, localized perched water, and the claystone may be another conduit for transport of leachate. Flow in the unsaturated zone is downward toward the regionally continuous aquifer in the Pierre Shale. The potentiometric surface for this aquifer is greater than 100 ft below land surface and is smooth in comparison with the land-surface topography.

EVALUATION OF THE PERMIT APPLICATION

The Location Evaluation Methodology requires that the permit writer evaluate:

1. The adequacy of data presented on a set of topographic maps provided by the applicant. These data include: scale, orientation, and date of each map; a wind rose; legal boundaries of the proposed site; access control; location of wells within and adjacent to the proposed site; land use within and adjacent to the proposed site; location of operational units (buildings and structures) within the proposed site; location of streams and areas that would be inundated by a 100-year flood within the proposed site; and location of drainage systems and flood-control barriers within the proposed site.

2. The acceptability of the site using five criteria: (1) Site characterization, (2) high-hazard and unstable terrains, (3) ability to monitor the location, (4) protected lands, and (5) ground-water vulnerability. Data presented on the maps and additional data provided in the application are used in the evaluation.

Data Presented in the Application

All required map data, in varying degrees of adequacy, were presented on topographic maps provided by the applicant. In addition, the applicant drilled, cored, or augered 80 test holes in the vicinity of the site. Thirteen of these holes were completed as water wells; the rest served as sample holes and were backfilled immediately on completion. Geotechnical analyses of 81 soil samples, including analyses for grain size, Atterberg limits, water content, compaction (moisture-density relation), and unconfined compressive strength, are documented in the application. Thirty standpipe tests for vertical hydraulic conductivity were done. Thirty-one borehole-packer tests and two single-well aquifer tests were done to determine hydraulic characteristics in the vicinity of the site. Laboratory tests for hydraulic conductivity were done on nine soil samples. Statistical summaries of the results from onsite hydraulic-conductivity tests are shown in tables 2 and 3.

Table 2.--*Statistical summary of onsite measurements of vertical hydraulic conductivity of site materials*

Material	Number of tests	Geometric mean (feet per day)	Range (feet per day)
Clay and silty to sandy clay (loess)---------------------------	7	3.8×10^{-4}	1.2×10^{-4} to 6.5×10^{-4}
Claystone (weathered Pierre Shale)--	23	3.2×10^{-4}	9.1×10^{-5} to 5.7×10^{-3}

Table 3.--*Statistical summary of onsite measurements of horizontal hydraulic conductivity of site materials*

Material	Number of tests	Geometric mean (feet per day)	Range (feet per day)
Clay and silty to sandy clay (loess)-------------------------	4	1.2×10^{-1}	3.1×10^{-2} to 2.7×10^{-1}
Clayey to silty sand-------------	1	1.2	---
Claystone (weathered Pierre Shale)--------------------------	21	3.3×10^{-2}	2.8×10^{-3} to 6.0×10^{-1}
Shale (unweathered Pierre Shale)--	[1]5	5.8×10^{-4}	2.4×10^{-4} to 1.9×10^{-3}

[1]Results from two of the borehole-packer tests are not included because the intervals tested would not accept water.

Loess and loess-derived soils, referred to as Group I materials in the application, are very silty, slightly sandy clay [USCS (Unified Soil Classification System) classes CL and ML (U.S. Bureau of Reclamation, 1974, p. 1-17)]. Clayey to silty sand (USCS classes SC and SM), also called Group I material in the application, or slightly silty, slightly sandy to sandy clay (USCS classes CL and CH), referred to as Group II material in the application, or both generally underlie the eolian deposits and range in thickness from less than 1 to about 40 ft. Underlying the sand and clay is fractured and unfractured claystone, which ranges in thickness from 40 to more than 100 ft. The claystone is derived from the Pierre Shale and is referred to as Group IV material in the application. Unweathered Pierre Shale, referred to as Group III material in the application, underlies the claystone. Depth to unweathered Pierre Shale ranges from about 70 to more than 110 ft below land surface; depth to the base of the Pierre is about 4,300 ft below land surface.

Evaluation of Maps for Adequacy of Data Presented

The maps provided by the applicant were evaluated according to guidelines in the Location Evaluation Methodology to determine if: (1) There were general inadequacies in the data presented; (2) available earth-science information could be used to verify the data presented; and (3) available earth-science information could be used to imporve the adequacy of the data presented. The results of the evaluation are listed below.

