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Criteria for Identifying Areas of Vulnerable Hydrogeology Under the Resource Conservation and Recovery Act

Statutory Interpretive Guidance

Guidance Manual for Hazardous Waste Land Treatment, Storage and Disposal Facilities

Interim Final

GUIDANCE CRITERIA FOR IDENTIFYING AREAS OF VULNERABLE HYDROGEOLOGY UNDER THE RESOURCE CONSERVATION AND RECOVERY ACT

RCRA STATUTORY INTERPRETIVE GUIDANCE

Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities

Interim Final

Office of Solid Waste
Waste Management Division
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

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NOTICE

This document has been reviewed by the Science Advisory Board to the Environmental Protection Agency at the request of Marcia E. Williams, Director, Office of Solid Waste. The Board is a public advisory group comprised of expert scientists that provides extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced expert assessment of scientific matters related to problems facing the Agency.

The Environmental Engineering Committee of the Board reviewed this document in draft form between December 1985 and April 1986 and provided comments in a report titled "Report on the Review of the Permit Writers' Guidance Manual for the Location of Hazardous Waste Land Treatment, Storage and Disposal Facilities, Phase II." Comments presented in that report were considered and revisions to the draft were made in preparing this document.

ACKNOWLEDGEMENTS

This manual was prepared by the Waste Management Division of the Office of Solid Waste. Glen R. Galen was the project officer and principal editor. Arthur Day, program manager, and George Dixon and Lauris Davies of the Land Disposal Branch also made major contributions to this manual.

Consultants played significant roles in the preparation of the guidance manual. William Doucette and Donald Lundy of Geraghty & Miller, Inc., and Charles Young, Diane Heineman, Alfred Leonard, Pablo Huidobro, Steven Konieczny, Michael Mills, John Rand, and Robert Clemens of GCA Corporation -- Technology Division, developed technical sections of the manual and provided technical assistance and background information. Joe English and Chris Eddy of Battelle Northwest developed the Technical Resource Documents attached as Appendices to this guidance manual. Jeff Goodman and his staff at ICF, Incorporated conducted an impact analysis of the ground-water vulnerability criteria. Keros Cartwright of the Illinois Geological Survey served as technical advisor to the project and provided thoughtful comment on the approach to location evaluation. Elizabeth Marcotte and Eric Hillenbrand of Sobotka and Company provided assistance in preparing the final version of the manual.

Special thanks are expressed to the personnel of EPA Regional Offices in Regions I, III, IV, V, VI, VII, and IX for technical assistance and support in preparation of the background information for Case Study Appendix E, and for peer review and work group participation in developing the manuals. Special thanks are also expressed to Harry Torno and members of the Environmental Engineering Committee of the EPA Science Advisory Board for their thoughtful review and commentary.

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EXECUTIVE SUMMARY

Section 3004(o)(7) of the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), requires the Environmental Protection Agency (EPA) to:

- Publish guidance criteria identifying areas of vulnerable hydrogeology.
- Promulgate regulations specifying criteria for the acceptable location of new and existing hazardous waste treatment, storage, and disposal (HWTSD) facilities as necessary to protect human health and the environment.

This guidance document responds to the first requirement -- the development of criteria for identifying areas of vulnerable hydrogeology. EPA is developing options to respond to the second requirement and expects to propose regulations in September 1987.

Section 3 of this guidance document specifies the method developed by EPA for determining ground-water vulnerability at hazardous waste facilities.1/ This method requires the calculation of the time of travel (TOT) of ground water along a 100-foot flow line originating at the base of a hazardous waste unit; Figure ES-1 shows an example of such a flow line. The 100-foot flow line distance provides a representative "sample" of the geologic materials at the site and represents a distance that

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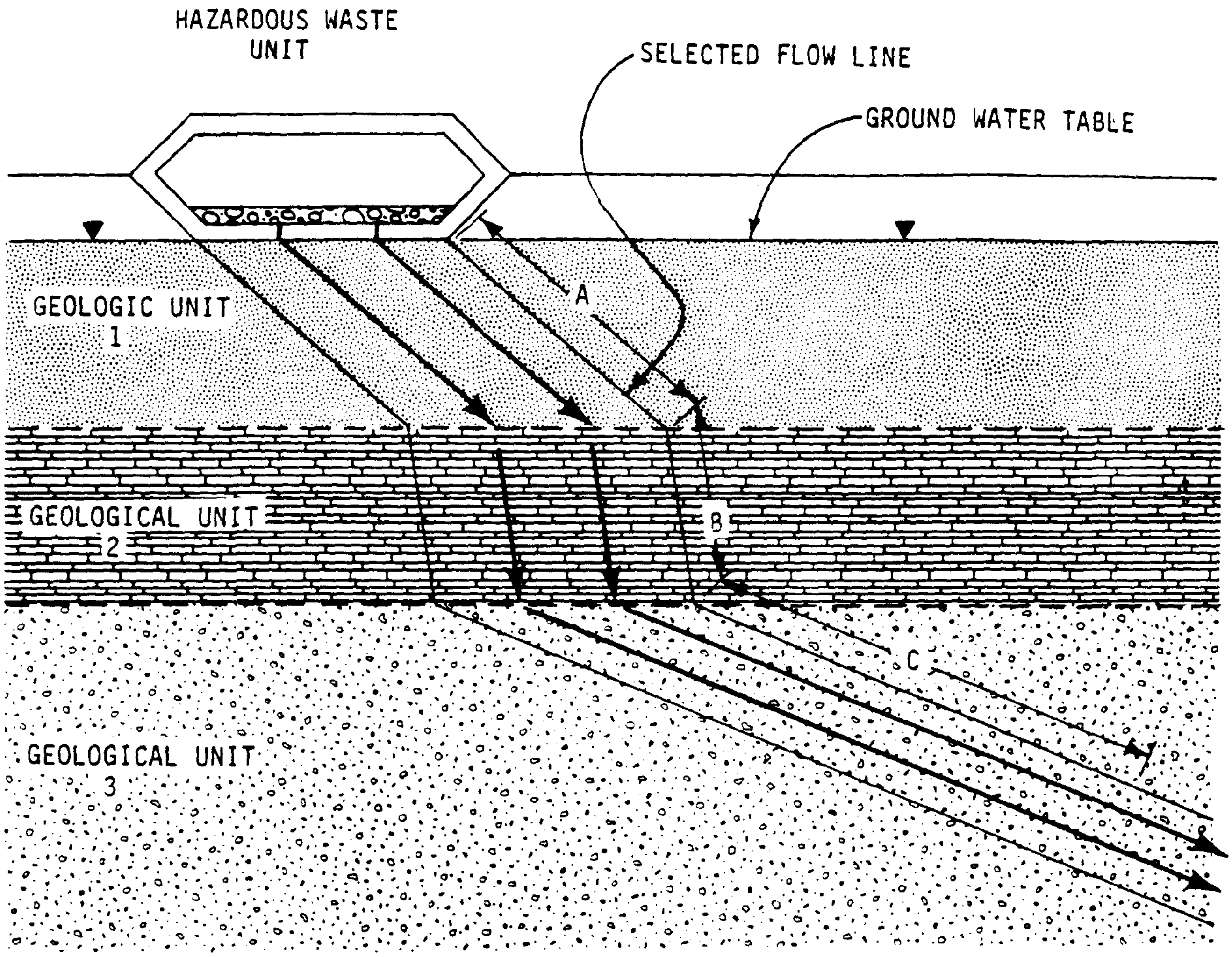
1/ The criteria are applicable only to hazardous waste facilities regulated under RCRA, and are not intended for use under any other statutory program, such as land application of pesticides. This document does not apply to "land treatment units" (or "land farms") regulated under 40 CFR 264 or 265 Subpart M, which characteristically utilize site soils as a treatment medium in which degradation, transformation, or immobilization of hazardous constituents occurs. Rather, this document applies to land-based treatment, storage, and disposal units (surface impoundments, waste piles, and landfills) regulated under 40 CFR 264 or 265 Subparts K, L, and N.

FIGURE ES-1: DIAGRAMMATIC CROSS SECTION OF MULTIPLE GEOLOGIC STRATA SHOWING SELECTED FLOW LINE BENEATH A HAZARDOUS WASTE UNIT



A, B, AND C ARE SEGMENTS OF THE SELECTED FLOW LINE

A + B + C = 100 FEET

EACH GEOLOGIC UNIT HAS DIFFERENT PROPERTIES THAT DETERMINE FLOW LINE DIRECTION a permit applicant is likely to have investigated in collecting hydrogeologic data necessary to meet the permit application information requirements contained in 40 CFR 270.14(c) for preparing a Part B permit application.

Locations with short TOTs (i.e., where the ground water moves fairly rapidly) are considered more vulnerable than those with long TOTs. In general, EPA uses a TOT along a 100-foot flow line (abbreviated "TOT_{100}") on the order of 100 years as the criterion for determining vulnerability. Sites having units used for the disposal of hazardous waste are vulnerable if the ground water takes less than on the order of 100 years to travel 100 feet; sites at which wastes are certain to be removed from land-based treatment or storage units at closure are vulnerable if their TOT_{100} is less than the time needed to implement a corrective action.

An evaluation of many hydrogeologic settings indicates that TOT_{100} values tend to cluster at various points within the continuum of possible values. This clustering of settings indicates that degrees of vulnerability exist, with locations characterized by very low TOT_{100} values being more vulnerable than those with higher values.

EPA expects that a small number of locations that marginally pass or fail the tests will exist. By using values of a general order of years rather than a specific number of years for the teat, EPA is providing the permit writer with discretion both in interpreting the test results and in making a final determination on vulnerability. Situations where units marginally pass or fail the test will require that the permit writer evaluate site-specific conditions, reliability of the sampling data and means of collection used to support the finding, and the basis for the final TOT value reported in more detail.

In constructing flow lines and calculating TOT values using this method, migration through the unsaturated zone is generally not considered in the calculation because at the locations of most existing facilities (in humid areas where recharge to ground water results in a high water table) the effect of the unsaturated zone on TOT is negligible. However, in areas with arid or semi-arid climates and thick unsaturated zones, the unsaturated zone may significantly affect TOT and should be considered in the TOT calculation. A method is provided in Appendix C to this document for incorporating unsaturated zone flow in TOT calculations.

