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POLLUTION PREDICTION TECHNIQUES

FOR WASTE DISPOSAL SITING

A State-of-the-Art Assessment

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*Separate Document - Available at Office of Solid Waste, Hazardous Waste Management Division, Washington, D.C.

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Project Participants

Weston also wishes to acknowledge the following personnel for their contribution to this project:

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SECTION I

EXECUTIVE SUMMARY

Introduction

Scope and Objectives. Passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) has mandated the restoration and protection of the quality of our Nation's surface waters, which will result in the decrease of a number of point-source discharges of wastes directly into streams. A significant potential for adverse impact on the Nation's groundwaters now exists due to this increased land disposal of solid and liquid residual wastes, particularly hazardous wastes.

Concurrently, there has been an increase in the amount of waste being generated, and many wastes continue to be disposed of in a "least-cost" way which contributes to environmental degradation. Landfilling, ponds, lagoons, and other indiscriminate land-disposal methods have proven in numerous instances to be ineffective for adequate protection of the health of both the public and the environment, particularly where hazardous wastes are involved. This can also be attributed to poor management practices, since technological and management guidelines regulating such disposal practices have, for the most part, been only recently enacted. With respect to hazardous wastes, a number of state regulatory agencies have only recently initiated the writing or adoption of such guidelines.

Sub-title C of the Resource Conservation and Recovery Act (RCRA) of 1976 (PL 94-580) will regulate hazardous waste on a national level for the first time. Section 3004, Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, and Section 3005, Permits for Treatment, Storage, or Disposal of Hazardous Waste, deals specifically with the disposal aspects of hazardous wastes. In order for such regulations to be effective, technologically-sound pollution prediction techniques of a national uniform nature must be used for the siting of waste disposal and management facilities.

Techniques which would predict the potential for groundwater pollution prior to the disposal of specific wastes at specific sites would be a useful tool for regulatory and enforcement agencies. However, contradictory expert opinion exists relative to the mechanisms and effectiveness of attenuation processes for waste renovation which are an integral part of the land-disposal/land-treatment process. This, in turn, has inhibited effective and consistent decision-making for determining the confidence with which one can dispose of a specific waste at a specific site.

The overall objective of this investigation is to provide a state-of-the-art assessment of pollution prediction techniques for waste-disposal siting. This assessment includes both current research and regulatory procedures relative to the land disposal/treatment of waste for the entire waste spectrum, exclusive of radioactive wastes. The emphasis, however, will be on that research and those regulatory procedures that deal specifically with hazardous waste. Furthermore, the emphasis is to be on those techniques which lead to pollution prediction through an assessment of attenuation of waste leachates.

Key specific objectives of this investigation are as follows:

1. Conduct interviews with acknowledged experts in the field of waste attenuation/management to assess current laboratory and field research techniques relative to pollution prediction and with selected domestic and foreign regulatory agencies to assess current regulatory procedures utilized for waste disposal siting, with emphasis on hazardous waste disposal.

2. Identify and assess the state-of-the-art of techniques to both predict and describe the pollution potential from specific wastes disposed of at specific sites.

3. Identify and assess the most useful water/soil/waste interaction and attenuation mechanisms which are indicative of the ability of a potential site to accept a specific waste for land disposal/treatment in an environmentally-safe manner.

4. Prepare detailed development plans for those techniques which best predict the groundwater pollution potential and the suitability for permitting of land disposal/treatment sites for both the short-term (within three years) and the long-term (within ten years).

Literature Search. A literature search was conducted to identify pertinent references on the behavior of contaminants in subsurface environments. A major portion of the literature search was conducted using the computerized Lockheed Dialog Retrieval Service. Additional references were obtained during expert interviews throughout the project.

A general discussion of literature search methodology can be found in Section III of this report. Specific discussion on related work and research can be found in Sections IV, V, and VI and in Appendix A of this report.

Processes Influencing Mobility and Attenuation of Chemical Waste Constituents in Soil-Water Systems

The soil is a dynamic system in which numerious chemical, physical, and biological reactions occur singly or simultaneously with time. Soil, under normal conditions, is able to transform or stabilize some hazardous constituents to equilibrium soil components.

For the purpose of this study, "attenuation" is defined as: "Any physical, chemical, and/or biological reaction or transformation occurring in saturated and/or unsaturated zones that brings about a temporary or permanent decrease in the maximum concentration or in the total quantity of an applied chemical or biological constituent in a fixed time or distance traveled."

Attenuation Mechanisms. The attenuation mechanisms can be categorized as physical, chemical, or biological. A description of the important mechanisms follows.

Physical Processes

1. Molecular diffusion is a spontaneous process resulting from the natural thermal motion of dissolved substances. This is generally considered an insignificant transport process; however, it modifies abrupt concentration differences between solutions of different concentrations in contact with one another.

2. Hydrodynamic dispersion is the result of variations in pore water velocity vectors within the soil. As shown in Figure 1, it tends to spread or reduce abrupt concentration changes in the soil with time. The process is effective in attenuating the maximum concentration of a pulse or slug of waste with time and distance as it moves through a soil profile.

3. Dilution of leachate by soil moisture and groundwater can provide effective attenuation of a given contaminant.

Chemical Processes

1. Adsorption-desorption or ion exchange influences the mobility of a hazardous constituent. When the reaction is reversible (which is generally the case for cation exchange), the attenuation is only an apparent one resulting from a reduction in constituent mobility. Figure 2 illustrates the influence of adsorption-desorption on constituent concentration distribution in the soil-water phase and compares it with a non-adsorbed constituent.

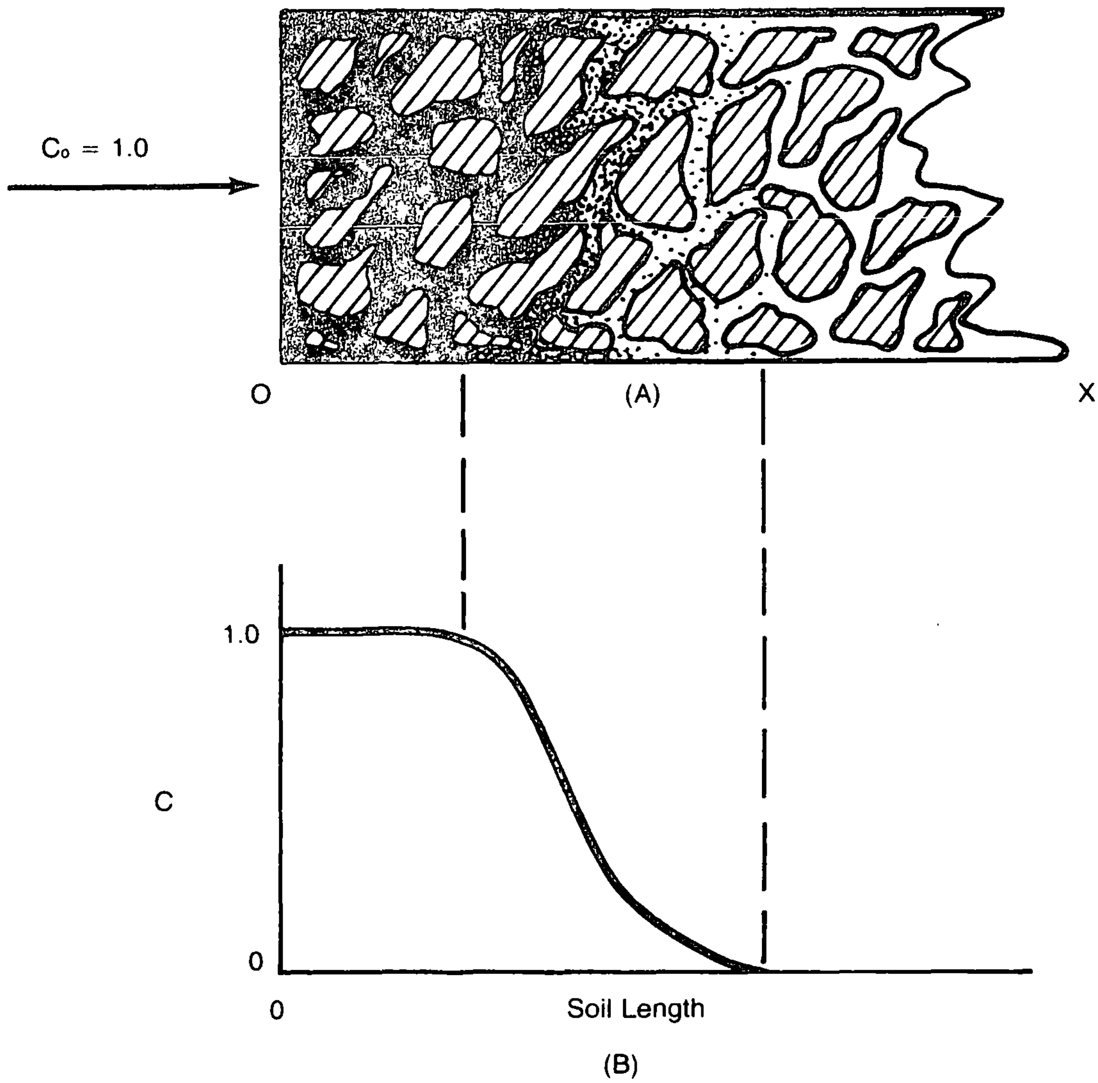


FIGURE 1 ATTENUATION BY DISPERSION:

(A) The crosshatched areas are soil particles, the solid area represents a soil solution with a constituent concentration of C_0, and white area represents a soil solution with a constituent concentration of zero.
(B) Average constituent concentration distribution in the soil as a function of soil length.

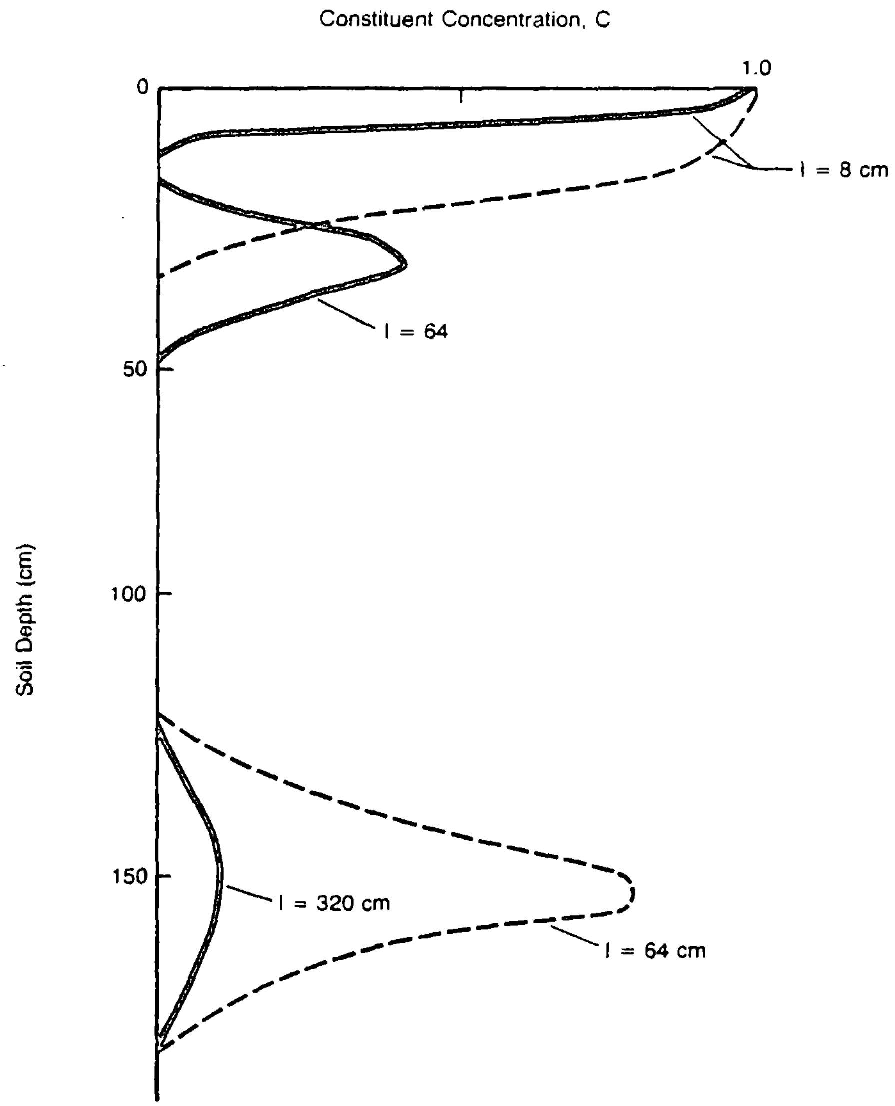


FIGURE 2 DISPERSION OF CONSERVATIVE AND NON-CONSERVATIVE IONS:

The solid line represents a constituent that exchanges with cations on the soil solid phase and the dashed line represents a conservative constituent such as chloride. The water content of the soil is 0.4 cm^3/cm^3 and the constituent concentration in the solution entering the soil is 1.0. The amount of solution that has been added at the soil surface is represented by I. The initial eight cm of solution entering the soil contained both contituents, whereas that which followed contained neither constituent.

2. Precipitation, as adsorption, involves the removal of a constituent from the soil water. Changing the constituent from a soluble to an insoluble phase reduces both the maximum as well as the total amount of constituent in the soil-water phase. This reaction is pH dependent and often occurs simultaneously with adsorption, which makes it difficult to separate the two processes.

3. Oxidation-reduction reactions influence the mobility and attenuation of constituents (especially trace and/or heavy metals) and are often initiated by biological activity. Oxidized constituents are less mobile than the reduced forms of the constituent, and reduced soil conditions contain more soluble constituents than the oxidized soil environment at the same soil pH.

Biological Processes (Biodegradation). Micro-organisms (e.g., bacteria, actinomycetes, fungi and algae, are an integral part of the soil. They transform wastes by such processes as oxidation, reduction, mineralization, and immobilization. The end products of these transformations are generally harmless, but some toxic metabolites have been produced.

Sufficiency of Attenuation. The degree of attenuation required for a waste constituent is generally based upon the maintenance of an acceptable groundwater quality. This is dependent on the amount and concentration of waste constituents and groundwater quality objectives. In general, no single process or reaction (physical, chemical, or biological) is responsible for the total observed attenuation of a waste constituent.

Several factors play key roles in attenuation. These include: waste quantity, potential for infiltration, type and concentration of contaminants in leachate, rate of leachate migration from the disposal site, and mass transport of the constituent in saturated and unsaturated media at the vicinity of the disposal site.

Pollution Prediction Techniques

Interviews were conducted with more than 40 non-regulatory experts in various professional disciplines relative to assessment of the attenuation of waste leachates and the development of pollution-prediction techniques. Numerous research endeavors have either been completed or are currently in progress. A summary assessment of those categorical techniques is given below, with a more detailed assessment found in the main report and its appendices.

Interviews were conducted with selected regulatory agencies to identify the decision procedures currently being used in the permitting (or rejection) of waste-disposal operations. It must be emphasized that many wastes categorized as hazardous wastes are not permitted for disposal with reliance on attenuation. It became readily apparent in the course of this investigation, therefore, that the presently used techniques which do not emphasize attenuation would also require inclusion and assessment.

Those pollution prediction techniques identified to date and assessed in this report can be categorized as follows:

- Criteria Listing
- Criteria Ranking
- Matrix
- Classification System (Decision Tree)
- Models (Mathematical)
- Laboratory Simulation (Column Studies)

It should be noted that a number of these techniques are interrelated (e.g., Criteria Listing with each of the others) or constitute "sub-routines" within a more encompassing decision-making technique (e.g., column studies and the Classification System).

Criteria Listing. The most basic and universally-applied identified is that of Criteria Listing. This approach was found to be used to a varying degree by each of the domestic and foreign regulatory agencies contacted.

The Criteria Listing approach consists of listing factors for both waste and site characterization and of obtaining data to adequately define each factor listed. An assessment of these data is then made by the review personnel on the basis of their level of expertise, the empirical data base gathered, and by comparison with pertinent appropriate examples.

The basic elements of the Criteria Listing approach are as follows:

- Waste characterization: type, amount, physical characteristics, chemical characteristics, and biological characteristics.

- Site characterization: location, topography, climatology, land use, soils, geology, and hydrology.

Examples of waste characterization and selected site characterization for Criteria Listing are shown in Tables 1 and 2, respectively. A summary assessment of Criteria Listing is given in Table 3.

TABLE 1

WASTE CHARACTERIZATION - CRITERIA LISTING*

Type:	Industrial SIC Plant name/location Waste stream Municipal - Specify waste/source Other - Specify waste/source
Amount:	Volume or weight Rate of generation
Physical:	Solid Liquid Sludge
Chemical:	pH Toxicity Major constituents Minor constituents
Biological:	Degradability Organic content

(* Compiled by Weston)

TABLE 2

SITE CHARACTERIZATION-
SELECTED CRITERIA LISTING

	California-State Water Resources Control Board	Illinois-Environmental Protection Agency	Minnesota-Pollution Control Agency	New York-Department of Environmental Conservation	Pennsylvania-Department of Environmental Resources	Texas-Water Quality Board	Ontario-Ministry of the Environment
GEOLOGY							
Backhoe Pits					■		
Borings	■	■	■		■	■	
Description of Geologic							
Profile	■	■	■	■	■	■	
Consolidated Deposits							
Bedrock Type(s)	■	■	■	■	■	■	
Formation Name		■			■		
Outcrop			■		■		
Degree of Weathering					■		
Depth to Bedrock		■		■	■	■	
Unconsolidated Deposits							
Type(s)	■	■		■	■	■	
Formation Name		■			■		
Texture		■			■		
Structure		■		■	■		
Fold Axis					■		
Bedding Planes					■		
Joint Planes					■		
Fault Planes					■		
Fracture Traces					■		
HYDROLOGY							
Surface Water							
Distance to Nearest Body			■	■			■
Type					■		
Quality				■			
Ground Water							
Depth to Water Table	■	■		■	■	■	■
Maximum				■	■		
Minimum	■		■	■	■		
Location and Date							
Measured		■			■	■	
Seasonal Fluctuations					■		

TABLE 3

SUMMARY ASSESSMENT OF CRITERIA LISTING

Pros

- Site-specific and quantitative data indentified.
- Comprehensive site description.
- Presently used by regulatory agencies
- Moderate cost/expertise requirements.
- Applies to hazardous and non-hazardous wastes

Cons

- No quantification of pollution potential.
- Potential high costs.
- Reliability largely dependent on the expertise of agency review personnel.

Criteria Ranking. The Criteria Ranking approach is based on measurements or estimates of waste and site parameters which are arbitrarily weighted based on their potential impact on the environment. Approaches have been developed which rate or rank wastes and landfill sites individually in order to allow a quantitative numerical comparison of various wastes and sites to one another. Those ranking approaches developed to date were intended to serve as a first step in waste and site evaluation. To date, however, neither approach has been applied to the prediction process for a new site.

A Numerical Rating System has been developed by LeGrand and Brown (1977) for a standardized approach for evaluation of groundwater contamination potential from waste disposal sources and other contamination sites with land disposal. The system evaluates four key geologic and hydrogeologic characteristics of the site and assigns a numerical value ranging from 0, indicating extremely poor conditions or a high contamination potential, to a 9 (5 in one case), indicating good conditions or a low contamination potential. The Numerical Rating System for a given site consists of a sequence of numbers and letters to provide a general overall rating of the site indicating its specific weak and strong characteristics. The system is designed to provide a quick first round assessment of site suitability, but is not intended to be adequate or substitute for the more advanced or detailed study which may be required for certain critical contamination potential situations. Step 9, Completion of the Site Numerical Rating, is shown on Table 4.

Another Criteria Ranking approach was developed by Pavoni, Haggerty and Lee in 1971-72, entitled Environmental Impact Evaluation of Hazardous Waste Disposal in Land. Five waste ranking formulae and ten site ranking formulae were developed to assign weighted values and to assess potential site suitability by comparison with each other. A full description of each of these Criteria Ranking approaches is given in Section V.

A summary assessment of the Criteria Ranking approach is given in Table 5.

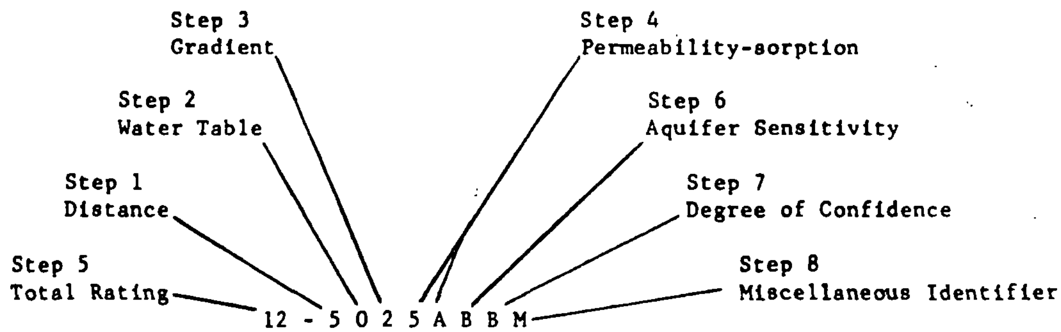
TABLE 4

COMPLETION OF NUMERICAL RATING
(from LeGrand and Brown, 1977)

STEP 9

Completion of site numerical rating

The total point value determined in Step 5 is recorded and then followed in sequence by the individual point values for the four key hydrogeologic factors: distance, depth to water table, water-table gradient, and permeability-sorption. This is followed, in turn, by the special site identifier suffixes: aquifer sensitivity, degree of confidence, and miscellaneous identifiers. An example of a site rating with brief explanations and interpretations is shown below. Full explanations of site ratings are in Sections 5.0 and 6.0.



<u>Explanation of sequence of digits and letters</u>

12 - Total point value as shown in Step 5
5 - The first digit is rating for ground distance - Step 1
0 - The second digit is rating for depth to water table - Step 2
2 - The third digit is rating for water-table gradient - Step 3
5 - The fourth digit is rating for permeability-sorption - Step 4
A - Represents a closely defined position (5A) in permeability-sorption scale - Step 4
B - Represents sensitivity of an aquifer to be contaminated - Step 6
B - Represents degree of confidence or reliability of overall rating - Step 7
M - Indicates special conditions (mounding of water table in this case) - Step 8

TABLE 5

SUMMARY ASSESSMENT OF CRITERIA RANKING

Pros

- Site-specific data identified.
- Quantitative data.
- Low to moderate cost/expertise involved.
- Quantitative predictive tool.

Cons

- Confidence of assigned values.
- Lack of testing and calibration.
- Not presently used by regulatory agencies.

Matrix. The use of a Matrix as a prediction technique in waste disposal siting is dependent upon the formulation of relationships between two major sets of interrelated variables (e.g., waste characteristics and soil characteristics). A Matrix approach of this type has been identified in this study as given in the Development of a Soil-Waste Interaction Matrix by C.R. Phillips.

It should be noted that this soil-waste interaction Matrix procedure does not entail the development of a "new" procedure, but rather basically combines soil and waste ranking systems that had previously been developed with little, if any, revision by LeGrand (1964 site ranking) and by Pavoni, Hagerty, and Lee (waste ranking).

An example of the waste-ranking parameters and calculations for weighted value assignments is shown in Table 6. A waste/site dependent matrix with values for all of the parameters considered is shown in Figure 3. A summary assessment of the Matrix approach is given in Table 7.

TABLE 6

WASTE PARAMETER FOR INPUT TO MATRIX

Factor Summary

WASTE

	Range
(1) Effects Group	
1. Human Toxicity, Ht	0-10
$Ht = \frac{10}{3} Sr$	
2. Groundwater Toxicity, Gt	0-10
$Gt = \frac{10}{7} (4 - \log_{10} Cc)$	
but for $Cc > 10^4$ mg/l, Gt = 0	
and for $Cc < 10^{-3}$ mg/l, Gt = 10	
3. Disease Transmission Potential, NDp	0-10
$NDp = \Sigma$ (contribution of subgroup A, B and C)	
(2) Behavioral Group	
(i) Behavioral Subgroup	
4. Chemical Persistence, Cp	1-5
$Cp = 5 \exp(-kt)$	
but if $Cp < 1$, Cp = 1	
where $C_6/C_1 = \exp(-kt)$	
5. Biological Persistence, Bp	1-4
$Bp = 4 \left(1 - \frac{BOD}{TOD}\right)$	

			SOIL GROUP		HYDROLOGY GROUP			SITE GROUP	
		SOIL-SITE / WASTE	Permeability NP (2½-10)	Sorption NS (1-10)	Water Table WT (1-10)	Gradient NG (1-10)	Infiltration NI (1-10)	Distance ND (1-10)	Thickness of Porous Layer HT (1-10)
EFFECTS GROUP		Human Toxicity Ht (0-10)	5 / 8 / 40	4 / 8 / 32	5 / 8 / 40	2 / 8 / 16	6 / 8 / 48	7 / 8 / 56	0 / 8
EFFECTS GROUP		Groundwater Toxicity Gt (0-10)	5 / 5 / 25	4 / 5 / 20	5 / 5 / 25	2 / 5 / 10	6 / 5 / 30	7 / 5 / 35	0 / 5
EFFECTS GROUP		Disease Transmission Potential Dp (0-10)	5 / 0 / 0	4 / 0 / 0	5 / 0 / 0	2 / 0 / 0	6 / 0 / 0	7 / 0 / 0	0 / 0
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Chemical Persistence Cp (1-5)	5 / 3 / 15	4 / 3 / 12	5 / 3 / 15	2 / 3 / 6	6 / 3 / 18	7 / 3 / 21	0 / 3
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Biological Persistence Bp (1-4)	5 / 4 / 20	4 / 4 / 16	5 / 4 / 20	2 / 4 / 8	6 / 4 / 24	7 / 4 / 28	0 / 4
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Sorption So (1-10)	5 / 5 / 25	4 / 5 / 20	5 / 5 / 25	2 / 5 / 10	6 / 5 / 30	7 / 5 / 35	0 / 5
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Viscosity Vi (1-5)	5 / 2 / 10	4 / 2 / 8	5 / 2 / 10	2 / 2 / 4	6 / 2 / 12	7 / 2 / 14	0 / 2
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Solubility Sy (1-5)	5 / 1 / 5	4 / 1 / 4	5 / 1 / 5	2 / 1 / 2	6 / 1 / 6	7 / 1 / 7	0 / 1
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Acidity/ Basicity pH (0-5)	5 / 1 / 5	4 / 1 / 4	5 / 1 / 5	2 / 1 / 2	6 / 1 / 6	7 / 1 / 7	0 / 1
CAPACITY-RATE GROUP		Waste Application Rate Ar (1-10)	5 / 4 / 20	4 / 4 / 16	5 / 4 / 20	2 / 4 / 8	6 / 4 / 24	7 / 4 / 28	0 / 4

FIGURE 3 EXAMPLE OF SITE DEPENDENT MATRIX
(C.R. PHILLIPS)

TABLE 7

SUMMARY ASSESSMENT OF THE MATRIX

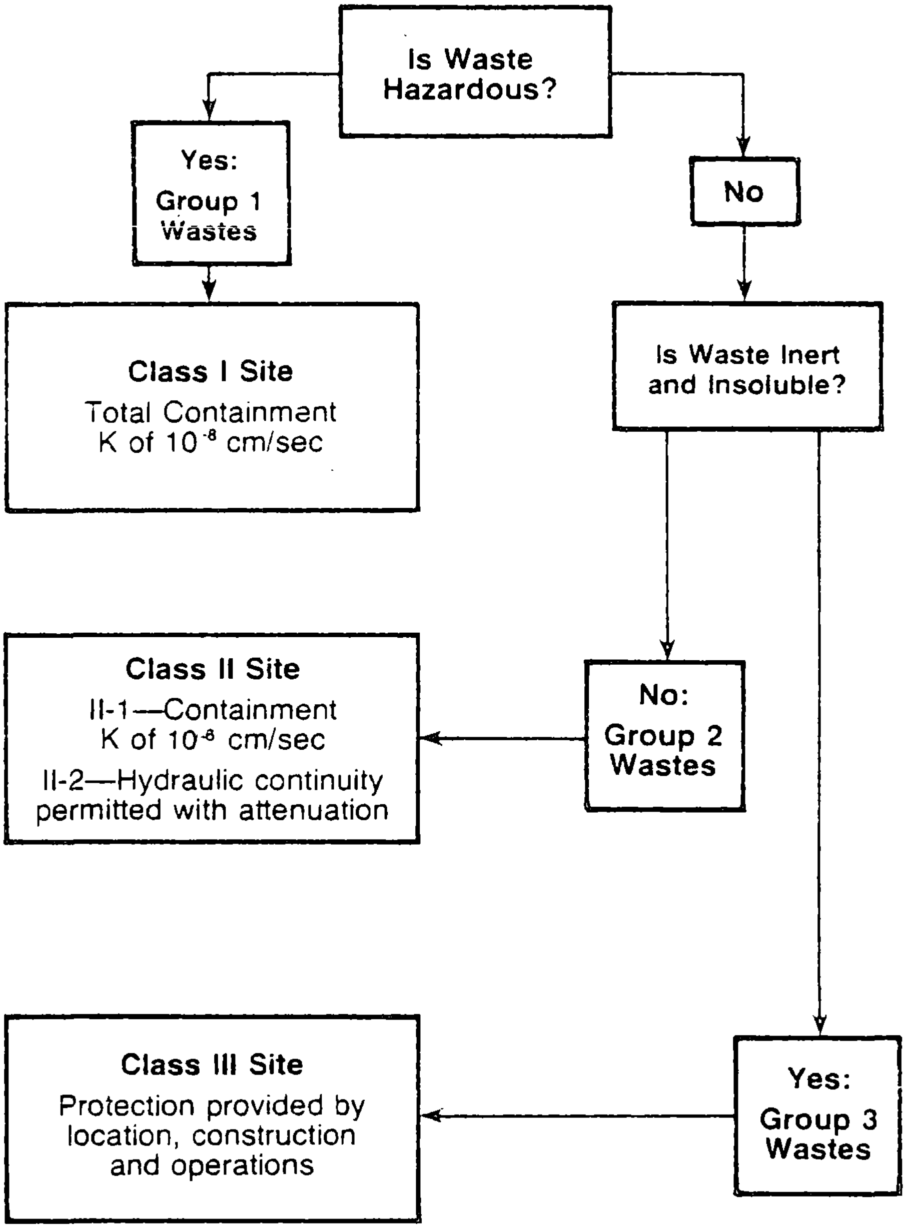
Pros

- Quantitative predictive tool.
- Identification of soil/waste parameters.
- Assessment of pollution potential.
- Low-moderate operating cost.

Cons

- Confidence of assigned values.
- Lack of testing, calibration and field verification.
- Not presently used by regulatory agencies.
- Difficulty of laboratory and field quantification of parameters.
- Specialized skills usually required.

Classification System (Decision Tree). The Decision Tree approach is a logical step-by-step process for assessment of the pollution potential in the site selection process. The Decision Tree approach begins with the most important question followed by a hierarchy of questions of decreasing criticality. In this manner, a "no" answer to an early important question can eliminate the site from further consideration and, from a practical standpoint, the expenditure of unnecessary money for additional site investigation. A "no" answer may also indicate that an alternative type of waste disposal site or disposal method should be utilized. This approach is in effect that developed by the California State Water Resources Control Board in their waste/site Classification System (as shown in Figure 4). A summary assessment of the Classification System is given in Table 8.



Based on "Disposal Site Design and Operation Information."
California State Waste Resources Control Board

FIGURE 4 CLASSIFICATION SYSTEM (DECISION TREE)

The basic approach taken in the California Classification System is a determination of the degree to which waste is hazardous and its assignment to one of three main classes of disposal sites. For each site class, varying degrees of protection are provided for surface and groundwater, with the system permeability being defined as the single most important and controlling site parameter. The wastes are classified as Group 1, 2 or 3, and the sites are classified as Class I, II, and III as shown in Table 9.

TABLE 8

SUMMARY ASSESSMENT OF CLASSIFICATION SYSTEM
(DECISION TREE)

Pros

- Site/waste comprehensive.
- Specifically addresses hazardous wastes.
- Presently used by regulatory agencies.
- Tested and verified.
- Low cost/expertise requirements.

Cons

- Insufficient data requirements.
- Local and regional availability of low permeability deposits.
- Little quantification of pollution potential.
- Possibly too conservative.

Simulation Models. Predicting the potential for groundwater pollution from waste disposal operations is complex because of the interactive and simultaneous processes that occur in a soil-water system. However, models can serve as a tool to simulate the performance of a certain disposal site. Models can be classified as: (1) descriptive models; (2) physical models; (3) analog models; and (4) mathematical models.

TABLE 9

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD DISPOSAL SITE DESIGN REQUIREMENTS

Site Type	Site Classification	Waste Classification	Permeability cm/sec	Soils	% Passing a No. 200 Sieve	Liquid Limit	Plasticity Index
Class I	Complete protection is provided for all time for the quality of ground and surface water. Geological conditions are naturally capable of preventing vertical and lateral hydraulic continuity between liquids and gases from the waste in the site and usable surface and ground waters. The disposal area can be modified to prevent lateral continuity. Underlain by usable ground water only under exceptional circumstances.	Group 1 Consisting of or containing toxic substances and substances which could significantly impair the quality of usable waters. Also accepts Group 2 and 3 wastes.	$\leq 1 \times 10^{-8}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
Class II	Protection is provided to water quality from Group 2 and Group 3 wastes.	Group 2 Consisting of or containing chemically or biologically decomposable material which does not include toxic substances or those capable of significantly impairing the quality of usable water.					
II-1	Overlying usable ground water and geologic conditions are either naturally capable of preventing lateral and vertical hydraulic continuity or site has been modified to achieve such capability.	Also accepts Group 3 Wastes.	$\leq 1 \times 10^{-6}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
II-2	Having vertical and lateral hydraulic continuity with usable ground water but geological and hydraulic features and other factors assure protection of water quality.		Not specified	Not specified	Not specified	Not specified	Not specified
Class III	Protection is provided from Group 3 wastes by location, construction and operation which prevent erosion of deposited material.	Group 3 Consist entirely of non-water soluble, non-decomposable inert solids.	-	-	-	-	-

In additition to the above groupings, models could be classified as: (1) empirical versus conceptual models; (2) stochastic versus deterministic models; (3) static versus dynamic models; and (4) spatial dimensionability (one, two or three dimensions considered). Table 10 lists a few example models and their classification into various groupings.