1. Buildings and other structures--Although the site-development plan indicates the location of structures, not all the structures are identified.

2. Areas inundated by a 100-year flood--The applicant stated that there were no areas within the proposed site that would be inundated by a 100-year flood. This statement was verified by an evaluation of the perennial streams nearest the site using methods described in McCain and Jarrett (1976).

3. Location of streams--The maps did not show the location of any intermittent streams within and adjacent to the proposed site. The location of such streams are shown on the relevant U.S. Geological Survey 1:24,000-scale topographic quadrangle maps (U.S. Geological Survey, 1973a, b).

4. Land use--Land use is shown only on a small-scale map. The land use is agricultural within and adjacent to the site, but the map does not distinguish between irrigated and nonirrigated lands. Well-permit data available from the Office of the State Engineer could assist in the delineation of irrigated and nonirrigated lands.

5. Drainage systems and flood-control barriers--Although details of the analysis and design of the uncontaminated stormwater routing and control system are adequately presented, few details of the potentially contaminated stormwater system are included. An additional, detailed description of an effective routing and control system for potentially contaminated stormwater would meet the requirements of the Location Evaluation Methodology regarding drainage and flood-control barriers.

Location Criteria of Concern at the Site

The U.S. Environmental Protection Agency (Office of Solid Waste, 1984a) describes five criteria for location acceptability: (1) Site characterization, (2) high-hazard and unstable terrains, (3) ability to monitor the location, (4) protected lands, and (5) ground-water vulnerability. The fifth criterion was explicitly omitted from this evaluation at the U.S. Environmental Protection Agency's request. The criterion, flow paths and 100-ft time of travel, was substituted. Location criteria of concern in the siting of the proposed landfill are: (1) Site characterization, (3) ability to monitor the location, and (5) flow paths and 100-ft time of travel. Location criteria 2 and 4 are not a concern at the proposed site because:

1. The potential high hazard posed by loess, which is classified as a weak and unstable soil in the Location Evaluation Methodology and which is the surface material at the proposed site, generally is easily mitigated because of the thinness of the loess layer and the general levelness of the land surface.

2. The proposed site is not within protected lands such as parks, wildlife refuges, wilderness areas, archaeological or historical sites, endangered- or threatened-species habitat, protected agricultural lands, protected watersheds, or wetlands.

Site Characterization

Site characterization is the description of geologic, hydrologic, and pedologic conditions at the site as presented in the application. The permit writer is responsible for deciding whether or not the site has been characterized sufficiently to support a detailed analysis of the potential for contamination of ground water in the vicinity of the site in the event of release of contaminants from the engineered containment structure.

The degree of hydrologic connection of the sand zones encountered in drilling is critical to the site characterization. The sand is associated either with the eolian deposits or with the Pierre Shale. Sand associated with the eolian deposits would be found in zones parallel to the deposits, that is, approximately parallel to the land surface. Sand in unreworked beds of the Pierre would be found in zones parallel to the bedding of the Pierre. According to Sharps (1980), soft sandstone interbeds are predominant in the upper 400 ft of the Pierre. Kiteley (1978) described member A and members D and C, undivided, of the Pierre Shale as sandstone and clayey sandstone layers about 35 mi northwest of the site. These members are in stratigraphic positions that may be at the top of the Pierre Shale and its derivatives at the site. Because the extent of erosion of the Pierre is unknown, the exact stratigraphic position of the top of the Pierre at the site is unknown; however, the Pierre may be the source of the sand encountered in the holes drilled at the site. The applicant's interpretation (U.S. Environmental Protection Agency, written commun., 1984) shows the sand lenses oriented at an angle oblique to both the apparent bedding and the land surface.

The applicant's argument that the sand intervals represent several individual sand lenses is based on the fact that they occur at differing altitudes. However, if the sand zones encountered during drilling are continuous, the sand lens would dip at no more than 4° (about 7-percent slope), as shown in figures 2 and 3.