The TOT concept integrates several hydrogeologic parameters into a single measure that reflects the potential for pollutant migration and subsequent human and environmental exposure. EPA developed the method for use with well-prepared, complete permit application data. Its usefulness and reliability depend heavily on the accuracy of application data for hydraulic conductivity, hydraulic gradient, and effective porosity (or gravity drainable porosity) for the entire area of the site.

The Introduction (Section 1) to this document describes how this guidance may relate to the hazardous waste permitting program and other RCRA programs designed to protect ground water. EPA recognizes that vulnerable hydrogeology cannot be the sole determining factor in making permitting decisions regarding certain locations for the purpose of siting or in permitting existing facilities. In general, the TOT method provides a trigger for more detailed review and evaluation of sites that are identified as having possibly vulnerable hydrogeologies. The extent of site review and evaluation necessary is related directly to the margin by which the location fails or passes the vulnerability criteria. Sites that fail by a wide margin would obviously require closer examination than sites that are deemed non-vulnerable. The results of this more detailed review may provide a basis for eventual permit conditions or modifications in design or operating practices. In addition, the Agency is examining hydrogeologic vulnerability and its relationship to corrective action requirements, specific facility design and operating standards, and the hazardous waste land disposal restrictions provision of HSWA in making permitting decisions; the conclusions of this study will serve as the basis for future rule and guidance development.

Section 2 explains EPA's reasons for selecting the TOT method as the basis for determining vulnerability. The TOT calculations can be used to identify those locations that minimize the potential size of a contaminant plume and maximize the time before a release from a unit can reach an aquifer. In addition, the TOT test results, as opposed to criteria based upon a risk analysis or environmental performance approach, can be calculated with relative ease using complete Part B permit application data.

Section 3 presents technical procedures for performing the TOT calculation. Section 4 describes situations where special engineering modifications, such as installing grout curtains, might be used to enhance TOT. Section 5 provides abstracts of supporting documents and references.

Several important technical references are included as appendices to this document. Appendix A, entitled Methods for Evaluating Hydrogeologic Parameters, describes how to determine hydraulic conductivity, gradient, and effective porosity. Appendix B describes how to construct flow nets to understand ground-water flow patterns at hazardous waste facilities. Appendix C describes how TOT can be estimated for the unsaturated zone in areas with arid or semi-arid climates where thick unsaturated zones are common.

Appendix D describes technical analyses of the TOT tests performed by OSW. EPA has assessed the utility of the TOT tests to identify hydrogeologic settings that minimize the potential for exposure to releases of hazardous waste via ground water with risk analyses using actual site performance data and theoretical modeling. Preliminary analysis of 228 HWLTSD facilities indicates that approximately 72 percent of this population is located in a vulnerable hydrogeology. The Office of Solid Waste is continuing its verification analysis of the TOT tests by studying facility performance in a range of geologic settings.

Constructing flow nets for a site and using the vulnerable hydrogeology calculation can provide a tool for ensuring that a location is properly characterized and the ground water at the site can be properly monitored. Site Characterization and the Ability to Monitor are two criteria discussed in the Phase I Location Guidance Manual that the facility owner or operator must meet as required by RCRA.

The TOT method is also useful in identifying the potential for the "basement seepage pathway," which is one way by which the public can be exposed to contaminated ground water. Once this pathway is identified, it might be minimized or eliminated by making certain facility design modifications. The basement seepage pathway is discussed in further detail in Section 2, as well as in Section 3.7 of Appendix D.

Alternate Concentration Limits (ACLs) are granted by EPA through the permitting process under RCRA Parts 264 and 270 and are established in the context of the facility Ground-Water Protection Standard under Section 264.92. The finding that an ACL is warranted at a specific facility is based on a sophisticated, site-specific analysis. Because of this, the Agency considers an approved ACL demonstration as taking precedence over a determination that the facility is in a vulnerable hydrogeology.

This document is being released as "Interim Final" Guidance to allow EPA to revise the manual if technical inaccuracies exist. An earlier draft (November 1985), referred to as the "Phase II" Location Guidance Manual, was reviewed by the Environmental Engineering Committee of the EPA's Science Advisory Board. This Vulnerable Hydrogeology Guidance reflects the Committee's comments and replaces the draft Phase II.

EPA will separately publish a notice in the Federal Register at a future date announcing the availability of a RCRA Technical Resource Document entitled, Methods for Evaluating Facility Location and Facility Case Studies. This document is a technical illustration of the application of both the TOT method and four criteria for facility location published by EPA in February 1985 in the document entitled, Permit Writers' Guidance Manual for Hazardous Waste Land Storage and Disposal Facilities - Phase I-- Criteria for Location Acceptability and Existing Applicable Regulations.

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1.0 INTRODUCTION

Section 3004(o)(7) of the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), requires EPA to:

- o Publish guidance criteria identifying areas of vulnerable hydrogeology.
- o Promulgate regulations specifying criteria for the acceptable location of new and existing hazardous waste treatment, storage, and disposal (HWTSD) facilities as necessary to protect human health and the environment.

EPA has prepared this manual in response to the first of these requirements. EPA is studying options to respond to the second of these requirements and intends to propose regulations specifying criteria for acceptable locations of new and existing HWTSD facilities by September 1987.

The purpose of this manual is to provide RCRA permit writers with a standardized technical method (or technical "guidance criteria") for evaluating hydrogeologic data submitted in permit applications for hazardous waste land treatment, storage, and disposal facilities[1/] to determine if the facilities are located in "areas of vulnerable hydrogeology." Although not specifically defined in HSWA, EPA considers "areas of vulnerable hydrogeology"

1/ The criteria are applicable only to hazardous waste facilities regulated under RCRA, and are not intended for use under any other statutory program, such as the land application of pesticides. This document does not apply to "land treatment units" (or "land farms") regulated under 40 CFR 264 or 265 Subpart M, which characteristically utilize site soils as a treatment medium in which degradation, transformation, or immobilization of hazardous constituents occurs. Rather, this document applies to land-based treatment, storage, and disposal units (surface impoundments, waste piles, and landfills) regulated under 40 CFR 264 or 265 Subparts K,L, and N.

to be areas in which the predominant natural hydrogeologic conditions are conducive to the subsurface migration of contaminants in a manner that may adversely affect drinking-water sources, sensitive ecological systems, or nearby residents. EPA believes that the intrinsic hydrogeologic vulnerability of a HWLTSD facility's location is one of several key determinants of the facility's long-term success in minimizing contaminant migration (other determinants include, for example, leaching properties of the waste). If both the engineered components (e.g., liners and cap) and the ground-water monitoring and response program should fail in some way at a facility, the effects of the resulting release of hazardous constituents on human health and the environment might differ significantly depending upon the hydrogeologic vulnerability of the location.

EPA intends to incorporate consideration of the hydrogeologic vulnerability of a facility's location into RCRA permitting decisions. Currently, EPA will be able to do so to only a limited extent due to the constraints of existing regulations. However, once regulations specifying criteria for acceptable location required under HSWA §3004(o)(7) have been promulgated, EPA will have much greater flexibility in considering the hydrogeologic vulnerability of a facility's location in permitting decisions.

EPA is currently developing a strategy for integrating existing and planned regulations and guidance developed or being developed in response to HSWA provisions (including minimum technological requirements, land disposal restrictions, location, and corrective action) by determining their relationship to one another and the Agency's Ground-Water Protection Strategy. When completed, this Integrated OSW Ground-Water Strategy will outline EPA's policy under existing regulations for evaluating permitting situations where either considering variances to standards or applying additional permit conditions may be appropriate, based upon the characteristics of the facility, its location, and the wastes accepted. The Strategy will also provide policies to be considered during future rulemaking, including that for Location Standards.

The Integrated OSW Ground-Water Strategy, and certain ways in which hydrogeologic vulnerability may eventually be considered in permitting decisions, are discussed briefly in Section 1.1 below. Section 1.2 discusses how the permit writer should use this document pending completion of the integrated strategy and promulgation of regulations for the location of HWLTSD facilities.

1.1 THE INTEGRATED OSW GROUND-WATER STRATEGY

OSW is developing an Integrated Ground-Water Strategy that will, among other things, consider how hydrogeologic vulnerability may be applied to facility permitting decisions. In addition, it will evaluate the relationship of each of the major components of the RCRA program mandated by HSWA. The Integrated OSW Ground-Water Strategy is, in part, a response to the Agency's 1984 Ground-Water Protection Strategy (GWPS), which called for program offices to develop policies for ground-water protection against a broad framework of ground-water classification and protection. Although OSW continues to support the ground-water classification framework proposed by the GWPS, the passage of HSWA necessitates a RCRA Strategy implementing that framework that differs from the examples provided in the 1984 Strategy (which predates HSWA).

Also in the context of the Integrated OSW Ground-Water Strategy, OSW is considering whether the vulnerability criterion might be used as a factor in considering waivers or variances from existing liner design requirements. For example, impoundments located in non-vulnerable areas might be candidates for a variance from the interim status surface impoundment liner retrofitting requirement as provided under §3005(j)(4). Likely, alternate liner designs, compared with those specified in the manual entitled, Minimum Technology Guidance on Double Liner Systems for Landfills and Surface Impoundments, EPA-OSW, May 24, 1985 (EPA/530-SW-85-014), might be considered for non-vulnerable areas. Furthermore, OSW is also considering using the vulnerable hydrogeology guidance criteria as a factor in evaluations under the hazardous waste delisting petitions program, exposure assessment evaluations under §3019, corrective actions under §3004(u), and closure plan evaluation.

Regulations being developed to implement the land disposal restriction and location criteria requirements of HSWA will expand the regulatory basis for establishing additional permit conditions as necessary to protect human health and the environment. The RCRA location standards will consider a number of risk-related factors, as discussed in the Agency's Regulatory Development Plan for Location Standards. Location factors under review include:

- o the vulnerable hydrogeology criteria, reflecting the site's natural ability to minimize release migration;
- o the degree of current contamination;
- o the feasibility of performing corrective action;
- o ground-water use and value factors (e.g., the ground-water classification framework of the EPA Ground-Water Protection Strategy); and
- o the relationship or representativeness of local versus sub-regional hydrogeology.