Of the different models discussed above, conceptual-mathematical models appear to be the most promising, but these are also the most complex for evaluating potential groundwater contamination for a given site. These models are generally based upon a set of equations which describe the relationships between different input and output variables and system parameters. These equations are derived using the principles of conservation of mass, energy and momentum, and constitutive relationships which define certain systems. Several models of this type are currently available.

Equations 6 and 7 (in Section V of this report) are examples of constituent-transport and water-flow equations, respectively. Mathematical solutions of Equations 6 and 7, or simplified versions of them, may be generated in several ways: (1) analytical methods, and (2) numerical methods which include finite differences, finite element, and method of characteristics.

Survey of Existing Mathematical Models. The literature contains hundreds of solutions of different variations of mathematical models. Section V of this report includes a detailed discussion of these solutions, a wide variety of models, and identifies methods for their solution and application.

Several problems related to model use are identified in Section V; however, they can be considered a promising tool for predicting groundwater contamination potential. Further research and investigations are needed prior to full implementation of such tools. Table 11 summarizes model development by type.

TABLE 10

EXAMPLE MODELS AND THEIR CLASSIFICATION INTO DIFFERENT GROUPINGS

Model Definition	TYPE OF MODEL				
	Descriptive (D) Physical (P) Mathematical (M)	Conceptual (C) Empirical (E)	Stochastic (S) Deterministic (De)	Static (St) Dynamic (Dy)	Spatial Dimension (1, 2, 3)
On-site inspection and decision using engineering judgment.	D	E	De	Dy	3
The Drexel University experimental landfill (field site only)	P	E	De	Dy	3
Batch equilibrium study to determine adsorption; shaker test; solid waste evaluation leachate test (subsystem models)	M	E	De	St	0
Column study to determine adsorption and/or migration of certain chemicals in given soil; thin-layer chromatography (subsystem models)	M	E	De	Dy	1
Criteria listing; classification system of the California State Water Control Board; matrix method.	D and M (Matrix)	E	De	St	-
One-dimensional unsaturated transport model of Bresler (1973) (subsystem model)	M	C	De	Dy	1
Two-dimensional saturated-unsaturated transport model of Duguid and Reeves (1976)	M	C	De	Dy	2
Model for groundwater flow and mass transport under uncertainty of Tang and Pinder (1977).	M	C	S	Dy	2

TABLE 11

SUMMARY OF MODEL DEVELOPMENT BY TYPE

ACTIVITY	STATE OF DEVELOPMENT			
	FLUID FLOW	MASS TRANSPORT		
		SINGLE-ION TRANSPORT		MULTI-ION TRANSPORT (+EXCHANGE)
		NO ADSORPTION NO DECAY	WITH ADSORPTION WITH DECAY	
1. Mathematical formulation of any model	0	0	D3	D3 - ?
2. Numerical solution of any model	0	0	D3	D3 - ?
3. Field calibration and testing:				
saturated/unsaturated transport	0	D3	D6	D6 - ?
saturated-only transport	0	0	D3	D6 - ?
unsaturated-only transport	0	0	D3	D6 - ?
4. Field verification:				
saturated/unsaturated transport	D3	D3	D6	D10 -?
saturated-only transport	0	D3	D3	D6 - ?
unsaturated-only transport	0	0	D3	D6 - ?
5. Methodology for laboratory and field quantification of major parameters[1] (any model)	0	D3	D3	D6 - ?
6. Methodology for quantification of leachate quality	NA	NA	0	0
7. Standard procedures for field testing, calibration and verification (any model)	D3	D3	D6	D10 -?
8. Ready for use as a decision procedure				
saturated/unsaturated transport	NA	D3	D6	D10-?
saturated-only transport[2]	NA	D3	D6	D10-?
unsaturated-only transport[2]	NA	D3	D3	D6 -?

0 = operational;
D3 = under development, likely to be operational within three years;
D6 = under development, likely to be operational within six years;
D10= under development, likely to be operational within ten years;
? = under development, not likely to be operational within ten years;
NA = not applicable

1) adsorption/exchange constants, dispersion coefficients, soil hydraulic properties, etc
2) if the indicated transport model is suitable for application at given site.

Soil-Leachate Column Studies. Soil-column studies have been used to simulate natural field conditions and to quantify the potential for a given soil to attenuate specific constituents. Most laboratory experiments are conducted using water-saturated soil or clay systems. Unsaturated soil-water conditions are difficult to control, and the soil water flow rates are extremely small for these cases. Soil-column studies are useful, but are frequently improperly interpreted. It is difficult to quantify the degree of attenuation based on presence or absence of leachate constituents in the column effluent. However, they remain a useful tool in determining hydraulic properties and dispersion coefficients for specific soil or clay materials.

Batch or Shaker Tests. Several types of experiments can be used for measuring adsorption characteristics, but the most widely used is the "batch" or "shaker" method. This procedure consists of combining a known volume of waste leachate of a predetermined composition with a given mass of air dry soil. The mixture is shaken until equilibrium is attained. Adsorption coefficients can be determined from the distribution of the constituents between the adsorbed and water phases. Batch or shaker adsorption tests can be useful in evaluating constituent mobility, but it may be misleading if appreciable complexing of constituents occurs during the contact period. However, if properly conducted, these tests can be used to provide necessary parameters for mathematical models.

Thin-Layer Chromatography. Soil thin layer chromatography (soil TLC) is analogous to conventional TLC, with soil substituted for the paper or solid absorbent phase. This procedure appears to correlate well with mobility "trends" observed in laboratory-column studies and in batch-adsorption experiments. The procedure consists of coating a glass plate with soil slurry (500-750μ) followed by drying. The "mobility" of constituents is then measured in relationship to migration of the water front as shown in Figure 5.

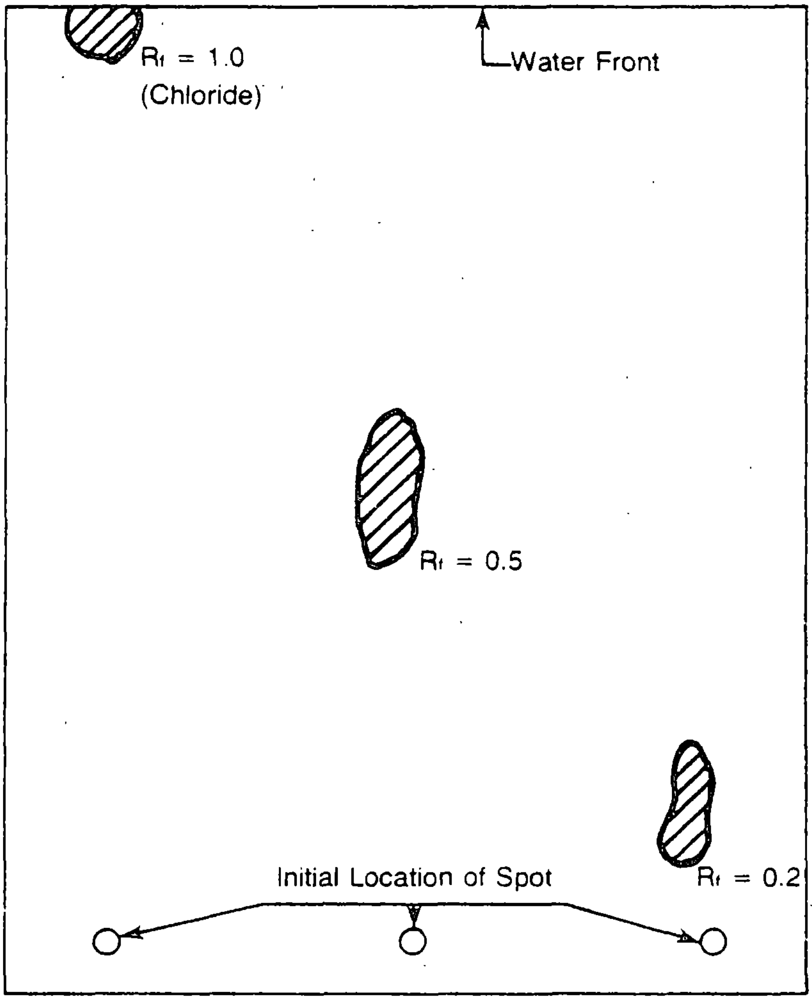


FIGURE 5 THIN-LAYER CHROMATOGRAPHY

The shaded areas represent three different constituent locations after the water front has migrated to 10-cm height above the initial location of each spot. The shaded area with an R_f equal to one represents a non-adsorbed constituent such as chloride with the least mobile constituent in the illustration having a R_f of 0.2.

Dilution Model. This type of model defines the potential for groundwater contamination strictly on the basis of: leachate dilution in groundwater, dilution in down-gradient well discharge, and travel times for leachate migration both to down-gradient wells and streams.

On-Going Research. Several researchers, research institutions federal agencies, and universities have developed, and are currently in the process of developing, mathematical models for the prediction of contaminant migration in subsurface environments. These include: the U.S. Geologic Survey; Battelle Pacific Northwest Laboratories; Oak Ridge National Laboratory; Colorado State University; Cornell University; Drexel University; Ecole de Mines, Fontainbleu, France; Institue de Mecanique des Fluides de Starbourg, Strass, France; New Mexico State University; Princeton University, the University of California, Davis; the University of Florida; the University of Cottingen, Germany; the University of New Mexico; Oregon State University of Oregon; the University of Waterloo; Utah State University; Technion - Israel; Institute of Technology and Intera/Intercomp Resources Development and Engineering, Inc.

Assessment. Models to be used as a decision procedure, whether they be mathematical or non-mathematical, should: (1) be rational; (2) represent the physical system; (3) be easy to understand; and (4) be economical to run. Modeling has the following advantages:

- Provide a quantitative prediction.
- Predict contamination potential before the fact.
- Identify soil/waste parameters.

- Perform multiple site/waste analysis.

- Can be versatile as a tool for ranking the site, for optimizing monetary design, and for defining waste management requirements.

- Can be a research tool.

Use of models as a decision procedure has the following limitations and disadvantages:

- Lack of testing and verification.
- Difficulty of quantifying input parameters.
- Complexity and requirements for a wide variety of expertise.
- Unknown accuracy and precision parameters and outputs.
- Unavailability of ready-to-use packaged models.

A summary assessment of models is given in Table 12.

TABLE 12

SUMMARY ASSESSMENT OF MODELS

Pros

- Quantitative - predictive tool.
- Identification of soil/waste parameters.
- Assessment of pollution potential.
- Versatility.
- Research tool.

Cons

- Insufficient understanding of some processes.
- Insufficient testing and calibration.
- Lack of field verification.
- Difficulty of laboratory and field quantification of parameters.
- Requires specialized skills and equipment.
- High operating cost.

Regulatory Agency Practices

Permit Procedures Utilized. Nine state regulatory agencies in six states and regulatory agencies in four foreign countries were contacted for an assessment of their waste-permitting procedures. Those agencies contacted are shown in Table 13. Also shown are selected factors in these programs with respect to: the permit procedure utilized for waste disposal siting; the status of regulations pertaining to both municipal and hazardous waste regulations; the mode of disposal required, i.e., containment or attenuation; the containment permeability required; and estimates of applicant costs, agency processing time in months, and agency review time by personnel type in hours.

The permit procedures utilized by each of those regulatory agencies contacted are the Criteria Listing or Classification System. The Classification System is used by regulatory agencies in California (see Table 8), Illinois, Texas, and the United Kingdom. The Criteria Listing approach is utilized by the other regulatory agencies contacted in Minnesota, New York, Pennsylvania, Ontario, Canada, The Netherlands and West Germany.

It is noteworthy that the same basic rationale and permit procedures utilized by the domestic regulatory agencies contacted are also utilized by the foreign regulatory agencies in Ontario, Canada and Western Europe for the permitting of waste disposal operations. As stated above, either the Criteria Listing or Classification System approach is utilized by the foreign regulatory agencies. In addition, a major consideration of waste disposal permitting relates to the attenuation or containment of waste leachate. Containment of both municipal and hazardous wastes is required in West Germany. Municipal waste disposal and the co-disposal of industrial waste that may sometimes be hazardous municipal waste is, on the other hand, permitted with reliance on attenuation of waste leachates produced in Ontario, Canada, The Netherlands, and the United Kingdom.

TABLE 13

SELECTED FACTORS IN THE ASSESSMENT OF REGULATORY AGENCY PERMIT PRACTICES

Regulatory Agency[1]	Permit Procedure	Status of Regulations[2]	Regulatory Authority[3]	Modd of Disposal[4]	Containment Permeability (cm/sec)	Applicant Costs for Permit Aquisition[5] Technical	Hearing	Time Process Permits - Range and Average (months)	Regulatory Staff Processing Time (hours) Technical	Admin.
Domestic										
California Regional Water Quality Control Board[1]	Classification System	Revised December 1976	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW: $\leq 1 \times 10^{-6}$	$250,000 to 800,000	$100,000	8-18; 12	80	12
California State Solid Waste Management Board	Classification System	Revised 1976	Municipal Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW: $\leq 1 \times 10^{-6}$			8-18; 12	NA[6]	NA
California Department of Health	Classification System	Feb. 1975 Being Revised	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW $\leq 1 \times 10^{-6}$			8-18; 12	NA	NA
Illinois Environmental Protection Agency	Classification System	Revised-Pending Approval mid-1978	Both	Containment	HW: I-$\leq 1 \times 10^{-8}$ II-$\leq 5 \times 10^{-8}$ MW: $\leq 1 \times 10^{-7}$	25,000 to 50,000		1-3; 1½	80	16
Minnesota Pollution Control Agency	Criteria Listing	Being Provided (Draft Reg. June 1977)	Both	Containment	HW: $\leq 1 \times 10^{-7}$	25,000 to 200,000	up to 50,000	6-12; 8	320	80
New York Department of Environmental Conservation	Criteria Listing	Revised August 1977	Both separate sections	Both as specified	HW: $\leq 1 \times 10^{-7}$			3-6; 3	35	5
Pennsylvania Department of Environmental Resources	Criteria Listing	Revised June 1977	Both	Both as specified	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$, if specified	15,000+	up to 60,000	6-18; 12	280	20
Texas Department of Health Resources	Classification System	Revised April 1977	Municipal Wastes	Containment	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$			2½-16; 7	83	17
Texas Water Quality Board[1]	Classification System	Revised-Pending Approval Late 1977	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$	50,000 to 200,000	5,000 to 10,000	6-12; 8	240	112
Foreign										
Canada - Ontario Ministry of the Environment	Criteria Listing	SW-Revised Feb. 1976 HW-Being Drafted	Both separate sections	Attenuation	not specified	50,000	20,000	8-36; 24	NA	NA
Netherlands - SVA	Criteria Listing	Being Revised	Both	Attenuation	not specified			NA		
United Kingdom - Greater London Council	Classification System	Revised 1976	Both	Attenuation	not specified	up to $2.63 million total		2-9; 3	NA	NA
West Germany - Office of State of Bavaria for Environmental Protection	Criteria Listing	SW-Revised Sept. 1976 HW-Being Drafted	Both	Containment	HW: not specified MW: $\leq 1 \times 10^{-6}$	20,000 to 90,000		6-24; 12	NA	NA

1 Indicates agency responsible for hazardous waste regulation.
2 Includes both municipal (MW) and hazardous wastes (HW) unless specified.
3 Municipal and/or hazardous wastes.
4 Municipal wastes only, all hazardous wastes require containment unless otherwise specified.
5 Costs given are gross estimates generally for off-site facilities.
6 Information not available.

The basic decision procedure utilized by each of the regulatory agencies contacted is based upon: (1) an objective quantification of both waste and site characteristics; (2) the combined technical expertise of the permit review team; and (3) by comparison with empirical data generated from analagous waste disposal operations. In the final analysis, therefore, a subjective decision is made based upon utilization of objective data and analysis to the degree that the data will permit. It is universally agreed by both regulatory and non-regulatory experts that this final decision must of necessity be subjective since no alternative procedure presently exists or is anticipated to exist within the near future that could be relied upon for a final objective decision.

Modes of Disposal. From an assessment of these regulatory programs, it has become clear that three major modes of land disposal of wastes exist. The first mode of disposal places reliance on the containment of wastes and waste leachates produced to avoid adverse impacts on surface and groundwater quality. The second mode of deposition relies on the assimilation of waste leachates into the environment to an acceptable degree by the various mechanisms of attenuation. The third mode relies on neither containment nor attenuation, but on the site construction and aesthetics.

Accordingly, three major classes of waste disposal sites have been defined with three corresponding major groupings of wastes. This Classification System is best exemplified in the California Waste Regulatory Program. It does apply generally, however, to those Classification Systems developed elsewhere, such as Texas, Illinois, (pending) and the United Kingdom.

These Classification Systems may be most aptly summarized as follows:

Site Type	Mode of Disposal	Waste Type
Class I	Containment	Group 1 - Hazardous
Class II	Limited containment, with attenuation	Group 2 - Decomposable, non-hazardous
Class III	Few controls, no containment or attenuation	Group 3 - Inert, insoluble

It is nearly universally agreed that hazardous wastes should be deposited in a Class I type site. Co-disposal of certain "hazardous" wastes with municipal wastes, however, is permitted on a case-by-case basis in a non-contained (Class II) site by some regulatory agencies. In addition, it is recognized that certain hazardous wastes must undergo some form of pretreatment (such as neutralization, fixation, or complexing) prior to land disposal or some other form of disposal such as incineration.

Although municipal wastes to date have been considered by many to represent Group 2 wastes, the current trend by an increasing number of regulatory agencies is for municipal wastes to be disposed of in a containment site as well. The third type of waste (Group 3), by virtue of it being inert and insoluble, requires little control other than obvious site construction and aesthetic considerations.

The over-riding element of consideration becomes one of the degree of risk associated with adverse environmental and public health impacts. It has become equally clear that, with few exceptions, attenuation has limited application to the safe disposal of many hazardous wastes given the current state of the art of prediction capabilities and economics of land disposal. The element of risk is simply too high for attenuation to be considered, particularly in light of the "maximum site utilization" philosophy mandated by current economics. This may change as the ability to model solute movement is improved. The Group 3 wastes, on the other hand, do not require the use of pollution-prediction procedures since no polluting wastes or leachates are involved.

The Group 2 wastes, those that are decomposable but non-hazardous, therefore, become the prime area for concentrated application of pollution-prediction techniques that emphasize attenuation. Pollution prediction techniques are needed that will more specifically define those wastes that can be reliable and permanently assigned to Group 1 and Group 3 wastes. Concurrently, pollution-prediction techniques are needed which will permit the assignment of wastes to a Group 2, Class II classification to maximize the beneficial attenuation capabilities of the environment while minimizing waste disposal costs.

Recommended Development Plans

Several types of pollution prediction techniques have been identified in the course of this study; these are: Criteria Listing, Criteria Ranking, Matrix, Classification System, and Simulation Models. Among these techniques, it is recommended that the following be more fully developed to provide a "standard" technique for waste disposal siting: (1) Criteria Listing, (2) Classification System, and (3) Simulation Models. Each of these development plans will require the multi-disciplinary team approach utilizing earth sciences (soils and hydrogeology), engineering, environmental, and chemical personnel. The Simulation Models development plan will require applied mathematicians and computer technician personnel as well.

Criteria Listing. It has been determined that Criteria Listing is currently the most widely-accepted approach utilized by regulatory agencies. Objectives of development of this procedure include: (1) development of a Criteria Listing for waste/site characterization; and (2) describing the best state-of-the-art methodology to quantify each of the Criteria Listed.

- Development Tasks:

  1. Develop a comprehensive Criteria Listing for waste/site characterization, where reliance will be placed upon attenuation of leachates produced.

  2. Develop a similar list for waste/site characterization, where containment of leachate would be required.

  3. Develop a matrix for Tasks 1 and 2 which will specify those criteria necessary for waste/site characterization with respect to different types of disposal.

  4. Develop procedures based on the best state-of-the-art methodology to evaluate field and laboratory data relative to each of the criteria listed.

  5. Develop a methodology for utilization of attenuation and containment practices.

  6. Prepare a user's manual for applying the procedure for assessment of site suitability.

- Development Time:

  The development of a Criteria Listing for various types of waste disposal will require an estimated four man years of effort by a multi-disciplinary team within the next three years.

- Development Cost:

  Costs estimated at $200,000 for the above-described level of effort can be expected.

Classification System. Several state regulatory agencies have been identified which presently utilize a Classification System approach for waste disposal siting. However, there is a need for further development of this procedure to achieve the following: (1) more definitive waste characterization; (2) more uniform site characterization; and (3) more uniform waste management techniques. To achieve these objectives, the following tasks have been identified:

- Development Tasks:

1. Identify and develop waste characterization techniques such as leaching tests, shaker tests, and thin-layer chromatography.

2. Develop uniform criteria for site characterization, particularly for containment, permeability, and thickness of the containment media.

3. Develop waste management requirements for different waste and site classes.

4. Establish a waste management task force with a balanced representation of governmental, industrial, consulting, and academic personnel.

5. Develop methodology for using the Classification System.

6. Prepare a user's manual and update reports.

- Development Time:

Due to the comprehensive nature of the Classification System approach, both short-term (within three years) and long-term (within ten years) development will be required. It is estimated that approximately five man-years of effort will be required for short-term development and a minimum of one man-years for each suceeding year of long-term development (seven additional years).

- Development Costs:

  Costs associated with these estimated times for development are estimated at $250,000 for the short term, and an additional $350,000 is estimated for the long term.

Simulation Models. Development of implementable simulation models will require a substantial effort both in the short term and the long term.

- Development Tasks:

  1. Establish and maintain a library of simulation models.

  2. Develop standardized sensitivity test procedures for numerical solutions of the models.

  3. Develop mathematical formulation and numerical solution of selected simulation models.

  4. Develop methodology for laboratory and field quantification of major model and simulation parameters.

  5. Develop methodology for quantification of waste leachate for specific soil and environmental conditions.

  6. Perform field testing, calibration, and verification of the models.

  7. Develop specific management models from detailed models.

  8. Obtain implementation assistance.

- Development Time and Costs

The level of effort for the above development activities is significant and is estimated to be as high as 150 man-years. The bulk of the output from these development tasks is expected to be beyond the short term (greater than three years); however, certain outputs can be expected within the short term. The associated development costs are also significant and are estimated at approximately $6 million over the next ten years.

Conclusions and Recommendations

Conclusions. The overall objective of this study was to provide a state-of-the-art assessment of pollution prediction techniques for waste disposal siting. Emphasis was placed on current research and regulatory procedures. Furthermore, the emphasis was on techniques which lead to pollution prediction through assessment of attenuation of waste leachates especially those from hazardous constituents. The following conclusions can be drawn from this broad-scoped investigation.

1. A number of pollution prediction techniques, many of them interrelated, have been identified which constitute useful tools to objectively assess to varying degrees the suitability of specific waste and waste/site disposal situations. It must be emphasized, however, that a team of multidisciplinary professionals and not the pollution prediction technique itself provides the ultimate "yes or no" decision. In addition to technical considerations, economic, politcal and legal considerations must also be given.

2. Each waste disposal site is permitted by the regulatory agencies contacted on a case-by-case basis. Specific waste types are likewise permitted or rejected on a case-by-case basis from these disposal sites.

3. A definition of attenuation has been developed for this project as follows: "Any physical, chemical and/or biological reaction or transformation occurring in saturated and/or unsaturated zones that brings about a temporary or permanent decrease in the maximum concentration or total quantity of an applied chemical or biological constituent in a fixed time or distance traveled."

4. Several attenuation mechanisms play a role in reducing the potential for groundwater contamination: physical processes include - molecular diffusion, hydrodynamic dispersion, and dilution; chemical processes include - precipitation, oxidation/reduction, and ion exchange; and biological processes include biodegradation.

5. Soil/waste interactions and attenuation mechanisms are becoming better understood, but are in need of additional definition and quantification, particularly for the waste streams that commonly contain more than one type of waste.

6. Attenuation mechanisms are capable of renovation of leachates from many non-hazardous wastes and some hazardous wastes, provided that the application rate does not exceed the soil-attenuation capacity. Examples of the former include on-lot septic systems. Examples of the latter include land farming of petro-chemical wastes, sludges and pesticides.

7. Attenuation that is adequate to prevent pollution, for those wastes amenable to attenuation, may in large part be dependent upon assimilation by dilution into either groundwater or surface water.

8. Within the limits of current knowledge, many wastes categorized as hazardous are not amenable to attenuation in the soil profile and must rely upon containment in secured landfills or other methods of disposal.

9. It was established that three modes of disposal exist: (1) reliance on containment of waste and/or leachate; (2) discharge of leachate with reliance on varying degrees of attenuation; and (3) no reliance on either containment or attenuation. These modes generally correspond to disposal of hazardous waste, non-hazardous waste, and inert (innocuous) waste, respectively.

10. The following pollution prediction techniques have been identified in this state-of-the-art assessment: Criteria Listing, Criteria Ranking, Matrix, Classification System, Models and Laboratory Simulation.

11. The identified pollution prediction techniques and procedures that are currently available, or could be further developed, can be viewed as tools for gathering information for waste and site characterization to provide the decision-making professionals with a systematic and rational approach for site selection, evaluation, and permitting.

12. Criteria Listing is the most basic and commonly-used procedure by regulatory agencies for evaluating groundwater pollution potential from land-disposal sites.

13. The Criteria Ranking and Matrix approaches to pollution prediction are useful techniques for an evaluation of a site or waste/site disposal situation on a preliminary or "first-cut" basis, particularly for the comparison between several candidate sites. They do not,

however, provide the degree of detailed waste/site characterization necessary for final evaluation and approval of a permit.

14. The Classification System (Decision Tree) is being increasingly utilized as a tool for waste-disposal siting. This procedure is comprehensive for both waste type and site type, and could be developed into a "uniform" procedure for site selection and approval.

15. Numerous types of simulation models exist including descriptive, physical, analog, and mathematical models, with Conceptual-mathematical models appearing to be the most promising tool for simulation of groundwater contamination potential.

16. The potential for using mathematical models as a groundwater simulation tool depends on developing standardized methodology for leachate characterization, attenuation parameters, and numerical solutions; however, the degree of field testing, calibration, and verification of these models does not yet allow for wide application as uniform pollution prediction techniques.

17. The degree of sophistication and level of development of mathematical- and computer-simulation models far exceed those of parameter quantification, laboratory simulation, and field testing and verification.

18. Several laboratory procedures, such as Thin-Layer Chromatography and Shaker and Column tests, measure the potential for attenuation; however, their results could best be used as "subroutines" in a permit procedure since they do not account for all the interacting parameters that relate to the site-permitting process.

19. European and Canadian waste disposal permitting procedures including hazardous waste disposal closely parallel those permitting procedures identified in the United States. The two basic philosophies of containment versus attenuation apply in these countries as well but it is noteworthy that, with the exception of West Germany, reliance is placed on attenuation of leachates from municipal and many hazardous wastes to a much larger degree than in the United States.

Recommendations.

1. It is recommended that the following pollution prediction techniques be further developed for implementation to waste disposal siting: (1) Criteria Listing; (2) Classification System, and (3) Simulation Models.

2. The recommended development plan for the short-term (within 3 years) is the Criteria Listing approach. This plan includes: development of a uniform criteria listing, waste containment requirements, an assessment matrix, field- and laboratory-quantification methodology, data use requirements, and preparation of a user's manual.

3. A recommended development plan which encompasses both the short-term (within 3 years) and the long-term (within 10 years) is the Classification System. This plan includes: identifying waste characterization techniques, developing criteria for site characterization, and establishing a waste management task force.

4. The recommended development plan for the long-term, although short-term outputs can be expected, is that associated with simulation models.

5. Decisions for waste/site selection and permitting must be made by a team of professionals with expertise in earth science, environmental science and engineering, chemistry and chemical engineering, and, where appropriate, applied mathematics and computer science, using the techniques identified in this study as tools to reach decisions which are environmentally sound, consistent, rational, and defensible.

SECTION II

INTRODUCTION

Background

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) have placed great emphasis on the restoration and protection of the quality of our Nation's surface waters. This emphasis has resulted in the decrease of large numbers of point-source discharges of wastes directly into streams. Increasingly, however, the land has become the major waste depository. A great potential for adverse impact on the Nation's groundwaters now exists due to this increased land disposal of solid and liquid residual wastes, particularly hazardous wastes.

Concurrent with these changes in waste disposal practices has been an increase in the amount of waste being generated. The recent (1977) EPA Fourth Report to Congress - Resource Recovery and Waste Reduction - 1975 states that past consumer gross discharge was 136.1 million tons or 3.2 pounds/capita/day. Similarly, recent EPA-generated figures for 14 major industrial waste sectors, presented at The National Conference on Hazardous Waste Management, indicate an annual total production of approximately 28.8 million metric tons and approximately 10.7 million metric tons of wet and dry potentially hazardous wastes, respectively, as shown in Table 14.

To further intensify the problem, many wastes continue to be disposed of in a "least-cost" way. Numerous case histories (including those in the EPA report (SW-634: 68-01-3703) entitled: Development of a Data Base for Determining the Prevalence of Migration of Hazardous Chemical Substances into the Ground Water at Industrial Land Disposal Sites) attest to the fact that groundwater pollution is occurring from such practices. Indiscriminate landfilling, ponds, lagoons, and other land-disposal methods have clearly proven in numerous instances to be ineffective for adequate

TABLE 14

U.S. POTENTIALLY HAZARDOUS WASTE QUANTITIES (1975 DATA)
(Million Metric Tons Annually)

Industry		Dry Basis	Wet Basis
1.	Batteries	0.005	0.010
2.	Inorganic Chemicals	2.000	3.400
3.	Organic Chemicals, Pesticides, Explosives	2.150	6.860
4.	Electroplating	0.909	5.276
5.	Paints	0.075	0.096
6.	Petroleum Refining	0.624	1.756
7.	Pharmaceuticals	0.062	0.065
8.	Primary Metals	4.429	8.267
9.	Leather Tanning and Finishing	0.045	0.146
10.	Textiles Dyeing and Finishing	0.048	1.770
11.	Rubber and Plastics	0.205	0.785
12.	Special Machinery	0.102	0.162
13.	Electronic Components	0.025	0.035
14.	Waste Oil Re-refining	0.075	0.057
	Totals (To Date)	10.731	28.811

protection of health of both the public and the environment. To a large degree, this can be attributed to poor management practices, since technological and management guidelines regulating such disposal practices, for the most part, have been enacted only recently. A number of state regulatory agencies are currently writing or adopting such guidelines for the regulation of hazardous wastes.

The Resource Conservation and Recovery Act (RCRA) of 1976 (PL 94-580) will regulate hazardous waste on a national level for the first time. Subtitle C - Hazardous Waste Management - mandates the EPA to promulgate regulations governing the following aspects of hazardous waste management within 18 months after the date of enactment (21 October 1976):

Section 3001 - Identification and Listing of Hazardous Waste.

Section 3002 - Standards Applicable to Generators of Hazardous Waste.

Section 3003 - Standards Applicable to Transporters of Hazardous Waste.

Section 3004 - Standards Applicable to Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

Section 3005 - Permits for Treatment, Storage, or Disposal of Hazardous Waste.

Section 3006 - Authorized State Hazardous Waste Programs.

Section 3007 - Inspections.

Section 3008 - Federal Enforcement.

Section 3009 - Retention of State Authority.

Section 3010 - Effective Date.

Section 3011 - Authorization of Assistance to States.

Sections 3004 and 3005 deal specifically with the disposal aspects of hazardous wastes. In order for such regulations to be effective, technologically-sound decision procedures must be used for the siting of waste-disposal operations. Furthermore, it is necessary that these decision procedures be of a uniform nature on a National level. Decision procedures, which would at least in part predict the potential for groundwater pollution from the disposal of specific wastes at specific sites, could be a helpful tool for regulatory and enforcement agencies. Such decision procedures could:

1. Evaluate the potential for groundwater degradation from a potentially-hazardous waste.

2. Determine whether a polluting quantity of waste is present in a given waste-disposal situation.

3. Ideally, determine the maximum safe loading of a given waste on a given land parcel.

Some contradictory expert opinion exists, however, regarding the mechanisms and effectiveness of attenuation processes for waste renovation which are an integral part of the land disposal/land treatment process. This, in turn, has inhibited effective decision making relative to the permitting of land disposal/treatment operations. The development of procedures for a uniform approach to the decision-making process by regulatory agencies would provide a consistent and effective basis for determining the confidence with which one can dispose of a specific waste at a specific site.

Scope and Objectives

The overall objective of this investigation is to provide a state-of-the-art assessment of the pollution prediction techniques for waste-disposal siting. This assessment is to include both current research and regulatory procedures relative to the land disposal/treatment of waste for the entire waste spectrum exclusive of radioactive wastes. The emphasis, however, will be on that research and those specific regulatory procedures which deal specifically with hazardous waste.

An assessment of the techniques currently being utilized or proposed for waste disposal/management will be made with particular attention given to their pollution-prediction capability. This assessment will be based upon: an identification of each procedure, their state of development, and their potential usefulness to regulatory agencies. In conducting this investigation, efforts were directed toward the formulation of several "standard" procedures.

The specific objectives of this investigation are as follows:

1. Conduct interviews with acknowledged experts in the field of waste attenuation/management to assess current laboratory and field research procedures relative to pollution prediction techniques.

2. Conduct interviews with select domestic and foreign regulatory agencies to assess current regulatory procedures being utilized for waste-disposal siting, with emphasis on hazardous waste disposal.

3. Identify and assess the state of the art of techniques to predict and describe the pollution potential from specific wastes being disposed of at specific sites.

4. Identify and assess the most useful water/soil/waste interaction and attenuation mechanisms which are indicative of the ability of a potential site to accept a specific waste for land disposal/treatment in an environmentally-safe manner.

5. Identify and assess the pollution prediction techniques currently utilized or under development which would be candidate procedures for further development into a "standard" procedure.

6. Estimate the cost, work scope, and time requirements associated with each candidate procedure identified.

7. Prepare a detailed development program for those techniques which best predict the groundwater pollution potential and the suitability for permitting of land disposal/treatment sites for both a short-term (within three years) and long-term (within ten years) basis.