Sand deposits encountered in the southeastern part of the proposed site (fig. 4) are considered in this report to be continuous. Of the test holes that penetrated the sand, the three drilled at low-altitude sites penetrated water-saturated sand. The water levels in these test holes indicate a hydraulic gradient toward the southeast, approximately equal to the land-surface slope in magnitude and direction. A comparison between these water levels and those in wells completed in the upper part of the Pierre Shale indicate that the water levels in the sand lens are considerably higher and probably are representative of water perched on underlying clay and claystone zones. The permeable sand zones provide the most probable pathway for contaminants leaching from the site, but more core-sample and water-level data are necessary to adequately define the system hydraulics.

The site characterization in the application is inadequate or inconsistent in the following aspects:

1. No water-level map was provided with the application. The water table, or tables where there are perched systems, need to be identified. Specifically, more water-level data for the sand lenses and for the unweathered Pierre Shale need to be collected to identify hydraulic gradients. Seasonal fluctuations in water-table altitudes need to be documented. The spring snowmelt period is of particular concern, because the saturated condition of the soil and the slow potential-evaporation rate may result in recharge to the aquifers and a water-table rise. In addition, contaminant transport likely would be greatest during this period.

2. Representations of wells and sample holes shown on the geologic sections (included in the application) do not match the data supplied in the sample logs (also included in the application) in all cases.

3. Hydraulic-conductivity data given are insufficient because the distribution of data is too sparse to resolve sand and clay lenses.

4. No porosity data are included in the application.

5. No background-monitoring site is indicated in the application.

The applicant contends that the uppermost aquifer is the Dakota Group or Sandstone (table 1), which is about 5,200 ft below land surface; however, nearby, shallow, small-capacity wells indicate the presence of a usable aquifer at shallow depths.

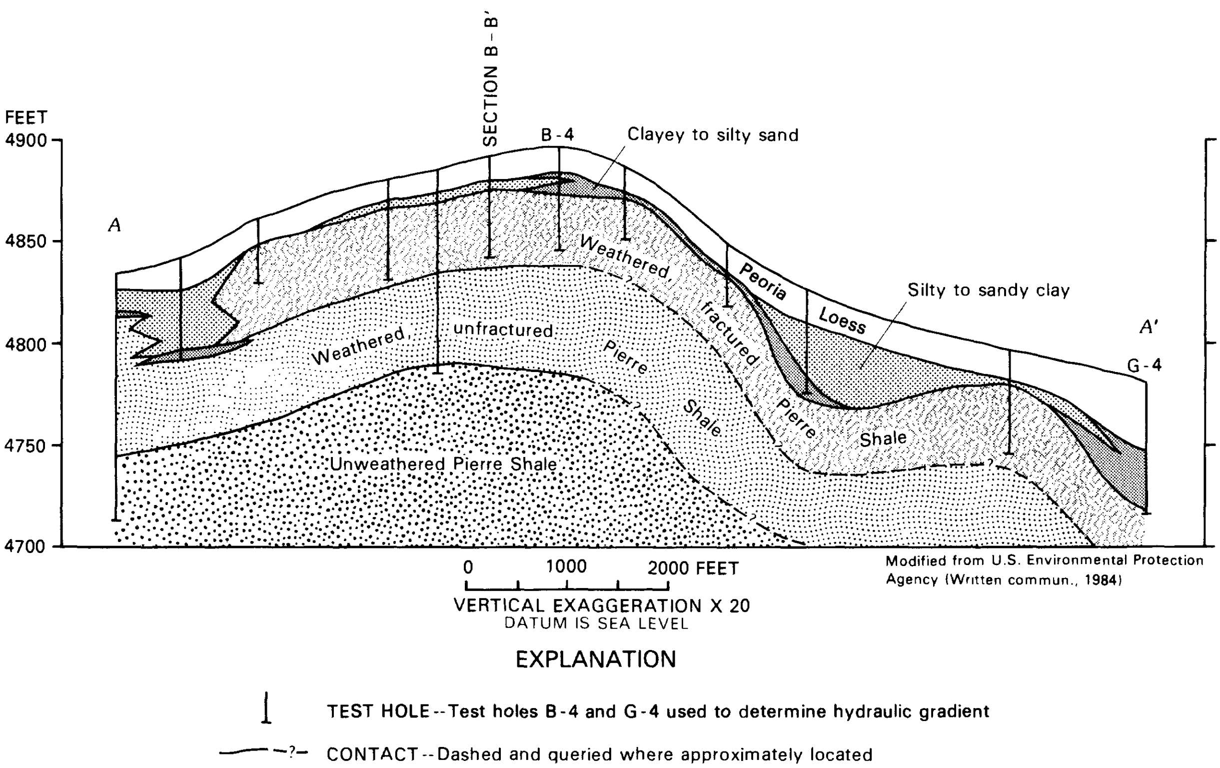


Figure 2.--Geologic section A-A'. (Trace of section shown in figure 4.)