OSW is considering whether the hydrogeologic vulnerability criteria could be used to identify locations where additional permitting standards would be adequate to provide additional protection, or locations where waivers or variances are most appropriate. For example, the vulnerability criterion may be used as a trigger for considering more stringent permit requirements, such as:

- o Precluding petition demonstrations under the land disposal restrictions program in settings characterized by complex hydrogeology.
- o Specifying more stringent corrective action requirements, and possibly waste removal, in certain areas with highly vulnerable hydrogeology.
- o Requiring waste removal at closure (clean closure) in certain sensitive or highly vulnerable locations.
- o Requiring more stringent unit designs and operating controls in certain locations. For example, additional engineered barriers (e.g., grout curtains) in areas where shallow subsurface flow of waste constituents may present a risk via the "basement seepage pathway" (This pathway is described briefly in Section 2 and in Appendix D).

OSW has not yet completed its assessment of potential uses for the hydrogeologic vulnerability criteria in evaluating additional permit conditions or requests for variances or waivers. The above examples of possible additional variances or requirements have been provided for illustrative purposes, and may not be included in final policy on the use of the criteria.

1.2 INTENDED USE OF THIS DOCUMENT

This document provides technical guidance criteria, in the form of a uniform method, to be used by permit writers in evaluating hydrogeologic data necessary to meet the permit application information requirements contained in 40 CFR 270.14(c) and submitted in RCRA Part B permit applications for hazardous waste facilities. Permit writers should use this method as guidance for determining the adequacy of the permit applicant's site characterization, evaluating the applicant's plans to monitor ground water at the site, determining the adequacy of hydrogeologic data submitted in permit applications, and identifying RCRA facilities located in areas of vulnerable hydrogeology.

The evaluation of flow lines at the location, together with the use of the TOT criteria, provide an excellent means of verifying whether the location can be properly characterized and whether the hydrogeologic conditions at the site are appropriate for proper ground-water monitoring. Permit writers are encouraged to use the guidance provided in the document and its appendices to construct ground-water flow nets for facility locations as a means of performing these activities, and to request, where appropriate, that applicants install additional piezometers as part of any further hydrogeologic studies they plan to perform in order to verify hydrogeologic information provided in the application.[2/]

Where results of the method indicate that a facility is located in an area of potentially vulnerable hydrogeology, the permit writer should undertake a more detailed evaluation of site characteristics and of the mitigation techniques proposed by the owner or operator, or require additional permit conditions or a contingent corrective action plan using existing regulatory authority under RCRA, to assure that ground-water contamination will be prevented or responded to quickly. Thus, the results obtained using this method should be used as a screen to determine the need for and degree of a detailed evaluation of site hydrogeology and of additional means for preventing ground-water contamination which may be necessary at the facility.

Additional permit conditions for facilities located in areas of vulnerable hydrogeology would not be necessary in the case where an owner or operator has successfully demonstrated that alternate concentration limits (ACLs) in the Ground-Water Protection Standard are justified. ACLs are granted by EPA through the permitting process under RCRA Parts 264 and 270 and are established in the context of the facility Ground-Water Protection Standard under Section 264.92. The finding that an ACL is warranted at a specific facility is based on a sophisticated, site-specific analysis. Because of this, the Agency considers an approved ACL demonstration as taking precedence over a determination that the facility is in a vulnerable hydrogeology.

[2/]Additional hydrogeologic studies should not be required or requested by the permit writer solely for the purpose of considering the question of vulnerability.

2.0 TECHNICAL BACKGROUND

The common definition of vulnerable is "capable of being physically wounded" or "open to attack or damage." This meaning may be applied to the concept of ground water and how vulnerable it is to contamination in various locations having certain hydrogeologic conditions. EPA considers ground water to be vulnerable if it is subject to "damage" by the introduction of contaminants that may easily enter the ground water and affect drinking-water sources, sensitive ecological systems, and other exposure pathways.

EPA is concerned that ground-water contamination, and potentially resulting human and environmental exposure, can occur as a result of failures of engineered controls and barriers, from human oversight, or after the end of the post-closure care period established by the current facility permitting standards. Once such contamination occurs, it can be both difficult and costly to clean up.

Determining how ground water can be vulnerable to contamination involves understanding the potential human and environmental pathways for exposure to such contamination. As the case studies in Appendix D illustrate, there are three general forms of potential exposure to contaminated ground water. The first is the well-recognized water well pathway, in which an aquifer contaminated by hazardous waste leachate is used to supply water for residential, commercial, agricultural, or industrial uses. The second means of exposure can occur when contaminated ground water discharges to surface waters, thereby endangering both the surface-water ecosystem and water users downstream. The third is herein termed the basement seepage pathway. Human exposure can occur when contaminated ground water seeps into residences through utility line apertures or walls. When these structures are permanently or seasonally affected by a shallow saturated zone which can be contaminated by releases from a waste management unit, the potential for contamination via the basement seepage pathway exists; this pathway is illustrated in Section 3.7 of Appendix D.

EPA believes that the ground-water vulnerability definition should respond to concerns for all three general pathways. EPA has investigated several methods or tests that could be used to identify vulnerable hydrogeology. The following sections discuss the criteria EPA used in evaluating these methods, the methods considered, and the method selected.

2.1 NECESSARY CHARACTERISTICS OF METHODS FOR IDENTIFYING VULNERABLE HYDROGEOLOGY

To evaluate alternative methods for identifying areas of vulnerable hydrogeology, EPA first determined the characteristics that an acceptable method should have in order to be useful within the structure of the permitting program. EPA decided that the tests should have the following characteristics:

- Their use should generally require no more information about the facility than that already required in Part B permit applications (see Section 270.14(c) for permit application information standards related to ground water).
- They should not require predictive analyses that require (1) unreliable estimates of technical parameters, and (2) parameters that the permit applicant or permit writer would find difficult to obtain.
- They should be reasonably predictive of results of more data-intensive analyses that could be used to evaluate hydrologic, geologic, and pedologic conditions at the facility location. They should also be flexible enough to make use of additional data that the permit applicant may provide to supplement a permit application.

- They should be consistent with EPA's overall policy for facility siting, which is that the location should serve to minimize the potential for exposure to wastes and constituents released as a result of the failure of engineered containment barriers such as liners and caps, or as a result of failure to operate the facility in accordance with standards.

- They should not unduly restrict the ability of the regulated community to find locations that conform to the definition. Nonvulnerable settings should be available within each major region of the Nation. An overly conservative definition that excluded all but a very small percentage of the land area, particularly if this area was found only within one Region, could encourage illegal disposal. This would obviously be counterproductive to EPA policy to minimize the potential for exposure to wastes.

- They should not unduly conflict with existing State siting criteria.

- Their use should be within the technical capabilities of owners and operators, professional consultants, and EPA Regional Office and State Agency permit writers.

2.2 APPROACHES CONSIDERED BY EPA

EPA examined the suitability of three general approaches against certain characteristics, which were:

- Parametric Criteria: Ground-water vulnerability would be based on one or more hydrogeologic parameters, such as maximum acceptable soil permeability or minimum acceptable depth to the water table beneath the hazardous waste management unit.

- Risk or Environmental Performance Criteria: A non-vulnerable location would be identified when a site-specific technical demonstration showed that the concentrations of hazardous constituents (or some surrogate) measured at some point of concern would be within certain environmental performance or health risk limits in the event of a release of hazardous constituents to the ground water.

- Integrated Criteria: Under this approach, a number of closely related geologic and hydrogeologic parameters would be collectively analyzed, with a result that describes the ability of the location to minimize the potential for exposure to releases.

Each of these approaches is discussed in more detail below.

2.2.1 Parametric Criteria

EPA does not believe that the use of a single geologic or hydrogeologic parameter is the best way to meet the overall objective of the vulnerability criterion, which is to minimize the potential for exposure. Using single properties of a location alone, e.g., depth to ground water, to characterize a setting provides limited technical information that would be inadequate upon which to base a decision about vulnerability of ground water. Single properties cannot be easily isolated from other hydrogeologic factors needed to describe the performance characteristics of a geologic terrain.

EPA examined criteria used by States for controlling the location of hazardous waste land disposal facilities. This analysis is available in the report entitled, Review of State Siting Criteria for the Location of Hazardous Waste Land Treatment, Storage, and Disposal Facilities (EPA, OSW, 1984, Draft Final). A significant conclusion from this examination is that a definition based on parametric criteria alone would be extremely difficult to apply in many States. This is due to the fact that a number of States have different numerical standards for the same parameter (e.g., permeability, depth to water, soil texture). An EPA definition based on such parameters might conflict with existing State programs and create difficulties for a State seeking authorization under Section 3006 of RCRA, if EPA tests for vulnerability were codified in a facility location standard. The States will undoubtedly have to amend their regulations to adopt Federal rules.

However, in instituting any new requirements EPA will attempt to minimize conflicts with existing State programs.

2.2.2 Risk or Environmental Performance Criteria

Of the possible criteria that can be used to define a vulnerable hydrogeology, EPA believes that well-conceived risk performance criteria, if properly conducted and supported with adequate data and analysis, can provide a sound basis for permit decisions. However, due to its complexity and data intensiveness, risk analysis may not always be a feasible means for determining vulnerable hydrogeology. Risk or environmental performance criteria require a predictive analysis of the fate and transport of hazardous constituents from the releasing unit. Although such analyses for certain chemicals may be possible (i.e., an alternate concentration limit (ACL) demonstration), most typically require detailed knowledge of the chemical composition of the waste or leachate as it enters the underlying soil or the ground water, and a sophisticated understanding of attenuation reactions and mechanical dispersion.

EPA rejected this approach because it is inconsistent with most of the initial objectives for the definition of criteria for a vulnerable hydrogeology (see Section 2.1). These analyses commonly employ numerical modeling to solve the many equations describing ground-water flow and solute transport. In addition, a risk-based approach presumes an adequate understanding of the toxicologic properties of all potential constituents in isolation or in mixtures. While EPA has such understandings of toxicology for many chemical compounds regulated under other EPA programs, its data base is incomplete for most hazardous waste streams and complex leachates. Regardless of the state of knowledge of toxicology, the application of fate and transport analysis requires sophisticated expertise and data typically unavailable in a permit application. In addition, a number of key parameters used in the analysis, such as constituent attenuation and dispersion, and the nature of the source term (i.e., waste or leachate composition and volume) must be estimated using professional judgment. Compounding this is the fact that some attenuation reactions, such as cation exchange, are reversible.