SECTION III

LITERATURE SEARCH

A literature search was conducted to identify pertinent references on the behavior of contaminants associated with waste-disposal projects. Primary emphasis was given to hazardous waste constituents excluding radioactive wastes. Unpublished material and administrative regulations at all governmental levels were excluded from consideration. The search was limited primarily to material published in the United States, with the exception of a few Canadian and European reports. Only a few references predate 1960.

Literature dealing with waste disposal with respect to environmental quality is voluminous, and no attempt was made to cover all references on the topic. References were selected on the basis of their significance and relevance to hazardous waste disposal. Where an abstract was not available to judge the value of the reference, the original reference was consulted to determine its pertinence. In a few cases, only reference titles could be located using available library facilities and within the time constraint of the study. When the title appeared to so warrant, the reference was included.

A major portion of the literature search was conducted using the computerized Lockheed Dialog Retrieval Service. Files searched include: (1) CAIN, which is the cataloging and indexing data base of the National Agricultural Library (NAL); (2) ENVIROLINE, which is produced by the Environment Information Center; (3) CA CONDENSTATES, which is the computer-readable file corresponding to the printed Chemical Abstracts; and (4) COMPENDEX, which is the machine-readable version of the Engineering Index.

Each file was searched using index words associated with hazardous waste disposal and processes influencing the fate of various contaminants frequently associated with municipal and industrial waste leachates. The same index words were not suitable for all files owing to the different terminologies used by various research groups. Numerous references contained in published bibliographies were also considered and included where the topic related directly to the disposal and fate of hazardous waste constituents.

It should be emphasized that the literature search effort in this project is not limited to the presentation in this section; rather it is integrated with various sections of the report. This approach was selected because of the wide variety of topics dealt with in this study. Instead of limiting the discussions pertaining to previous work and research activities to one section, it was incorporated in appropriate sections in the report as follows:

- Section IV includes discussion of work related to processes influencing mobility and attenuation of contaminants in soil-water systems.

- Section V includes discussion of work related to different decision procedures (Criteria Listing, Matrix, Decision Tree, Models, and Simulation).

- Appendix A includes a listing of key references related to attenuation.

All references selected for inclusion in this report were placed under one of five topical areas and are found in Appendix A. The topical areas are: Part I - Toxic Metals; Part II - Toxic Organics; Part III - Critical Parameters for Waste Disposal; Part IV - Disposal Procedures, Models, and Guidelines; and Part V - Reviews, Symposia Proceedings, and State-of-the-Art Publications. Additional references on mathematical modeling are given as Part VI - Mathematical Models.

Because many papers and reports embrace more than one subject, references were assigned to the topic which seemed most appropriate. Consequently, the reader is advised to consider closely-related topics.

Key publications of the various non-regulatory experts contacted are provided with their respective write-up in Appendix B.

SECTION IV

PROCESSES INFLUENCING MOBILITY AND ATTENUATION OF CHEMICAL-WASTE CONSTITUENTS IN SOIL-WATER SYSTEMS

The soil is a dynamic system in which numerous chemical, physical, and biological reactions occur singly or simultaneously with time. Because of these reactions, the soil is frequently considered a good receptacle for the disposal of municipal and industrial wastes. Under normal conditions, the soil is able to transform or stabilize many hazardous waste constituents to equilibrium soil components. These reactions occur in both water-saturated and unsaturated soils, and are frequently referred to as attenuation processes or reactions.

Definition

The word "attenuation" has been used by many to describe a beneficial result frequently obtained following the application of a waste to a soil. Because of the variable usage of the word attenuation, its use in this report will be understood to mean:

> "Any physical, chemical, and/or biological reaction or transformation occurring in saturated and/or unsaturated zones that brings about a temporary or permanent decrease in the maximum concentration or total quantity of an applied chemical or biological constituent in a fixed time or distance traveled."

This definition infers nothing about the mobility of a waste constituent contained in the soil and is consistent with the dictionary definition (Funk and Wagnalls Standard College Dictionary, 1971):

> "Attenuate: To reduce in value, quantity, size, or strength; weaken, impair."

The Soil-Water System

Soils are composed of mineral, organic, solution, and gaseous phases. The mineral phase consists of various particle sizes (sand, silt, and clay) which together form a rigid or semi-rigid porous skeleton. The quantity of each size fraction contained in a soil influences the pore-size distribution of a soil, and the solution- and gaseous-phase content. Clay particles possess large surface areas and are generally electrically charged and adsorptive in nature. Aluminum and iron hydroxide gels, oxides, and mixed hydroxide/oxide compounds coat, as well as form, particles which react with constituents in the soil water.

The organic phase is composed of stable organic components (lignin, waxes, and resins) from plants and living and dead micro-organisms. This phase is generally confined to the soil surface, but may extend to a considerable depth in decreasing quantities. The organic phase is dynamic and effective in transforming or attenuating many toxic or hazardous organic constituents into acceptable substances under proper soil conditions.

The soil-water phase is the medium responsible for transporting most constituents through the soil. Soil water, as used in this report, is both soil moisture in the unsaturated zone and groundwater in the saturated zone. The soil water is constantly moving in response to differences in potential energy originating from water additions, gravitational field, soil-water pressure head, evaporation, temperature, osmotic effects, and plant extraction of water. The rate at which the soil water moves through a soil is important in predicting the distribution and depth to which a potentially-hazardous constituent may move in a given time.

The gaseous phase and its composition is influenced by pore-size distribution, degree of soil-water saturation, and biological activity. The composition of the gas or air phase includes oxygen, carbon dioxide, nitrogen, and methane. Under anaerobic (water saturated or high biological activity) conditions, the solubility and chemical form of a material may change drastically.

The soil water, organic, and gaseous phases of the soil are changing constantly and, as a result, play a major role in the reactions that occur in the soil. These reactions influence the mobility and attenuation of hazardous waste constituents. In the following discussion, specific examples are used to illustrate how various reactions influence the mobility and attenuation of selected waste constituents. The reactions will be classified as either physical, chemical, or biological, even though some could be correctly considered under more than one classification.

Attenuation Mechanisms

Physical Processes. Three physical processes influence the mobility and attenuation of a waste constituent in a soil system; these are: molecular diffusion, hydrodynamic dispersion, and dilution.

Molecular Diffusion. Molecular diffusion is a spontaneous process resulting from the natural thermal motion of dissolved substances. Experimentation has shown that the net rate of movement of a chemical component from a region of high concentration to one of low concentration is proportional to the difference in concentration between the two regions, and is essentially independent of the absolute concentration in each region.

These observations have been developed into what is known as Fick's Law. The proportionality constant in Fick's Law, D, is called the diffusion coefficient. Molecular diffusion coefficients in free solution are greater than those in soils where the solid phase obstructs and restricts the motion of the molecule. Reversible adsorption-desorption or cation-exchange reactions also reduce the apparent diffusion coefficient of a substance in a soil.

Diffusion is generally considered an insignificant transport process when the soil water is transient. Molecular diffusion, however, does modify abrupt concentration differences between solutions of different concentrations in contact with one another. The interface between a landfill leachate front and the soil water which is devoid of any constituents found in the leachate is an example. This apparent attenuation occurs over a short soil depth.

Hydrodynamic Dispersion. The soil solution flowing through a soil does not move at the same rate in pore sequences of different sizes. Within a given pore the flow rate is slower near the walls than in the center of the pore. The soil water also flows faster in the larger pores than in the small pores. These two effects, plus the tortuous (twisting) path the water must follow as it moves through the soil, tend to spread or reduce abrupt concentration changes in the soil with time. This phenomenon is called hydrodynamic dispersion and is illustrated in Figure 6.

Hydrodynamic dispersion differs from molecular diffusion in that it occurs only in the presence of a net movement of soil water. Experimentation has shown that the hydrodynamic dispersion phenomenon can be described analytically by an equation similar in form to that of Fick's Law for molecular diffusion. However, the magnitude of the dispersion coefficient is larger than the molecular diffusion coefficient, and is generally equal to or larger in magnitude than the average pore-water velocity or interstitial flow rate. The dispersion coefficient includes both molecular diffusion and hydrodynamic mixing owing to pore-size distribution.

Hydrodynamic dispersion is effective in attenuating the maximum constituent concentration in a pulse or slug of waste with time and distance as it moves through a soil profile. This apparent attenuation does not apply to the total quantity of the constituent in the pulse, only its maximum concentration. For large leachate inputs such as those associated with large landfills, hydrodynamic dispersion will not be an effective attenuation process.

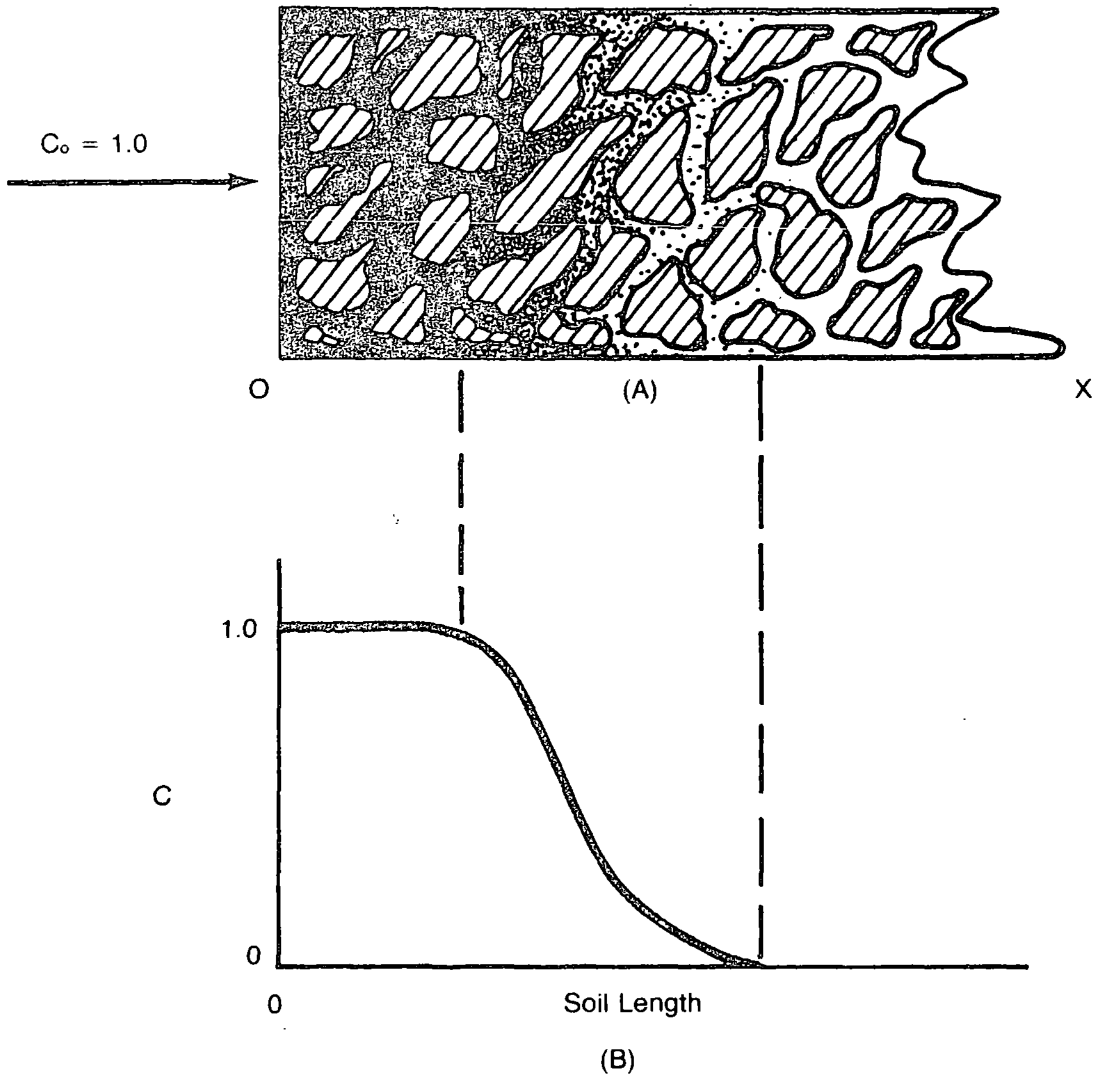


FIGURE 6 ATTENUATION BY DISPERSION

(A) The crosshatched areas are soil particles, the solid area represents a soil solution with a constituent concentration of C_o, and white area represents a soil solution with a constituent concentration of zero.
(B) Average constituent concentration distribution in the soil as a function of soil length.

Dilution. A dilution in constituent concentration frequently occurs when the soil water in the unsaturated zone enters the zone of saturation below the water table. If the region of soil between the water table and the bottom of a landfill is unsaturated, the vertical transport rate of the leachate from the disposal site will be orders of magnitude smaller than that when the soil is saturated. As the waste leachate approaches the zone of saturation, which is flowing approximately perpendicular to the leachate, the flow or stream lines in the unsaturated zone near the water table are altered by the presence of the water table. The change in degree of water saturation and flow rate as the leachate enters the groundwater results in a reduction in the leachate concentration. The dilution is enhanced further as the leachate moves downgradient through the aquifer.

The amount of dilution occurring depends upon the water flow rate in both zones. This process can provide further attenuation of the contaminant entering the saturated zone. Attenuation by dilution should be given more serious consideration when evaluating a site for waste disposal since it is considered by many to be the most important attenuation mechanism.

Chemical Processes. There are three types of reactions which are basically chemical in their nature: adsorption-desorption or cation exchange, precipitation, and oxidation/reduction.

Adsorption-Desorption or Ion Exchange. The mobility of a soluble hazardous constituent in a soil-water system is significantly influenced by adsorption-desorption or cation-exchange reactions between the constituent and soil. In order to quantitatively describe the influence of adsorption on mobility, the adsorption-desorption or cation exchange characteristics of the constituent and soil must be described analytically. Numerous equations have been developed to describe the adsorption characteristics of various soluble constituents to soils. The Freundlich, Langmuir, and first-order kinetic equations are the most commonly-used adsorption equations. Adsorption equations based on thermodynamics are difficult to use in systems as complex as hazardous waste leachates because of the number of constituents present.

When a soil and waste constituent are combined, a specific fraction of the constituent is associated with the solution phase and another portion with the solid or soil phase. This partitioning between the solid- and soil-water phases can be used to predict the mobility of a constituent in a soil-water system. If the soil-water and adsorbed phases are in equilibrium, their relationship to one another can frequently be described with the Freundlich Equation:

$$S = KC^N \qquad (1)$$

where: S is the adsorbed constituent concentration per mass of soil (e.g., μg/g); C is the constituent concentration in solution (e.g., μg/ml); and K and N are empirical coefficients that vary with the constituent, composition of the waste, and soil.

Adsorption-desorption or cation exchange are the most common reactions generally associated with the attenuation of hazardous constituents in soils. However, when the reaction is reversible, which is generally the case for cation exchange, the attenuation is only an apparent one resulting from a reduction in constituent mobility. For example, the larger the value of K in Equation (1), the less mobile the constituent is, and the more time that is required for the contaminant to move to a given depth in the soil. The mobility of a constituent is reduced because each time a constituent is adsorbed to the soil phase, its migration is temporarily stopped. As shown in Figure 7, when a constituent such as cadmium (Cd^{+2}) becomes adsorbed, it remains that way an average finite time, t_d (time for desorption to occur), before it is desorbed. In this time interval, its downstream motion through the soil pore is halted, while a nonadsorbed constituent such as chloride (Cl^-) continues to move at the average pore-water velocity. Once the constituent is desorbed by another cation, a mean time, t_a (time for adsorption to reoccur), elapses before it is adsorbed again. During this time, the constituent is carried forward at the mean pore-water velocity. Thus, the greater the t_d, the more adsorption and slower a given constituent moves. K in Equation (1) is proportional to t_d/t_a.

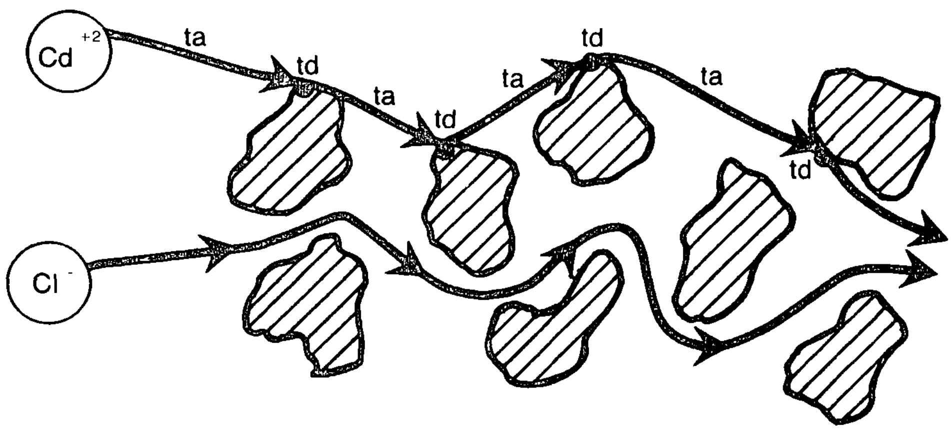


FIGURE 7 ATTENUATION BY ADSORPTION/DESORPTION

If the pulse of leachate containing the contaminant is small, then the maximum concentration of the contaminant in the soil water will be attenuated owing to hydrodynamic dispersion. This is illustrated in Figure 8 where the dashed line represents a conservative ion (e.g., chloride) and the solid line represents a cation (e.g., cadmium) that exchanges with other ions on the solid phase of the soil as it moves through the soil profile. Because of cation exchange, it takes five times more water (320 cm versus 64 cm) to move the cadmium to the same soil depth as that of the chloride. The spreading or smearing of the constituent pulse as it moves through the soil profile is approximately proportional to the square root of time. Because of ion exchange, part of the constituent is now associated with the solid phase, and part is

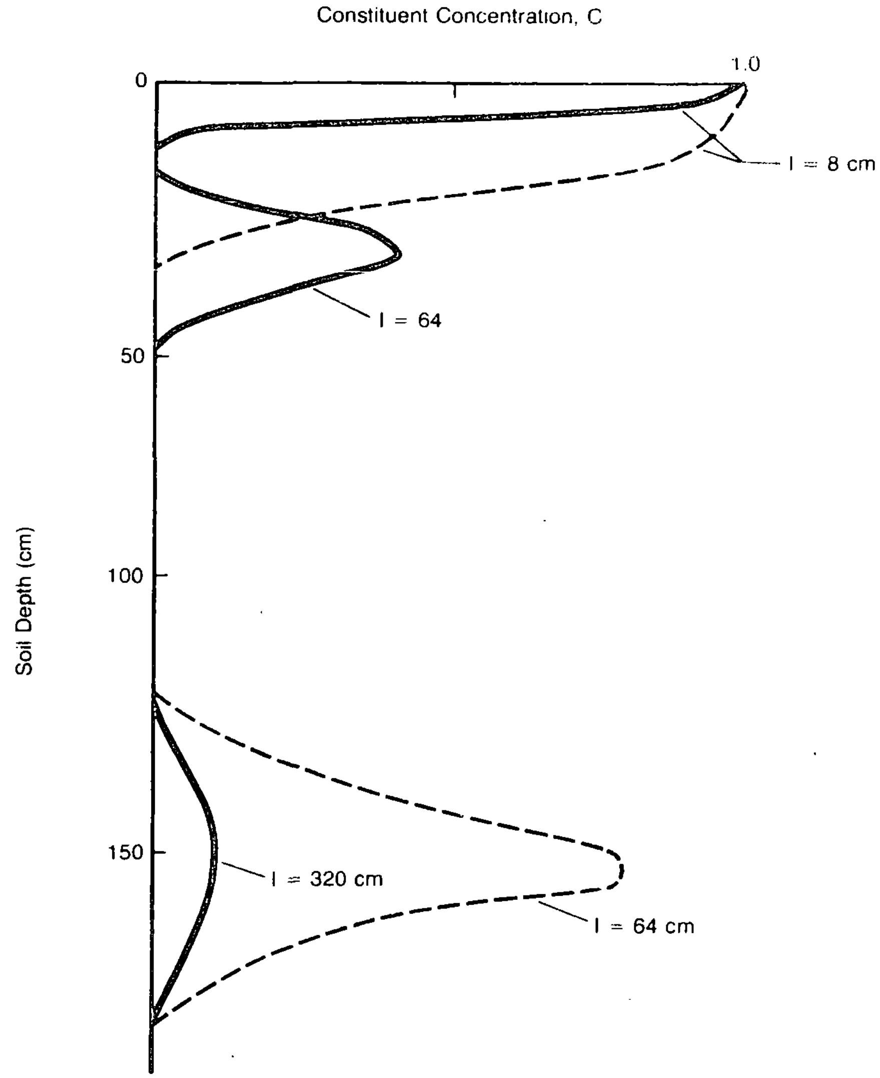


FIGURE 8 DISPERSION FOR CONSERVATIVE AND NON-CONSERVATIVE IONS

The solid line represents a constituent that exchanges with cations on the soil-solid phase and the dashed line represents a conservative constituent such as chloride. The water content of the soil is 0.4 cm^3/cm^3 and the constituent concentration in the solution entering the soil is 1.0. 1 is the amount of solution that has been added at the soil surface. The initial eight cm of solution entering the soil contained both constituents, whereas that which followed contained neither constituent.

in the soil-water phase. When the waste source is large and enters the soil for a long time period, the maximum constituent concentration in the soil water will not exhibit appreciable attenuation. However, if the waste pulse is small in comparison to the vertical distance to the water table, attenuation of the maximum concentration may be observed.

The mobility of a waste constituent will also be influenced by the concentration of the substance in solution when the adsorption isotherm is non-linear (e.g., N = 0.7 in Equation (1)). Figure 9 presents a simulated relative-concentration distribution in a soil profile receiving two input constituent concentrations (C_o = 10 and 5,000 μg/ml). C_o represents the input concentration or leachate concentration at the waste-soil interface. For the simulations presented in the figure, the soil bulk density, soil-water content by volume, average pore-water velocity, and dispersion coefficient were 1.4 g/cm^3, 0.3 cm^3/cm^3, 3.0 cm/hr, and 1.0 cm^2/hr, respectively.

A pulse of leachate with a constituent concentration of C_o = 10 and 5,000 μg/ml was introduced at the soil surface for 22 hours and followed by an input of water without the constituent for an additional 48 hours (total of 70 hours). The curves in the figure were simulated assuming adsorption was reversible and described by Equation (1). The figure illustrates that a hazardous waste constituent will be more mobile at high concentrations than at low concentrations when N is less than 1.0. Both curves are asymmetrical in shape owing to the nonlinearity (N = 0.7) of the adsorption isotherm. Results similar to those shown have been observed for 2,4-D amine.

The cation-exchange capacity of a soil will vary with the type of clay mineral present, quantity of clay, amount of organic matter, and, in some instances, soil pH. Surface area of the solid phase has in many cases been shown to be proportional to the K in Equation (1). In general, increases in soil pH result in higher cation-exchange capacities. However, over a pH range of 5 to 7, the increase in cation exchange probably does not generally exceed 30 percent of the original value.

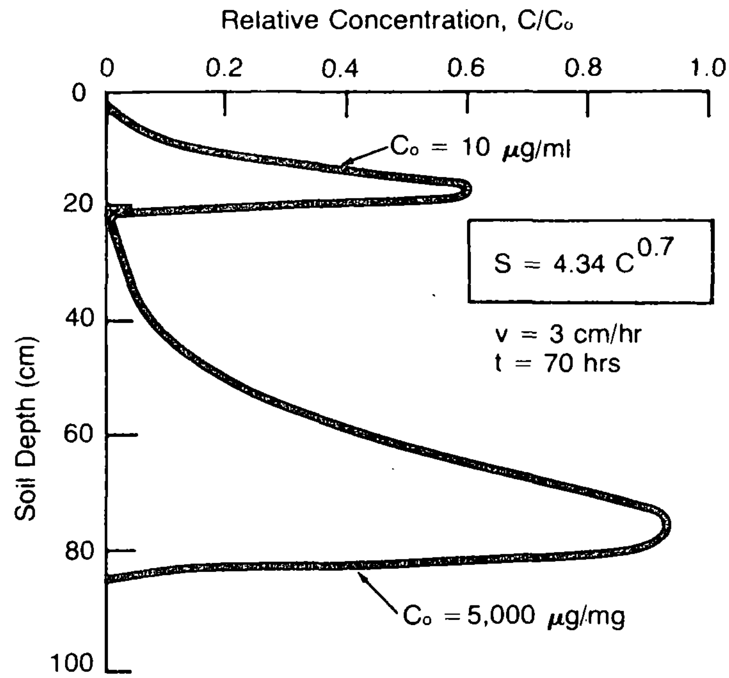


FIGURE 9 DISPERSION AS AFFECTED BY SOURCE CONCENTRATION

Simulated relative 2,4-D concentration distributions in the soil solution phase; the soil solution is flowing through the pores at an average velocity, V, of 3 cm/hr.

A major problem in defining the mobility of a given constituent in a soil is that it varies with the composition of the waste and species of initial cations on the soil-exchange complex. The exchange of metal cations (e.g., Cu^{+2}, Zu^{+2}, Cd^{+2}, etc.) with common cations such as Na^{+} and Ca^{+2} is reduced in the presence of large quantities of Na^{+} and Ca^{+2}. This competition of exchange sites varies with each waste and soil. From a practical standpoint, cation exchange does not effectively lower the total-salt concentration in the soil water, and toxic metal cations are not significantly retained by cation exchange under soil conditions where soluble salts are present in high concentrations.

Precipitation. Adsorption and precipitation reactions are difficult to distinguish from one another in soils. Both processes involve the removal of a constituent from the soil water. Precipitation in the following discussion will be defined in its strictest chemical sense, i.e., formation of well-defined solid phases. Precipitation reactions involving trace and heavy metals in soils are so closely related to pH that it is nearly impossible to separate the two.

Numerous references can be cited to the effect that trace and heavy metals, in general, form insoluble or very slightly soluble precipitates at neutral or greater than neutral pH values. This is an effective attenuation reaction in that it reduces both the maximum as well as the total amount of a constituent in the soil water. Conversely, a decrease in soil pH will result in an increase in the solubility of many precipitates. The solubility of a group of common trace and heavy metal compounds is given in Table 15. When a saturated aqueous solution of a sparingly soluble salt such as $PbSO_4$ is prepared, the following equilibrium exists:

$$PbSO_4 \rightleftharpoons Pb^{+2} + SO_4^{-2} \qquad (2)$$

TABLE 15

SOLUBILITY PRODUCT CONSTANTS FOR VARIOUS COMPOUNDS*

Substance	Solubility Product Constant ($mole^n/l^n$)
Carbonates	
Cadmium carbonate	8.5×10^{-13}
Cobolt carbonate	1.4×10^{-13}
Cupric carbonate	2.3×10^{-10}
Lead carbonate	7.3×10^{-14}
Zinc carbonate	1.6×10^{-11}
Chlorides	
Lead chloride	1.0×10^{-4}
Mercurous chloride	2.1×10^{-18}
Hydroxides	
Cadmium hydroxide	5.3×10^{-15}
Chromic hydroxide	7.0×10^{-31}
Cupric hydroxide	1.6×10^{-19}
Lead hydroxide	4.0×10^{-15}
Mercuric hydroxide	3.0×10^{-26}
Zinc hydroxide	1.8×10^{-14}
Sulfates	
Lead sulfate	1.06×10^{-8}
Sulfides	
Cadmium sulfide	3.6×10^{-29}
Cobalt sulfide	3.0×10^{-26}
Cupric sulfide	8.5×10^{-45}
Lead sulfide	3.4×10^{-28}
Nickel sulfide	1.4×10^{-24}
Zinc sulfide	1.2×10^{-23}

*These compounds could form from chemicals in wastewater at approximately room temperature.

The solubility product, K_{sp}, for the above case is $(Pb)^2 \times (SO_4)^2$ where (Pb) and (SO_4) are expressed in moles of solute per liter of water. Thus, the smaller the solubility product, the more sparingly soluble the salt. The type of precipitate formed is dependent upon the composition of the waste and the soil water and solid phases. Also, microbial activity can significantly alter the soil pH and CO_2 concentration, which in turn would change both the solubility of a precipitate and the forms in which it could exist.

Hydrous oxides of Mn and Fe furnish the principal mechanisms for the precipitation (attenuation) of Co, Ni, Cu, and Zn and other metals in soils. Very small amounts of hydrous oxides of Mn and/or Fe are sufficient to control the heavy-metal concentration in soil water and, thus, attenuate or reduce the concentration of the constituent in the soil water. The ultimate depth to which a constituent can move is significantly influenced by the precipitation rate, constituent concentration in the soil water, and velocity at which the soil water is flowing through the soil. Precipitation results in a net decrease in the amount of a constituent remaining in solution with time, whereas, for cation exchange, the amount of an exchangeable constituent in the soil water does not change with time. Since precipitation and adsorption occur simultaneously in the soil, it is difficult to separate the two processes.

Oxidation/Reduction. Oxidation-reduction reactions influence the mobility and attenuation of waste constituents (especially trace and heavy metals). Most such reactions in soils are initiated by biological activity. The inorganic ions released are free to take part in a multitude of strictly chemical reactions. Oxidation-reduction reactions in soils are important in a waste management program since oxidation can be initiated to produce complexes and compounds that are less mobile. Reduced forms are generally more soluble than oxidized forms of heavy metals.

Biological Processes

Biodegradation. Micro-organisms are an integral part of the soil. The primary micro-organisms are bacteria, actinomycetes, fungi, algae, and soil animals. These organisms transform waste components by such processes as oxidation, reduction, mineralization, and immobilization. The end products of these transformations are generally harmless, but some toxic metabolites have been known to be produced.

The bacteria are the most numerous and biochemically active group. Bacteria are responsible for such important processes as nitrification, denitrification, nitrogen fixation, and sulfur transformations. The fungi are involved in humus formation and certain mineral transformations. The actinomycetes are very effective in transforming resistant organic compounds. The nitrogen-fixing ability of algae in flooded soils is very important agriculturally and ecologically. Earthworms are important in maintaining the soil structure and aeration of certain soils.

The importance of soil micro-organisms to attenuation may not be readily apparent at first, but they are quite important. Generally, pesticides are transformed and/or degraded by micro-organisms to less toxic compounds. For example:

$$2,4\text{-D} + O_2 \xrightarrow{\text{oxidation}} CO_2 + H_2O + Cl^- \qquad (3)$$

or

$$2,4\text{-D} + O_2 \xrightarrow{\text{oxidation}} 2,4\text{-D Metabolite} + O_2 \xrightarrow{\text{oxidation}} CO^2 + H_2O + Cl^- \qquad (4)$$

A microbiological process common in municipal waste disposal is denitrification. This reaction occurs under anaerobic conditions in the presence of a carbon source. For example:

$$NO_3 \qquad NO_2 \qquad N_2,\ N_2O\ \text{(gases)} \qquad (5)$$

These reactions represent attenuation processes that are irreversible; thus, these reactions should be employed or encouraged were possible.

Sufficiency of Attenuation

The degree of attenuation required for a waste constituent is generally established based upon that necessary for the maintenance of an acceptable groundwater quality. Two factors impact on this goal: identification of the amount of waste constituent that will be attenuated for a given waste disposal site, and definition of acceptable groundwater quality. Groundwater quality limits are established from limits set for safe drinking water (Table 16). In a number of instances the natural groundwater quality may be poor. Under these conditions, background data and the advice of State and Federal government agencies should be consulted for groundwater quality constraints. From these sources and guidelines, the required groundwater quality can be established and the required attenuation for a given site and waste constituent can be identified.

In general, no single process or reaction (physical, chemical, or biological) is responsible for the total observed attenuation of a waste constituent. For example, the cadmium solution concentration is reduced as a result of chemical and biological processes which produce precipitation, with these latter reactions occurring near the waste application site. The equilibrium cadmium solution concentration depends upon the chemical form of the precipitate and its solubility (Table 15). Attenuation of the cadmium by precipitation may not be sufficient to meet drinking water standards (Table 16); however, the dilution that occurs as the cadmium enters the zone of saturation below the waste disposal site

TABLE 16

DRINKING WATER QUALITY CRITERIA

Parameter	EPA 1977 National Interim Primary Drinking Water Standards Maximum Contaminent Levels (MCLS)	USPHS 1962 Drinking Water Standards Recommended Limit
CHEMICAL - INORGANIC, mg/L		
Arsenic	0.05	0.01
Barium	1.0	
Cadmium	0.010	
Chloride		250
Chromium (Cr^{+6})	0.05	
Copper		1
Cyanide	0.2	0.01
Fluoride	Limits set according to annual average of the maximum daily air temperatures (1.4-2.4)	1.3
Iron		0.3
Lead	0.05	
Manganese		0.05
Mercury	0.002	
Nitrate - Nitrogen	10	10
Selenium	0.01	
Silver	0.05	
Sulfate		250
Total Dissolved Solids (TDS)		500
Zinc		5
CHEMICAL - ORGANIC, mg/L		
Alkyl Benzene Sulfonate (ABS) Used before 1965		0.5
Carbon Chloroform Extract (CCE)	0.7	0.2
Phenols		0.001
PHYSICAL		
Turbidity, TU	1 desirable 5 max.	5 max.
Color, Units		15
Odor, Number		3
PESTICIDES - mg/L		
(a) Chlorinated Hydrocarbons (Insecticides)		
Endrin	0.0002	
Lindane	0.004	
Methoxychlor	0.1	
Toxaphene	0.005	
(b) Chlorphenoxys (Herbicides)		
2,4-D (Dichlorophenoxy acetic acid)	0.1	
2,4,5-TP Silvex (Trichlorophenoxypropionic acid)	0.01	

may provide the necessary attenuation to meet groundwater-quality standards. The sufficiency of attenuation is thus achieved through a series of reactions and not one single reaction.

Obviously the greater the amount of waste applied at a given site, the greater the amount of leachate that will be produced with time, and the greater the potential for adverse environmental impact. The amount of waste alone, however, is not generally as important as: the type of waste applied, the concentration of the potential contaminants within that waste, and the solubility of those potential contaminants. The rate of hydrologic flux or flushing of the waste by rain which infiltrates and moves through the landfill to produce the leachate is also of significant importance. Undiverted surface water runoff onto the site and groundwater flow within the base of the site can also contribute to this hydrologic flux.