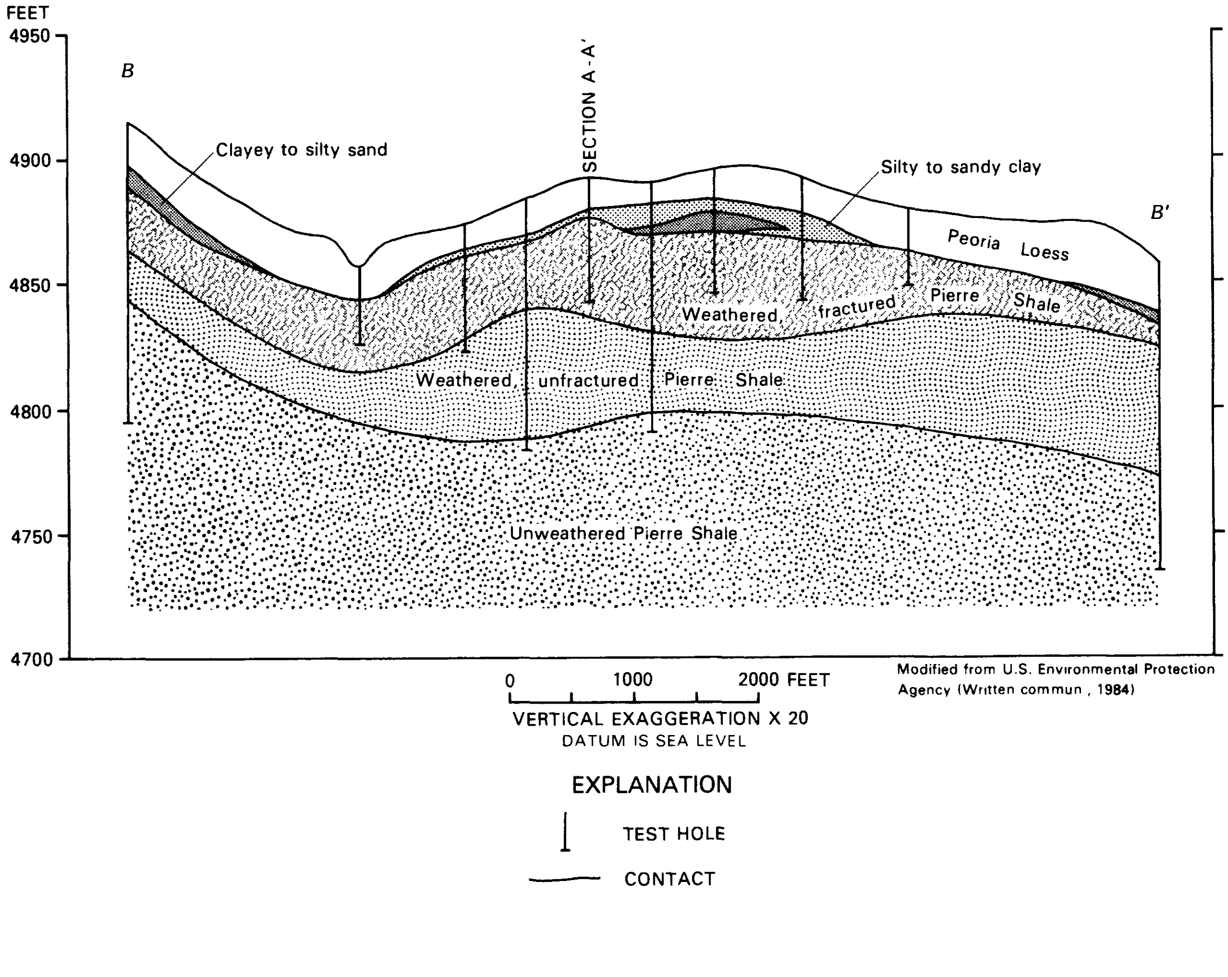