2.2.3 Integrated Criteria

EPA believes that an integrated approach is the best way to meet the objectives of the vulnerable hydrogeology definition. The Time of Travel (TOT) test outlined by EPA in this manual and described in detail in Section 2.3, integrates information on geologic characteristics and the direction and rate of ground/water flow that should be provided in a complete Part B permit application, as required by the permit application information requirements under 40 CFR 270.14(c). The test does not require predictive analyses of the fate and transport of waste constituents. It also does not create a potential for significant conflict with State policies because it establishes a method of site analysis that can be easily applied to most (if not all) current State rules. Use of the TOT method supports two of the location criteria developed by EPA under existing regulations (i.e., the ability to characterize a site and the ability to monitor a site), which were published in the Permit Writers' Guidance Manual for Hazardous Waste Land Storage and Disposal Facilities - Phase I (EPA, OSW, 1984, Final Draft), because the information needed to address those criteria is also used in the analysis of ground-water vulnerability. The technical expertise needed to apply the definition is well within the capabilities of permit applicants and those permit writers who are already responsible for assessing compliance with the ground-water monitoring standards.

Finally, EPA believes that the test method described in the next Section is justified by analyses of exposure potential and health risk using actual facility performance data and theoretical modeling. As discussed in Appendix D, EPA has calibrated the vulnerable hydrogeology definition using such performance data and theoretical modeling. This calibration shows that the integrated criteria approach (i.e., Time of Travel) is not arbitrary; rather, it provides an initial indication of those locations at which the potential for adverse exposure is significant and it can be consistent with the results of more sophisticated analyses in many situations.

The use of an integrated approach to define the potential for contaminants to enter the ground water is being used by other Agency offices. For example, the Office of Pesticide Programs and the Office of Ground-Water Protection are studying "DRASTIC," a standardized system for evaluating ground-water pollution potential using hydrogeologic settings. The system has two major portions: (1) the designation of large, mappable geologic units termed hydrogeologic settings, and (2) the superposition of a relative rating system that incorporates several hydrogeologic factors.

2.3 TIME OF TRAVEL (TOT) TESTS FOR IDENTIFYING VULNERABLE HYDROGEOLOGY

Certain hydrogeologic settings are characterized by conditions that make the ground-water resource at a site particularly vulnerable to contamination in the event of a release from a facility. EPA has selected an integrated Time of Travel method as a means of rationally considering the principal hydrogeologic parameters that determine ground-water vulnerability to contamination using one unified calculation. In the TOT method, hydrogeologic vulnerability is determined by calculating the TOT of water along the first 100 feet of a ground-water flow line originating at the hazardous waste management unit. This calculation, abbreviated as the TOT_{100}, requires data on hydraulic conductivity (also often called permeability), the hydraulic gradient, and the effective porosity of sediments (or gravity drainable porosity of rock).

Using this calculation, ground water at a site is characterized as nonvulnerable to contamination from land-based hazardous waste management activities by its natural hydrogeologic conditions if these ground-water flow conditions are characteristic of aquitards (or in some senses, aquicludes); ground water is vulnerable if flow conditions are characteristic of aquifers. EPA has analyzed the characteristic TOT_{100} values of aquitards and has found that these values are clustered around 100 years or more. Therefore, EPA intends to use TOT_{100} values on the order of 100 years or greater as characteristic of aquitards. These conditions define non-vulnerable hydrogeologies for RCRA hazardous waste land disposal facilities only. For those land storage or treatment facilities where it is certain that wastes will be removed at closure, the vulnerability of the ground water is related to the time that would be necessary to correct a problem in the event that design and operating controls in place at the facility failed. The objective of the TOT_{100} calculation should be to determine whether contamination could migrate beyond this distance in less time than is needed to effectively recognize and respond to a release through successful implementation of a corrective action plan under Section 264.100. This determination must be site-specific. Permit writers should be sure to first determine that wastes and contaminated soils will indeed be removed from the site at closure before considering a vulnerability for TOT_{100} that is less than on the order of 100 years. Permit writers should closely examine the owner or operator's closure plan and financial assurance for closure in making this determination.

The general definitions of aquitard and aquifer are somewhat imprecise because, when applied to a specific location, strata are considered aquifers or aquitards based upon the relative flow conditions in the strata at that location and on the ability of the geologic materials to bear ground water.

An aquifer is defined in EPA's hazardous waste regulations at 40 CFR 260.10 as a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of ground water to wells or springs. An aquitard is not similarly defined, but is considered in the professional liturature to have a permeability that is not sufficient to allow the completion of production wells within it (Freeze and Cherry, <u>Groundwater</u>, 1979, pg.47). The term aquiclude, as classically defined, is a saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients (Ibid). Very few formations fit this definition, in that most formations contribute ground water to regional flow systems over very long (or geologic) periods of time. EPA considers the term "aquitard" to best characterize geologic formations with TOT_{100} that are on the order of 100 years or more.

As long as contaminated ground water is entrained within the aquitard, human exposure via drinking water exposure should not occur. Similarly, exposure through the "basement seepage" pathway is unlikely, provided that there are no sand lenses or soil fractures within the aquitard to transmit flow. Such features should be identified during the flow-line characterization process described in Section 3; case studies in Appendix D illustrate this analysis procedure.

EPA believes that aquitards minimize the potential for exposure to wastes released from units as a result of failures of engineered barriers or human action by acting as passive control systems. A location with a short TOT implies both a higher rate of potential migration of contaminants, and a higher volume of ground-water flow. This is because both TOT (or seepage velocity) and flow volume (or specific discharge) are directly proportional to hydraulic conductivity and hydraulic gradient. Similarly, a location characterized by hydrogeologic conditions that encourage a long TOT minimizes the potential for exposure to a release both in terms of time and volume of potentially contaminated ground water.

A 100-foot flow line for the interval over which the travel time calculation is to be made represents a distance that a permit applicant is likely to have investigated for the Part B permit application. This distance should provide a fairly representative "sample" of the geologic materials at the site. Investigations over a shorter distance might fail to encounter important geologic units (e.g., sand lenses) or structures (e.g., fracture zones, solution cavities) that if present, could influence the rate and direction of ground-water flow. Investigations over a larger interval might require an applicant to gain access to adjoining properties for test drilling. If access were refused, neither the applicant nor EPA could reliably apply the definition to the site.

If the permit writer encounters a case where such non-vulnerable aquitards overlie, for example, a major high yielding aquifer, then data should be examined, as feasible, to determine the degree to which the 100-foot distance is representative of the local ground-water flow system, and hence, of risk of exposure.

EPA is further analyzing the time period used to characterize a vulnerable hydrogeology by evaluating numerous facility case studies, but considers the 100 year timeframe to be supported by analyses already completed. Appendix D describes this analytical work. Generally, the analyses show that locations tested have clearly either passed or failed the TOT tests by a wide margin. The pattern evolving from the analyses completed to date show very few locations that fall very close to the 100-year level.

However, EPA expects that a small number of locations that marginally pass or fail the tests will exist. By using values of a general order of years rather than a specific number of years for the test, EPA is providing the permit writer with discretion both in interpreting test results and in making a final determination on vulnerability. Situations where units marginally pass or fail the test will require the permit writer to evaluate site-specific conditions, reliability of the sampling data and means of collection used to support the finding, and the basis for the final TOT value reported, in more detail. In certain hydrogeologic settings that marginally pass or fail the TOT test, use of additional containment barriers, such as slurry walls and grout curtains, may be appropriate means of modifying facility design and operation to enhance meeting the TOT criterion. Section 4 describes the conditions where the permit writer may want to consider additional containment barriers.

2.3.1 Distinction between Treatment or Storage Units and Disposal Units

EPA believes that a distinction in the TOT tests for treatment or storage facilities and for disposal facilities is warranted in certain situations. The distinction is justified by a comparison of potential exposure and health risk at sites where wastes are present for a finite period with sites at which wastes are present indefinitely. This analysis is described in Section 2.0.2 of Appendix D.

A shorter time frame for land-based treatment or storage units may be justified for several reasons. Wastes and contaminated soils are removed from treatment or storage units at the time of their closure while wastes remain in disposal units after closure.

The owner or operator of a treatment or storage unit is present at the facility during this operating period to conduct ground-water monitoring and response activities. Thus, the potential for exposure to contaminated ground water as a result of waste constituent discharges from treatment or storage units during their operating period should be less than the potential that exists after the owner or operator's period of responsibility for monitoring and response ends. This means that a greater range of hydrogeologic conditions at locations reflected by the shorter TOT test time frame can be tolerated for treatment or storage units. The criterion for treatment and storage units is proposed as a margin of safety to identify locations where a release could rapidly develop into a large, extensive plume of contamination before a corrective action could be effective. Instituting an effective corrective action program at any location, be it a storage or disposal facility, will take some time, especially in situations where a contaminant plume is large. The permit writer should first determine that the unit will, in fact, be closed as a storage unit, and not as a disposal unit. The time needed to detect a release that requires corrective action, to modify the permit to implement this action, and to have this action succeed are site-specific. Times for these factors should be less than the TOT calculation for the 100-foot flow distance at the site.

2.3.2 Use of Engineered Barriers

A significant issue is the extent to which special engineering methods might be used to modify ground-water flow patterns and velocity at a site, thereby changing the TOT at the site to bring the test value within a more acceptable range. The starting point for the flow lines used in the TOT_{100} analysis is at the base of the treatment, storage, or disposal unit. This point is beneath or beyond any synthetic liner and leachate collection system. The very purpose of the vulnerability criterion is to describe locations that minimize the potential for exposure in the result of failure of engineered containment barriers (i.e., synthetic liners, caps). Thus, it would be inconsistent with this purpose to allow a time credit for those barriers. It is also difficult to know whether or when synthetic barriers might fail (i.e., release wastes beyond the initial design specifications of the barrier).

The flow line should, however, include well constructed clay liners that may underlie synthetic liners and leachate collection systems as part of a composite liner system. While clay liners are engineered structures, they are composed of materials that are similar or identical to existing, naturally occurring soils at the site. It would be inconsistent not to consider clay barriers at a site in the TOT calculation solely because they were placed there by human action rather than by natural occurrences. Before considering any clay barrier, the material must meet the minimum technology requirements and construction quality assurance for clay liners. Minimum technology requirements are discussed in the manual entitled, Minimum Technology Guidance on Double Liner Systems for Landfills and Surface Impoundments, EPA-OSW, May 24, 1985, (EPA/530-SW-85-014). Quality assurance for the construction of clay liners is discussed in the manual entitled, Construction Quality Assurance for Hazardous Waste Land Disposal

Facilities, EPA-ORD/OSW, October 1985, (EPA/530-SW-85-021).