A very important factor in the waste management aspect to minimize the hydrologic flux is the type and permeability of the cover material used at the disposal site. The permeability of the cover material will control the rate of water movement through the waste, and, therefore, the rate of leachate migration through the soil to the underlying water table. A slow rate of leachate migration from a disposal site, in many cases, can result in significant attenuation due to hydrodynamic dispersion and dilution of the leachate constituents in both the unsaturated and saturated portions of the flow system by soil water and groundwater, particularly the latter. In this way, the "attenuation capacity" of the site is not exceeded. Management of the waste disposal site resulting in slow rates of leachate migration, however, will prolong the active life of the site undergoing biological and chemical degradation and leaching.

The sufficiency of attenuation for a given waste constituent may be acceptable at one site and inadequate at another location owing to differences in hydrology. Arid regions in the United States have had fewer groundwater contamination problems resulting from waste disposal operations than the more humid regions for this reason. This difference, however, does not mean that greater attenuation exists under arid conditions. In the arid regions, less water passes through the unsaturated zone per year; thus, it takes longer for a constituent to travel a given distance in the soil. Also, the arid-region soils frequently have a higher soil pH, which is beneficial in reducing the toxic- and heavy-metals concentration in the soil water by precipitation.

Good management practices and economic considerations also affect the sufficiency of attenuation. Many disposal operations have developed leachate problems with significant adverse environmental impacts due to poor management practices even though the engineering design and site characterization were sound. Operational functions, such as depth of filling, proper placement and maintenance of cover material, and acceptance and concentration of liquid wastes, are examples of poor management practices. In addition, the emphasis on disposal operations today is the large multi-lift landfill due to the economy of scale and the great difficulty in acquiring disposal sites. Such "mega-sites" in many instances automatically preclude the reliance on attenuation due to the great potential for exceeding the attenuation capacity of the given site.

Because of the number of reactions that may occur within the unsaturated and saturated zone of soil, it is difficult to simulate the behavior of a specific waste constituent. Many of the conceptual models that have been developed are complex with numerous coefficients and parameters. Calibration of these models has established the coefficients and parameters for a given waste constituent and site, but these values may or may not be applicable to another waste and/or site. Therefore, procedures are needed to measure these coefficients independently. With reliable models, the sufficiency of attenuation could be better established prior to waste application for a given waste and site as well as the management procedures necessary to ensure such sufficiency of attenuation.

SECTION V

SUMMARY OF POLLUTION PREDICTION TECHNIQUES

Introduction

Numerous research activities are currently underway to define and to clarify the various attenuation mechanisms and their importance in the renovation of municipal and industrial solid, liquid, and sludge wastes. Much research is also being conducted for developing additional techniques that will provide an assessment of the potential for pollution of surface and groundwaters in a given waste/soil situation.

Interviews were conducted therefore with a number of non-regulatory experts engaged in work related to the attenuation of wastes and the development of pollution prediction techniques. A list of those experts contacted and their affiliation can be found in Table 17. A contact form which summarizes the interviews and pertinent material published by each expert and their associates is found in Appendix B (arranged alphabetically). Concise comments on the approach taken, state of development, and availability as a prediction technique are given. A more detailed presentation and assessment of those techniques which warrant consideration for further development is given below and in Section VII, Recommended Development Plans.

Interviews were also conducted with selected regulatory agencies, both domestic and foreign, to identify and to assess their waste disposal permitting procedures. A listing of those regulatory agencies contacted, the rationale for their selection, and an overall assessment of their permitting procedures is given in Section VI, Regulatory Agency Practices. The permit procedures identified that are presently being used by these regulatory agencies are Criteria Listing and Classification System.

TABLE 17

NON-REGULATORY EXPERTS CONTACTED

Dr.L. Boersma
Dr. Eugene Elzy
Dr. Thomas Lindstrom
Oregon State University

Dr. Herman Bouwer
U.S. Water Conservation Laboratory

Mr. John D. Bredehoeft
U.S. Geological Survey

Dr. J. Bromley
Dr. A. Parker
Dr. D.C. Wilson
Dr. I. Harrison
Harwell Laboratory
Institute of Geological Sciences
Oxfordshire, United Kingdom

Mr. Nolan A. Curry
Private Consultant

Dr. Elliot Epstein
U.S. Department of Agriculture
Agricultural Research Service

Dr. Graham J. Farquhar
University of Waterloo

Dr. Allan Freeze
Geologic Survey
British Columbia

Dr. Wallace H. Fuller
University of Arizona

Dr. James Gibb
Illinois State Water Survey

Dr. Eugene A. Glysson
University of Michigan

Dr. Robert A. Griffin
Dr. Neil F. Shimp
Dr. Keros Cartwright
Illinois State Geologic Survey

Dr. D. Joseph Hagerty
University of Louisville

Dr. Robert K. Ham
University of Wisconsin

Mr. Martin J. Houle
Dugway Proving Ground
Department of Army

Dr. Lenny Konikow
Mr. David Grova
U.S. Geological Survey

Dr. Donald Langmuir
Pennsylvania State University

Mr. Harry E. LeGrand
Private Consultant

Dr. Hans Mooij
Environment Canada

Dr. Michael R. Overcash
North Carolina State University

Mr. John G. Pacey
Emcon, Inc.

Dr. Albert L. Page
University of California--
at Riverside

Dr. Collin R. Phillips
Chemical Engineering Research
Consultants, Ltd.

Dr. George Pinder
Dr. Robert Cleary
Dr. M. van Genuchten
Princeton University

Dr. Frederick G. Pohland
Dr. Wendell Cross
Mr. James Hudson
Georgia Institute of Technology

Mr. Frank A. Rovers
Conestoga - Rovers and Associates

Dr. Dwight A. Sangrey
Cornell University

Mr. Michael J. Stiff
Mr. P.J. Maris
Mr. Chris Young
Water Research Centre
(Medmenham Lab)
Stevenage, United Kingdom

Mr. William H. Walker
Geraghty & Miller

Dr. Raul Zaltzman
West Virginia University

The interviews with these regulatory agencies and non-regulatory experts have resulted in the identification of procedures which warrant further consideration as "standard" waste disposal-siting procedures.

- The procedures identified to date can be categorized as follows:
- Criteria Listing.
- Criteria Ranking.
- Matrix.
- Classification System (Decision Tree).
- Models (Mathematical).
- Laboratory Simulation (e.g., soil columns).

For each of these procedures, a description, its state of development and application, an assessment of its advantages and disadvantages, and its availability as a "standard" decision procedure are presented. It is noteworthy that a number of the techniques identified are interrelated (e.g., Criteria Listing with each of the others) or constitute "sub-routines" within a more comprehensive decision procedure (e.g., column studies with the classification system).

While many promising procedures are under development or have in fact been developed, only the Criteria Listing and Classification System approaches have been sufficiently tested to be routinely used. In addition, due to the complex nature and definition of attenuation mechanisms, and the number of approaches that are available both to define these interactions and to predict the resultant pollution potential, it must be emphasized that differences of opinion exist among both the experts and the regulatory agencies.

Criteria Listing

Description. The most basic and universally-applied decision procedure identified is that of Criteria Listing. This approach is utilized to a varying degree by each of the regulatory agencies contacted, both domestic and foreign.

The Criteria Listing approach consists of listing factors for both waste and site characterization and of obtaining data to adequately define each factor listed. An assessment of these data is then made on the basis of the ability (or lack of it) for a given site to attenuate or renovate a given waste. When a given waste/site situation does not lend itself to the prevention of adverse environmental impacts (particularly groundwater pollution), the waste/site characteristics must be evaluated from the standpoint of containment or "storage". Such containment of wastes must be provided by virtue of the natural site conditions, with reliance predominantly on the natural low permeability of the deposits or on the utilization of engineered modifications such as liners.

The basic elements of the Criteria Listing approach are as follows:

- Waste characterization - type, amount, physical characteristics, chemical characteristics, and biological characteristics.
- Site characterization - location, topography, climatology, land use, soils, geology, and hydrology.

In the Criteria Listing approach, quantitative data are obtained, but there is no attempt to rank or assign weighted values to the criteria, with the result that each is assumed to have equal importance in the assessment of pollution potential.

State of Development/Application. A composite waste characterization has been compiled by the contractor based on those regulatory agencies contacted, as shown in Table 18.

TABLE 18

WASTE CHARACTERIZATION -- CRITERIA LISTING*

Type:	Industrial SIC Plant name/location Waste stream Municipal - Specify waste/source Other - Specify waste/source
Amount:	Volume or weight Rate of generation
Physical:	Solid Liquid Sludge
Chemical:	pH Toxicity Major constituents Minor constituents
Biological:	Degradability Organic content

*(compiled by Weston)

A detailed and generally complete Criteria Listing has been compiled for site characterization as shown in Table 19. The criteria are those that would both independently and dependently affect site suitability and the prediction of pollution potential. The predominant dependent influence of these criteria results from complex interrelationships among the parameters. For example, the mere presence of limestone (as an independent variable) may lead to the prediction of a high potential for pollution of groundwater. Other pertinent parameters which act in a dependent manner and require evaluation for an adequate assessment of the pollution potential in a given waste disposal situation on limestone

TABLE 19

SITE CHARACTERIZATION -- CRITERIA LISTING*

	California-State Water Resources Control Board	Illinois-Environmental Protection Agency	Minnesota-Pollution Control Agency	New York-Department Environmental Conservation	Pennsylvania-Department Environmental Resources	Texas-Water Quality Board	Ontario-Ministry of the Environment
PHYSIOGRAPHY							
Site Location	■	■		■	■	■	■
Topographic Map	■	■		■	■	■	■
Site Boundaries	■	■	■	■	■	■	■
Topographic Setting		■		■	■	■	■
Topography	■		■	■	■		■
LAND USE - Surrounding Site	■	■		■	■	■	
Water Wells	■	■	■	■	■		■
Springs	■		■	■	■		
Swamps	■		■	■	■		■
Streams	■	■	■	■	■		■
Reservoirs		■		■	■		■
Other Bodies of Water		■	■	■	■		
Sinkholes			■		■		
Underground and/or Surface Mines		■			■		
Mine Pool Discharge Points					■		
Mining Spoil Piles or Mine Dumps					■		
Quarries					■		
Sand and Gravel Pits					■		
Gas and Oil Wells					■		
Diversion Ditches		■			■		
Water Quality Monitoring Points					■		
Occupied Dwellings		■	■	■	■		■
Roads			■	■	■		■
Power Lines				■	■		

*Black denotes information specifically requested.

TABLE 19
(CONTINUED)

	California	Illinois	Minnesota	New York	Pennsylvania	Texas	Ontario
Pipelines				X	X		
Public Buildings					X		
Abandoned Canal					X		
Public Park			X				
CLIMATOLOGY							
Precipitation Data							
Maximum				X	X		
Average			X	X	X		
Maximum Monthly					X		
Station of Record					X		
Length of Historical Record					X		
Runoff			X				
Flooding Frequency	X		X	X	X	X	X
Source of Information					X		
SOILS							
Auger Holes (Borings)	X	X	X		X	X	
Backhoe Pits					X		
SCS Mapping					X		
Physical Properties							
Texture (USDA)	X	X		X	X	X	
Depth to Mottling					X		
Depth to Fragipan					X		
% Coarse Fragments					X		
Permeability (Percolation)	X	X	X	X	X	X	
Liquid Limit	X					X	
Plastic Limit						X	
Plasticity Index	X					X	
Sieve Analysis	X					X	
Chemical Properties							
Soil pH						X	X
Cation Exchange Capacity		X		X		X	

TABLE 19
(CONTINUED)

	California	Illinois	Minnesota	New York	Pennsylvania	Texas	Ontario
GEOLOGY							
Backhoe Pits					■		
Borings	■	■	■		■	■	
Description of Geologic Profile	■	■	■	■	■	■	
Consolidated Deposits							
Bedrock Type(s)	■	■	■	■	■	■	
Formation Name		■			■		
Outcrop			■		■		
Degree of Weathering					■		
Depth to Bedrock		■		■	■	■	
Unconsolidated Deposits							
Type(s)	■	■		■	■	■	
Formation Name		■			■		
Texture		■			■		
Structure		■		■	■		
Fold Axis					■		
Bedding Planes					■		
Joint Planes					■		
Fault Planes					■		
Fracture Traces					■		
HYDROLOGY							
Surface Water							
Distance to Nearest Body			■	■			■
Type					■		
Quality				■			
Ground Water							
Depth to Water Table	■	■		■	■	■	■
Maximum				■	■		
Minimum	■		■	■	■		
Location and Date							
Measured		■			■	■	
Seasonal Fluctuations					■		

TABLE 19
(CONTINUED)

	California	Illinois	Minnesota	New York	Pennsylvania	Texas	Ontario
Depth to Perched Water Table		■	■		■		
Direction(s) of Flow		■	■	■	■		
Rate of Flow		■			■		
Point(s) of Discharge					■		
Aquifer Characteristics	■	■				■	
Monitoring Points		■	■	■	■	■	■
Number		■		■	■	■	
Location		■		■	■	■	
Type		■		■			
Quality					■		
Baseine	■	■	■	■	■	■	
Frequency of Sampling		■			■		
Specified Parameters		■			■		

bedrock are: the thickness, texture, and drainage characteristics of soils overlying this bedrock; the lithology, actual degree of fracturing, and solution activity in the bedrock; and the depth to the water table.

The format for this site-characterization Criteria Listing is Module 5A- Supplementary Geology and Groundwater Information -- which is used by the Division of Solid Waste Management and the Division of Water Quality Management, Pennsylvania Department of Environmental Resources. Table 15 presents those site factors considered in Criteria Listing by Pennsylvania and five other states as well as the Province of Ontario.

The required criteria are those that are specifically listed in the guidelines, rules and regulations, or permit applications currently in effect for each agency. In certain cases, a "hydrogeologic report" is required which may not individually require the criteria shown in the table, but would in fact require that those items be described. This table does give some indication of the variable degree of detail required by those regulatory agencies contacted.

It is noteworthy that the Criteria Listing approach is used by such regulatory agencies as the New York State Department of Environmental Conservation, the Pennsylvania Department of Environmental Resources, the Minnesota Pollution Control Agency, the Netherlands Institute for Waste Disposal, West Germany Bavarian Environmental Protection Agency, and the Ontario Ministry of the Environment. Personnel in each of these agencies have stated that the decision for waste/site permitting is based upon objective description and quantification of both waste and site characteristics, the combined expertise of the permit review personnel, and by comparison with empirical data generated from existing analogous waste/site disposal situations. In the final analysis, therefore, a subjective decision is made based upon utilization of objective data and analysis to the degree that the data will permit.

It is important to realize that there is near unanimous agreement among the experts, both regulatory and non-regulatory, that the final decision for approval or denial of a waste permit must be made by the multidisciplinary review personnel, using but not relying totally on the pollution prediction techniques available to them. This fact results from the realization that there are complex interrelationships between waste/site characteristics which are variable in space and time. Furthermore, these interrelationships are not sufficiently understood at present, nor are expected to be sufficiently understood in the foreseeable future to place complete reliance on the prediction techniques. This is not to say that other procedures do not exist which will prove invaluable aids in making the final decision, but rather, each waste/site situation can be taken to be somewhat unique and, therefore, judgment value and subjective decision making will always be necessary. It is important to realize that economic, political and legal considerations must also be given.

Assessment. There are both advantages and disadvantages to the use of Criteria Listing as a pollution prediction technique. The advantages of this approach by comparison with the other techniques are described as follows:

1. Data Requirements - The data requirements for the Criteria Listing approach are comprehensive in that waste-specific data are required for waste characterization. In addition, site-specific data are required to describe soils, geology, groundwater, and groundwater/surface water interrelationships for site characterization. Quantitative data are also required to adequately define the aerial distribution and variation with depth of the various deposits present at a given site. This approach provides the application reviewer with a three-dimensional definition of the physical features present

at the site in order to better assess their impact on attenuation of waste leachates for prevention of groundwater pollution. This approach also affords an assessment of the range in values or variations of the quantitative data defined.

2. Moderate Cost/Expertise Requirements - This approach is generally used at moderate cost and expertise requirements in comparison with the other techniques. However, this approach requires the application of a great deal of judgment on the part of the reviewer. Therefore, a high level of expertise of the various disciplines involved with waste site assessment (e.g., soils, geology, environmental and chemical engineering, and biology) would be beneficial to the permitting process.

3. Presently Being Used - The Criteria Listing approach is the most universal approach taken by consultants for assessment and design of waste disposal facilities, and by regulatory agencies which permit such facilities.

There are potential disadvantages, however, to the use of Criteria Listing as a decision procedure. The disadvantages of this approach are as follows:

1. No Quantification of Pollution Potential - Utilization of this approach does not result in a direct quantification of the pollution potential. Rather, an assessment is made based upon experience, data development for the site in question, and by comparison with empirical data developed at other sites for the pollution potential at the proposed site. As such, the assessment of a candidate site relies heavily on the level of expertise of the reviewing personnel.

2. Potential High Cost - Variation and complexities in the natural site conditions may result in a high cost to the applicant to obtain the quantitative data necessary for site assessment. This potential cost can be avoided by terminating further site investigations once this condition is recognized. The actual cost can also be offset by the value associated with obtaining a site in a critical location.

A summary assessment of the pros and cons of Criteria Listing is given in Table 20.

TABLE 20

SUMMARY ASSESSMENT OF CRITERIA LISTING

Pros

- Site-specific and quantitative data identified.
- Comprehensive site description.
- Presently used by regulatory agencies.
- Moderate cost/expertise requirements.
- Applies to hazardous and non-hazardous wastes.

Cons

- No quantification of pollution potential.
- Potential high costs.
- Reliability largely dependent on the expertise of agency review personnel.

Availability. The Criteria Listing represents an on-line decision procedure presently being used by research groups, consultants, and regulatory agencies in each of the states contacted for the design and permitting of land disposal facilities. It must be re-emphasized that the assessment of the pollution potential relies largely on the level of expertise of the reviewing personnel. Despite this limitation, the Criteria Listing approach is and will continue to be a major decision procedure due to the basic site and waste characterization data which it defines.

Criteria Ranking

Description. Criteria Ranking approaches have been developed by several investigators and were intended to enable decision-making personnel to determine whether or not the placement of a waste in a specific land site would have a deleterious effect on the surrounding landfill ecosystem. Approaches have been developed which rate or rank waste and landfill sites individually in order to allow a quantitative numerical comparison of various wastes and sites to one another. These Criteria Ranking systems are based on measurements or estimates of waste and site parameters which are arbitrarily weighted based on their potential impact on the environment.

State of Development/Application. Criteria Ranking approaches developed to date were intended to serve as a first step in waste and site evaluation that was to be verified and upgraded by others. Unfortunately, the Criteria Ranking systems developed to date have not been adequately verified.

LeGrand-Brown Numerical Rating System. A Criteria Ranking approach has been developed by LeGrand and Brown (1977) which is described as a Numerical Rating System. This system, entitled, "Evaluation of Ground Water Contamination Potential from Waste Disposal Sources" (see LeGrand-Brown Contact form, Appendix B), replaces the earlier point count system developed by LeGrand in 1964 entitled, "System for Evaluation of Contamination Potential from Some Waste Disposal Sites".

The Numerical Rating System is based upon the experience gained by many individuals to establish the more favorable and least favorable conditions for prevention of ground water contamination. Four key hydrogeological factors or variables are used. These four factors which are considered to represent the simplest and most easily determined and effective factors for a wide variety of applications are as follows:

1. Distance from a contamination source to the nearest well or point of water use;

2. Depth to the water table;

3. Gradient of the water table;

4. Permeability and sorption capacity of the subsurface materials through which the contaminant is likely to pass. (Permeability and sorption were separate factors in the earlier point count system).

The Numerical Rating System has been developed by assigning a 0 rating for the least favorable setting for each factor and a 9 rating (5 in one case) for the most favorable setting for each factor as shown on Table 21. Intermediate numerical values will be defined by interpolating between the least favorable and the most favorable settings on a scale or nomograph. For each site, the estimated numerical value for each of the four factors is added, and the total expressed is the number between 0 and 32 that characterizes the site.

As shown on Table 21 the rating and expression of identifying characteristics are performed in steps. The first four steps involve the recording of estimated values for each of the four hydrogeological parameters indicated above. The fifth step is accomplished by adding

TABLE 21

COMPLETION OF NUMERICAL RATING*

KEY HYDROLOGIC FACTORS

STEP 1	Point Value	0	1	2*	3	4	5	6	7	8	9
Determine distance on ground between contamination source and water supply Record Point Value	Distance in feet	30	50	75	100	150	200	300	500	1000	2500 or more

*Where water table lies in permeable consolidated rocks (II in Step 4), no more than 2 (followed by ·) points should be allotted on distance scale.

STEP 2	Point Value	0	1	2*	3	4	5	6	7	8	9
Estimate the depth to water table Record Point Value	Depth in feet of water table below base of contamination source more than 5% of the year	0	2	4	7	15	25	50	75	100	200 or more

*Where water table lies in permeable or moderately permeable consolidated rocks (II in Step 4), no more than 2 (followed by ·) points should be allotted, regardless of greater depth to water table.

STEP 3	Point Value	0	1	2	3	4	5
Estimate water-table gradient from contamination site Record Point Value	Water-table gradient and flow direction (related, in part, to land slope)	gradient greater than 2 percent toward water supply and is the anticipated direction of flow	gradient greater than 2 percent toward water supply but not the anticipated direction of flow	gradient less than 2 percent toward water supply and is the anticipated direction of flow	gradient less than 2 percent toward water supply but not the anticipated direction of flow	gradient almost flat	gradient away from all water supplies that are closer than 2500 feet

*from LeGrand and Brown, 1977

TABLE 21
(continued)

STEP 4

Estimate permeability-sorption for the site of the contamination source. (See Sect. 5.1)

Record Point Value

Point Value is determined from Matrix. For single type of unconsolidated material over bedrock, point value is determined by its thickness alone. For combination of unconsolidated materials, point value must be interpolated.

Thickness in feet of unconsolidated material over bedrock.	Clean Coarse Gravel I	Clean Coarse Gravel II	Clean Coarse Sand I	Clean Coarse Sand II	Clean Fine Sand I	Clean Fine Sand II	Sand with a Little Clay I	Sand with a Little Clay II	Thin Layers of Sand and Clay I	Thin Layers of Sand and Clay II	Clayey Sand I	Clayey Sand II	Even Mixture of Sand and Clay I	Even Mixture of Sand and Clay II	Sandy Clay I	Sandy Clay II	Clay I	Clay II	
(1) 100+	OA	OA	OA	OA	2A	2A	4A	4A	5A	5A	6A	6A	7A	7A	8A	8A	9A	9A	100+
100	OB	OJ	OB	OJ	2B	2D	4B	3D	5B	4H	5D	4K	7B	5K	8B	6K	9B	6M	100
90	OB	OJ	OB	OJ	2B	1E	4B	3D	5B	4H	5D	4K	6B	5K	7C	5L	8C	6M	90
80	OC	OK	OC	OK	2B	1E	4B	3D	5B	4H	5D	4K	6B	4M	7C	5L	8C	5M	80
70	OC	OL	OC	OL	2B	1F	4C	3E	5C	4J	5E	4L	6C	4M	7D	4P	8D	5M	70
60	OD	OL	OD	OL	2C	1F	4C	2E	5C	3G	5E	3J	6C	4N	7D	4P	8D	5N	60
50	OD	OM	OE	OM	2C	1G	4C	2E	4D	3G	5F	3J	6D	3J	7E	4Q	8E	4R	50
40	OE	OM	OE	OM	1B	OS	4D	2F	4E	3H	5F	3K	6E	3K	6G	4Q	7F	4S	40
30	OF	ON	OF	ON	1C	OT	3B	2F	4F	3H	5G	2G	6F	2J	6G	3L	7G	3M	30
20	OG	OP	OG	OP	1D	OU	3C	1H	4G	2G	5H	2H	5H	2K	6H	2L	7H	3N	20
10	OH	OQ	OH	OQ	OQ	OV	2D	1J	3F	1J	4G	1J	5J	1K	6J	1L	6L	2M	10
(2) 0	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	5Z	OZ	0

I - over shale or other poorly permeable, consolidated rock

II - over permeable or moderately permeable, consolidated rocks (some basalts, highly fractured igneous and metamorphic rocks, and cavernous carbonate rocks - also fault zones).

(1) - suffix A means because of depth, bedrock is not to be considered, for example, a coastal plain situation (see sect. 5.1)

(2) - suffix Z means bedrock is at surface, i.e., there is no soil (see sect. 5.1)

STEP 5

Add all Point Values determined in Steps 1 through 4 above.

Record Total Point Value

Total Point Value	0 - 5	6 - 7	8 - 13	14 - 20	21 - 25	26 - 32
Description of Site in Relative Hydrogeologic Terms only. (without regard to type of contaminant.)	VERY POOR to POOR because one or more key factors must have values of less than 2.		FAIR if no separate value is less than 2	GOOD to if all separate values are 3 or greater	VERY GOOD if all separate values are 3 or greater	EXCELLENT if all separate values are 3 or greater

TABLE 21
(continued)

SPECIAL SITE IDENTIFIER SUFFIXES

STEP 6	A	B	C
Sensitivity of Aquifer (choose appropriate category)	A permeable, extensive aquifer capable of easy contamination.	Aquifer of moderate permeability not likely to be contaminated over a large area from a single contamination source.	Limited aquifer of low permeability, or slight contamination potential from a source.

STEP 7	A	B	C
Degree of confidence in accuracy of rating values (choose appropriate category)	Confidence in estimates of ratings for the parameters is high, and estimated ratings are considered to be fairly accurate	Confidence in estimates of ratings for the parameters is fair	Confidence in estimates of ratings for the parameters is low, and estimated ratings are not considered to be accurate

STEP 8

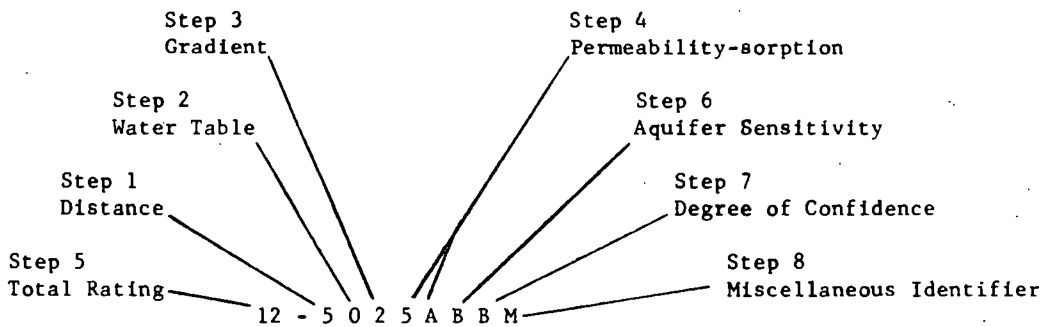
Miscellaneous Identifiers (add if appropriate)

A. Alluvial valley - a common hydrogeologic setting - especially important because of the general high permeability and prevalence of down-gradient water supplies
B. Designates property boundary when ground distance from a contamination site is to boundary rather than to a water supply
C. Special conditions require that a comment or explanation be added to the evaluation
D. Cone of pumping depression near a contamination source, which may cause contaminated ground water to be diverted toward the pumped well
E. Distance recorded is that from a water supply to the estimated closest edge of an existing plume rather than to the original source of contamination
F. Indicates the contamination source is located on a ground water discharge area, such as a flood plain, and would likely cause minimal ground water contamination
M. Mounding of the water table beneath a contamination site - common beneath waste sites where there is liquid input or reduced infiltration capacity
P. Percolation may not be adequate - the permeability-sorption digit suggests the degree to which percolation may be a problem, a digit of 7 or more being a special warning of poor percolation
Q. Designates a "recharge or transmission" part of an extensive aquifer that is sensitive to contamination - may be suggested by a low rating on the permeability-sorption scale and A or B rating for Step 6
S. Indicates that the most likely water supply to be contaminated is a surface stream, rather than a well or spring

TABLE 21
(continued)

COMPLETION OF NUMERICAL RATING

STEP 9 Completion of site numerical rating	The total point value determined in Step 5 is recorded and then followed in sequence by the individual point values for the four key hydrogeologic factors: distance, depth to water table, water-table gradient, and permeability-sorption. This is followed, in turn, by the special site identifier suffixes: *aquifer sensitivity, degree of confidence,* and *miscellaneous identifiers.* An example of a site rating with brief explanations and interpretations is shown below. Full explanations of site ratings are in Sections 5.0 and 6.0.



<u>Explanation of sequence of digits and letters</u>

12 - Total point value as shown in Step 5
5 - The first digit is rating for ground distance - Step 1
0 - The second digit is rating for depth to water table - Step 2
2 - The third digit is rating for water-table gradient - Step 3
5 - The fourth digit is rating for permeability-sorption - Step 4
A - Represents a closely defined position (5A) in permeability-sorption scale - Step 4
B - Represents sensitivity of an aquifer to be contaminated - Step 6
B - Represents degree of confidence or reliability of overall rating - Step 7
M - Indicates special conditions (mounding of water table in this case) - Step 8

the separate point values determined in the four steps and describing the site in relative terms on a scale from very poor to excellent. It should be emphasized that descriptive terms are only expressions of the site hydrogeologic conditions relative to those conditions for all possible sites and do not relate to a site in terms of specific wastes or contaminant characteristics.

A useful feature of this updated Numerical Rating System is that a given site may rate high on several parameters and be unacceptable because of the serious problem of one of the parameters. For example, the site may be ideal in all respects except for a high water table. The total point value from Step 5 is, therefore, not expected to stand alone, but is followed in sequence with the values of the separate parameters which allows both the weak and strong features of the site to be graphically recorded.

The Numerical Rating System is designed to provide a quick assessment on a first round or preliminary basis of the contamination potential from a given waste disposal site, but it is not intended to be adequate or substitute for a more detailed study that will in most cases be required. The authors state that two apparent problems with the system are the need for good data and the skill required to use the system. They go on to state that, "the relation between certain factors is not always distinctive and the determination of specific values for such factors as permeability, sorption, and water table gradient woud be almost impossible to obtain at early stages of a particular evaluation of contamination potential". They further state that, "the proper weight to be assigned to values of each factor and a good formulation of these values are difficult". Rough approximate values of the factors are readily available at early stages for many waste disposal situations and serves as a useful qualitative evaluation on a preliminary basis. Examples of application of these systems to septic tank operations, sanitary landfills, water lagoons, non-point contamination sources on land, and burial grounds for radioactive and other toxic wastes are given. In addition, a series of questions and problems with discussion relating to the use of the Numerical Rating System is also provided.

Pavoni, Hagerty, and Lee Rating System. Another Criteria Ranking system was developed by Pavoni, Hagerty, and Lee in 1971-1972 and published as Environmental Impact Evaluation of Hazardous Waste Disposal in Land. (See Hagerty contact form, Appendix B.) This procedure was intended to serve as a decision-making tool to determine: (1) the hazardousness of various waste substances; (2) the suitability of various land sites to contain waste substances; and (3) the feasibility of disposing of a specific waste substance at a specific site.

This procedure basically encompasses two ranking formulae: one for waste products, and one for landfill sites. Each ranking formula is comprised of weighted parameters which characterize the waste or site. Waste parameters which were interpreted to result in direct impairment to living organisms were weighted highest, followed in order by parameters which indicated persistence in the environment, and parameters which indicated mobility in landfill ecosystems. Site parameters which would immediately affect waste transmission were weighted highest, followed in order by parameters which would affect waste transmission once the waste was in contact with water, parameters which characterized the receiving groundwater, and parameters which represented factors outside the immediate disposal site.

The five waste ranking formulae developed by Pavoni, Hagerty, and Lee are as follows:

- Human Toxicity (HT) - Range of 0 to 39

  $Ht = 13\ Sr$
  where Sr = Sax rating

- Groundwater Toxicity (Gt) - Range of 0 to 42

  $Gt = 6\ (4 - \log Cc)$
  where Cc = smallest critical concentration (mg/l) for humans, aquatic life, or plants.
  but if $Cc > 10^4$ mg/l, Gt = 0
  and if $Cc < 10^{-3}$ mg/l, Gt = 42

- Disease Transmission Potential (Dp) - Range of 0 to 105

  Dp based on mode of disease contraction, pathogen life state, and ability of pathogen to survive in various environments

- Biological Persistence (Bp) - Range of 0 to 16

  $$Bp = 16 \left(1 - \frac{BOD}{TOD}\right)$$
  where BOD = Biochemical oxygen demand of waste
  TOD = Theoretical oxygen demand of waste

- Waste Mobility (M) - Range of 0 to 16

  $M = 7 - c + \log s$
  where c = net valence of waste
  s = solubility of waste (mg/l) in water

The total waste rank is developed by totaling the results of the five waste-ranking formulae as follows:

Hazardous Waste Rank = Ht + Gt + Dp + Bp + M

The hazardousness of a waste is then correlated with its total waste rank as follows:

Rank	Hazardousness
0-30	Nonhazardous
31-60	Slightly hazardous
61-80	Moderately hazardous
> 80	Hazardous

Examples of waste rankings were developed by Pavoni, Hagerty, and Lee and are shown as follows:

Waste Compound	Rank
Waste Paper	7
Inert Ash	18
Sulfur	21
Anthracene	27
Steel Wool	31
Benzoic Acid	38.6
Ferrous Sulfate	42
2 Ethyl Hexanol -1	45
Propionic Acid	51
Monoethanolamine	59
Furfural	62
Aluminum Oxide	63.5
Malic Anhydride	68
Napthlene	68.5
Acetic Acid	68.9
Acridine	72
Methyl Bromide	72
DDT	74
Aluminum Sulfate	76
Aniline	78
Copper Sulfate	86
Phenol	88
Acetone Cyanhydrin	91
Cadmium Chloride	99
Potassium Cyanide	102
Dieldrin	103
Primary Sludge	104
Arsenic Diethyl	107

The ten site-ranking formulae developed by Pavoni, Hagerty, and Lee are as follows:

- Infiltration Potential of Site (Ip) - Range of 0 to 20

$$Ip = \frac{i}{(FC)H}$$

where i = infiltration (inches)
FC = field capacity of the soil expressed as a decimal
H - thickness of cover soil layer (inches)

- Bottom Leakage Potential of Site (Lp) - Range of 0 to 20

$$Lp = \frac{1000 \quad \sqrt[3]{K}}{T}$$

where K = bottom soil permeability (cm/sec)
T = bottom soil thickness (ft)

- Filtering Capacity of Soil (Fc) - Range of 0 to 16

$$Fc = -4 \log \frac{2.5 \times 10^{-5}}{\emptyset}$$

where Ø = average particle diameter (inches)

- Adsorptive Capacity of Soil (Ac) - Range of 0 to 10

$$Ac = \frac{10 \ (Or)}{(\log CEC) + 1}$$

where Or = organic content expressed as a decimal
CEC = cation exchange capacity

- Organic Content of Groundwater (Oc) - Range of 0 to 10

OC = 0.2 BOD
where BOD = biochemical oxygen demand of groundwater (mg/l)

- Buffer Capacity of Groundwater (Bc) - Range of 0 to 10

Bc = 10 - Nme
where Nme = smallest number of milliegulvalents of either an acid or base required to displace the groundwater pH below 4.5 or above 8.5.