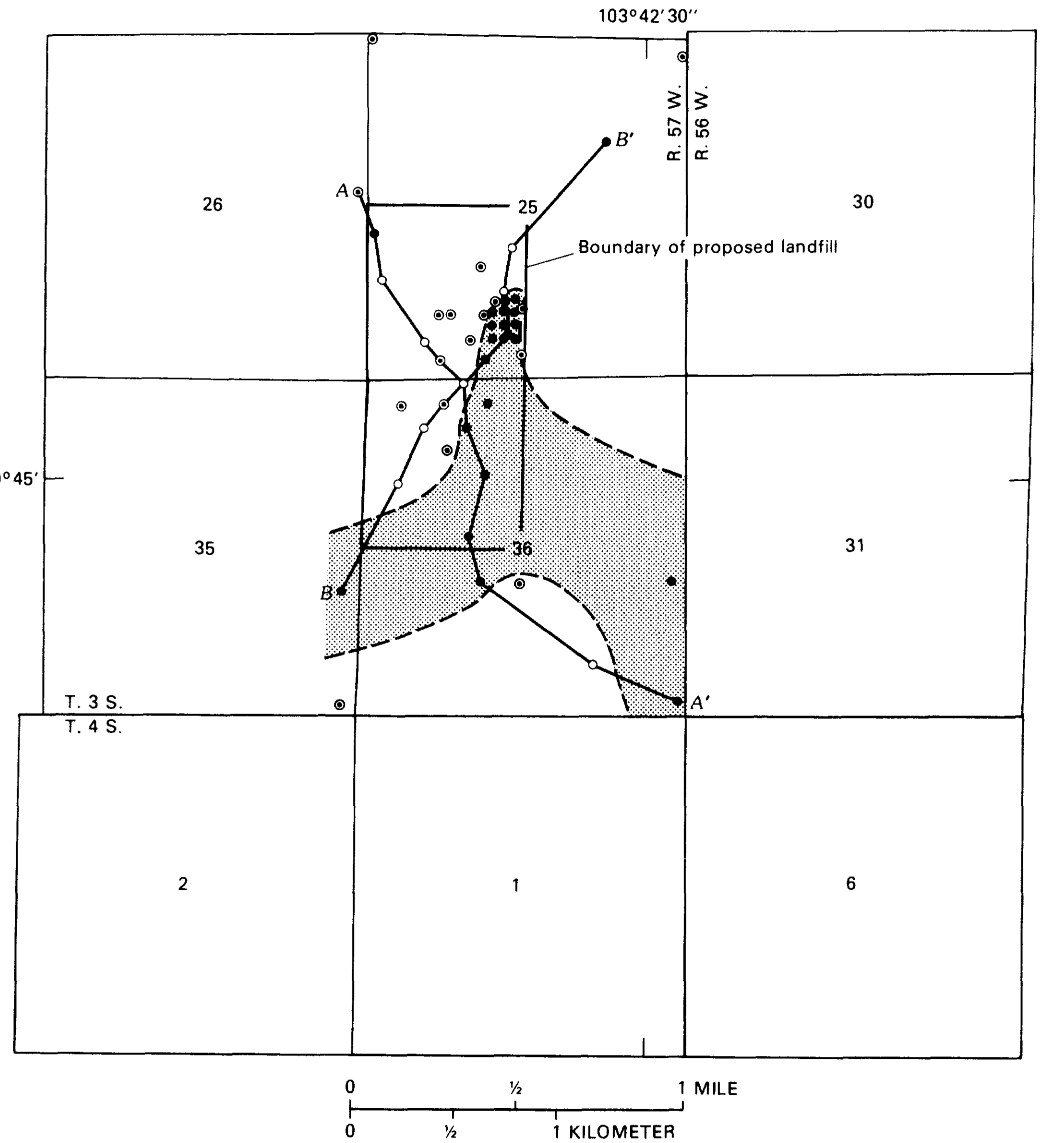