Additionally, the Agency believes that engineering methods beyond those already required in the facility permitting standards can also be used to increase travel time at specific types of locations. Section 4.0 describes those situations in detail. In general, slurry walls or grout curtains can be considered for use as passive barriers to flow at sites that predominantly meet the TOT_{100} tests (i.e., within 25 percent) based solely on the geologic terrain beneath the site. Some locations composed predominantly of clayey sediments may have minor, thin sand lenses interspersed through the clays. A slurry wall or grout curtain used to impede flow through such small lenses could be an acceptable engineered modification.

Engineered structures would not be acceptable in all locations because these structures may serve as only temporary measures in reducing TOT where the site is predominantly unsuitable. Ground-water flow in geologic settings characterized by complex fracturing of rock and sediments, and thick layers of sand and gravel can be temporarily adjusted by slurry walls or grout curtains. Use of these devices might cause the location to temporarily meet the TOT_{100} tests. However, engineered structures used in such predominantly unsuitable locations are likely to eventually fail, and might not be adequately constructed, just as synthetic liners and covers. These geologic settings would not predominantly meet the TOT_{100} tests if engineered structures were absent, and are not appropriate for considering engineered modifications.

3.0 TECHNICAL METHODS TO DETERMINE GROUND-WATER VULNERABILITY

To determine ground-water vulnerability, a time-of-travel (TOT) calculation is performed to estimate how long a contaminant moving at the velocity of ground water will take to migrate the first 100 feet along a ground-water flow line originating at the base of the hazardous waste management unit. The 100-foot distance is a criterion that is easily comprehended and that in most cases should be within the facility boundary. The chosen flow path should exhibit the fastest migration route; this should represent the "worst case" condition at the location. Appendix B describes how flow nets can be used to identify these flow paths. Care should be exercised to ensure that the flow net includes the effects of regional geologic structures (e.g., large-scale fracture patterns or formation discontinuities), so that these effects are integrated into the 100-foot flow path to adequately represent migration at the site.

TOT along the potential constituent release flow path(s) provides both a relative measure of the protection offered by a natural ground-water flow system and a means of comparing the range of natural hydrogeologic systems. Appendix D of this document, and the Technical Resource Document entitled, Technical Methods for Evaluating Facility Location, present TOT analyses for selected case studies.

The following sections explain the use of the TOT tests, and describe how initial calculations can be modified to account for data reliability and additional engineered containment.

3.1 INFLUENCE OF THE UNSATURATED ZONE

The calculation of time of travel in this guidance manual is restricted to flow in the saturated zone. A determination of flow velocities in the unsaturated zone requires extensive characterization of soil moisture content, capillary pressure, head (tension), and hydraulic conductivity relationships. Typically, unsaturated hydraulic conductivity and effective porosity values are orders of magnitude less than those values measured under saturated conditions. However, information on such unsaturated zone properties is not explicitly or routinely required in a Part B application. If the depth to water is relatively shallow, the permit applicant or permit writer can assume that the thickness of the unsaturated zone does not significantly influence the TOT_{100} calculation. The Agency thinks that the contribution of the unsaturated zone to time of travel is insignificant at most facility locations, with the exception of sites in arid or semiarid climates (e.g., certain portions of the Basin and Range Province of the western U.S.). Where the unsaturated zone is of a significant thickness greater than tens of feet (e.g., 50 feet), its influence on time of travel can be estimated by using the methods described in Appendix C.

3.2 TIME OF TRAVEL (TOT) ANALYSIS

Time of travel (TOT) in a saturated, porous flow regime is calculated from the following equation:

$$\text{Time} = \frac{\text{Travel Distance}}{\text{Seepage Velocity}} \quad (1)$$

Based upon the vulnerability criterion, Travel Distance is set at 100 feet. For a site to have non-vulnerable hydrogeology, the calculated TOT must be on the order of 100 years for waste management units located over ground water. As the final factor in the equation, the ground-water velocity term consequently dictates whether a facility passes the TOT tests.

The velocity calculation uses information required in a Part B permit application specific to ground-water flow; data concerning waste constituent transport, such as dispersion, are not required. The seepage velocity term used in the TOT equation is an average linear velocity, $\overline{V}$, derived from Darcy's equation for saturated flow:

$$\overline{V} = \frac{K\ I}{n_e} \qquad (2)$$

where K is saturated hydraulic conductivity, I is the hydraulic gradient (equal to the change in head divided by the length of the flowpath (dh/dl)), and n_e is the effective porosity. The average linear velocity, $\overline{V}$, represents the rate of ground-water flow through pore spaces only. It is indicative of the contaminant migration rate under the following conditions:

- leaking waste constituents are miscible with water,
- ground-water flow occurs under saturated conditions along a single flow line,
- contaminants move advectively without dispersion, and
- contaminants are not retarded or degraded within the ground water.

As shown in equation (2), $\overline{V}$ is proportional to K and I, and inversely proportional to n_e. Because this equation is a linear relationship, the effect of parameter variability on $\overline{V}$ is easy to determine. For example, if K or I is increased an order of magnitude, $\overline{V}$ will increase one order of magnitude. Conversely, a doubling of n_e will decrease the calculated $\overline{V}$ to one-half its original value. As this type of sensitivity analysis demonstrates, accurate measurements of K, I, and n_e are required. Site-specific values for each of these parameters, especially K and I, can only be obtained from a thorough hydrogeologic investigation. The importance of each variable is discussed in detail below.

3.2.1 Hydraulic Conductivity

Hydraulic conductivity (K) is a measure of the ease by which a medium transmits ground water. It is one of the few physical parameters that assumes values that may span more than 13 orders of magnitude. Although this entire range may not be exhibited at a single site, hydrogeologic investigations often reveal heterogeneity in K values that range over many orders of magnitude. Aquifer heterogeneity may be related to either a single stratum that is a geologically-complex depositional environment (i.e., braided stream deposits or some glaciated terrains), or a well-defined system of layered strata, such as a sand-clay-sand sequence. Depending on test-well placement, fractured bedrock typically exhibits extreme variability in measured conductivities.

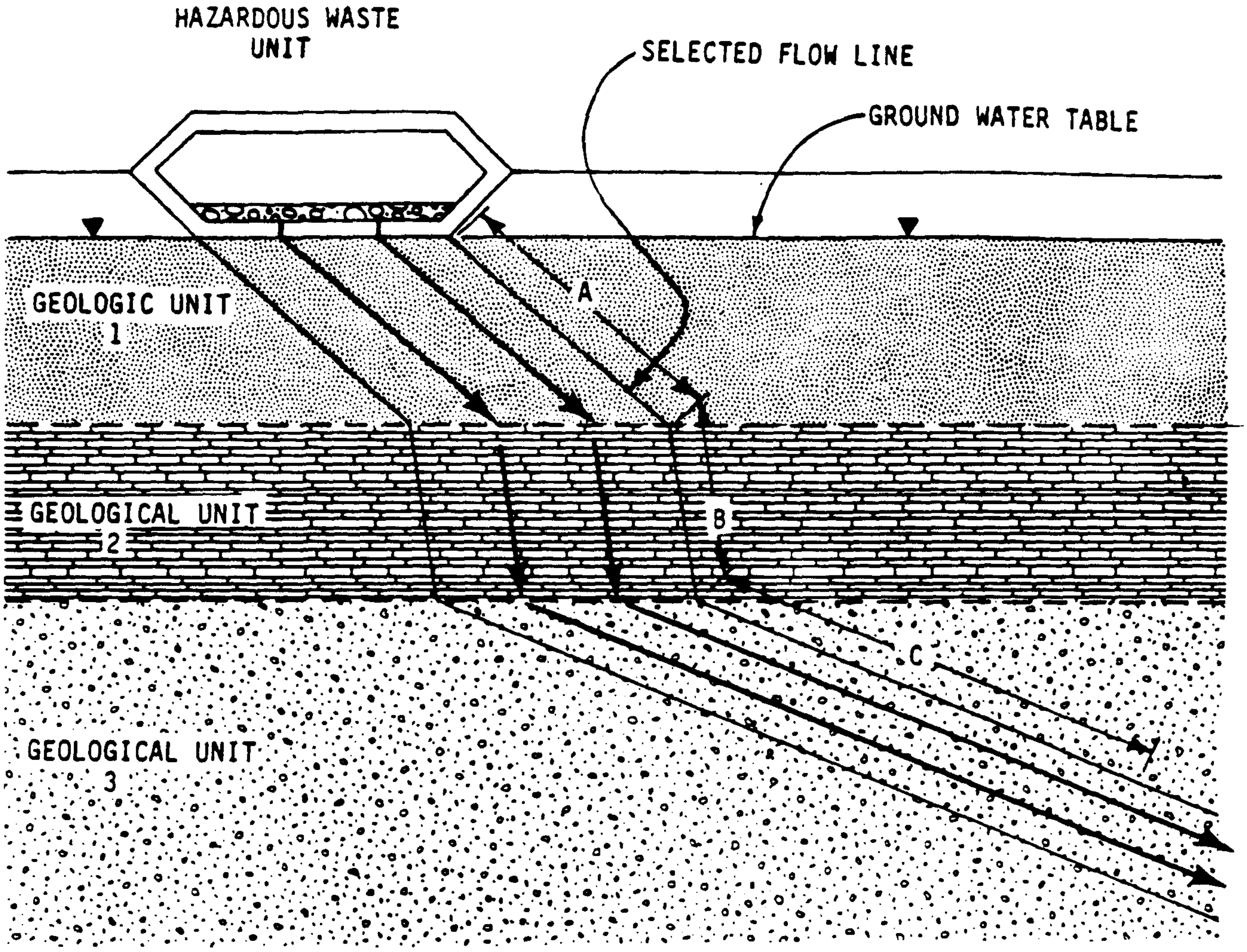
To accurately characterize complex flow domains, an appropriate number of piezometers should be placed throughout the saturated zone. Nested piezometers are used to determine both K values for stratified deposits and the magnitude of the vertical component of the gradient of flow. It is difficult to specify a minimum number of piezometers and aquifer tests that would be applicable for all potential HWLTSD sites. The permit applicant and permit writer must determine the degree of complexity of the saturated zone, using the permit applicant's site characterization when evaluating the accuracy of reported K values. Default values based on soil texture taken from the literature and laboratory-derived values for K, instead of field measured data, are not acceptable. Section 3.3 provides guidance on data reliability.