- Potential Travel Distance (Td) - Range of 0 to 5

Td based on distance groundwater must travel to nearest water supply.

- Groundwater Velocity (Gv) - Range of 0 to 20

$$Gv = \frac{S}{\log\ (1/K + 1)}$$

where S = gradient (ft/mile)
K = permeability (cm/sec)

- Prevailing Wind Direction (Wd) - Range of 0 to 5

Wd based on relation of prevailing wind direction to population density surrounding site.

- Population Factor (Pf) - Range of 0 to 7

Pf - log p
where p = population within a 25-mile radius of the site.

The total site rank is developed by totaling the results of the ten site-ranking formulae as follows:

Landfill Site Rank = Ip + Lp + Fc + Ac + Oc + Bc + Td + Gv + Wd + Pf

The lower the landfill site rank, the more suitable the site may be considered for waste disposal. Examples of site rankings were developed by Pavoni, Hagerty, and Lee for the two landfill sites described as follows:

Parameter	Site No. 1	Site No. 2
Yearly rainfall	43 in.	43 in.
Soil type	clean sand	heavy clay
Infiltration rate (% of rainfall)	75	10
Field capacity	0.05	0.40
Permeability	10^{-3}	10^{-8}
Soil cover (inches)	60	24
Bottom thickness (feet)	20	15
Average particle diameter (mm.)	0.25	0.002
Organic content of soil	0.5	0
Groundwater BOD	10	10
Cation exchange capacity	0	80
Buffering capacity (meg)	7	4
Groundwater travel distance	750	750
Gradient (ft/mile)	5	5
Population within 25 miles	10^6	10^6
Prevailing wind direction	WNW	WNW

- Site No. 1 ranking parameters are as follows:

Ip = 10.8	Bc = 7.0
Lp = 5.0	Td = 5.0
Fc = 10.4	Gv = 1.66
Ac = 5.0	Wd = 4.05
Oc = 2.0	Pf = 6.0

- Site No. 2 ranking parameters are as follows:

Ip = 0.45	Bc = 4.0
Lp = 0.145	Td = 5.0
Fc = 2.0	Gv = 0.625
Ac = 0.0	Wd = 2.9
Oc = 2.0	Pf = 6.0

The total landfill rank for Site No. 1 is 56.9. The total landfill ranking for Site No. 2 is 23.1. Consequently, Site No. 2 which has a much smaller ranking than Site No. 1 would be more conducive to land disposal.

In summary, the numerical ranking system developed by Pavoni, Hagerty, and Lee was intended to provide decision makers with a quantitative assessment of both the hazardousness of various wastes and the suitability of various land sites for waste disposal. The approach for both waste ranking and site ranking appears to be arbitrary. It should be noted here that the waste ranking portion of the Pavoni, Hagerty, and Lee system was incorporated with minor revisions into the soil/waste interaction matrix described later in this report.

Assessment. Generally, the Criteria Ranking approach is useful in that it results in a quantifiable assessment of waste/site characteristics. This quantifiable assessment affords an identification of the more important variables by assigned point counts, and a comparison of the total waste/site situation (bottom-line figures). Its greatest use lies in the comparison between two or more sites under consideration for disposal of a given waste.

The following advantages are associated with the Criteria Ranking approach:

1. Data Requirements - As in the Criteria Listing approach, site-specific data are necessary to adequately assess the potential for pollution. Quantitative site-specific data, however, may not be developed as comprehensively as in the Criteria Listing, since the weighted values assigned in the Criteria Ranking are generally assigned to what is assumed to be a representative value for a given parameter and may not accurately account for the variation in one or more site parameters.

2. Low to Moderate Cost/Expertise - The cost and level of expertise requirements utilizing this approach are generally in the low-to-moderate range in comparison with the other procedures.

3. Quantitative Predicting Tool - The Criteria Ranking approach is structured to be a predictive tool based upon quantitative inputs and outputs. Its predictive capacity results from the "bottom line" figure or output that affords a comparison of the site in question with some "standard" or, as may commonly be the case, a comparison between two proposed sites.

The major disadvantages of the Criteria Ranking approach at present are as follows:

1. Confidence of Assigned Values - Perhaps the most significant disadvantage of the Criteria Ranking approach is the confidence level of the arbitrarily-assigned values or points of a given parameter. The representativeness of the quantitative data obtained for a given parameter cannot be assumed. More important,

however, is the question of the weighted value assigned to a given parameter, both in the range of points associated with that parameter and in the absolute value assigned. As a result, the validity of the "bottom line" number generated by a series of arbitrarily-assigned values can be questioned, particularly since verification of this approach has not been conducted.

2. Lack of Testing and Calibration - The several Criteria Ranking systems identified have had insufficient testing and calibration to be relied upon for use as a predictive tool at this time. This would include assessment of the representativeness and validity of the range and actual points assigned to a given parameter. In addition, there is a lack of field verification of the approach.

A summary assessment of the Criteria Ranking approach is given in Table 22.

TABLE 22

SUMMARY ASSESSMENT OF CRITERIA RANKING

Pros

- Site-specific data identified.
- Quantitative data.
- Low-to-moderate cost/expertise involved.
- Quantitative predictive tool.

Cons

- Confidence of assigned values.
- Lack of testing and calibration.
- Not presently used by regulatory agencies.

Availability. The Criteria Ranking approach could be available as a prediction tool within three years provided that it were to undergo actual case-history testing, calibration, and verification.

Matrix

Description. The use of a Matrix as a decision tool in waste-disposal siting is dependent upon the formulation of relationships between two major sets of interrelated variables, i.e., waste characteristics and soil characteristics. A Matrix approach of this type has been identified in this study as given in the Development of a Soil/Waste Interaction Matrix by C.R. Phillips. (See Phillips contact form in Appendix B.)

State of Development/Application. It should be noted that the soil-waste interaction Matrix presented by Phillips does not entail the development of a "new" procedure. The approach basically combines soil- and waste-ranking systems that had previously been developed with little, if any, revision. The site-ranking portion of the Phillips' system was developed by LeGrand in 1964, whereas the waste-ranking portion of Phillips' system, with minor revision, was developed by Pavoni, Hagerty, and Lee in 1972 (both of which were described previously).

In this Matrix, wastes are described by parameters arranged into: an effects group (human toxicity, groundwater toxicity, and disease transmission potential); a behavioral performance subgroup (chemical persistence, biological persistence, and sorption); a behavioral properties subgroup (viscosity, solubility, and acidity/basicity); and a capacity-rate group (waste application rates). Points are arbitrarily allocated to each waste parameter based on empirical formulae (Table 23).

Soil sites are described in this Matrix by parameters arranged into: a soil group (permeability and sorption); a hydrology group (water table, gradient, and infiltration); and a site group (distance to point of use,

TABLE 23

WASTE PARAMETER FOR INPUT TO MATRIX

Factor Summary

WASTE

(1) Effects Group — Range

1. Human Toxicity, Ht — 0-10

$Ht = \frac{10}{3} Sr$, (Sr = Sax rating)

2. Groundwater Toxicity, Gt — 0-10

$Gt = \frac{10}{7} (4 - \log_{10} Cc)$, Cc = smallest critical concentration)

but for Cc $>10^4$ mg/l, Gt = 0

and for Cc $<10^{-3}$ mg/l, Gt = 10

3. Disease Transmission Potential, NDp — 0-10

NDp = Σ(contribution of subgroup A, B and C)

(2) Behavorial Group

(i) Behavioural Subgroup

4. Chemical Persistence, Cp — 1-5

$Cp = 5 \exp(-kt)$

but if Cp <1, Cp = 1

where $C_6/C_1 = \exp(-kt)$

5. Biological Persistence, Bp — 1-4

$Bp = 4 \left(1 - \frac{BOD}{TOD}\right)$

TABLE 23
(continued)

WASTE	Range
6. Sorption, Sp	1-10
$Sp = 11 - C_0/C_1$	
but if $C_0/C_1 > 10$, $Sp = 1$	
where C_0 = initial concentration C_1 = concentration after 1 day contact	
(ii) <u>Behavorial Properties Subgroup</u>	
7. Viscosity, Vi	1-5
$Vi = 5 - \log_{10} \mu$	
where μ = centipoises	
but if $\mu > 10^4$, $Vi = 1$	
and if $\mu < 1$, $Vi = 5$	
8. Solubility, Sy	
$Sy = 3 + 0.5 \log_{10} S$	
where S = mg/l of a constituent	
but if $S < 10^{-4}$, $Sy = 1$	
and if $S > 10^4$, $Sy = 5$	
9. Acidity/Basicity, Ab	
From table of waste pH vs Ab factor.	0-5
pH = 7 or 8 gives Ab = 0; acid pH gives higher Ab than alkaline pH	

TABLE 23
(continued)

WASTES	Range
(3) Capacity-Rate Group	
10. Waste Application Rate, Ar	1-10

$$Ar = \frac{9}{2} \log_{10} (Rf.Co)^{\frac{1}{2}}.NS + 1$$

where NS = sorption parameter for *site*
Rf = volumetric rate factor,

defined from table of Rf vs volumetric

application rate (gall/ft^2, day)

Co = 5 + 1.25 $\log_{10}$ C where C = mg/l concentration

but if C $< 10^{-4}$, Co = 0

and if C $> 10^{4}$, Co = 10

and thickness of the porous layer for two-media sites). Points are arbitrarily allocated to each soil-site parameter based on empirical formulae (Table 24).

A total waste score and a total soil-site score is obtained by summing the individual point scores for the parameters. A combined waste-soil-site score is obtained as the product of the total waste and the total soil-site point scores, and is scaled to one of ten possible classes of acceptability, with class 5 (barely acceptable) dividing the acceptable classes (1 to 5) from the unacceptable classes (6 to 10).

Waste-Soil-Site Classes

	Acceptable					Unacceptable				
	1	2	3	4	5	6	7	8	9	10
Waste-Soil-Site Point Score	45-100	100-200	200-300	300-400	400-500	500-750	750-1000	1000-1500	1500-2500	2500-

A Matrix approach is also used to combine waste-parameter point scores, enabling the interactions between individual waste parameters and individual soil-site parameters to be entered as matrix elements. These interactions are represented by the product of the waste parameter and the soil-site parameter point scores.

This Matrix Approach also defines a site-dependent Matrix (requiring data pertaining to a specific site) versus a site-independent submatrix (requiring data for only a given soil without reference to a specific site's topography, hydrology, depth, etc.). The site-dependent Matrix is the complete Matrix as shown in Figure 10, while the site-independent submatrix is an abbreviated matrix as shown in Figure 11. Phillips recommends the following decision procedure using the site-independent and site-dependent approach: (1) define specific waste characteristics;

TABLE 24

SOIL PARAMETERS FOR INPUT TO MATRIX

SOIL-SITE

(1) Soil Group — Range

1. Permeability, NP — $2\frac{1}{2}$-10

$$NP = \frac{10}{P_{max} + 1} (P_{max} + 1 - P)$$

where P = permeability point score from LeGrand

P_{max} = maximum value of P from LeGrand

(P_{max} = 3 for loose granular single media sites, two media sites and radioactive disposal sites)

2. Sorption, NS — 1-10

$$NS = \frac{10}{S_{max} + 1} (S_{max} + 1 - S)$$

where S = sorption point score from LeGrand

S_{max} = maximum value of S from LeGrand

(S_{max} = 6 for loose granular site or for two media site;

S_{max} = 7 for radioactive disposal site.)

TABLE 24
(continued)

(2) Hydrology Group — Range

3. Water Table, NWT — 1-10

$$NWT = \frac{10}{WT_{max} + 1}(WT_{max} + 1 - WT)$$

where WT = water table point score from LeGrand

WT_{max} = maximum value of WT from LeGrand

(WT_{max} = 10 for loose granular and two media sites,

and for radioactive waste disposal sites.)

4. Gradient, NG — 1-10

$$NG = \frac{10}{G_{max} + 1}(G_{max} + 1 - G)$$

where G = gradient point score from LeGrand

G_{max} = maximum value of G from LeGrand

(G_{max} = 7 for loose granular and two media sites;

G_{max} = 3 for radioactive disposal sites)

5. Infiltration, NI — 1-10

NI is defined from infiltration I

into site by table of I vs NI

(3) Site Group

6. Distance, ND — 1-10

$$ND = \frac{10}{ND_{max} + 1}(D_{max} + 1 - D)$$

TABLE 24
(continued)

where D = distance point score from LeGrand

D_{max} = maximum value of D from LeGrand

(D_{max} = 11 for loose granular media sites and two-media sites; D_{max} = 13 for radioactive disposal sites.)

7. Thickness of Porous Layer, NT 1-10

(For two-media sites only; thickness of layer $<$100 ft. If thickness $>$100 ft, omit factor and consider as single media site or granular material.

$$NT + \frac{10}{T_{max} + 1} (T_{max} + 1 - T)$$

where T = thickness of porous layer point score from LeGrand

T_{max} = maximum value of T from LeGrand

T_{max} = 6.

			SOIL GROUP		HYDROLOGY GROUP			SITE GROUP	
		SOIL-SITE / WASTE	Permeability NP (2½-10)	Sorption NS (1-10)	Water Table WT (1-10)	Gradient NG (1-10)	Infiltration NI (1-10)	Distance ND (1-10)	Thickness of Porous Layer NT (1-10)
EFFECTS GROUP		Human Toxicity Ht (0-10)							
		Groundwater Toxicity Gt (0-10)							
		Disease Transmission Potential Dp (0-10)							
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Chemical Persistence Cp (1-5)							
		Biological Persistence Bp (1-4)							
		Sorption So (1-10)							
	Behavioural Properties Subgroup	Viscosity Vi (1-5)							
		Solubility Sy (1-5)							
		Acidity/ Basicity pH (0-5)							
CAPACITY-RATE GROUP		Waste Application Rate Ar (1-10)							

FIGURE 10 FORMAT OF SOIL-WASTE INTERACTION MATRIX (C.R. PHILLIPS)

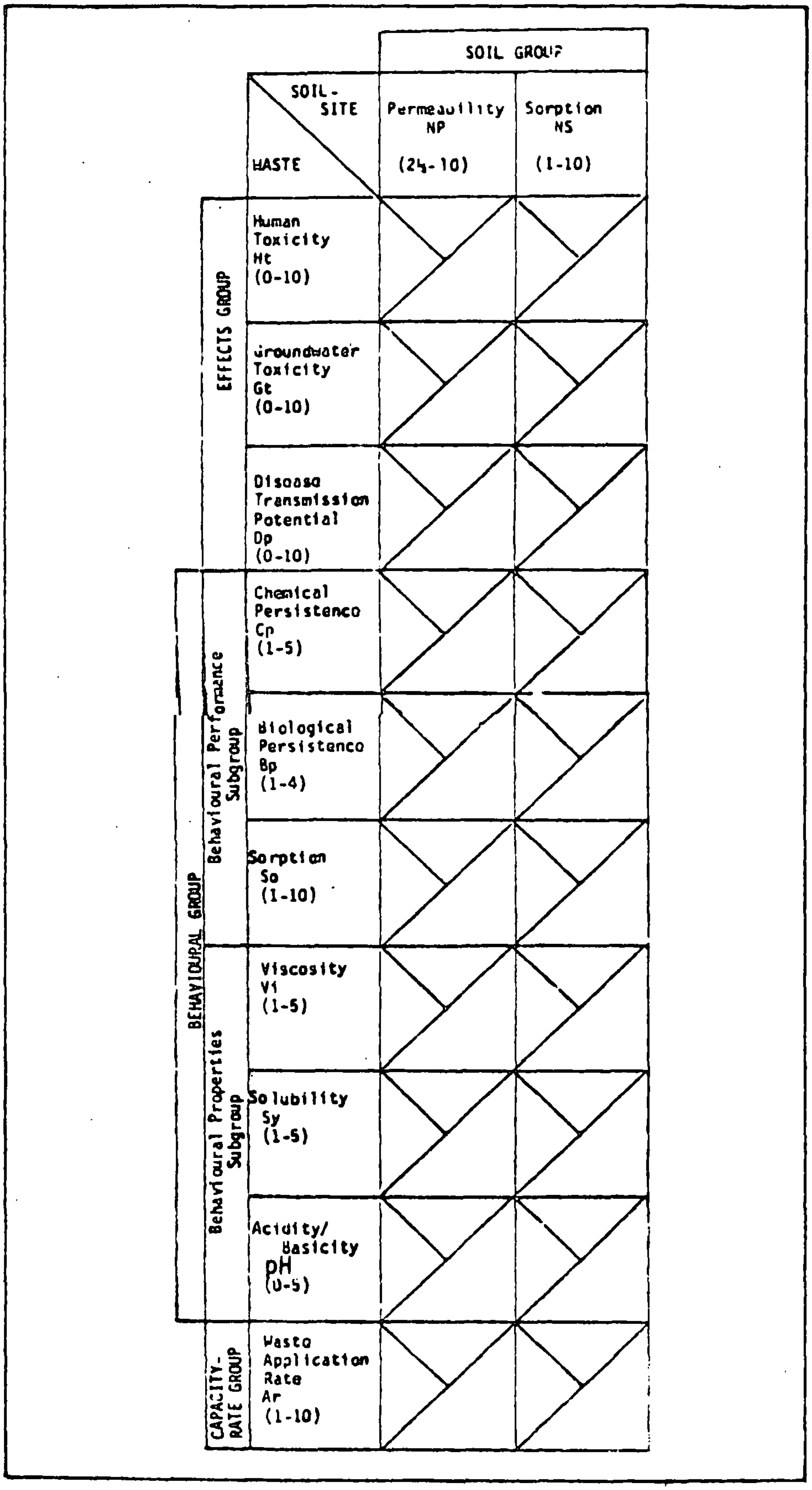


FIGURE 11 SITE INDEPENDENT SUBMATRIX (C.R. PHILLIPS)

(2) define specific common soil characteristics; (3) enter site-independent submatrix; (4) if outcome favorable (point score less than 225), define specific site characteristics; and (5) compare site using complete Matrix.

A hypothetical example of how the Matrix can be utilized as a decision tool for a single-media site has been developed by Phillips. In this example, the specific-waste and common-soil characteristics are defined in a site-independent Matrix. (See Figure 12.) The total waste-soil point score from the site-independent Matrix is 297 which is unacceptable, but reasonably close to the suggested acceptance criterion of 225. Entry into the complete site-dependent Matrix is desirable for the confirmation of the conclusion with site-specific information. (See Figure 13.) The total waste-soil point score from the site-dependent Matrix is 957, which results in a waste-soil site class of 7 and is unacceptable according to Phillips' proposed waste-soil site classes.

A similar soil/waste interaction Matrix is being developed in Canada for the evaluation of municipal refuse disposal siting. (See Rovers contact form in Appendix B.) This matrix was not available at the time of preparation of this report, but is expected to be available by late 1977.

Assessment. Utilization of the Matrix approach as a decision procedure offers several distinct advantages:

1. Quantitative Predictive Tool - The Matrix approach is structured to be a predictive tool based upon quantitative data inputs and outputs. Its predictive capacity results from the "bottom line" figure or output that affords a comparison of the site in question with some "standard" or, as may commonly be the case, a comparison between two proposed sites.

Group	Subgroup	Waste \ Soil-Site	Permeability NP (2½-10): Waste value	Permeability NP: Soil value	Permeability NP: Product	Sorption NS (1-10): Waste value	Sorption NS: Soil value	Sorption NS: Product
EFFECTS GROUP		Human Toxicity Ht (0-10)	8	5	40	8	4	32
EFFECTS GROUP		Groundwater Toxicity Gt (0-10)	5	5	25	5	4	20
EFFECTS GROUP		Disease Transmission Potential Dp (0-10)	0	5	0	0	4	0
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Chemical Persistence Cp (1-5)	3	5	15	3	4	12
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Biological Persistence Bp (1-4)	4	5	20	4	4	16
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Sorption So (1-10)	5	5	25	5	4	20
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Viscosity Vi (1-5)	2	5	10	2	4	8
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Solubility Sy (1-5)	1	5	5	1	4	4
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Acidity/Basicity pH (0-5)	1	5	5	1	4	4
CAPACITY-RATE GROUP		Waste Application Rate Ar (1-10)	4	5	20	4	4	16

FIGURE 12 EXAMPLE OF SITE INDEPENDENT SUBMATRIX (C.R. PHILLIPS)

Group	Subgroup	SOIL-SITE / WASTE	Permeability NP (2½-10)	Sorption NS (1-10)	Water Table HT (1-10)	Gradient NG (1-10)	Infiltration NI (1-10)	Distance ND (1-10)	Thickness of Porous Layer HT (1-10)
			SOIL GROUP		HYDROLOGY GROUP			SITE GROUP	
EFFECTS GROUP		Human Toxicity Ht (0-10)	5 / 8 / 40	4 / 8 / 32	5 / 8 / 40	2 / 8 / 16	6 / 8 / 48	7 / 8 / 56	0 / 8
EFFECTS GROUP		Groundwater Toxicity Gt (0-10)	5 / 5 / 25	4 / 5 / 20	5 / 5 / 25	2 / 5 / 10	6 / 5 / 30	7 / 5 / 35	0 / 5
EFFECTS GROUP		Disease Transmission Potential Dp (0-10)	5 / 0 / 0	4 / 0 / 0	5 / 0 / 0	2 / 0 / 0	6 / 0 / 0	7 / 0 / 0	0 / 0
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Chemical Persistence Cp (1-5)	5 / 3 / 15	4 / 3 / 12	5 / 3 / 15	2 / 3 / 6	6 / 3 / 18	7 / 3 / 21	0 / 3
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Biological Persistence Bp (1-4)	5 / 4 / 20	4 / 4 / 16	5 / 4 / 20	2 / 4 / 8	6 / 4 / 24	7 / 4 / 28	0 / 4
BEHAVIOURAL GROUP	Behavioural Performance Subgroup	Sorption So (1-10)	5 / 5 / 25	4 / 5 / 20	5 / 5 / 25	2 / 5 / 10	6 / 5 / 30	7 / 5 / 35	0 / 5
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Viscosity Vi (1-5)	5 / 2 / 10	4 / 2 / 8	5 / 2 / 10	2 / 2 / 4	6 / 2 / 12	7 / 2 / 14	0 / 2
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Solubility Sy (1-5)	5 / 1 / 5	4 / 1 / 4	5 / 1 / 5	2 / 1 / 2	6 / 1 / 6	7 / 1 / 7	0 / 1
BEHAVIOURAL GROUP	Behavioural Properties Subgroup	Acidity/Basicity pH (0-5)	5 / 1 / 5	4 / 1 / 4	5 / 1 / 5	2 / 1 / 2	6 / 1 / 6	7 / 1 / 7	0 / 1
CAPACITY-RATE GROUP		Waste Application Rate Ar (1-10)	5 / 4 / 20	4 / 4 / 16	5 / 4 / 20	2 / 4 / 8	6 / 4 / 24	7 / 4 / 28	0 / 4

FIGURE 13 EXAMPLE OF SITE DEPENDENT MATRIX

2. Identification of Soil/Waste Parameters - Because the Matrix is structured to generally result in a "bottom line" figure, this approach does result in the ability to predict pollution potential by comparison of that figure with a standard or with another site under consideration.

3. Low to Moderate Cost - The Matrix approach would have the same general cost requirements as the Criteria Ranking approach, which is low to moderate.

The Matrix system does have the following disadvantages:

1. Confidence of Assigned Values - As in the Criteria Ranking approach, perhaps the most significant disadvantage of the Matrix is the level of confidence of the generally arbitrarily-assigned values or points of a given parameter. The representativeness of the quantitative data obtained for a given parameter and the appropriations of the weighted value assigned to that parameter, both in the range of points associated with that parameter and in the absolute value assigned, can be questioned. As a result, there would be some question as to the validity of the "bottom line" number generated by a series of arbitrarily-assigned values until field verification can be conducted.

2. Lack of Testing and Calibration - The single Matrix approach developed to date has not been tested or calibrated, and cannot be relied upon at this time for use as a predictive tool. In addition, the representativeness and validity of the range and points assigned to a given parameter and points actually assigned for a given waste/soil interaction have not yet been assessed. There has also been a lack of field verification of this approach.

3. Difficulty of Data Quantification - As in the Models and Simulation techniques described in the following pages, use of the Matrix approach factors such as sorption, has inherent limitations due to the difficulty in quantification by present laboratory and field methods.

4. Level of Expertise - Utilization of the Matrix approach may require a high level of expertise for proper assignment of values and assessment of the interrelationship of the parameters as well as a proper assessment of the "bottom line" output values.

A summary assessment of the Matrix approach identified is given in Table 25.

TABLE 25

SUMMARY ASSESSMENT OF THE MATRIX SYSTEM

PROS

- Quantitative predictive tool.
- Identification of soil/waste parameters.
- Assessment of pollution potential.
- Low-moderate operating cost.

CONS

- Confidence of assigned values.
- Lack of testing, calibration and field verification.
- Not presently used by regulatory agencies.
- Difficulty of laboratory and field quantification of parameters.
- Specialized skills usually required.

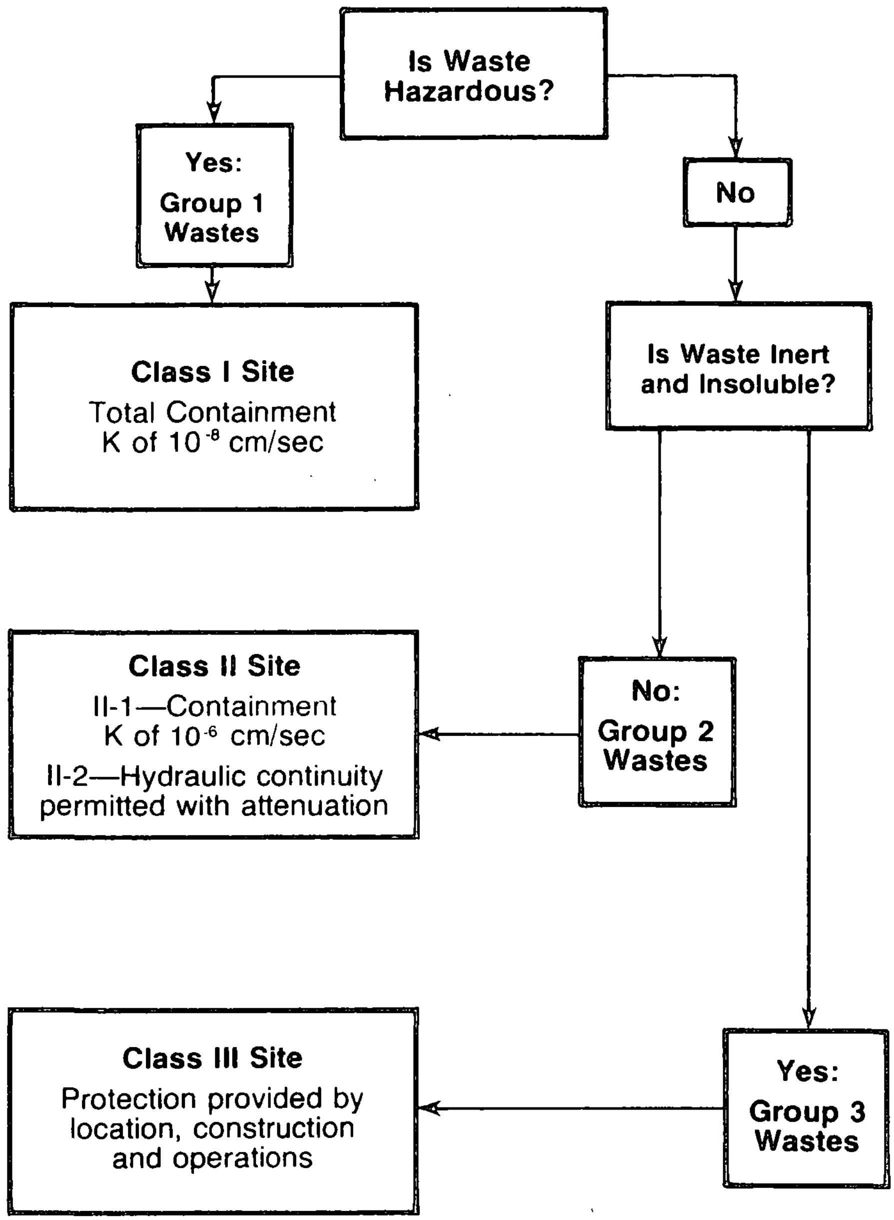
Availability. The Phillips' Matrix has not been verified to date; however, it will shortly be applied to a case study industrial waste disposal site in Canada. Information regarding the application of Phillips' Matrix to this case site will not be available until late 1977. If the system proves to be reliable, following verification in Canada, it could be utilized as a decision procedure within three years.

Classification System (Decision Tree)

Description. The Decision Tree approach is a logical step-by-step process which can be particularly useful as a decision tool for assessment of the pollution potential in the site-selection process. The Decision Tree approach begins with the most important question followed by a hierarchy of questions of decreasing criticality. In this manner, a "no" answer to an early important question can eliminate the site from further consideration and, from a practical standpoint, the expenditure of unnecessary money for additional site investigation. A "no" answer may also indicate that an alternative type of waste disposal site or disposal method should be utilized. An example of the Decision Tree approach is given in Figure 14. The initial question and subsequent question in this example relates to the degree of hazardousness of a given waste. This approach is, in effect, that developed by the California State Water Resources Control Board in their waste/site Classification System.

State of Development/Application. The Classification System was developed in California and was adopted in December 1972 by enactment of the Disposal Site Design and Operation Information, as published by the State Water Resources Control Board. This system has been revised somewhat, with the latest revision made in December 1976. (See California, Appendices C and D.) It is noteworthy that this approach was also in use on an informal basis for a period of approximately ten years.

The basic approach taken in this Classification System is a determination of the degree to which waste is hazardous and its assignment to one of three main classes of disposal sites. For each site class, varying degrees of protection are provided for surface and groundwater, with the system permeability being defined as the single most important and controlling site parameter. The wastes are classified



Based on "Disposal Site Design and Operation Information." California State Waste Resources Control Board

FIGURE 14 CLASSIFICATION SYSTEM (DECISION TREE)

as Group 1, 2 or 3, and the sites are classified as Class I, II-1, II-2, and III. A description of the characteristics of each waste/site type is given in Table 26.

Similar Classification System approaches have been developed by the Texas Department of Health Resources for municipal wastes and the Texas Water Quality Board for industrial wastes. These Classification Systems are shown in Tables 27 and 28, respectively. The Illinois Environmental Protection Agency has new solid/industrial waste management guidelines, and a classification system approach, as shown on Table 29, is expected to be enacted by late 1977.

Interestingly, the Department of the Environment in the United Kingdom has stated that "At first sight it might be thought that the way to deal with the selection of landfill sites was to categorize wastes on the basis of their pollution potential and sites on the basis of their ability to contain wastes. Particular categories of waste could then be linked with particular categories of sites to produce a series of definitive recommendations. Unfortunately neither wastes nor sites lend themselves to such categorization and it is necessary to produce a more generalized scheme which can be modified and adapted for local use."

In the licensing of waste disposal sites, as indicated in Waste Management Paper No. 4 (See United Kingdom, Appendix C and D), three classes of disposal sites are recognized: (1) those providing a significant element of containment for wastes and leachates; (2) those allowing slow leachate migration and significant attenuation; and (3) those allowing rapid leachate migration and insignificant attenuation. They recognize that these classes will not be as well defined as this and, for example, many sites which provide an element of containment will also permit the slow migration of leachates. However, they considered that such a generalized classification is a useful guide and, if correctly used, is capable of practical application.

TABLE 26

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD
DISPOSAL SITE DESIGN REQUIREMENTS

Site Type	Site Classification	Waste Classification	Permeability cm/sec	Soils	% Passing a No. 200 Sieve	Liquid Limit	Plasticity Index
Class I	Complete protection is provided for all time for the quality of ground and surface water. Geological conditions are naturally capable of preventing vertical and lateral hydraulic continuity between liquids and gases from the waste in the site and usable surface and ground waters. The disposal area can be modified to prevent lateral continuity. Underlain by usable ground water only under exceptional circumstances.	Group 1 Consisting of or containing toxic substances and substances which could significantly impair the quality of usable waters. Also accepts Group 2 and 3 wastes.	$\leq 1 \times 10^{-8}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
Class II	Protection is provided to water quality from Group 2 and Group 3 wastes.	Group 2 Consisting of or containing chemically or biologically decomposable material which does not include toxic substances or those capable of significantly impairing the quality of usable water. Also accepts Group 3 Wastes.					
II-1	Overlying usable ground water and geologic conditions are either naturally capable of preventing lateral and vertical hydraulic continuity or site has been modified to achieve such capability.		$\leq 1 \times 10^{-6}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
II-2	Having vertical and lateral hydraulic continuity with usable ground water but geological and hydraulic features and other factors assure protection of water quality.		Not specified	Not specified	Not specified	Not specified	Not specified
Class III	Protection is provided from Group 3 wastes by location, construction and operation which prevent erosion of deposited material.	Group 3 Consist entirely of non-water soluble, non-decomposable inert solids.	-	-	-	-	-

TABLE 27

TEXAS DEPARTMENT OF HEALTH RESOURCES
REQUIREMENTS FOR MUNICIPAL SOLID WASTE DISPOSAL*

Site Type	Site Classification	Soil Thickness	Permeability cm/sec	Liquid Limit	Plasticity Index	Drinking Water Protection	Flood Protection	Frequency of Compaction and Cover
Sanitary Landfills Site Type I	Considered to be the standard sanitary landfill for disposal of municipal solid waste and is encouraged in all cases. Required in a county with a population >100,000 or sites serving >5,000 persons, or the same population equivalent.	3'** (0.91 m)	$\leq 1 \times 10^{-7}$**	Not less than 30	Not less than 15	Not within 500' of drinking water supply well, intake of a water treatment plant, or raw water intake which furnishes water to a public water sy-system for human consumption. If closer than 500', engineering data shall be presented to show that adequate protection to drinking water sources is provided.	Levees constructed to provide protection from a 50 yr. frequency flood.	All solid waste shall be compacted and covered at least daily except for areas designated to receive only brush and/or construction-demolition wastes which shall be covered at least monthly.
Sanitary Landfills Site Type II	May be authorized by the Department for a site survey serving <5,000 or same population equivalent when relevant factors indicate a frequency of less than daily compaction and cover will not result in any significant health problems.	"	"	"	"	"	"	Up to seven (7) days.
Sanitary Landfills Site Type III	May be authorized by the Department for a site serving <1,500 persons or same population equivalent using the same considerations as applicable to a site Type II operation.	"	"	"	"	"	"	Up to thirty (30) days.
Sanitary Landfills Type IV	For disposal of brush and construction-demolition wastes that are free from other solid wastes.	"	"	"	"	"	"	As necessary.