Figure 3.--Geologic section B-B'. (Trace of section shown in figure 4.)



EXPLANATION

SAND LENS

APPROXIMATE BOUNDARY OF SAND LENS

A——A' TRACE OF GEOLOGIC SECTION--Sections shown in figures 2 and 3

TEST HOLE--Sample log shows sand present

TEST HOLE--Sample log shows no sand present

TEST HOLE--Used in geologic section. Sample log shows no sand was penetrated, but test hole well is too shallow to conclude sand is absent in near-surface materials at the location

Figure 4.--Distribution of sand within and adjacent to the site of the proposed landfill.

Although soil and rock below a proposed disposal cell may be unsaturated, the unsaturated condition does not impose an absolute barrier to the downward flow of water, contrary to the assumption made in the application. A zone that is not fully saturated will be variably effective as a barrier, depending on the degree of saturation. A small water content in a porous medium causes relative permeability to water to be small; however, as more water enters the zone, relative permeability increases. A fine-grained material having a water content less than the specific retention tends to imbibe water, if free water is available, because of capillary pressure. For these reasons, the unsaturated zone below the site would become a less effective barrier as saturation increases. Model simulations documented in the application indicate that drainage of the water contained in unsaturated Groups I and II materials occurs. This drainage recharges the uppermost aquifer.

Ability to Monitor the Location

Effective monitoring is dependent on a thorough understanding of the geohydrologic system. Shortcomings in the site characterization inevitably will lead to problems in monitoring the location. Specific inadequacies of the application relevant to this criterion are described in this section.

The characterization of the site in the application is inadequate with respect to: (1) Hydraulic-gradient, (2) location of a background-monitoring site, (3) identification of uppermost aquifer, and (4) potential flow path (see next section). Additional water-level data are necessary to: (1) Define horizontal and vertical hydraulic gradients, (2) delineate areas of perched water, (3) predict flow paths from the site, (4) estimate recharge, and (5) select a suitable background-monitoring site. Only general flow directions (that is, vertically downward and lateral) are described in the application. A more detailed understanding of the possible flow paths and hydraulic gradients is necessary to locate monitoring wells effectively. More data are necessary to determine if, and how, the site can be monitored.

Flow Paths and 100-Foot Time of Travel

Flow paths and 100-ft time of travel are evaluated together because time of travel is dependent on the flow path. Neither flow paths nor times of travel were defined in the application. Detailed analysis of possible flow paths from the proposed site is not possible using the information supplied in the application; however, general flow paths may be inferred. Two possible flow directions were described and modeled in the application: (1) Lateral flow through the Group I material, and (2) vertically downward flow through the Group II material. No further refinement of the geology, beyond the designation Group I or II, was modeled. To represent the flow system more accurately, individual clay and sand lenses of significant size relative to the site need to be considered.

Ground water may flow in the following directions: (1) Vertically downward through the unsaturated zones above the regional water table, (2) laterally and vertically through sand lenses, (3) laterally and vertically through claystone, and (4) laterally through the saturated part of the upper part of the Pierre Shale. Lateral flow in the unweathered shale will be relatively slow because of its small value of hydraulic conductivity (table 3). At places at the site where disposal cells are proposed, sand was encountered about 2 ft below land surface--shallow enough to intersect the proposed cells. These sand zones would provide a short pathway for rapid movement of contaminated water from the active site. Additional drilling is required to delineate the extent of the sand lenses and their hydraulic interconnection to assess their potential for transmitting contaminated water from the site. The assumed flow direction is southeastward from the site.

The 100-ft time-of-travel calculations are summarized in table 4. Average pore velocities were calculated using the following equation:

$$\bar{v} = \frac{K \, dh/dl}{P}$$

where $\bar{v}$ = average pore velocity (length/time);
K = hydraulic conductivity (length/time);
dh/dl = hydraulic gradient (dimensionless); and
P = porosity (dimensionless).

Times of travel for other flow paths are longer, by at least one order of magnitude, than for the flow path through the sand lens. Because none of the hydraulic properties on the right side of the equation are known with certainty, upper and lower limits of a reasonable range for each hydraulic property also are included in table 4. The limit for a particular hydraulic property that would result in a shorter 100-ft time of travel is in the "Conservative estimate" column, and the limit that would result in a longer 100-ft time of travel is in the "Liberal estimate" column. The hydraulic properties in an individual column were used to calculate the 100-ft time of travel in that column.