EPA has published proposed acceptable methods for determining hydraulic conductivity in Test Method 9100: Methods for Determining Saturated Hydraulic Conductivity and Saturated Leachate Conductivity, for addition to the Agency's technical guidance manual entitled, Test Methods for Evaluating Solid Waste: Physical/Chemical Methods; OSW, SW-846. Appendix A contains a condensed version of Method 9100 describing the field methods that should be used to determine K.

Assuming that the site characterization provided in the Part B permit application (see Section 2.1, Phase I Location Guidance Manual, February 1985) provides an adequate basis for calculating TOT, the next step is to assess the K value(s) used in the calculation. Equation (2) assumes that for the representative flow line (or segment) taken from a flow net, K remains constant. In reality, this 100-foot flow line may traverse several strata of varying conductivities. If the permit applicant reports a range of K values along this flow path, the largest hydraulic conductivity value should be used to simulate worst-case conditions, unless the flow path can be divided into distinct segments with unique values of K, I, and n_e. If this is possible (see Figure 3.2.1-1 for example), the individual travel times of these segments can be summed.

Hydraulic conductivity may often be reported in several different units. Table 3.2-1 lists conversion factors for the common units. Certain permit applicants may report transmissivity instead of hydraulic conductivity. Transmissivity is derived by multiplying hydraulic conductivity by the aquifer thickness and is expressed in units of length squared per unit time. Therefore, hydraulic conductivity can be obtained by simply dividing transmissivity by the aquifer thickness. However, values of K derived from this manipulation of transmissivity may not be reliable for the 100-foot flow line scale used in this analysis. If the original value of transmissivity was obtained by a large scale aquifer (or pump) test, using pumping or observation wells that may have penetrated a number of distinct geologic units, the resulting value of K will not be characteristic of any one geologic unit. Values for K derived from aquifer (or pump) tests are not acceptable for use in the TOT analysis unless other subsurface investigations (e.g., test borings with continuous flight sampling) show that the geologic materials over the interval in question are uniform.

FIGURE 3.2.1-1: CROSS SECTION OF MULTIPLE GEOLOGIC STRATA SHOWING SELECTED FLOW LINE BENEATH A HAZARDOUS WASTE UNIT



A, B, and C are segments of the selected flow line.

A + B + C = 100 feet

Each geologic unit has different properties that determine flow line direction.

TABLE 3.2-1: HYDRAULIC CONDUCTIVITY CONVERSION FACTORS

Meters Per Day (m/d^{-1})	Centimeters Per Second (CM/s^{-1})	Feet Per Day (ft/d^{-1})	Gallons Per Day Per Square Foot ($gas/d^{-1}/ft^{-2}$)
1	1.16×10^{-3}	3.28	2.45×10^{1}
8.64×10^{2}	1	2.83×10^{3}	2.12×10^{4}
3.05×10^{-1}	3.53×10^{-4}	1	7.48
4.1×10^{-2}	4.73×10^{-5}	1.34×10^{-1}	1

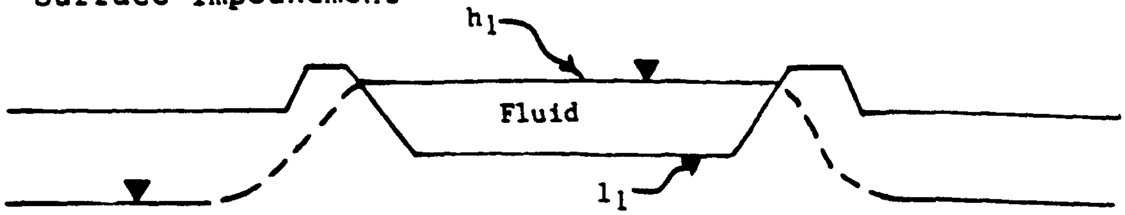
3.2.2 Hydraulic Gradient

Hydraulic gradient (I), the driving force of ground-water flow, is determined by dividing the change in head over the distance between the points of measurement along the flow length. Gradients can range from greater than 1.0 near a point of ground-water discharge, to less than 0.0001, a value associated with extensive areas of flat terrain. Factors influencing hydraulic gradients include: (1) aquifer characteristics, (2) conditions at the boundaries of the flow domain under consideration (i.e., river elevation, ground-water discharge from the underlying bedrock into a sand and gravel aquifer, etc.), and (3) system inputs and outputs (i.e., rainfall, evapotranspiration, etc.). System inputs/ outputs may include man-induced aquifer stresses such as groundwater discharge or recharge at a well, or seepage from a HWLTSD facility.

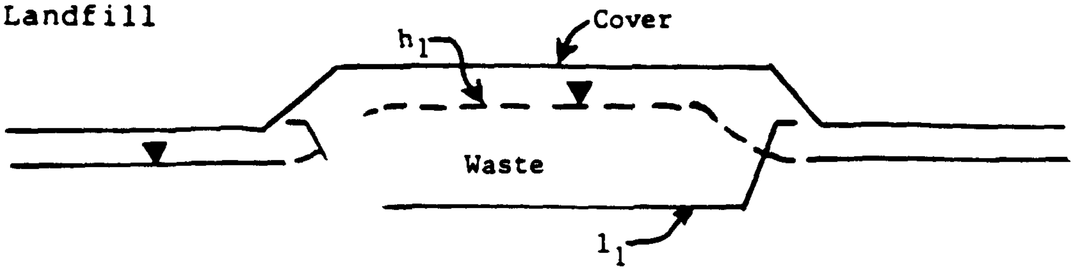
Selecting the initial value for head is a function of the unit being examined. For surface impoundments, this initial head is the maximum elevation of fluid within the impoundment (see Figure 3.2.2-1(a)). For landfills, the initial head is the maximum height of the saturated zone within the waste and cover after unit closure, unless the fluid level can be higher prior to this time (see Figure 3.2.2-1(b)). This height selection should assume that any synthetic liner present in the unit will eventually not function in the long-term and liner failure will occur. For a waste pile, the initial head depends on whether the unit has an approved liner as specified in the design and operation standards under 40 CFR Part 264. For waste piles

FIGURE 3.2.2-1: SELECTING INITIAL VALUES FOR HEAD AND THE FLOW LINE

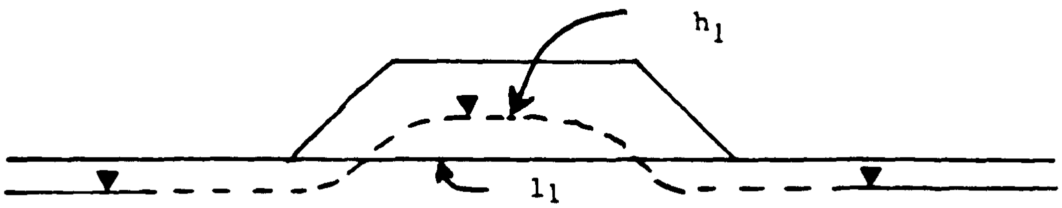
(a) Surface Impoundment



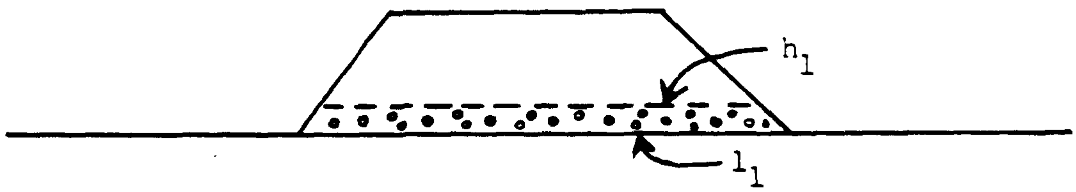
(b) Landfill



(c)(1) Waste Pile without liner



(c)(2) Waste Pile with liner



Where h_1 = initial head and l_1 = initial point for flow line, used in the expression for hydraulic gradient:

$$I = \frac{dh}{dl} \approx \frac{h_1 - h_2}{l_1 - l_2}$$

where l_2 is the elevation of the end of the 100-foot flow line and h_2 is the head at l_2.

without liners as specified in Part 264, the initial head is the maximum height of the saturated zone within the waste in the unit (see Figure 3.2.2-1(c)(1)). For waste piles with approved liners, the initial head is located one foot above the liner (see Figure 3.2.2-1(c)(2)). This height selection assumes a properly functioning liner beneath the waste pile during the short-term, active life of a storage unit from which waste will be removed prior to closure. The initial points of the flow lines for each unit are also shown on these figures.

Unlike hydraulic conductivity, I is susceptible to orders of magnitude change due to aquifer stress, most often in the form of aquifer exploitation as a water resource, but also due to seasonal fluctuations. Therefore, for borderline sites, the permit writer should carefully consider aquifer characteristics, the areal extent of the aquifer, and the potential for future ground-water use in the vicinity of the HWLTSD facility.

As mentioned in Section 3.2.1, nested piezometers should be used in site investigations to obtain information on the vertical component of the hydraulic gradient. Further information on the use of nested piezometers is presented in Appendix B. Appendix A provides additional information on evaluating artificial and seasonal influences on I, as well as methods for estimating the maximum height of the saturated zone within a landfill with no leachate collection system.

3.2.3 Effective Porosity

Effective Porosity (n_e (%)) is the amount of interconnected pore space in soils or sediments through which fluids can pass, expressed as a percent of bulk volume. Although effective porosity is important in determining TOT, its impact on $\overline{V}$ is limited to a much smaller range of potential values, unlike K and I. A thorough site characterization should provide measured values of n_e. However, effective porosity data may not be available for some sites; it can be estimated with little influence on the validity of the TOT calculation. Table 3.2-2 gives default estimates of effective porosity to be used when field data are not available for calculating TOT. Where actual field data are available, they should be used instead of default values.

Effective porosity should not be confused with total porosity, specific yield, or gravity drainage. Use of any of these parameters as an estimate or substitute for effective porosity can affect resulting estimates of TOT by several orders of magnitude in some cases. In some cases, such as for coarse grained soils, the use of gravity drainable porosity or specific yield may be acceptable. Appendix A presents an expanded discussion of the relationship between effective porosity and other terms.

3.2.4 Necessary Precautions

In performing TOT analysis for determining ground-water vulnerability, the permit writer must recognize that the rate of travel and the initial appearance of hazardous wastes at the 100-foot end point are not being predicted. The permit applicant and permit writer cannot predict when the engineered containment structures will malfunction or, in many cases, what the concentrations of the released waste constituents will be at that time. Darcy's law assumes that the constituents are traveling advectively in an aqueous phase within the ground water.