* Minor amounts (5% or less by weight or volume) of Class I Industrial solid waste may be accepted under certain conditions, at Type I sites which have a permit from or have filed a permit application with the Texas Department of Health Resources without special Department approval.

** or equivalent (e.g., liner equivalent degree of impermeability).

TABLE 28

TEXAS WATER QUALITY BOARD
INDUSTRIAL SOLID WASTE MANAGEMENT
(PENDING APPROVAL)

Waste Class	Wastes Included	Implace Soil Thickness	Compacted Soil Liner Thickness	Permeability cm/sec	% Passing No. 200 Sieve	Liquid Limit	Plasticity Index	Monitor Wells	Leachate Collection	Depth to Water Table*	Flood Protection
I	Any industrial solid waste or mixture of industrial solid wastes, which, because of its concentration, or physical or chemical characteristics, is toxic, corrosive, flammable, a strong sensitizer or irritant, generates sudden pressure by decomposition, heat or other means, and may pose substantial present or potential danger to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed; including hazardous wastes identified or listed by the administrator of the Environmental Protection Agency pursuant to the Federal Solid Waste Disposal Act.	4' (1.22 m)	3' (0.91 m)	$\leq 1 \times 10^{-7}$	≥ 30	≥ 30	≥ 15	Yes	Yes	50'	Below 50 yr. flood - diversion dikes 2' above 50 yr. flood elevation around perimeter of site. Above 50 yr. flood - structure for diverting all surface water runoff from 24 hr., 25 yr. storm.
II	Any industrial solid waste or combination of industrial solid waste which cannot be described as Class I or Class III as defined in this regulation.	3' (0.91 m)	2' (0.61 m)	$\leq 1 \times 10^{-7}$	≥ 30	≥ 30	≥ 15	Yes	-	10'	Above 50 yr. flood - structure for diverting all surface water runoff from 24 hr., 25 yr. storm.
III	Essentially inert and essentially insoluble industrial solid wastes, usually including brick, rock, glass, dirt, certain plastics, rubber, etc. not readily decomposable	-	-	-	-	-	-	-	-	-	-

* Depends on permeability and thickness of material at site.

TABLE 29

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
DIVISION OF LAND/NOISE POLLUTION CONTROL
(PENDING APPROVAL)

Site	Maximum Permeability	Thickness of Confining Layer	Depth to Aquifer	Flood Frequency	Theoretical Confinement Time	Monitoring	Site Pollution Potential	Waste	Module
Class I	$1x10^{-8}$ cm/sec natural	10' (3.05 m)	10' (3.05 m)	100 yr. line or maximum known elevation. No marginal lands.	500 yrs	Yes	Very low	All wastes excluding radioactive	E A,B,C F
Class II	$5x10^{-8}$ natural	10' (3.05 m)	10' (3.05 m)	100 yr. line or maximum known elevation. No marginal lands.	250 yrs.	Yes	Low	General putrescible, special, specified hazardous wastes, all Class III, IV and V.	E A,B,C F
Class III	$1x10^{-7}$ natural or engineered	10' (3.05 m)	10' (3.05 m)	100 yr. line or maximum known elevation. No marginal lands.	150 yrs.	Usually yes	Low to Moderate	General municipal, certain special, all Class IV and V.	E A,B,C F
Class IV	$5x10^{-7}$ natural or engineered	5' (1.52 m)	0'	No marginal lands	-	May	Moderate	Demolition and construction, bulky, landscape wastes and inert, insoluble materials. All Class V.	A,B,C F
Class V	Little or no confinement, or sufficient site information to determine the pollution potential of the site has not been provided.	-	-	-	-	-	-	Inert, noncombustible material.	G

Assessment. The following advantages are associated with the Classification System approach:

1. Site/Waste Comprehensive - The Classification Systems identified to date are comprehensive from a site/waste standpoint, in that all wastes, excluding radioactive wastes, will be assigned to a specific site type or class for either containment or attenuation of pollutants. It is noteworthy that the majority of wastes following the on-line and impending guidelines of the Classification System will undergo land disposal for prevention of surface and groundwater pollution by containment rather than reliance upon attenuation. In each state contacted, hazardous waste will be contained by natural low-permeability deposits.

2. Addresses Hazardous Wastes - Each of the Classification Systems identified specifically addresses hazardous wastes or hazardous "substances".

3. Presently Being Used - The Classification System in California has been on-line and used for a period of nearly five years and has, in that time, been tested and verified in a number of specific instances. The Illinois and Texas Classification Systems are just coming on-line and, therefore, have yet to be tested and verified.

4. Low Cost/Expertise Requirements - As a result of the rather simplified breakdown of wastes, primarily into two end-member categories (hazardous and inert insoluble wastes), use of this system can be expected to result in lower cost and expertise requirements in comparison with the other decision procedures.

The following disadvantages are associated with the Classification System:

1. Insufficient Data Requirements - Although the Classification System is relatively simplistic in its format, an argument could be made that there is insufficient required input data in comparison to the other decision procedures. Comparison of Table 20 (California Classification System) with the Criteria Listing (Table 14) readily indicates the difference in the degree of quantification required. Reliance is generally placed on a limited amount of data necessary to define the containment capability of a site and its proximity to surface and groundwater resources. The key site parameters in the Classification System are the depth to water, thickness of the confining layers and, most important, the permeability of the confining layers. This latter parameter is addressed in the following paragraph.

2. Availability of Low Permeability Deposits - Each of the Classification Systems previously identified relies on the presence of a deposit with a natural low permeability. Artificial liners or synthetic permeability reduction materials are utilized only in certain instances, and are generally held in questionable (at best) or low esteem. The presence of naturally-occurring deposits with a permeability of 1 x 10-7 cm/sec or less is not common in many areas. In fact, such a permeability may be totally absent within large geographic areas. Disposal practices with reliance on containment, therefore, would be required to utilize synthetic liners at certain sites to meet the low permeability requirements, or waste would be transported to adjacent states (or areas) where the required permeability conditions are present.

3. Little Quantification of Pollution Potential - Utilization of the Classification System, in effect, results in a relative quantification of pollution potential by definition of the waste/site characteristics. This by itself is not necessarily a disadvantage, but, coupled with the conservatism of the approach (described next), results in it being a potential limitation to the cost-effective utilization of this approach.

4. Possibly Too Conservative - Use of the Classification System for the placement of decombustible waste in sites where the mode of deposition is by containment as opposed to attenuation of migrating pollutants can possibly lead to an overly-conservative approach. Given the unknowns of many soil/waste interactions, however, most regulatory agencies feel that this approach, although admittedly conservative, must be taken in light of the current state of the art for prediction of pollution potential.

The major potential disadvantage of the approach is that wastes which would be amenable to disposal with reliance on attenuation would, in fact, be relegated to a containment site where they would occupy "valuable space".

A summarization of the advantages and disadvantages of the Classification System is given in Table 30.

Availability. The Classification System is presently being utilized as the basic decision procedure for waste disposal siting for seven individual regulatory agencies contacted. Its on-line utilization and comprehensive nature relative to a variety of waste types makes it ideally suited as a "standard" decision procedure. This approach, however, is in need of continuing refinement, particularly in what may

TABLE 30

SUMMARY ASSESSMENT OF CLASSIFICATION SYSTEM
(DECISION TREE)

Pros

- Site/waste comprehensive.
- Specifically addresses hazardous wastes.
- Presently used by regulatory agencies.
- Tested and verified.
- Low cost/expertise requirements.

Cons

- Possible insufficient data requirements.
- Local and regional availability of low permeability deposits.
- Little quantification of pollution potential.
- Possibly too conservative.

be most often called "sub-routines" for waste characterization. Such refinements are discussed in Section VII, Recommended Development Plan.

Simulation Models

Description. Predicting the potential magnitude of groundwater pollution associated with the land disposal of wastes (solid or liquid) is a complex technological undertaking. The simultaneous presence of numerous interactive mechanisms (physical, chemical, and biological) makes it difficult to obtain a description in advance of a potential pollution by a given waste for a specific hydrogeologic setting. Consequently, many investigators have resorted to the construction of "models" for evaluating the performance of a certain waste disposal site. Several definitions pertinent to this discussion are given below.

A waste disposal system (e.g., landfill or lagoon) is defined as a set of physical, chemical, and biological processes which act upon specific input variables (precipitation, amount and type of waste, etc.), and convert these into output variables (amount and concentration of leachate leaving the landfill, pollutant concentration in groundwater, etc.). From a management viewpoint, the waste disposal system should, in addition to the disposal site itself, include the groundwater aquifer under or immediately downgradient to the site.

In the above definition, a variable is understood to be a characteristic of the system that can be measured, and may take on different values at different times (amount and type of waste, precipitation/evaporation, etc.). A parameter, on the other hand, is a characteristic of the system which remains essentially constant with time (permeability of the underlying aquifer, geometry of a landfill, soil/waste adsorption constants, etc.).

A waste disposal (landfill) model may be considered to be a simplified representation of a real system. As a result of simplifications, different types of models exist; for example, a scaled-down replica of the system is as much a model of the system as is a highly sophisticated mathematical model using partial differential equations. Even when an experienced engineer evaluates a proposed waste disposal site and uses his experience to make a decision regarding the suitability of the site for waste disposal, he uses a certain "model", since subjective judgment is a decision tool.

Models can be classified in several ways. A possible classification is given below. (For a more extensive discussion of models and simulation procedures, see Fishman, 1973, or Maisel and Gnugnoli, 1972; note all references cited in this section are given in Appendix A, Part VI.)

Descriptive Models. These models are expressed in one's "native" language (Emshoff and Sisson, 1970). An expert may not rely upon well-defined procedures, but may use their general qualitative judgment to evaluate a proposed waste disposal site (descriptive model). An important advantage of this type of model is its low cost. The greatest limitation of this modeling technique, however, is that its predictions are subjective. Different experts may reach different conclusions based upon this modeling approach.

Physical Models. Physical models are those which represent scaled-down versions of the true situation (i.e., a globe is a physical model of the earth). Unfortunately, only a few physical models of waste disposal sites exist today, for example, the laboratory and scaled-down field landfills built by Drexel University in cooperation with the Pennsylvania Department of Health (Fungaroli and Steiner, 1973). This laboratory facility was operated under controlled environmental conditions, and the field site was maintained under natural (no control) conditions.

Although these scaled-down facilities were constructed primarily to study the behavior of a sanitary landfill, the field site should be viewed as a physical model of the landfill later constructed in the immediate vicinity of the experimental landfill. In fact, the field facility may still be regarded as a physical model for other sites in Pennsylvania or elsewhere, provided the hydrogeological environment remains essentially the same, and similar wastes and management procedures for the landfill are used. Generally, extrapolation outside the region of study is difficult due to the occurrence of unique local conditions such as waste, soils, hydrology, and management. Additional examples of scaled-down simulated laboratory landfills are given by Quasim (1965) and Pohland (1975).

Although physical (scaled-down) models of waste disposal sites are generally lacking, experiments can be conducted to aid field personnel in making accurate predictions. Data may be generated, either through field or laboratory experimentation which can be used to assess the behavior of specific waste constituents associated with a given disposal site. Experimentation may include column leachate studies to determine the rate at which certain constituents move through a soil, thin-layer chromatography leading to estimates of constituent migration rate, or batch equilibration studies (all described below) to characterize constituent adsorption to soils. Unfortunately, this information does not define a waste disposal "model", and as such cannot be used as a prediction tool. On the other hand, it may provide necessary information (i.e., dispersion coefficient, adsorption constants, etc.) for use in mathematical models.

While it is obvious that scaled-down physical models can provide useful information about the type and concentrations of chemicals expected from a certain waste/soil combination, their practicability as a decision tool appears doubtful. They are not only costly to build, but time-consuming to use, expecially when one considers the number of chemical and biological processes that may occur over a period of several years or decades.

Analog Models. These models employ the convenient transformation of a given property into another which behaves in a similar manner. The problem in question is then solved in the substitute state, and the answer is translated back into the original properties. Examples of analog models are block diagrams, slide rules, or plant layouts. Electronic analog models have found widespread application in groundwater flow modeling. Electronic devices and properties (currents, voltages, diodes, and resistors) are used to simulate the components of the groundwater system. Because of the cost of building large-scale geometric problems, it appears doubtful that many analog models will be used in the near future to simulate large water-quality problems. An application of an analog model for chemical transport through soils is given by Bennet et al. (1968).

Mathematical Models. These models are concise mathematical expressions of the waste disposal system. Generally, mathematical equations can be used to express relationships that exist between various system parameters and the input and output variables. Depending upon the method of analysis, this type of model may range from a few simple equations (criteria ranking) to hundreds of complex mathematical expressions which can be solved only through the use of digital computers. In the latter case, a set of partial differential equations is derived, based on physical principles (such as the equations of continuity and mass transport), which is subsequently solved using either analytical or numerical techniques. These models have been viewed by several researchers as a potentially-useful approach for describing contaminant migration from a waste disposal site into an underlying groundwater system. This modeling approach will be described in greater detail below.

In addition to the above classification of models, several distinctions between models can be made, depending upon the method of analysis defined by the model and the approach used to solve a particular problem. These classification schemes, among others, include the following.

Empirical versus Conceptual Models. Models can be classified as empirical or conceptual depending upon whether or not the assumed physical processes use input variables to produce output variables. Empirical models are based completely on observation and/or experimentation. However, the distinction between empirical and conceptual models is not always clear. Several models describing adsorption of a particular chemical onto soil are empirical in nature (e.g., linear adsorption, Freundlich isotherm), while others are based upon physio-chemical theory (e.g., cation exchange equations). The use of column-leaching studies to measure the migration of contaminants through soil is an empirical approach, although it may yield certain parameters (dispersion coefficients and adsorption constants) required in conceptual models.

Differential equations used to describe mass transport of a constituent through a porous media constitute a conceptual model. These equations are generally based upon conservation of mass, energy, and momentum. However, empirical relations are frequently used in their derivation (adsorption, zero- or first-order degradation effects, and Darcy's law for fluid flow). Certain writers have used the term "black box" to indicate the empirical nature of certain models, while the term "white box" or synthetic model has been used to describe conceptual models.

Stochastic versus Deterministic Models. In a deterministic model, all input variables and system parameters are assumed to have fixed mathematical or logical relationships. As a consequence, these relationships completely define the system, and a single solution is obtained. Stochastic or probabilistic models, on the other hand, take into account the randomness or uncertainties that are associated with system parameters or input variables. Several stochastic models exist, depending upon the basic assumptions made about the physical processes and the type of mathematics used in the model. Two groups of stochastic models of interest in simulating water-quality problems are:

1. Stochastic models where the system parameters and input variables are characterized by assumed probability distributions (normal, log-normal, etc.). Using the Monte-Carlo simulation technique, output variables are generated which are characterized by certain probability distributions. In this approach, the basic model is thought to be exact, but the complexity of the system under consideration is such that its parameters are more properly defined by probability (or frequency) distributions. The one-dimensional stochastic groundwater flow model discussed by Freeze (1975) is an example of such a model.

2. Another type of stochastic model results when the system parameters or input variables are uncertain, either because of a lack of reliable input data or due to measurement errors. Uncertainty may also result from the use of an over-simplified model where different mechanisms are sometimes lumped together, thus leading to less well-defined parameters. The appropriate parameters are then characterized by a mean and variance, but no probability distributions are assumed. The model then generates a mean and variance for each output variable which can be used to construct a confidence interval, but no frequency distribution. An example of this type of approach is given by Tang and Pinder (1977) who describe a model for flow and mass transport based on uncertainties.

<u>Static versus Dynamic Models</u>. This distinction depends upon how the time dimension is viewed in the model. Static models are those which evaluate steady-state conditions, i.e., where the input variables do not change with time. When the input variables change with time, dynamic models result. Although static models, which are much simpler and require less computational effort than dynamic models, could be used to describe certain subsystems of the waste disposal/groundwater system (for example, description of fluid flow in the unsaturated zone under the disposal site), it appears that the whole system is dynamic and should be modeled accordingly.

Spatial Dimensionality of the Model. Although a waste disposal site and the underlying groundwater system constitute a three-dimensional model, useful and accurate results can often be obtained with models which consider only one or two spatial dimensions. For example, a one-dimensional model can be used successfully to describe the rate of contaminant migration through and below a landfill to the groundwater table. While considerable insight can be obtained with such a model, it stops short of providing accurate information regarding groundwater pollution under and immediately downgradient to the landfill because of the dilution of the landfill leachate by the flowing groundwater. This process cannot be evaluated with a one-dimensional model. An exception to this obviously occurs when the water table lies far below the soil surface and evaporation greatly exceeds the average yearly precipitation. In general, however, it seems that, at a minimum, a two-dimensional cross-sectional model must be formulated. Two-dimensional models can also be applied on an areal basis. Here the system parameters and the input and output variables represent averaged quantities along the vertical dimension.

Table 31 lists a few example models and their classification into different groupings. When these models are used to evaluate the physical/chemical behavior of constituents present in proposed waste disposal sites, including an evaluation of the pollution potential of the underlying groundwater aquifer, the model is said to "simulate" the system. The following definition for simulation is used here (adapted from Shannon, 1975):

> "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of either understanding the behavior of the system, or of evaluating various strategies, within the limits imposed by a criterion or set of criteria, for operation of the system."

TABLE 31

EXAMPLE MODELS AND THEIR CLASSIFICATION INTO DIFFERENT GROUPINGS

Model Definition	Descriptive (D) Physical (P) Mathematical (M)	Conceptual (C) Empirical (E)	Stochastic (S) Deterministic (De)	Static (St) Dynamic (Dy)	Spatial Dimension (1, 2, 3)
	TYPE OF MODEL				
On-site inspection and decision using engineering judgment.	D	E	De	Dy	3
The Drexel University experimental landfill (field site only)	P	E	De	Dy	3
Batch equilibrium study to determine adsorption; shaker test; solid waste evaluation leachate test (subsystem models)	M	E	De	St	0
Column study to determine adsorption and/or migration of certain chemicals in given soil; thin-layer chromatography (subsystem models)	M	E	De	Dy	1
Criteria listing; classification system of the California State Water Control Board; matrix method.	M	E	De	St	-
One-dimensional unsaturated transport model of Bresler (1973) (subsystem model)	M	C	De	Dy	1
Two-dimensional saturated-unsaturated transport model of Duguid and Reeves (1976)	M	C	De	Dy	2
Model for groundwater flow and mass transport under uncertainty of Tang and Pinder (1977).	M	C	S	Dy	2

The process of simulation hence includes both construction of a model and its actual use for studying the system, i.e., for evaluating groundwater pollution potential due to the construction of a proposed waste disposal site.

State of Development/Application. Of the different models discussed above, conceptual-mathematical models appear to be the most promising, but also the most complex for evaluating potential groundwater contamination problems for given waste-disposal sites. Conceptual-mathematical models are generally based upon a set of equations which describe relationships between different input and output variables and system parameters. These equations are derived using the principles of conservation of mass, energy, and momentum, and constitutive relationships which define certain systems. After suitable simplifications, the governing equations generally reduce to a set of coupled non-linear partial differential equations. One of these equations will describe fluid flow, and the others pertain to the transport and behavior of different chemical constituents associated with the waste leachate.

Several models of this type are currently available, the differences between them stemming mostly as a result of the number of simplifications made during derivation of the basic equations, the method of solving the equations, or the type of boundary conditions used.

The following partial differential equations for the mass transport of soluble waste constituents (density independent) and water in a saturated-unsaturated three-dimensional medium can be used to simulate a land disposal site and the underlying groundwater system.

- <u>Constituent Transportation Equation</u> (See also Duguid and Reeves, 1976; van Genuchten, et al., 1977)

$$\underset{(a)}{\frac{\rho \partial S_k}{\partial t}} + \underset{(b)}{\frac{\partial \Theta C_k}{\partial t}} = \underset{(c)}{\frac{\partial}{\partial x_i}\left(\Theta D_{ij} \frac{\partial C_k}{\partial x_i}\right)} - \underset{(d)}{\frac{\partial}{\partial x_i}\left(q_i C_k\right)}$$

$$\pm \underset{(e)}{\sum_{m=1}^{l_1}\left(\alpha_m \Theta C_k{}^m\right)} \pm \underset{(f)}{\sum_{m=1}^{l_2} R_k} \pm \underset{(g)}{QC_k{}^*} \qquad (6)$$

- <u>Water Flow Equation</u> (See also Reeves and Duguid, 1975; Neuman, 1973

$$\left(\frac{\Theta}{n} S_s + C\right)\frac{\partial h}{\partial t} = \frac{\partial}{\partial x_i}\left(K_{ij} \frac{\partial h}{\partial x_i} + K_{ij}\right) \pm Q \qquad (7)$$

$$i, j = 1, 2, 3$$

The symbols are defined in Table 32. The different terms in the constituent transport equation describe the following processes:

(a) changes in adsorbed constituent concentration.

(b) changes in solution constituent concentration.

(c) diffusion/dispersion effects.

(d) convective transport of the constituent by the fluid.

(e) production (+) or decay (-) reactions.

(f) additional chemical/soil or chemical/chemical interactions (precipitation, chemical transformations, cation exchange reactions, volatilization, etc.).

(g) constituent concentration changes resulting from water sources (+) or sinks (-).

TABLE 32

EXPLANATION OF SYMBOLS USED IN THE MASS TRANSPORT AND FLOW EQUATIONS

Symbol	Explanation
C_k	Solution concentration of chemical species k (ML^{-3})
C^*	Constituent concentration of the source or sink term (ML^{-3})
C	Specific soil-water capacity, (L^{-1})
D_{ij}	Dispersion coefficients (tensor) (L^2T^{-1})
h	Soil-water pressure head (L)
K_{ij}	Soil hydraulic conductivity (tensor) (LT^{-1})
n	Porosity (L^0)
q_i	Volumetric water velocity (LT^{-1})
Q	Soil-water source or sink term, $Q = Q_w \ (x_i - x_{wi})$ (T^{-1})
Q_w	Strength of source or sink term (L^3T^{-1})
R_k	Rate term expressing soil/chemical or chemical/chemical interactions $(ML^{-3}T^{-1})$
S_k	Adsorbed constituent concentration of chemical species k (M^0)
S_s	Specific storage coefficient (L^{-1})
S_w	Degree of water saturation (L^0)
t	Time (T)
x_i	Distance in i-th coordinate direction (L)
x_{wi}	i-th coordinate of source or sink
m	m-th order rate constant for production or decay $(M^{1-n}L^{3n-3}T^{-1})$
$\propto$	Dirac delta function
ρ	Soil (dry) bulk density (ML^{-3})
Θ	Volumetric water content (L^0)

Equation 6 reveals that the volumetric water velocity, q_i, is necessary to obtain a solution to the equation. For this it is necessary to solve Equation 7. This may be done once, leading to a steady-state flow field ($\frac{\partial h}{\partial t} = 0$), or may be done continuously during the solution process, i.e., in a transient manner. Whatever solution procedure is used, the volumetric flux, q_i, is obtained from Darcy's law:

$$q_i = - K_{ij} \frac{\partial h}{\partial x_i} + K_{ij} \tag{8}$$

The constituent transport equation is also coupled to the water flow equation through the dispersion coefficient, D_{ij}. The magnitude of D_{ij} depends upon the volumetric flow velocity, q_i, and the soil-water content (determined from the pressure head).

When k = 1 in Equation 6, transport of only a single chemical constituent is considered (e.g., chloride, pesticide, or trace metal). Adsorption, if present, can then be modeled by employing an equation describing the dependency of the sorbed constituent concentration, s, on the solution concentration, c, through the use of an appropriate adsorption isotherm. Several models for describing adsorption and/or ion exchange are available. These equations may be classified into two broad categories: equilibrium models which assume instantaneous adsorption of the chemical, and kinetic models which consider the rate of approach towards equilibrium. Table 33 presents some of the most frequently-used adsorption models. Not included in the table are those models which describe competition between two ionic species, such as the commonly-used cation exchange equations. Except for a few cases (e.g., Lai and Jurinak, 1971), generally two or more transport equations must be solved for such multi-ion problems (k = 2,3,...).

TABLE 33

PARTIAL LIST OF EQUATIONS USED TO DESCRIBE ADSORPTION REACTIONS

MODEL	EQUATION	REFERENCE
1. Equilibrium		
1.1 (linear)	$s = k_1 c + k_2$	Lapidus and Amundson (1952) Lindstrom et al (1967)
1.2 (Langmuir)	$s = \frac{k_1 c}{1 + k_2 c}$	Tanji (1970) Ballaux and Peaslee (1975)
1.3 (Freundlich)	$s = k_1 c^{k_2}$	Lindstrom and Boersma (1970) Swanson and Dutt (1973)
1.4	$s = k_1 c e^{-2 k_2 s}$	Lindstrom et al (1971) van Genuchten et al (1974)
1.5 (Modified Kjelland)	$s = \frac{c s_m}{c + k_1 (1-c) \exp\left[k_2 (c_m - 2c)\right]}$	Lai and Jurinak (1971)
2. Non-equilibrium		
2.1 (linear)	$\frac{\partial s}{\partial t} = k_r (k_1 c + k_2 - s)$	Lapidus and Amundson (1952) Oddson et al (1970)
2.2 (Langmuir)	$\frac{\partial s}{\partial t} = k_r \left(\frac{k_1 c}{1 + k_2 c} - s\right)$	
2.3 (Freundlich)	$\frac{\partial s}{\partial t} = k_r (k_1 c^{k_2} - s)$	Hornsby and Davidson (1973) van Genuchten et al (1974)
2.4	$\frac{\partial s}{\partial t} = k_r e^{k_2 s} (k_1 c e^{-2 k_2 s} - s)$	Lindstrom et al (1971)
2.5	$\frac{\partial s}{\partial t} = k_r (s_m - s) \sinh\left[k_2 \left(\frac{s_m - s}{s_m - s_i}\right)\right]$	Fava and Eyring (1956) Leenheer and Ahlrichs (1971)
2.6	$\frac{\partial s}{\partial t} = k_r c^{k_1} s^{k_2}$	(Enfield et al, 1976)

k_1 and k_2 are constants, k_r represents a rate constant (T^{-1}), and s_i and s_m represent initial and final (or maximum) adsorbed concentrations, respectively (after van Genuchten and Cleary, 1977).

Most of the equilibrium models in the table are special cases of non-equilibrium models and follow directly from them by setting the time derivative, $\frac{\partial s}{\partial t}$, equal to zero. All adsorption models in the table, except model 2.6, represent reversible adsorption reactions. Model 2.6 was used by Enfield and Bledsoe (1975) to describe orthophosphate adsorption. This model represents an irreversible reaction which does not allow for desorption of the chemical (adsorption remains positive at all times).

To complete the mathematical description of the system considered, one needs additional relations describing the geometry of the system and the initial and boundary conditions imposed on the partial differential equations. These auxiliary conditions may, or may not, include such information as: (1) initial constituent concentration distributions; (2) type and concentration of potential contaminants; (3) geometry of the waste disposal site; (4) aquifer configurations (two- or three-dimensional); (5) precipitation/evaporation data; and (6) location (and concentration) of rivers, open surface water bodies, or wells.

Once the governing equations and the initial and boundary conditions are defined, solutions for the concentration of the constituent can be generated by straight-forward, albeit very sophisticated, mathematical manipulations. The solution procedure is generally such that the flow equation is solved first to develop values of the soil-water pressure head distribution and estimates of the volumetric flow velocity, q, dispersion coefficient, D_{ij}, and soil-water content, θ. In order to do this, and provided an unsaturated zone is considered in the model, one needs additional information on the relationships between the soil-water pressure head, hydraulic conductivity, and soil-water content. Extensive and time-consuming experimentation is required to obtain these functional relationships. This places a significant burden on the reliability of the description of water transport processes in the unsaturated zone.

Mathematical solutions of Equations (6) and (7), or simplified versions of them, may be generated in several ways. Basically two approaches are currently used for this purpose: analytical and numerical methods. These two approaches are discussed briefly.

Analytical Methods. In order to obtain an analytical solution of the transport equation (Equation 5), one generally must assume a constant fluid velocity, dispersion coefficient, physical parameters, and input variables. Exact, explicit expressions for the constituent concentration can then be generated through the use of integral and differential calculus. Although the advantages of having analytical solutions are numerous (ease of use, and low cost of operation once derived), the necessity of having to make various simplifying assumptions in order to solve Equation 6 severely restricts the applicability of analytical solutions to waste disposal/groundwater contamination problems. In spite of these restrictions, it appears that some of the available two- and three-dimensional analytic solutions (Kuo, 1976; Want et al, 1977; Yeh and Tsai, 1976) may be applied to well-defined hydrogeologic systems and should not be excluded from consideration. Another example is the analytical study by Larson and Reeves (1976) who describe a transport model which predicts the flow of water and trace contaminants through a layered unsaturated soil medium.

Numerical Methods. While some situations may lend themselves to analytical methods, most field problems of interest have such complex physical and chemical characteristics that the flexibility of a numerical approach is required. When numerical techniques are used, the partial differential equations are generally reduced to a set of approximating algebraic equations, which subsequently are solved using methods of linear algebra. The most common numerical methods used are finite differences, finite element, or the method of characteristics.

When <u>finite difference</u> techniques are used, the derivatives in the governing partial differential equations are approximated with appropriate difference equations. This method has been used successfully in groundwater flow problems, but its application to groundwater quality studies is limited. This is partly a result of the procedure's inability to reproduce accurately the irregular boundaries of the system. Also, the possible introduction of numerical dispersion (the artificial smearing of a concentration front) or of the occurrence of undesirable oscillations in calculated concentration distributions has limited its use when dispersive transport was small compared to convective transport.

In general, finite difference techniques are numerically the simplest to use and the easiest to program. The method can yield accurate results when the area of interest is subdivided into a sufficiently fine grid of square or rectangular elements. The finite difference procedure has found frequent application in the simulation of one-dimensional unsaturated transport problems (Bresler, 1973; Wood and Davidson, 1975, among others). Two-dimensional applications are limited (Bresler, 1975; Fried and Ungemach, 1971).

The dependent variables in the <u>finite element method</u>, pressure head and concentration, are generally approximated by a series of basic trial or shape functions and associated coefficients. The approximating series is then substituted into the governing equations, and the resulting errors or "residuals" are minimized through the use of weighted-residual theorems. In the Galerkin method, the locally-based shape functions are the same as the weighting functions. The approximate integral equations derived in this way are evaluated using the finite-element method of discretion to minimize computational effort. Generally, a set of linear equations is obtained which can be solved by using appropriate matrix inversion subroutines or other methods. The domain of interest is again subdivided into elements which, unlike finite differences, can attain nearly any particular shape desired (triangular, rectangular, including elements having curved sides). A more-detailed discussion of the finite element method can be found in several recent studies (Hutton and Anderson, 1971; Pinder, 1973; Pinder and Gray, 1977).

The finite element method has been successfully applied to field problems involving mass transport. In some cases, numerical dispersion remained a problem, but it is less than that observed using the finite difference method. While the finite element method requires a somewhat more complex manipulation in generating solutions than the finite difference method, its solutions are generally more accurate, assuming the same net. Important advantages of the finite element method are its flexibility in describing irregular geometrical boundaries, its ease of introducing nonhomogeneous properties and anisotropy, and the possibility of using small elements in areas of relatively rapid change.

The method of characteristics, as generally used in groundwater quality simulation studies, employs a finite difference approach for the flow equation, while the constituent transport equation is solved with a set of characteristic equations. These characteristic equations are obtained from the main equations by deleting the convective transport terms and including them in separate equations. One must design for this purpose a standard finite difference network and insert "marker particles" or moving points into each finite difference cell. The marker particles are moved through the network as prescribed by local fluid velocities, thereby describing exactly the effects of the convective transport terms. The effects of the remaining terms in the transport equation are superimposed on the updated positions of the marker particles using the concentrations at these moving points and an appropriate finite difference scheme. The method is fairly simple in concept and has been shown to produce acceptable results for a wide variety of field problems (Bredehoeft and Pinder, 1973; Robertson, 1974; Konikow and Bredehoeft, 1974). An important drawback of this particular method is that it is not easy to program in two or three dimensions.

There exists a variety of other numerical models which can be applied to groundwater contamination problems. Most of these methods are not based upon direct solution of the governing partial differential equations. The most primitive are those using a lumped parameter approach, i.e., models which do not take into account the spatial variability of the system parameters or input and output variables (Hornsby, 1973; Gelhar and Wilson, 1974; Donigian and Crawford, 1976; Mercado, 1976). The mass balance equations are generally formulated, and the different input and output variables are a function of time. For the distributive approach, the mass balance equations are applied directly to a number of well-defined cells, layers, or elements. The elements assume instantaneous mixing, and the values of the independent variables are represented by the node located in the center of each element.

A rigorous analysis of this approach shows that, for an explicit time, a finite difference approximation of the governing equations is obtained. This approach assumes that all significant physical and chemical mechanisms are taken into account when formulating the mass balance equation. Examples of this type of approach are given by Tanji et al. (1967) and Orlob and Woods (1967).