Table 4.--*One-hundred-foot time-of-travel calculations*

[Flow path: southeastward along the sand lens.
Material: clayey to silty sand]

Hydraulic property and time of travel	Conservative estimate	Best estimate	Liberal estimate
Hydraulic conductivity (feet per day)---	12.0	1.2	0.12
Hydraulic gradient (dimensionless)------	.0198	.0198	.0173
Effective porosity (dimensionless)------	.15	.30	.45
Average pore velocity (feet per day)----	1.6	.08	.005
100-foot time of travel-----------------	9 weeks	3.5 years	59 years

Hydraulic conductivity of the materials along the flow path is dependent on degree of saturation. Although the sand apparently is unsaturated at higher altitudes in the proposed active site, some wells just outside the proposed active site penetrated saturated sand at lower altitudes. During a wet spring, sand in the proposed active site also may become saturated. Normally, most storm water runs off or is evapotranspired; however, if water were to collect in a cell, the likelihood of the sand zones becoming saturated in the event of a leak would increase. For these reasons, the value of hydraulic conductivity used in calculations was assumed to be that for the saturated material (tables 2 and 3). Only one test, a borehole-packer test, was used in determining the hydraulic conductivity of the sand. This type of test generally is reliable; however, because only one test was made, the spatial variability, which may be large, is unknown. For this reason, the limits of a range of values of hydraulic conductivity encompassing two orders of magnitude were used in calculations.

Because the data supplied are insufficient to define the hydraulic gradient, the average land-surface slope, measured between test holes B-4 and G-4 (fig. 2), was used as the hydraulic gradient. This technique, according to the Location Evaluation Methodology, may overestimate hydraulic gradient by as much as 100 percent. However, assuming the sand lens is saturated for part of its thickness and is unconfined between the two test holes used for the time-of-travel estimates, the minimum hydraulic-head difference would be the difference in altitude between the bottom of the sand zone at test hole B-4 and land surface at test hole G-4. This difference is indicated by the liberal hydraulic-gradient estimate.

Because the application does not include any data for either effective or total porosity, the effective porosity of clayey to silty sand is assumed. The Location Evaluation Methodology supplies default values for effective porosity for use in the time-of-travel analysis where the actual effective porosity of the site materials is unknown. The default values are based on the USCS (U.S. Bureau of Reclamation, 1974, p. 1-17). Geotechnical analyses documented in the application indicate that the materials in the sand lenses are in USCS classes SC and SM. For these soil classes, the Location Evaluation Methodology reports an "effective porosity of saturation" of 0.10. However, effective porosity can have either of two meanings: (1) The porosity due to interconnected voids, or (2) specific yield. The first definition is the quantity that would be used to determine average pore velocity in the time-of-travel calculations; however, 0.10 is a likely value for specific yield for clayey to silty sand (Johnson, 1967, p. D8). Freeze and Cherry (1979, p. 149) report a range of values for porosity of clean, eolian sand of 30 to 45 percent. Because the material in the sand lenses is not pure sand, but is clayey to silty sand, the value assumed for effective porosity for the "best estimate" is the low end of the range--30 percent. Effective-porosity values used in the time-of-travel calculations are estimates based on texture and type of material. According to the Location Evaluation Methodology, inherent error may be as large as 100 percent; however, effective porosity of the clayey to silty sand probably is in the range from 0.15 to 0.45.

SUMMARY AND CONCLUSIONS

The proposed hazardous-waste landfill site is not within protected lands. Loess, the surface material at the site, is a weak and unstable soil; therefore, the terrain may be classified as high hazard. The hazard may be mitigated by compacting or removing the loess. Based on the data included in the application, the applicant has not demonstrated ability to monitor the location. Based on interpretation of data supplied in the application, the probable flow path for contaminated water from the site is southeastward along the sand lenses. More core samples and water levels need to be collected to verify this conclusion.

The 100-ft time of travel along a sand lens, based on the best estimates of hydraulic properties, is calculated to be 3.5 years. Factors involved in the estimation are uncertain; thus, the 100-ft time of travel may range from 9 weeks to 59 years. Time-of-travel estimates for other flow paths probably would be considerably larger and would be as variable.

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