TABLE 3.2-2: DEFAULT VALUES FOR EFFECTIVE POROSITY FOR USE IN TIME OF TRAVEL (TOT) ANALYSES

Soil Textural Classes	Effective Porosity of Saturation[a]
Unified Soil Classification System	
GS, GP, GM, GC, SW, SP, SM, SC	0.20 (20%)
ML, MH	0.15 (15%)
CL, OL, CH, OH, PT	0.01 (1%)[b]
USDA Soil Textural Classes	
Clays, silty clays, sandy clays	0.01 (1%)[b]
Silts, silt loams, silty clay loams	0.10 (10%)
All others	0.20 (20%)
Rock Units (all)	
Porous media (nonfractured rocks such as sandstone and some carbonates)	0.15 (15%)
Fractured rocks (most carbonates, shales, granites, etc.)	0.0001 (0.01%)

[a]These values are estimates and there may be differences between similar units. For example, recent studies indicate that weathered and unweathered glacial till may have markedly different effective porosities (Barari and Hedges, 1985; Bradbury et al., 1985).

[b]Assumes de minimus secondary porosity. If fractures or soil structure are present, effective porosity should be 0.001 (0.1%).

Certain constituents in a ground-water flow regime can be retarded to a velocity less than the average linear velocity due to sorption or degradation. However, sorption and cation exchange are reversible. In addition, every geologic media has a finite retarding capacity. When the total mass and concentrations of compounds released from the unit are unknown, one cannot know if this capacity is adequate to stop or impede the migration of the compounds. Mechanical dispersion is a transportation mechanism that can reduce both the peak and steady-state concentrations of the contaminant and can also hasten the arrival or the leading edge of the plume. However, dispersion rates are generally unpredictable.

If the permit writer encounters a case where such non-vulnerable aquitards overlie, for example, a major high yielding aquifer, then data should be examined, as feasible, to determine the degree to which the 100-foot distance is representative of the local ground-water flow system, and hence, of risk of exposure.

3.3 MODIFYING TOT_{100} FOR DATA RELIABILITY

TOT_{100} can be modified to reflect the reliability of the values of the hydraulic parameters used in the calculation. The modification is performed by multiplying TOT_{100} by a reliability factor. Reliability can be judged on both the basis of test statistics and the expected error of test procedures. For example, hydraulic conductivity can be roughly estimated from grain size distribution. However, the accuracy of this procedure results in a two order of magnitude range when compared with

Table 3.3-1: RELIABILITY FACTORS FOR ADJUSTING THE CALCULATION OF TOT_{100}

Reliability Factor	Reliability Adjustment General Reliability Class Good	 Fair	 Poor	Comment
Hydraulic Conductivity (K)	---	.10	.01	
Effective Porosity (n_e)	---	---	---	If n_e is not quantitatively determined, use the default value from Table 3.2-2.
Hydraulic Gradient (I)	---	.90	.50	

more precise, direct measurements. Consequently, EPA does not consider it to be an acceptable method for calculating hydraulic conductivity, as discussed in Section 3.2.1. Table 3.3-1 presents reliability factors for adjusting the TOT calculation for three classes of reliability for each of the three hydraulic properties: hydraulic conductivity, hydraulic gradient, and effective porosity. The reliability of an estimated parameter is related both to the type and number of tests performed on the strata of interest and to site-specific hydrogeologic conditions at the location. The number of tests recommended are based on professional judgement and field observation experience. Although specific numbers are recommended, the appropriate number of tests performed can be determined on a case-by-case basis. The reliability of various test procedures, and the recommended type and number of tests are listed in Table 3.3-2. The TOT_{100} value should be multiplied by the appropriate reliability value from the Table, after determining the reliability class of each of the parameters. When the permit applicant reports fewer tests than recommended for a particular parameter, the reliability designation for that parameter estimate should be reduced by one category. Examples of the use of reliability factors to modify TOT are presented in the Technical Resource Document entitled Technical Methods for Evaluating Facility Location.

The permit writer must scrutinize the overall validity of the calculated TOT_{100} before making the final determination of vulnerability. TOT values in excess of 1000 years should be

TABLE 3.3-2: RELIABILITY OF TESTS FOR DETERMINING HYDRAULIC FACTORS: HYDRAULIC CONDUCTIVITY, EFFECTIVE POROSITY, AND HYDRAULIC GRADIENT

Hydraulic Factor Test Procedure*	INHERENT ERROR	RELIABILITY	COMMENT
Hydraulic Conductivity - Lateral			
a. In-situ testing: 'slug test,' auger hole method	Standard test	Good	Needs a minimum of five slug tests or auger hole method tests per strata.
b. Multiple aquifer tests*	Standard test	Fair to good	
c. Undisturbed core samples and permeameter test	Underestimates by factor of 10 to 100	Fair to poor	Needs a minimum of ten samples per strata to account for spatial variability.
d. Inference from grain size or texture	May overestimate or underestimate by factor of 10 to 100	Poor	This procedure may be fairly accurate for coarse textures, sands only.
e. Disturbed core samples and permeameter	Underestimate by factor of 100 to 10,000	Very poor	Unusable data. Unacceptable method.

*See Method 9100 for specification of approved tests, in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, U.S. EPA, SW-846, April 1984.

TABLE 3.3-2: RELIABILITY OF TESTS FOR DETERMINING HYDRAULIC FACTORS: HYDRAULIC CONDUCTIVITY, EFFECTIVE POROSITY, AND HYDRAULIC GRADIENT (Continued)

Hydraulic Factor Test Procedure*	INHERENT ERROR	RELIABILITY	COMMENT
<u>Hydraulic Conductivity - Vertical</u>			
a. Undisturbed core samples and permeameter	Standard test	Good	Needs a minimum of ten samples per strata to account for spatial variability.
b. Multiple aquifer tests	Standard test	Fair to good	
c. In-situ testing: 'slug test' auger hole method	Overestimates by factor of 10 of 100	Fair to poor	Needs a minimum of five slug tests or auger hold method tests per strata. Fairly precise in course textures, sands, gravels.
d. Inference from grain size or texture; Hazen Method	May overestimate or underestimate by factor of 10	Poor	This procedure may be fairly accurate for coarse textures, sands, gravels.
e. Disturbed core samples and permeameter	Underestimate by factor of 100 to 10,000	Very poor	Unusable data. Unacceptable method.

*See Method 9100 for specification of approved tests, in <u>Test Methods for Evaluating Solid Waste, Physical/Chemical Methods</u>, U.S. EPA, SW-846, April 1984.

TABLE 3.3-2: RELIABILITY OF TESTS FOR DETERMINING HYDRAULIC FACTORS: HYDRAULIC CONDUCTIVITY, EFFECTIVE POROSITY, AND HYDRAULIC GRADIENT (Continued)

Hydraulic Factor Test Procedure	INHERENT ERROR	RELIABILITY	COMMENT
<u>Porosity-Effective</u>			
a. Undisturbed core, gravity drain test	50%	Good	Standard test.
b. Undisturbed core, break-through curve analyses	Unknown	Good to fair	Specialized test for low conductivity materials.
c. Estimate based on texture and type of material	100%	Fair	
<u>Hydraulic Gradient - Lateral</u>			
a. Water level - piezometric isopleth map	10-20%	Good	Standard method.
b. 3-point method	20-50%	Fair	Common method for aquifer testing.
c. Surface topography	Overestimates up to 100%	Fair	Applicable to shallow sat-urated zones only (within 50 feet of surface).

TABLE 3.3-2: RELIABILITY OF TESTS FOR DETERMINING HYDRAULIC FACTORS: HYDRAULIC CONDUCTIVITY, EFFECTIVE POROSITY, AND HYDRAULIC GRADIENT (Continued)

Hydraulic Factor Test Procedure	INHERENT ERROR	RELIABILITY	COMMENT
<u>Hydraulic Gradient - Vertical</u>			
a. Piezometer nests	10%	Good	Standard practice.
b. Assumption of 1.0	Unknown	Fair	Applicable to unsaturated zone only. Gradients >1.0 are possible in the saturated zone.
<u>Hydraulic Gradient - Change</u>			
Change due to changes in surface hydrology or pumping well installation	0-1000% plus	Poor	Gradients less than .10 are most susceptible to man-induced changes.

very rare and if they are reported, the permit writer should double check each hydraulic component, including the flow path. Strata with vertical hydraulic conductivities that are 1000 or more times greater than lateral conductivities are rare and should be closely evaluated. Differences in conductivity of 1000 or more between strata are uncommon and also need close examination. Hydraulic gradients of less than 0.01 are extremely shallow. In these cases, the gradient value used in the calculation should reflect the potential for gradient changes as a result of pumping well installation or surface-water management effects (i.e., water table drawdown from land drainage or water table mounding from irrigation). Appendix A contains an expanded discussion on gradient fluctuations.

3.4 USE OF ADDITIONAL CONTAINMENT STRUCTURES

In most cases, the influence of engineered structures beyond the cap and synthetic liner (which are never factors in the TOT_{100} calculation) should not be included in the calculation to adjust the TOT. As discussed in Section 4.0 and in the report Investigation of Slurry Walls (OSW, June 1985), EPA will consider such additional barriers as slurry walls and grout curtains as enhancements to TOT only in certain hydrogeologic settings. These settings should not be complex, and hydrologic and geologic conditions at the location should be such that they predominantly satisfy the vulnerable hydrogeology criteria.

Under certain conditions, these additional barriers could particularly be considered for minimizing the potential for exposure via the basement seepage pathway. These barriers can be considered where minor sand lenses or soil fractures exist in the shallow saturated zone, and where the criteria are otherwise satisfied because the hydraulic conductivity of the predominant native materials approach aquitard conditions that make placement of production wells less likely. Generally, there are no field-supported data that demonstrates that the engineered structures described above are effective in formations that have overall native permeabilities greater than $1x10^{-4}$ cm/second.

4.0 APPLICATIONS OF ENGINEERED STRUCTURES

Modifying the design and operation of HWLTSD facilities as a means of eliminating or minimizing the potential for exposure due to migration of wastes may be appropriate in certain hydrogeologic settings. Less vulnerable ground-water conditions can be created in these settings through the use of additional passive containment barriers, such as slurry walls and grout curtains. These additional engineering measures should only be considered in non-complex settings that predominantly satisfy the tests for ground-water vulnerability (i.e., test values are calculated to be within twenty five percent of the required values). They cannot be relied upon to make an obviously vulnerable site, such as a sand and gravel aquifer, nonvulnerable. Section 4.3 describes the types of hydrogeologic settings in which these methods can be considered.