A very similar approach was followed by Elzy et al. (1974), who applied a vertical-horizontal routing model to the transport of hazardous wastes from a landfill site. A more elaborate, but still somewhat similar model, is the "polygonal finite difference model" of Hassan (1974). The two-dimensional elements take the form of a polygonal network. Hassan used his model to estimate concentrations of total dissolved solids in a multi-layered groundwater basin in the Santa-Calleguas area of California. Additional refinement of this method will eventually lead to an "integrated finite difference" approximation of the governing partial differential equations.

Each of the numerical schemes discussed above appear to have specific advantages and disadvantages for application to field problems. These may be separated into factors affecting the accuracy, efficiency, and assessibility of the particular method. While important differences in accuracy and efficiency between the finite element and finite difference methods are known to exist (Gray and Pinder, 1976; van Genuchten, 1977), it is not clear to what extent these differences become important when simulating large-scale field problems. The accuracy and efficiency in programming, as well as the general setup of the model and its assessibility, are also important factors which determine the usefulness of a particular solution scheme.

Existing Mathematical Models. A compilation is given in this section of the different types of models currently available for possible use in groundwater quality evaluation studies. The list of models in Table 34 is not intended to be complete; other models exist as either published, unpublished, or under development by various organizations. The purpose of Table 34 is to demonstrate the existence of a wide variety of models, to characterize their most important capabilities and limitations, to identify the method of solution, and to show their application. The models are differentiated into four distinct groups: 1) both saturated and unsaturated transport models; 2) saturated-only model; or 3) unsaturated-only transport models; and 4) analytical transport models. Each group will be discussed briefly.

Unfortunately, no one model exists as yet which simulates all of the physical, chemical, and biological processes associated with a waste disposal site, i.e., a model which solves Equations 6 and 7 when k is large.* The complexity of the processes which operates simultaneously and in an interactive manner are such that the resulting program would be impractical to use, Assuming for the moment that the knowledge for construction of such a general model was available and that the vast amount of input data needed was available, the resulting program would be so large and bulky that the cost of operating it would be too high.

Partially-Saturated Transport Models. The models in this group are based upon Equations 6 and 7 (see page 135), or upon appropriate simplifications of these equations. The different models simulate either a three-dimensional system (model A2), or a two-dimensional cross section. No cation-exchange reactions are considered in any of the models in this group, although at least three take into account adsorption (single-ion) and/or decay (models A1, A3, and A5).

*See Appendix A, Part VI: (6) Dungund and Reeves, 1976 and Van Genuchten et. al., 1977; (7) Reeves and Dungund, 1975 and Newman, 1973.

TABLE 34

PARTIAL LIST OF AVAILABLE TRANSPORT MODELS FOR APPLICATION TO GROUND WATER QUALITY PROBLEMS

Model No	Model References	Geometry of model 1)	Method of solution 2)	Type of flow 3)	Type of soil 4)	Type of chemical interactions 5)	application/ comments
A. SATURATED-UNSATURATED TRANSPORT MODELS							
A1	Duguid and Reeves (1976, 1977)	2D,C	LFE	Tr	L,An	Ad, De	transport of radionuclides from a waste-disposal site
A2	Segol (1976, 1977)	2D,3D	HFE	Tr	L,An	-	-
A3	van Genuchten et al (1977)	2D,C	HFE	Tr	L,An	Ad, De	leachate movement from a hypothetical landfill
A4	Sykes (1975)	2D,C	HFE	St	L,An	-	contaminant movement from a landfill
A5	Elzy et al. (1974)	2D,C	O	Tr	-	Ad, De	contaminant movement from a landfill
A6	Perez et al. (1974)	2D,C	FD	Tr	L	-	groundwater pollution from agricultural sources
B. SATURATED-ONLY TRANSPORT							
B1	Gupta et al (1975)	3D	HFE	Tr	L, An	-	Simulates rising connate water through a vertical fault in multi-aquifer system (steady state flow application only)

TABLE 34
(continued)

Model No	Model references	Geometry of model 1)	Method of solution 2)	Type of flow 3)	Type of soil 4)	Type of chemical interactions 5)	applications/comments
B2	Gureghian and Cleary (1977)	3D	LFE	St	An	Ad, De	applied to an existing landfill on Long Island
B3	Pickens and Lennox (1976)	2D,C	TFE	St	L,An	Ad	contaminant transport from a hypothetical landfill
B4	Schwartz (1975, 1977)	2D,C	MOC	St	An	Ad,Ce,De	hypothetical study of subsurface pollution by radioactive wastes (1975); model analysis of a proposed waste-management site (1977)
B5	Bredehoeft and Pinder (1973)	2D,A	MOC	Tr	An	-	movement of salt water in confined limestone aquifer; predicted future concentrations and tested effects of protective pumping.
B6	Konikow and Bredehoeft (1974a,b)	2D,A	MOC	Tr	An	Ad, De	used calibrated model to evaluate effects of different irrigation practices on salinity changes in an alluvial stream-aquifer system.
B7	Robertson (1974), Robertson and Barraclough (1973)	2D,A	MOC	Tr	An	Ad, De	Transport of industrial and low-level radioactive wastes into the Snake River Plain aquifer, Idaho. Simulated 20 year history of pollution.
B8	Robson (1974)	2D,A	MOC				Pollution of shallow aquifer by seepage from sewage treatment ponds; predicted future concentrations and tested alternative watermanagement plans.
B9	Robertson (1975)	2/3D	A/MOC	Tr	An, L	Ad, De	Three-segment model for flow, including ability to simulate perched water in the unsaturated zone (see also B7)
B10	Konikow(1976)	2D,A	MOC	St			Simulated 30 year history of groundwater pollution by chloride from an unlined disposal pond into the underlying alluvial aquifer.
B11	Helweg and Labadie (1976)	2D,A	MOC	Tr	An	-	Adapted version of B6; used as a cost-effective salinity management technique for stream-aquifer systems.

TABLE 34
(continued)

Model No	Model references	Geometry of model[1)]	Method of solution[2)]	Type of flow[3)]	Type of soil[4)]	Type of chemical interactions[5)]	applications/comments
B12	Grove (1976)	2D,	FE			Ad, De	Transport of industrial and low-level radio-active wastes into interbedded basalt flows and unconsolidated sediments.
B13	Reddell and Sunada (1970)	2D, A,C	MOC	Tr	An	-	Three-dimensional formulation, two-dimensional application only.
B14	Ahlstrom and Baca (1974)	2D,A	MOC	St/Tr	An	Ad, Ce	Considers adsorption and exchange of several macro- and micro-ions.
B15	Pinder (1973)	2D, A	HFE	St	An	-	described and predicted future concentrations of hexavalent chromium seeping from a waste disposal pit into underlying glacial outwash aquifer
B16	Thoms et al. (1977); Martinez et al. (1975)	2D, A	HFE	St	-	Ad, De	describes groundwater pollution from salt dome leachates.
B17	Besbes et al (1976)	2/3D,A	FD	Tr	L	-	**Areal model** for multilayered aquifersystem; predicted concentration changes after dam construction in the Kairouan Plain, Tunesia.
B18	Fried (1971,1975) Fried and Ungemach (1971)	2D,A	FD	Tr	-	-	flow part based on Boussinesq equation; describes pollution by NaCl from large salt dumps into alluvial aquifer in Northeastern France.
B19	Lessi (1976)	2D,C	HFE	Tr	L	-	applied to solute transport in a heteroge-neous aquifer.

TABLE 34
(continued)

Model No	Model references	Geometry of model 1)	Method of solution 2)	Type of flow 3)	Type of soil 4)	Type of chemical interactions 5)	applications/comments
SALTWATER INTRUSION MODELS							
B25	Pinder and Page (1977)	2D,A	TFE	Tr	-	-	vertically integrated sharp-interface salt water intrusion model. No transport equation is solved.
B26	Segol, Pinder and Gray (1975)	2D,C	HFE	St	An	-	calculating the position of the saltwater front.
B27	Lee and Cheng (1974)	2D,	MOC	Tr	An	-	seawater encroachment in coastal aquifers.
B28	Green and Cox (1966)	2D,	MOC			-	storage of fresh water in underground reservoirs containing saline water.
B29	Pinder and Cooper (1970)	2D,C	MOC	St	-	-	calculating the transient position of a saltwater front.

TABLE 34
(continued)

Model No	Model references	Geometry of model[1)]	Method of solution[2)]	Type of flow[3)]	Type of soil[4)]	Type of chemical interactions[5)]	applications/comments
C	UNSATURATED-ONLY TRANSPORT MODELS						
C1	Bresler (1975)	2D,C	FD	Tr	-	-	describes two-dimensional transport of solutes under a trickle source
C2	Hildebrand and Himmelbau(1977), Hildebrand(1975)	1D	FD	Tr	-	-	transport of nitrate in a sand column
C3	Bresler (1973)	1D	FD	Tr	-	-	compared results with field data on chloride transport during infiltration
C4	Wood and Davidson(1975) Davidson et al.(1975a, 1975b)	1D	FD	Tr	-	Ad	applied to pesticide transport
C5	Ungs et al. (1976)	1D	FD	Tr	-	Ad, De	compared results with observed field data on chloride transport during infiltration
C6	Selim et al. (1976a)	1D	FD	Tr	-	Ad	applied to transport of 2,4-D in soils
C7	Shah et al. (1975)	1D	FD	St	L	Ad	applied to phosphorus transport is soils; assumes constant dispersion coefficientand kinetic model for phorphorus adsorption
C8	Kirda et al, (1973)	1D	FD	Tr	-		applied to anion movement in soil columns
C9	Tanji et al. (1967a,b) Tanji et al. (1972)	1D	FD	St	L	Ad, Ce,	approximate solutions for cation exchange in field soils
C10	Dutt et al. (1972)	1D	FD	Tr	L	Ad, Ce	
C11	Rubin and James(1973)	1D	LFE	St	-	Ad, Ce	

TABLE 34
(continued)

Model No	Model references	Geometry of model[1)]	Method of solution[2)]	Type of flow[3)]	Type of soil[4)]	Type of chemical interactions[5)]	applications/comments
C12	van Genuchten and Pinder (1977)	1D	HFE/FD	Tr	L	Ad,De,Ce	modeling of leachate and soil interactions in an aquifer.
C13	Gureghian et al. (1977)	1D	FD	Tr	L	Ad,De,Ce	simulation of pollutant transport in Long Island, N.Y.
C14	King and Hanks (1973, 1975)	1D	FD	Tr	-	Ad,De,Ce	applied to irrigation return flow quality studies. Includes plant root uptake of water.
C15	Gaudet et al. (1977)	1D	FD	St	-	-	applied to soil with mobile and immobile water
C16	Selim et al. (1977)	1D	FD	St	L	Ad	applied to Cl and 2,4-D movement in two-layere soil column.
C17	Warrick et al. (1971)	1D	FD/A	Tr	-	-	approximate analytical solution of transport equation; applied to field irrigation study with chloride.
C18	Smajstrala et al. (1975)	1D	MOC	Tr	-	-	miscible displacement in soils

TABLE 34
(continued)

Model No	Model references	Geometry of model[1)]	Method of solution[2)]	Type of flow[3)]	Type of soil[4)]	Type of chemical interactions[5)]	applications/comments
D	ANALYTICAL TRANSPORT MODELS.						
D1	Kuo(1976), Shen(1976) Cleary et al. (1973), Wang et al. (1977), Yeh and Tsai(1976), Cleary (1976), among others	2,3D	A	St	-	(Ad,De)	various applications and assumptions
D2	Lapidus and Amundson (1952), Brenner (1962) Lindstrom et al (1967) Lindstrom and Boersma (1971, 1973), Lindstrom and Stone (1974a,b), Cleary and Adrian(1973) Marino(1974), Ogata (1961), van Genuchten and Wierenga (1976), Selim and Mansell (1976), among others	1D	A	St		(Ad, De)	various applications, including - zero and first order decay - linear equilibrium adsorption, - first order kinetic adsorption, - solute transfer between mobile and immobile water - decaying boundary conditions

1)
1D = one-dimensional
2D = two-dimensional
3D = three-dimensional
A = Areal (2D only)
C = Crossectional (2D only)

2)
A = Analytical
FD = finite differences
LFE = linear finite elements
TFE = triangular finite elements
HFE = mixed/higher order finite elements
MOC = method of characteristics
0 = other

3)
Tr = Transient
St = Steady-state

4)
L = layered
An = anisotropic

5)
Ad = adsorption
Ce = cation exchange (multi-ion transport)
De = decay

The models in this group are probably the most appropriate because they consider the unsaturated-flow conditions in a landfill or under the waste-disposal site. For example, aerobic decomposition of hazardous organic wastes (including pesticides) and certain oxidation-reduction reactions could be taken into account in such models. Also, one of the more important attenuation mechanisms, dilution of leachate by flowing groundwater, can be much more clearly defined with saturated-unsaturated transport models. Unfortunately, inclusion of the unsaturated zone also places a considerable burden on the effective and economical use of the model. The highly non-linear character of the governing equations during saturated-unsaturated flow makes its solution more difficult, and, generally, small time steps in the numerical algorithm are necessary to ensure a correct solution. This can lead to high computer costs when simulations are to be made for a period of several years (Segol, 1974; Duguid and Reeves, 1976).

Several simplifications can be made to circumvent some of these problems. For example, the use of monthly average rain/evaporation data (van Genuchten et al, 1977; Duguid and Reeves, 1977) rather than hourly or daily data or assume steady-state flow conditions altogether (Skyes, 1975). While steady-state flow conditions may be justified in some cases, it appears that predictions of the amount and quality of leachate reaching the groundwater may be inaccurate when evaporation on a yearly basis is of equal magnitude or high than precipitation. Also, seasonal water changes cannot be described with the steady-state model.

Another problem associated with the unsaturated zone is the need for additional input data. For example, the nonlinear relationships between moisture content, pressure head, and hydraulic conductivity have to be determined for each soil type present in the system. In addition, and of equal importance, the different soil-chemical interactions occurring in the unsaturated zone have to be quantified. Thus, it appears that the technology for modeling contaminant transport is far less advanced than that for modeling fluid flow, especially with respect to adsorption and exchange reactions in the unsaturated zone.

Notwithstanding these problems, the partially-saturated transport models appear to be the most promising tools for evaluating potential groundwater contamination from waste disposal sites. Much research is still needed before the models in this group can be applied in a practical, accurate, and economical way. Problems related to contaminant transport and the need for quantification of the many adsorption/exchange reactions in the unsaturated zone will require more study.

Saturated-Only Transport Models. In these models, the dynamics of the unsaturated zone between the waste disposal site and the groundwater table are ignored. Hence, important mechanisms associated with unsaturated flow and contaminant transport are not taken into account, unless they are represented in an approximate way through data adjustments. To use these models it is necessary to have a method of quantifying the amount and quality of leachate reaching the groundwater table. Given that this can be done beforehand, i.e., in a predictive way, the models listed in this group appear to be useful tools for groundwater contamination simulations. The need for describing the unsaturated zone becomes much less when the waste disposal site is in direct contact with the saturated zone.

Many of the models listed in this category use the method of characteristics (MOC) for solution of the transport equation, and are either extensions, simplications, or otherwise adaptations of the areal models for fluid flow and mass transport (Pinder and Bredehoeft, 1968; Bredehoeft and Pinder, 1973).

Models of this type have found application in a wide variety of practical field problems, mostly in cases where groundwater pollution was observed and wehre calibration of the model to field data was possible. Some additional work seems necessary to determine the accuracy of these models for use in a purely-predictive context, i.e., where calibration of the model is not possible, or purposely sidestepped. Also, for the models in this group, it seems again that the technology for describing fluid flow is well ahead of that for describing mass transport of adsorbing chemicals (generally for non-conservative species). Provided the necessary data can be obtained, models in this group are probably sufficiently tested, and, hence, could be used within a few years for prediction of TDS (total dissolved solids) concentrations.

A special class of saturated-only transport models is provided by the salt water intrusion models (models B25-B29). These models differ from the other (cross sectional) models in this group in that they consider density-dependent flow, and, as such, are applicable to contaminant transport from water disposal sites. Table 35 gives a summary assessment of the models in this group.

Unsaturated-Only Transport Models. Because these models consider only the unsaturated zone, they cannot be used to describe contaminant migration in groundwater systems. The models (one-dimensional) in this category are useful when studying the mechanisms of pollutant transport in the unsaturated zone, especially the transient waste/soil interactions associated with column-leaching studies. Another and important application of these models results when they are used simultaneously with saturated-only transport models. These models can be used to predict the amount and type of leachate reaching the groundwater table, information which is used as input for the saturated-only transport model (see, for example, model A6).

TABLE 35

SUMMARY OF MODEL DEVELOPMENT BY TYPE

ACTIVITY	STATE OF DEVELOPMENT			
	FLUID FLOW	MASS TRANSPORT		
		SINGLE-ION TRANSPORT		MULTI-ION TRANSPORT (+EXCHANGE)
		NO ADSORPTION NO DECAY	WITH ADSORPTION WITH DECAY	
1. Mathematical formulation of any model	0	0	D3	D3 - ?
2. Numerical solution of any model	0	0	D3	D3 - ?
3. Field calibration and testing:				
saturated/unsaturated transport	0	D3	D6	D6 - ?
saturated-only transport	0	0	D3	D6 - ?
unsaturated-only transport	0	0	D3	D6 - ?
4. Field verification:				
saturated/unsaturated transport	D3	D3	D6	D10 -?
saturated-only transport	0	D3	D3	D6 - ?
unsaturated-only transport	0	0	D3	D6 - ?
5. Methodology for laboratory and field quantification of major parameters[1] (any model)	0	D3	D3	D6 - ?
6. Methodology for quantification of leachate quality	NA	NA	0	0
7. Standard procedures for field testing, calibration and verification (any model)	D3	D3	D6	D10 -?
8. Ready for use as a decision procedure				
saturated/unsaturated transport	NA	D3	D6	D10-?
saturated-only transport[2]	NA	D3	D6	D10-?
unsaturated-only transport[2]	NA	D3	D3	D6 -?

0 = operational;
D3 = under development, likely to be operational within three years;
D6 = under development, likely to be operational within six years;
D10= under development, likely to be operational within ten years;
? = under development, not likely to be operational within ten years;
NA = not applicable

1) adsorption/exchange constants, dispersion coefficients, soil hydraulic properties, etc
2) if the indicated transport model is suitable for application at given site.

Analytical Models. Analytical transport models, especially the two- and three-dimensional models, appear to have limited application to actual (field) groundwater contamination problems. Their application is restricted to those cases wherein the geohydrology of the area is very simple (flow in one direction, constant porosity, dispersivity, and conductivity). The different one-dimensional analytical models (Models Ds) are again potentially fuseful as tools for identification and quantification of waste/soil interactions when used in conjunction with column-leaching experiments for quantification of adsorption constants, dispersion coefficients, etc.

Existing Non-Mathematical Simulation Models. Numerous non-mathematical simulation models currently exist which may be generally categorized into: (1) soil-leachate column studies; (2) batch or shaker tests; (3) thin layer chromatography; and (4) a dilution model. Considerable research has been conducted to date in utilizing soil-leachate column studies. (See Appendix B.) Significant column studies have been conducted by: Fuller and Korte, at the University of Arizona; Griffin, et al., at the Illinois State Geological Survey (IGS); Farquhar and Rovers at the University of Waterloo, Canada; and Bromley, et al., at Harwell Laboratory, the United Kingdom.

Batch or shaker test research has also been conducted by Griffin, et al. (IGS) and is currently being utilized or proposed for use as a waste characterization procedure by most of the regulatory agencies contacted. Thin layer chromatography research is also being conducted by Griffin et al. (IGS). A dilution model has been described by D.B. Oakes of the Water Research Centre, the United Kingdom.

Each of these basic procedures is described in the following text.

Soil-Leachate Column Studies. Because of the complex nature of most waste leachates and the number of processes that may occur within the saturated or unsaturated soil to influence the behavior of a waste constituent, soil-column studies have been used to simulate natural field conditions. These experiments have been used to quantify the potential for a given soil to attenuate specific constituents commonly present in municipal and industrial waste. These experiments have used soils which represent the major soil orders throughout the United States and clays commonly used for liners in landfills. Regression equations using this data base have been developed to estimate the mobility or attenuation of various constituents using fundamental chemical and physical properties of the soil.

The soils or clays used in laboratory column studies are initially air-dried and passed through a 2-mm screen. The size (radius and length) of the columns (glass or plastic) used to confine the soil or clay varies, but it generally exceeds 2.5 cm in radius and 15 cm in length. The air-dried materials are uniformly packed into columns using various techniques. A procedure frequently used to pack the columns consists of adding increments of soil and tamping the soil with a rod approximately 1 cm in diameter. Uniformity of packing is determined based upon the amount of soil packed into equal-column increments. The average bulk density for the packed materials is approximately 1.5 g/cm^3 for silt and clay materials, and greater than 1.6 g/cm^3 for sands.

Most laboratory experiments are conducted using water-saturated soil or clay systems. Unsaturated soil-water conditions are difficult to control, and the soil-water flow rates are extremely low for these cases. In order to water saturate these materials it is necessary to evacuate the soil columns or purge the air from the porous materials with CO_2. The soils or clay should be initially wet with a dilute calcium salt solution (for example, 0.01 N $CaCl_2$ or $CaSO_4$). The calcium prevents dispersion and maintains constant pore geometry.

The columns should be constructed in such a manner that the inflow solution can be changed without seriously interrupting the experiment. The outflow end of the column should be designed to facilitate effluent solution collection for analysis. Measurements of the input solution volume with time should be possible for monitoring the solution or leachate flow rate through the soil column. The physical position (vertical or horizontal) of the column is not important except in regulating solution flow rates for some experimental cases. The solution flow rate through the saturated porous material may be controlled: with a peristaltic pump, with constant solution head on the top of the soil or clay material, or by gas pressures. The procedure used generally depends upon funds available and necessity of maintaining a constant flow rate. Flow rate is an important variable for many soil or clay materials and specific adsorbed constituents. Inadequate equilibrium conditions or resident times in the column can influence a waste constituent's mobility. Insofar as possible, constant solution flow rates should be maintained.

The solution used to initially wet the soil or clay column is generally applied until three to five pore volumes (amount of water contained in the saturated or unsaturated soil column) have been eluted. This procedure aids in establishing equilibrium conditions prior to the application of a waste leachate. Anaerobic conditions similar to those existing for natural conditions under landfills are also established during this period.

After preconditioning the soil or clay column, the waste leachate is applied. If anaerobic conditions are to be maintained, the waste leachate must also be kept anaerobic. Following the application of the leachate, effluent sample collection is initiated. The effluent sample size depends upon the number of analyses to be performed and the volume required for each analysis. Maintaining the effluent solution anaerobicly may be necessary if the chemical form (oxidized or reduced) of a given constituent is one of the experimental variables to be measured. Constituents that do not interact with the solid matrix (for example, chloride) should reach approximately one-half their inflow concentration in the effluent following the application of one leachate pore volume. Constituents which interact with the soil matrix (ion exchange) will be retarded in their movement through the column. The extent of the retardation depends upon the ease with which a constituent exchanges with the other materials existing on the exchange complex. This is illustrated in Figure 15.

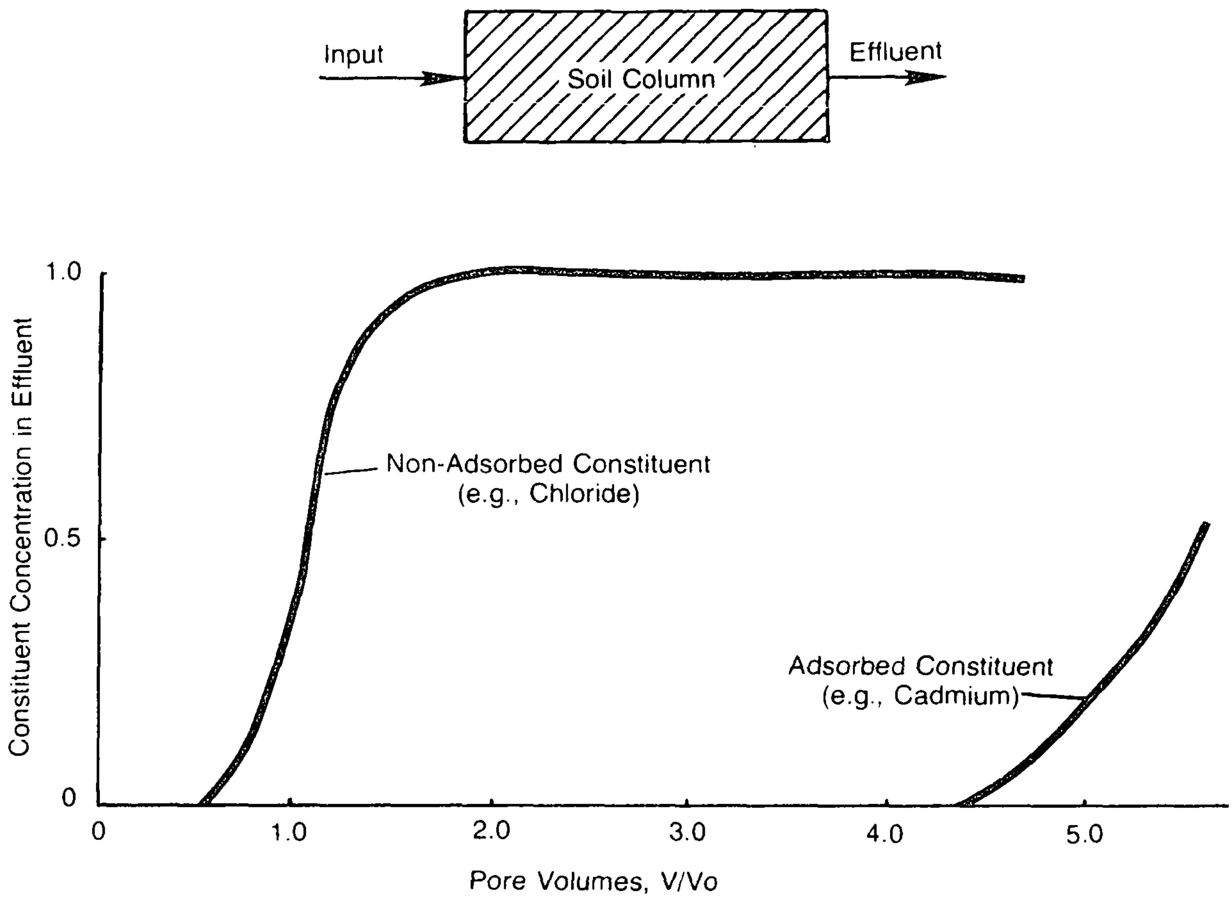


FIGURE 15 SOIL-LEACHATE COLUMN ANALYSIS

Simulation of constituent concentration in the effluent leaving a soil column versus the number of pore volumes of water that have passed through the column. Pore volume is total volume of effluent passed through the column (V) divided by volume of water held by the soil column (V_o). Input concentration of each constituent is 1.0

The number of pore volumes required for a specific constituent to reach a given concentration in the effluent has been used to develop "attenuation numbers". These attenuation numbers generally are more directly related to constituent mobility (ion exchange) than attenuation as defined in this report. The number of pore volumes required for a constituent to appear in the effluent may be used to define ion exchange or adsorption-desorption parameters for a constituent and soil or clay system.

The distribution of specific constituents within a column of soil or clay at the end of an experiment can be measured by sectioning the column and analyzing each increment for the constituent(s) in question. This procedure provides insight into the presence of chemical and physical processes other than ion exchange. For example, if the concentration of a given constituent in a soil increment near the input is higher than the constituent concentration in the leachate (following correction for adsorbed fraction), the constituent may have precipitated. Concentration distributions are useful in identifying chemical and physical processes occurring within the saturated or unsaturated soil or clay system.

Modifications of the previously-described column studies have been used to simulate various natural field conditions. For example, the leachate is frequently applied directly to the dry soil or clay system without the pretreatment. Also, a series of columns have been used with the effluent from one column being the input to the next column. These modifications and others are used in order to more closely simulate natural field conditions. However, the results are interpreted in a similar manner.

Soil-column experiments are useful, but are frequently improperly interpreted. If a leachate constituent appears in the effluent, attenuation as described in this report may or may not have occurred to a significant degree. Also, if after a predesignated number of pore volumes have passed through the column and the constituent is not in the effluent, this does not mean that the constituent was attenuated. For example, if the constituent's mobility is reduced to a very low value, it will require a long time for it to reach the effluent end of the column, but it will appear eventually in the effluent. These and other misinterpretations are commonly made using column studies.

Column studies are also useful in determining hydraulic properties and dispersion coefficients of specific soil or clay materials. Because the dispersion coefficient is a function of fluid flow rate and degree of water saturation, several displacements of a constituent through the porous material may be necessary.

Batch or Shaker Tests. Interest in the adsorption-desorption characteristics of specific constituents in various waste leachates and soils and soil combinations has increased significantly in the past decade. This interest is a result of the fact that adsorption-desorption parameters can be used to predict the mobility of waste constituents in field soils and the efficiency and/or environmental safety of given wastes applied to or buried in the soil.

Several types of experiments can be used for measuring adsorption characteristics, but the most widely used is the "batch" or "shaker" method. This procedure consists of combining a known volume of waste leachate of a predetermined composition with a given mass of air dry soil. The mixture is shaken until equilibrium is attained. If the constituents of interest are adsorbed, their concentration in the solution phase of the mixture will decrease. The equilibrated solution is generally separated from the solid phase by centrifugation or filtering. The resulting relative distribution of the constituents between the adsorbed and soil-water phases depends on factors such as: soil properties, temperature, and salt concentration of the original leachate and soil. The batch method has been specified in the Protocol for Adsorption Tests, recently published by the United States Environmental Protection Agency in its guidelines for registering pesticides in the United States Federal Register, 1975, 40 (123): 26881-26895.

Adsorption equilibria data are generally described by the empirical Freundlich equation:

$$S = KC^N$$

$$\log x/m = \log K + N \log C$$

where S is the amount (x) of adsorbed constituent per unit amount of soil (m); C is the equilibrium solution concentration of the constituent; and K and N are empirical constants. The adsorption coefficient, K, can be obtained by plotting log x/m ($[C - C_o]/m$) where C_o is the original concentration of the constituent in the leachate) versus log C, yielding a linear curve of slope N. The units of x/m and C are often in μg/g and μg/ml, respectively. When C is 1.0 μg/ml, the corresponding value of log x/m is equal to log K. Deviations of the value of N from unity, a common observation, reflects the nonlinearity of the adsorption process. If N were unity, the K would be identical with the partition coefficient.

Adsorption isotherms which follow the Freundlich relationship given by Equation 8 may be obtained using the above procedure and various original solution concentrations, C_o. The adsorbed constituent concentration S, is plotted versus the equilibrium solution concentration of the constituent, C, for each Co. The results of such an experiment are illustrated in Figure 16 for two constituents. The absorption isotherm described by S = 10 C represents a constituent which is less mobile in the soil than that described by S = 1.0 C. Both constituents are adsorbed and would be retarded in their movement through a column of the type used in the adsorption experiments.

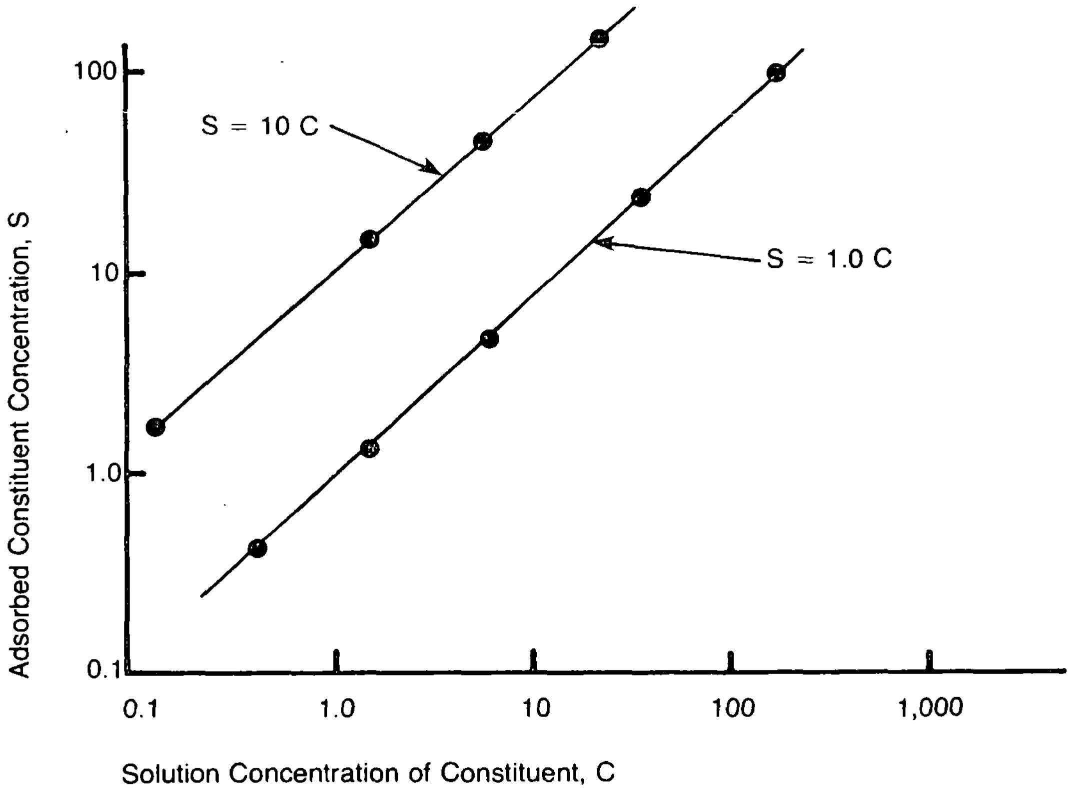


FIGURE 16 SIMULATED ADSORPTION ISOTHERMS
Described by the Freundlich Relationship in Equation 8; Isotherms are Linear (N = 1.0).

The batch adsorption experiments are useful in evaluating constituent mobility, but may be misleading if appreciable complexing of the constituents occurs during the contact period over which the batch experiment is conducted. The complexing of the constituent would result in a reduction in the equilibrium solution concentration over and above that associated with adsorption. These results would suggest that the constituent was adsorbed to the soil in larger amounts than was actually the case. Using this type of information, one would conclude that the constituent was less mobile than the data obtained from a column experiment. The complexing of the constituent would represent attenuation as described and used in that report.