The term "engineered structures" does not refer to the tures of the facility (such as liners and caps) that are cu required by RCRA regulations. It refers to additional act passive control measures beyond current regulatory requi that are installed at the facility. An active control is an engineered feature that the owner or operator m or operate at his discretion to directly control the volume, and direction of the ground-water flow syste of an active control measure is a ground-water count system that can be used to change flow direction. S may be appropriate for lowering a water table, conta plume, or collecting contaminated ground water for s treatment. This technology is useful only as an immediate corrective action measure to eliminate the potential for exposure due to a waste release. It may not be a feasible perpetual care measure because of the high cost of maintenance, operation, and collection/ treatment facilities. Passive control measures are engineered features used to control the ground-water flow direction and velocity, but which are not "operated" or adjusted by the owner or operator after the system is installed. Passive measures include various types of ground-water flow barriers such as slurry walls, grout curtains, and interceptor trenches. Grout curtains and concrete slurry walls that are used for ground-water containment may also serve as effective gas barriers in the unsaturated zone.

The ensuing sections describe how certain passive engineered structures may be used to both minimize the potential for exposure at new and existing facilities and reduce the rate of waste migration to create less vulnerable ground-water conditions. Active engineered structures are not considered to be appropriate means to change a vulnerable setting into a nonvulnerable one.

4.1 SLURRY WALLS

Slurry walls and cutoff walls are subsurface barriers that are emplaced to redirect or reduce ground-water flow. Slurry trenching usually involves excavating a trench and backfilling it to create a wall composed of soil-bentonite, bentonite-cement, or an asphalt mixture which may be mixed with excavated soil. At a HWLTSD facility, a slurry wall may be installed on the upgradient side of the facility, forcing the ground water to flow around the wastes. A slurry wall may also be installed downgradient of a site to divert ground-water flow, or installed to totally encircle the facility and contain contaminated ground water beneath the facility. These barrier walls, once installed, must often be accompanied by ground-water pumping systems to control hydraulic gradients that may be altered by the wall installation.

If a slurry wall is to be installed at a site, the owner or operator should submit detailed information regarding waste compatibility; methods of excavation, keying the wall to bedrock, and quality control; and possible changes in hydraulic gradients. These factors will influence the performance of the slurry wall in its ability to control ground water flow. A supporting document entitled, Investigation of Slurry Walls, OSW, June 1985 (Draft), contains information on the ability of slurry walls to minimize contaminant migration and how these structures can be used most effectively at RCRA facilities.

4.2 GROUT CURTAINS

Grout curtains are engineered structures used to control ground-water flow and waste contaminant migration. More costly than slurry walls, grout curtains are primarily used to seal spaces in porous or fractured rock where other ground-water controls would not be practical.

The method of installing a grout curtain is to drill holes to the desired depth and inject the grout, under pressure, into the voids. The grout may be one of two main types - suspension grouts or chemical grouts.

Grout curtains can be used to retard or reroute the flow of ground water in porous rock. As with slurry walls, a grout curtain can be placed upgradient from a waste site to redirect ground-water flow. Problems may arise, however, in placing a grout curtain downgradient from a site. It is possible that a grout will lose its integrity in the presence of leachate or contaminated ground water; extensive testing should be done to assure that a grout would withstand extreme conditions at a site and maintain its design integrity.

4.3 CONDITIONS APPROPRIATE FOR ADJUSTING TOT BASED UPON THE PRESENCE OF ENGINEERED STRUCTURES

In certain hydrogeologic settings, passive measures to control the ground-water flow systems at existing units may be effective in minimizing ground-water flow, thus decreasing the vulnerability of the ground water. The effect of a passive measure in changing the velocity of the ground-water flow system should be considered when calculating the TOT. The effect of engineered barriers, for example, may greatly reduce the ground-water flow velocity along each 100-foot segment of a flow path beneath the facility. The barrier may also result in different hydraulic gradients that must be considered in calculating TOT.

Passive engineered barriers and the extent to which these control ground-water flow should only be considered in adjusting the TOT in aquitard-like settings that predominantly satisfy the TOT tests (i.e., within 25 percent) and that are not considered complex. Accepting passive engineered barriers in hydrogeologic settings that do not predominantly satisfy the TOT tests would clearly encourage the location of facilities in vulnerable settings. This would be inconsistent with EPA's overall policy for evaluating facility location, which is that the location should serve to minimize the potential for exposure to wastes and constituents released as a result of the failure of engineered containment barriers.

Geologic complexity refers to the characteristics of geologic stratification and structure. Geologically-simple locations are typically characterized by a pancake-like arrangement of geologic units having distinct boundaries that can be identified in the subsurface investigation. Physical properties within each unit vary little from one part to another and physical conditions provide a stable setting. Locations become more complex when geologic units are dipping or folded, when units end abruptly or are discontinuous, when the boundaries become obscure, when physical properties vary greatly within a layer (i.e., changes in permeability values over several orders of magnitude , or when soil conditions are unstable. The most complex sites are those where information about geologic units and their physical properties cannot be correlated based on boring data. In the worst case, all subsurface features seem to be random, making predictions of ground-water movement difficult or impossible. Terrains commonly found to be geologically complex include the following:

- Shallow bedrock areas composed of highly folded, fractured, or faulted formations,
- Karst areas,
- Alluvial materials,

- Glaciated regions composed of fractured sediments, and
- Certain High Hazard and Unstable Terrains (see Section 2.2 of the Phase I Location Guidance).

A location may predominantly satisfy the TOT tests in the following way. For example, a site may be located in a geologic setting composed primarily of a massive clay. However, thin lenses of sand are found in some test borings. These sand lenses do not appear to be continuous or interconnected. However, there is a potential for ground water to flow over a part of the 100-foot interval through one or more of these lenses. To minimize the potential movement of contaminants through these sand lenses, a slurry wall or grout curtain installed downgradient of the unit may serve as a passive barrier that enhances the containment property of the location.

When the slurry wall or grout curtain can be shown to have acceptable design properties (e.g., resistant to degradation by leachate), its effect on the TOT calculation can be considered as any other geologic unit by adding the TOT through it to the TOT calculated for the flow line on either side of the barrier. Of course, the presence of this barrier may alter hydraulic gradients at the site. Consequently, changes in these gradients as a result of the barrier should be assessed.

5.0 SUPPORTING DOCUMENTS AND REFERENCES

5.1 SUPPORTING DOCUMENTS

The Office of Solid Waste has analyzed a substantial number of issues related to facility location during the past two years. In addition to the Vulnerable Hydrogeology and Phase I location guidance documents, the following reports and guidances have been prepared or are in preparation to support the RCRA location program.

- Review of State Siting Criteria for Hazardous Waste Land Treatment, Storage, and Disposal Facilities (January 1984)

  This report describes various State regulatory approaches and guidance manuals to control siting of hazardous waste facilities. State statutory requirements, regulatory standards, technical guidance manuals, and State site selection and mapping studies are described. State siting criteria can be divided into three main categories. One set of criteria define locations inadequate for siting of hazardous waste management facilities. The second set defines hydrologic and geologic features considered necessary for suitable sites. A third set includes setback criteria defining separation distances between the facility and off-site structures or geologic and hydrologic features.

- Permit Writers' Guidance Manual for Hazardous Waste Land Treatment Units (Draft in preparation)

  Land treatment units are subject to many of the same location concerns as are storage and disposal facilities; however, land treatment units are functionally different from storage and disposal units and require a different approach in evaluating location. While storage and disposal units are designed to contain hazardous constituents, land treatment units are sited and operated to rely on natural soil conditions to degrade or transform hazardous constituents. For this reason, a separate location guidance manual for use by permit applicants and writers in evaluating land treatment units is being developed. The guidance focuses on methods to recognize soil conditions that have a high probability of success in meeting the treatment demonstration requirement for land treatment unit permits.

- Data file of 225 Hazardous Waste Management Facilities, Superfund Sites, and Site Enforcement Cases

  This data file provides a variety of technical information about facilities located in various hydrogeologic settings. Each data file is being reviewed to provide supporting information for development of future location standards. Some of the facilities have been examined either as location case studies included in the Technical Resource Document entitled, Technical Methods for Evaluating Facility Location, or in studies found in Appendix D of this guidance.

- Technical "White Paper" Series (February 1985; Draft Final)

  The following reports have been developed on a variety of technical issues related to facility siting and are available to permit applicants and writers to serve as background information:

  - Use of Isotope Techniques in Estimating the Age and Flow Direction of Ground Water at Hazardous Waste Sites

- Characterization of Vertical Gradients and Impacts in Siting Under Saturated Conditions

- Technical Issues Regarding Aquifers Containing Variable Density Water and Their Effects on Ground-Water Flow Systems

- Technical Criteria for Defining Various Locational Settings

- Water Table Slope/Flow Gradient Relationship

- Techniques for Time of Travel (TOT) Calculations

- Review of RCRA 40 CFR Part 264.18 Location Standards

° Results of Technical Peer-Review Committee Meeting for Facility Locational Policy Development (Phase I) (September 1984; Draft Final)

The objectives of the Committee were: 1) to identify technical issues related to the siting of hazardous waste management facilities, 2) to provide general comments on the draft Phase I Location Guidance Manual and suggestions for corrections or addition of material to the document, and 3) to present case study examples illustrating various technical issues related to location.

° Investigation of Slurry Walls, OSW, June 1985 (Draft Supporting Document)

This report examines the ability of slurry walls to minimize contaminant migration in order to assess how they could be used at RCRA facilities. Reviewers of early drafts of the vulnerable hydrogeology guidance manual raised several questions on the use of manmade engineered structures, such as slurry walls. One major question focused on the amount of credit, if any, that a facility should be given if a slurry wall already exists or is proposed as a means of containing contaminants. Also, if a slurry wall is given credit, should it be factored into calculating the contaminant TOT?

- Regulatory Development Plan -- Location Standards for RCRA Hazardous Waste Facilities, Office of Solid Waste, U.S. Environmental Protection Agency, December 1985.
- Report on the Review of the "Permit Writers' Guidance Manual for the Location of Hazardous Waste Land Treatment, Storage, and Disposal Facilities Phase II", Environmental Engineering Committee, Science Advisory Board, U.S. Environmental Protection Agency, June 1986.