The batch adsorption experiments, if properly conducted, can be used to provide necessary parameters for mathematical models. This is a procedure that has found wide acceptance as a good indication of constituent mobility. However, the procedure has not been adequately tested with complex leachate wastes where various processes may occur simultaneously.

Batch or shaker test procedures have been developed by many of the regulatory agencies contacted. Where utilized, they are described in Appendix C.

Thin Layer Chromatography - Until recently, methods for investigating the mobility of various waste constituents in soils were based upon field- or soil-column studies. These studies were time consuming and costly to conduct. The soil thin-layer chromatography procedure (soil TLC) is an alternate technique. The method is analogous to the conventional TLC, with soil substituted for the paper or solid adsorbent phase. The procedure appears to correlate well with mobility "trends" observed in laboratory-column studies and batch adsorption experiments.

The procedure consists of dry-sieving coarse-textured soils to less than 500μ, and medium- or fine-textured soils to less than 250μ. Frequently it is necessary to put the soil through a crusher-siever to obtain this size range. Clean glass plates 20 by 20, 10 by 20, or 5 by 20 cm are used to hold the soil layer. The soil is slurried with water until moderately fluid, then promptly applied to the glass plate using a variable-thickness TLC spreader. Thicknesses of 500μ for medium- and fine-textured soils, and 750μ for coarser soils are generally used. Plates may be stored air-dry indefinitely.

A horizontal line is scribed across the soil 11.5 cm above the base to stop water movement during chromatography development. A radioactive isotope of the constituent of interest is added to the leachate from the disposal site for use as a tracer. The leachate is then spotted at 1.5 cm from the base; thus, the constituent can potentially move 10 cm. After spotting, the plate is immersed in 0.5 cm of water and removed when the water front reaches the scribed line made on the plate. The plates during development are kept in a closed chamber to prevent evaporation during the vertical upward movement of water.

After the soil has wet to 10 cm, the plate is air dried and an X-ray film is placed in direct contact with the soil plate. The resultant autograph indicates the distance a constituent has moved which is measured as the frontal or retardation factor, R_f. The R_f value is the distance the center of the constituent spot moved up the plate divided by the distance the water front moved (10 cm). This is illustrated in Figure 17.

The Illinois Geological Survey Laboratory is currently using the soil thin layer chromatography procedure to identify the extent of adsorption and its impact upon a given constituent's mobility in the soil. This research group is also using multiple-regression equations

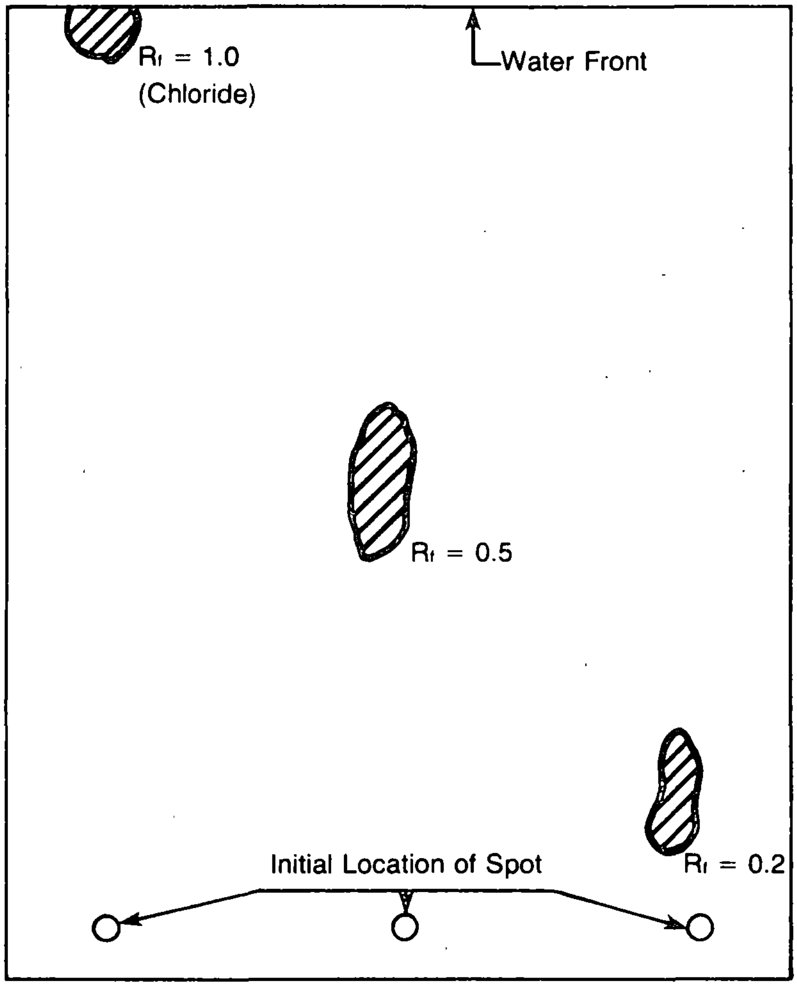


FIGURE 17 THIN-LAYER CHROMATOGRAPHY

The shaded areas represent three different constituent locations after the water front has migrated to the 10-cm height above the initial location of each spot. The shaded area with an R_f equal to one represents a non-adsorbed constituent such as chloride with the least mobile constituent in the illustration having a R_f of 0.2.

to determine the relative importance of various soil parameters to the R_f values obtained from a number of soils and given waste constituents. These equations would then allow mobility predictions to be made for a given waste constituent (assuming similar leachate composition) using a few basic soil (physical and chemical) parameters.

The soil TLC procedure does not measure attenuation or the potential for a given constituent to attenuate after being placed in a soil. This procedure measures only the mobility of a constituent in comparison to water which does not interact with the solid matrix. The retardation factor, R_f, measured by TLC is inversely ($^1/R_f$) proportional to the adsorption coefficient, K, measured in the batch or slurry tests for adsorption.

Dilution Model. D.B. Oaks, of the Water Research Center, Medmenham Laboratory, published a paper in January 1976 entitled Dilution of Tip Percolates in Groundwater. This paper describes a mathematical "model" approach to define and evaluate the effects of leachate attenuation strictly by: dilution in groundwater, dilution in down-gradient well discharge, and travel times for leachate migration both to down-gradient wells and streams.

Consider a tip of dimension L meters in the direction of groundwater flow, and W meters transverse to this direction. If the infiltration rate from the tip to the water table is I m/a (meters/annum) and the concentration of some pollutant in the tip leachate is C mg/l, then the volume of leachate reaching the water table each year is IWL m_3, and the mass of pollutant carried with the leachate is IWLC gm/a (gram-meter/annum). If the groundwater flow rate is U m/a and the depth of mixing of percolate and groundwater is B m., then the effective volume of groundwater with which the leachate mixes is UWB m^3/a and the concentration of pollutant in the groundwater is given by:

$$c(gw) = \frac{IWC}{IWL + UWB} = \frac{IC}{I + UB/L}$$

Hence the dilution factor, defined here as the ratio of concentration in groundwater beneath the tip to concentration in the leachate, is given by

$$d = \frac{I}{I + UB/L}$$

Typical values of UB are given in Table 36 for chalk, sandstone, and gravel aquifers.

TABLE 36

AQUIFER PROPERTIES

Aquifer	UB (m^2/d)
Chalk	3 to 10
Sandstone	0.5 to 2
Gravel	10 to 20

Two sizes of tip were considered, with lengths of 50 m and 300 m, respectively. A recharge rate, I, equal to 0.3 m/a (meter/year), was used in all calculations. The calculated dilution factors are given in Table 37.

TABLE 37

DILUTION FACTORS

	Tip length L (m)	
Aquifer	50	300
Chalk	$0.4\ 10^{-2} - 0.1\ 10^{-1}$	$0.2\ 10^{-1} - 0.7\ 10^{-1}$
Sandstone	$0.2\ 10^{-1} - 0.7\ 10^{-1}$	$0.1 - 0.3$
Gravel	$0.2\ 10^{-2} - 0.4\ 10^{-2}$	$0.1\ 10^{-1} - 0.2\ 10^{-1}$

Of practical interest is the concentration of pollutant in water discharged from a pumping well in the vicinity of a landfill site. If a well is located directly down gradient from a tip, it is likely that all of the percolate will be induced to flow to the well. The dilution factor, defined now as the ratio of concentration of pollutant in the well discharge to concentration in the tip percolate, has been estimated for each size of tip and is shown in Table 38. The dilution factors in this case are independent of the aquifer type, but are dependent on the abstraction rate.

TABLE 38

DILUTIONS IN WELL DISCHARGE

Well Discharge Rate (mgd)	Tip Dimensions (m)	
	50 x 50	300 x 300
0.5	$0.9\ 10^{-3}$	$0.3\ 10^{-1}$
1	$0.5\ 10^{-3}$	$0.2\ 10^{-1}$
2	$0.2\ 10^{-3}$	$0.8\ 10^{-2}$
5	$0.9\ 10^{-4}$	$0.3\ 10^{-2}$

On-Going Research. Several researchers, research institutions, federal agencies, and universities have developed, and are currently in the process of developing, mathematical models for the prediction of contaminant migration in subsurface environments. The following modeling activities are the most pertinent to this study:

USGS Modeling Activities. The U.S. Geological Survey is probably the single-most active agency modeling quantitative and qualitative aspects of groundwater. Their degree of sophistication, level of effort, and expertise in modeling parallels or exceeds the capabilities of most agencies and research institutes working in this field. From its multimillion dollar modeling program, the U.S.G.S. has developed, or is developing, the following: (1) two-dimensional models for coupled flow of water and transport of conservative and non-conservative trace constituents in saturated media. (2) two-dimensional models for transport of conservative and non-conservative constituents in unsaturated media.

Table 39 gives a listing of the status of groundwater quality and quantity modeling within the U.S.G.S. Currently several of the two- and three-dimensional models for describing the transport of conservative species in saturated media have been field tested and verified. U.S.G.S. personnel recognize that the mathematical development and numerical solution procedures far exceed their ability to quantify the major leachate and hydrogeologic parameters required for conducting simulations. The effective use of simulation models is apparently greatly impaired by a lack of data and procedures to quantify the various system parameters and input data, and future research should address itself to these shortcomings.

TABLE 39

STATUS OF GROUNDWATER MODELING, U.S. GEOLOGICAL SURVEY

	Phase of activity: Devel-op-men-tal	Veri-fica-tion	Op-era-tion-al	Con-tinued im-prove-ment	Principal U.S. Geological Survey investigators	Recently published selected references
FLOW						
Saturated						
Two-dimensional						
Analytical	--	--	×	×	S. S. Papadopulos, R. L. Cooley.	Cooper (1966), Papadopulos (1967), Papadopulos (1966), Cooper and others (1965).
R-C Analog Networks	--	--	×	×	S. M. Longwill	Skibitzke (1960), Patten (1965), Stallman (1963b).
Numerical—Finite difference	--	--	×	×	P. C. Trescott	Trescott (1973), Pinder (1969), Maddock (1970).
Finite element—Galerkin	--	--	×	×	G. F. Pinder[1], R. L. Cooley	Pinder and Frind (1972), Frind and Pinder (1973).
Finite element—Variational	--	--	×	--	R. T. Hurr	Hurr (1972).
Three-dimensional						
R-C Analog Networks	--	--	×	×	S. M. Longwill	Skibitzke (1960), Stallman (1963a), Patten (1965).
Numerical (Finite difference)	--	--	×	×	P. C. Trescott	Trescott (1975), Bredehoeft and Pinder (1970).
Partly (or entirely) unsaturated						
One-dimensional						
Analytical[2]	--	--	×	--	C. D. Ripple, J. Rubin, T. E. A. Van Hylckama.	Ripple, Rubin, and Van Hylckama (1972), Stallman and Reed (1966).
Numerical—Finite difference	--	--	×	×	J. Rubin and C. D. Ripple	Rubin (1967, 1968a).
Finite element—Galerkin	--	×	--	--	do	
Two-dimensional						
Numerical—Finite difference	--	--	×	×	do	Rubin (1968b).
Cylindrical Region						
Numerical—Finite element—Galerkin	--	×	--	--	do	Doherty (1972).
LAND SUBSIDENCE—Induced by ground water extraction						
Analytical	--	--	×	--	F. S. Riley	Riley (1969).
R-C Analog and Analytical	--	--	×	--	D. G. Jorgensen	Jorgensen (1975).
Numerical and Analytical	--	--	×	×	D. C. Helm	Helm (1974, 1975).
COUPLED GROUND WATER—*stream systems*						
Numerical—Finite difference	--	×	--	--	G. F. Pinder[1] and S. P. Sauer	Pinder and Sauer (1971).
Numerical and Analytical	--	--	×	--	A. F. Moench, V. B. Sauer, M. E. Jennings.	Moench, Sauer, and Jennings (1974); Lockey and Livingston (1975).
COUPLED GROUND WATER—RAINFALL-RUNOFF MODELS—Numerical	--	×	--	--	J. E. Reed and M. S. Bedinger and John Terry.	
COUPLED GROUND WATER—ECONOMIC SYSTEMS—Numerical	--	--	×	×	T. Maddock, III and J. D. Bredehoeft.	Bredehoeft and Young (1970), Young and Bredehoeft (1972), Maddock (1972, 1973, 1975).
COUPLED FLOW AND TRANSPORT OF CHEMICAL CONSTITUENTS						
Saturated system						
Conservative (or nonconservative trace constituents)						
Uniform density, inorganic						
Two-dimensional						
Analytical	--	--	×	--	A. Ogata	Ogata (1976, 1970), Grove (1970).
Numerical—Characteristics	--	--	×	×	L. F. Konikow and J. D. Bredehoeft.	Konikow and Bredehoeft (1973), Robertson (1974), Bredehoeft and Pinder (1973).
Finite difference	--	×	--	--	D. B. Grove	
Finite element—Galerkin	--	--	×	×	D. B. Grove, J. Rubin, G. F. Pinder.	Pinder (1973).
Finite difference and finite element—Galerkin	--	×	--	--	D. B. Grove	
Variable Density						
Two-dimensional						
Analytical[2]	--	×	--	--	A. Ogata	Henry (1964).
Analog and Analytical[2]	--	--	×	--	G. D. Bennett	Bennett and others (1968).
Numerical—Characteristics	--	--	×	--	G. F. Pinder[1]	Pinder and Cooper (1970).
Finite difference[2]	--	×	--	--		Henry (1964).
Finite element—Galerkin	--	×	--	--	do	Segol, Pinder, and Gray (1975).
Three dimensional						
Numerical—Finite element—Galerkin	--	×	--	--	do	
Nonconservative, major constituents						
Uniform density						
Inorganic constituents (one-dimensional)—Numerical	--	×	--	--	D. B. Grove, W. W. Wood, J. Rubin, and R. V. James.	Rubin and James (1973).
Organic constituents (two-dimensional)—Numerical	×	--	--	--	J. B. Robertson and D. F. Goerlitz.	
Unsaturated						
Nonconservative, Major constituents						
Uniform density, inorganic constituents—Numerical	×	--	--	--	J. Rubin and R. V. James	
COUPLED FLOW AND TRANSPORT OF HEAT						
Single phase (hot water)						
Two dimensional						
Numerical—Finite difference	--	×	--	--	C. R. Faust and J. W. Mercer	Faust and Mercer (1976).
Integrated Finite difference	--	×	--	--	M. L. Sorey	Sorey (1975).
Finite element—Galerkin	--	×	--	--	J. W. Mercer and G. F. Pinder[1].	Mercer, Pinder and Donaldson (1975); Mercer and Pinder (1975).
Three dimensional						
Numerical—Finite element—Galerkin	×	--	--	--	G. F. Pinder[1]	
Two Phase (steam-water)						
Two-dimensional						
Numerical—Finite difference	--	×	--	--	C. R. Faust and J. W. Mercer	Faust and Mercer (1976).
Finite element—Galerkin	--	×	--	--	J. W. Mercer and C. R. Faust	Mercer and Faust (1975), Faust and Mercer (1975).
Three-dimensional						
Numerical—Finite element—Galerkin	×	--	--	--	G. F. Pinder[1]	
COUPLED FLOW AND TRANSPORT OF CONSERVATIVE (OR NONCONSERVATIVE TRACE) CONSTITUENTS AND HEAT (SINGLE PHASE)						
Two-dimensional						
Numerical—Finite difference[2,3]	--	×	--	--		Henry and Hilleke (1972).
Three-dimensional						
Numerical—Finite difference[3]	--	×	--	--	D. B. Grove, S. P. Larson	Intercomp (1976).

[1] Part-time investigator with USGS.
[2] Model limited to steady-state conditions.
[3] Model prepared for USGS under contract.

Pacific Northwest Laboratories. Pacific Northwest Laboratories (Richland, Washington), operated by Batelle for the U.S. Energy Research and Development Administration, has been involved for several years with modeling both water quality and water quantity. This work is needed for nuclear waste management at the Hanford Atomic Energy complex at Hanford, Washington. This complex has served as a depository for wastes from spent fuel in nuclear reactors. The major emphasis of this modeling effort is related to the movement of radio-nuclides in partially-saturated soils. Their work has resulted in many research publications on partially-saturated flow, radionuclide transport, and characterization of the hydraulic properties of the unsaturated zone (Reisenauer, 1973; Reisenauer, et al, 1975; Ahlstrom and Baca, 1974; among others).

Oak Ridge National Laboratory (ORNL). The ORNL has been extensively involved in modeling transport processes in saturated- and partly-saturated zones. Part of their research effort is concerned with the behavior of intermediate-level radioactive liquid wastes. This waste was deposited at the ORNL between 1951 and 1965 and contains a variety of fission products. The major radioactivity is associated with ^{137}Cs and ^{106}Ru, although lesser amounts of ^{90}Sr and other waste products are present in the waste. Because of the long half-life of ^{90}Sr (28 years), the transport of this constituent through the soil should be followed (simulated) for a period of at least 100 years. Current research at this laboratory is concerned with the use of average steady-state rainfall data instead of transient values in the models: this speeds up the calculations for the unsaturated zone, making partially-saturated transport models more practical and economical to use. Modeling efforts have resulted in many research reports (Reeves and Duguid, 1975; Duguid and Reeves, 1976; Larson and Reeves, 1976; Endelman, et al, 1974).

University Modeling Activities. Several universities are currently actively involved with the modeling of groundwater contamination or closely-related problems. A list of some of the most active groups is given below (see also Appendix B).

The Department of Civil Engineering at Colorado State University has long been actively involved with the modeling of water quality and quantity problems. Much of this research is published in the series Hydrology Papers, issued by this university. Recent work includes research by Helweg and Labadie (1976) and and Kraeger and Rovey (1975). Drs. D. Mc Whorter and D.K. Sunada have recently developed a saturated-only model for application to land areas distrubed by mining activities. This model, based on Boussinesq's equation, is applicable to both confined and unconfined aquifers. No dispersion is considered in the model.

Dr. A. Klute and co-workers at the same university have been involved with the formulation of transport processes in the unsaturated zone. Recent work is published by Cameron and Klute (1977) and by Gilham, et al., (1976).

Dr. D.A. Sangry and others (K. Wheeler) of Cornell University are presently developing a two-dimensional finite element model for simulation of contaminant migration in soils. The model, however, is not expected to be ready for another three years.

Dr. A.A. Metry and co-workers at Drexel University have developed and applied several two-dimensional transport models to contaminant migration from an experimental landfill in Kennett Square, Pennsylvania. Results of this work is documented in several publications by Metry (1972, 1976).

J. Jessi and P. Goble at Ecole des Mines, Fontainebleu, France have developed a finite element transport model for application to radionuclide transport in a single-layered confined aquifer. A. Dreyfus and co-workers (M. Besbes, P. Armisen, J.P. Delhomme) at the same school have developed an integrated finite difference model for the simulation of solute transport in a multi-layered aquifer. The model has been applied to several field problems (P. Goblet, E. Ledoux, Centre d'informatique Geologique, Ecole des Mines, 35 Rue Saint-Honore, 77305--Fontainebleau, France).

Dr. J.J. Fried and co-workers (M.A. Combarnous, P.O. Ungemach) at Institut de Mecanique des Fluides de Strasbourg, France are actively involved with the modeling of salt transport in single- and multi-layered aquifer systems. J. Lessi at this Institute recently completed a thesis on the numerical simulation of pollutant transport in a saturated porous medium. Other research work has been reported in many publications, references of which can be found in a recently published book by Fried (1975). (Institut de Mecanique des Fluides de Strasbourg, Universite Louis Pasteur, Strasbourg, France).

G. Vachuad and co-workers (M. Vauclin, J.L. Thony, J.P. Gaudet, R. Haverkamp, and D. Khanji) at Institut de Mecanique, Grenoble, France are actively involved with the description of fluid flow and mass transport in saturated-unsaturated soils. Recent work concerns the existence of mobile/immobile water fractions in unsaturated soils, and attempts are being made to include this concept in existing one- and two-dimensional flow models (Vachuad, et al, 1976; Gaudet, et al., 1977; Khanji, et al., 1974; Haverkamp, et al., 1977). (Institute de Mecanique, Universite Scientifique et Medicale de Grenoble, B.P. 53, 38040--Grenoble-Cedex, France).

Dr. P.J. Wierenga and co-workers (F. De Smedt, M.Th. van Genuchten, J.H. Dane and B. Sisson) at New Mexico State University have developed several models for describing transport processes in the unsaturated zone. These models have been applied for heat transfer (Westcot and Wierenga, 1974), fluid flow (Dane and Wierenga, 1975), and the movement of adsorbing chemicals (Wierenga et al., 1975; O'Connor et al., 1976; van Genuchten and Wierenga, 1976, 1977). A one-dimensional, transient, finite difference model was recently developed for the simulation of pesticide movement in layered soils.

Dr. G.F. Pinder and co-workers (M.Th. van Genuchten, A.M. Shapiro) at Princeton University have developed several one- and two-dimensional finite element models for contaminant transport in unsaturated and saturated/unsaturated soils. A two-dimensional cross-sectional model (van Genuchten et al., 1977) is currently being tested using an existing landfill site in Pennsylvania. A similar model is under development for multi-ion transport from land disposal sites.

Dr. R.W. Cleary and co-workers (A.B. Gureghian and S. Ward), also at Princeton University have developed a one-dimensional multi-ion finite difference transport model for application to a wastewater recharge area on Long Island (Gureghian et al., 1977), and a three-dimensional finite element saturated-only transport model for application to an existing landfill, also on Long Island (Gureghian, 1977). Application of these models is currently being tested in the field.

Dr. S.K. Gupta and others at the University of California, Davis have recently developed a three-dimensional finite element, saturated-only transport model (Gupta, et al., 1975). Its application to actual field problems is currently being tested. Drs. D.R. Nielsen and J.W. Biggar and co-workers at the same university are actively involved with field testing several one-dimensional transport models. Major emphasis of current research is directed to the spatial variability of field soils, including proper formulation of the soil-hydraulic parameters in the unsaturated zone. Recent research is documented in several publications (Warrick, et al., 1977; Biggar and Nielsen, 1976; Van de Pol, 1977; Nielsen, et al., 1973).

Dr. J.M. Davidson and Co-workers (H.M. Selim, R.S. Mansell, P.S.C. Rao) at the University of Florida have developed and applied several one-dimensional transport models to the movement of adsorbed chemicals in soils. These models include a one-dimensional, transient, unsaturated finite-difference model for 2,4-D movement in soils (Selim, et al., 1976), and several steady-state models for study of the adsorption mechanisms of pesticides and phosphorus into soil (Davidson, et al., 1972; Davidson and McDougal, 1973; Rao, et al., 1976; Selim, et al., 1976).

Drs. R.R. van der Ploeg and W. Ehlers at the University of Gottingen, Germany have developed several one- and two-dimensional soil-water flow models for application to field infiltration and redistribution. Current research is concerned with the transport of solutes in the unsaturated zone in combination with the unsaturated flow programs (van der Ploeg and Bennecke, 1974; van der Ploeg, 1974; Ehlers and van der Ploeg, 1976). (Institut fur Bodenkunde und Waldernahrung, Georg-August Universitat, Gottingen, Germany).

Dr. Logan and co-workers at the University of New Mexico have developed several transport models for simulating the behavior of radionuclides in soil. Their work includes a fault-free model for determination of the release of radionclides and their impact on the environment. Part of this investigation is a groundwater multi-ion transport model for radionuclides in soils.

Dr. E. Elzy and others at the University of Oregon have developed a simple, vertical-horizontal routing model for simulation of hazardous contaminants from landfills (Elzy, et al., 1974). This model is currently being updated (October, 1976). The model was used by the Oregon Department of Environmental Quality to evaluate the impact of pesticides on groundwater quality. Another model has recently been developed (Ungs, et al., 1976) for the simulation of one-dimensional transport of adsorbing chemical in unsaturated soils. Research at this university has been directed towards the formulation and analytical solution of one-dimensional, saturated-only transport models for the movement of adsorbing chemicals in soils (Lindstorm and Boersma, 1971, 1973; Lindstorm and Stone, 1974).

Dr. G.J. Farquhar and co-workers at the University of Waterloo are presently constructing a three-dimensional finite-element model for predicting leachate concentrations at given points downgradient from a landfill. Several other researchers at this university have developed or are presently developing and testing two- and three-dimensional transport models. They include: a three-dimensional saturated/unsaturated transport model (Segol, 1975); a two-dimensional cross-sectional, saturated/unsaturated model (Sykes, 1975); and a two-dimensional saturated-only model (Pickens and Lennox, 1976).

Dr. R.J. Hanks and co-workers (L.G. King, S.W. Childs, D. Melamed) at Utah State University have developed several one-dimensional transport models for application to irrigation return flow studies (King and Hanks, 1973, 1975; Childs and Hanks, 1975). Recent work is concerned with the presence of sources and sinks in the root zone due to solute precipitation and dissolution processes (Melamed, et al., 1977).

Drs. J. Bear, D. Zoslovasky, S. Irmoy, and co-workers at Technion - Israel Institute of Technology have developed and solved various water- and solute-transport models for evaluating problems associated with irrigation and groundwater quality. Many of these models were developed to study processes and, thus, were not applied to large land areas or aquifer systems. Considerable expertise exists in this laboratory, and many of the projects currently underway should be of value to other scientists working in this area.

Several other organizations, notably consulting firms, have developed or are presently developing groundwater transport models. A three-dimensional FD/MOC model has been developed by INTERA/INTERCOMP Resource Development and Engineering, Inc. for simulation of contaminant transport in heterogeneous aquifers. The model considers adsorption processes and has been applied to groundwater contamination from surface mining, and to tritium transport at the Hanford Reservation, Washington (INTERA Environmental Engineers, Inc., INTERCOMP Resource Development and Engineering, Inc., 1201 Dairy Ashford, Suite 200, Houston, Texas 77079).

Assessment

While present assessments of the state of the art in groundwater contamination modeling demonstrate that mathematical models can be used successfully for evaluating potential pollution problems from waste disposal sites, it is not clear whether or not they possess the inherent capability to serve as tools for site selection or approval procedures. If a mathematical model were to be used as a decision procedure, it should have at least the following characteristics:

1. The model should be rational, mathematically sound, and accurately represent the complete system.

2. The model should include all significant physical, chemical, and biological mechanisms that would influence the migration of contaminants from the waste disposal site through the unsaturated zone into the groundwater system.

3. The model should be sufficiently simple so that it would be accessible to individuals other than the modeler himself (i.e., to engineers and other experts).

4. The model should also be economic. Costs associated with execution of the model and for maintaining a technical staff for quantification of the model parameters should be kept to a "reasonable" minimum.

Assuming for the moment that a model, either currently available or under development, can be found which satisfies all of the above requirements, its use as a decision procedure has numerous advantages. The following discussion gives a brief description of the advantages and benefits associated with the use of simulation models as a decision procedure. (See also Grimsrud et al., 1976 for an excellent discussion of the main advantages and limitations of the use of mathematical models for water-quality simulations.)

Advantages. The following advantages can be stated for the use of development and simulation models.

Quantitative Predictions. The simulation of a proposed waste disposal system in a given hydrogeologic setting can result in the quantitative prediction of the contamination potential to a receiving groundwater system. This feature alone gives a computer simulation model a unique advantage over other procedures. Types and levels of contaminants at various points and at different time intervals can easily be quantified. In addition, the shape of a contamination plume, if present, can be described by such a model.

Predictions Before the Fact. Simulation of possible leachate migration from a proposed waste disposal site into the groundwater system would give decision makers an advance picture as to the potential for groundwater pollution before a site is formally accepted for waste disposal. Such information can be used to modify the design, to alter management procedures, or to reject the site as an acceptable site for waste disposal.

Identification of Soil/Waste Parameters. If a computer simulation model is used to simulate the behavior of a proposed site, it may be possible to determine the key parameters that control the pollution potential of that site, and hence lead to suggestions for proper modification of these key parameters. For instance, if the lack of reactive earth materials (e.g., clays) is the key factor for migration of certain toxic elements, another site could be selected or clays could be imported to the original site.

Multiple Site/Waste Analysis. Simulations can be a useful tool in matching different types of wastes and disposal sites. Models could optimize the waste/site interactions in a manner that would minimize the pollution potential from each site.

Versatile Tool. A simulation model is a versatile tool; useful applications include: (1) ranking of several candidate sites with respect to their pollution potential; (2) optimization of monitoring locations for early detection of contaminants; (3) design and location of contaminant retrieval systems (e.g., wells) for optimum recovery of contaminants from current sites when it is clear that unacceptable pollution is present; and (4) potential use as a tool to determine effective management practices of waste disposal sites (e.g., waste segregation, lining, impervious covers, etc.).

Research Tool. An advantage of simulation models, not directly associated with its use as a decision procedure, but of equal importance, results when the model is used to study the performance of established waste disposal sites. Because many of the interactive soil-physical and chemical processes operating on the waste are not sufficiently understood, simulation of existing disposal sites with given waste/soil combinations may lead to a greater understanding of how these complex interactive processes behave. This in turn may lead to the formulation of new theories, for example, regarding the existence of certain adsorption mechansims, or certain chemical chain or precipitation reactions. Thus, the models are a valuable research tool for studying certain components in the system.

Disadvantages. The following is a brief discussion of the main disadvantages and limitations associated with simulation models as a decision procedure.

Lack of Testing and Verification. Probably the most serious limitation for the immediate application of simulation models to site selection and approval procedures is the general lack of testing, calibration, and field verification of available models. This shortcoming is significant in that it can be expected that decisions based on predictions by untested, uncalibrated and/or unverified models will be challenged in the courts and, hence, may create an unnecessary burden on regulatory agencies.

Input Parameters. A successful simulation is dependent upon the availability and accuracy of the different system parameters and input variables. This is another significant limitation for direct application of models as a decision procedure. Some of the difficulties in quantifying such parameters are:

1. Lack of understanding of certain soil/waste interactions. Although much has been learned in recent years about the physical and chemical interactions between soils and certain chemicals, much remains to be done to quantify these relations into formulas for use in simulation models. This is especially true for those systems containing adsorption and/or exchange reactions, chemical chain reactions, and decay.

2. Lack of standard procedures for quantifying major input variables (for example, adsorption and/or exchange constants, decay constants, and dispersion coefficients).

3. General lack of field data on hydrogeologic parameters and behavior of contaminants (especially non-conservative ones) in subsurface environments. There is uncertainty about precision and accuracy of major hydrologic and geochemical parameters.

4. Difficulty and cost of conducting laboratory and field experiments for quantification of input data.

<u>Complexity of Models</u>. Computer simulation models are generally not easily understood by the "average" technical staff that would be associated with site selection or approval. The use of simulation models requires a degree of expertise for analyzing the system, quantifying the model input parameters, executing the model, and interpreting its results. While simplification of such models would overcome some of these limitations, it would also impair the accuracy of the model and its capability to describe the true processes in the system. Furthermore, using models without an understanding of their logic, capabilities, and limitations may result in misrepresentations of the physical system and lead to unrealistic results. Some of the required expertise includes: (1) mathematics (computer science, programming, and systems analysis); (2) engineering; (3) earth sciences (soil physics, soil chemistry, and hydrogeology); and (4) laboratory and field experimentation.

<u>Equipment and Facilities</u>. The use of simulation models requires that sophisticated equipment and certain facilities be available. These include: (1) a computer, and possibly plotters and other data-processing facilities for execution of the model; and (2) laboratory and field equipment for quantification of waste/soil characteristics and major input parameters (adsorption and cation exchange properties, dispersion coefficients, soil hydraulic properties, etc.).

<u>Accuracy and Precision</u>. The accuracy and precision of most existing models are still uncertain. Many factors contribute to this:

1. Unknown accuracy of the main parameters entering the model (as discussed above).

2. Many of the transport phenomena simulated in currently-available models are limited to those which can be expressed in an explicit manner. The successful use of a simulation model requires that the different mechanisms present in the system can be quantified. Because many of the complex soil-physical, chemical, and biological processes are still under discussion, their quantification into reliable mathematical expressions remains doubtful (if not impossible). For example, it is known that extreme variations in quantity and quality of leachate occur in time, probably as an interplay between such variables as rainfall/evaporation, temperature, pH, and age of the waste. Reliable predictions of leachate generation cannot be obtained before these interrelationships have been studied in detail and certain quantitative relationships have been established.

3. Oversimplification of the actual physical processes occurring at the site and/or the receiving aquifer in order to complete the simulation. For example, heterogeneity of the site and the receiving aquifer are generally only included in a very approximate manner (e.g., channeling processes in a sanitary landfill, fractured flow in an aquifer, etc.).

Costs. The above limitations of using simulation models generally result in higher costs. These costs are associated with modeling expertise, sophisticated computers, laboratory and field experimentation, calibration and field verification of the model, and defending the model results. A summary assessment of models is given on Table 40.

TABLE 40

SUMMARY ASSESSMENT OF MODELS

PROS

- Quantitative - predictive tool.
- Identification of soil/waste parameters.
- Assessment of pollution potential.
- Versatility.
- Research tool.

CONS

- Insufficient understanding of some processes.
- Insufficient testing and calibration.
- Lack of field verification.
- Difficulty of laboratory and field quantification of parameters.
- Requires specialized skills and equipment.
- High operating cost.

Availability

In spite of the many limitations described above, the use of computer-simulation models as a decision procedure for landfill siting has an excellent potential because of its predictive approach. The usefulness of a simulation model is a direct consequence of the type of questions being asked since the model should be commensurate with these questions. For example, many currently-available models possess the capability of describing the migration of a contaminant plume or of TDS, chloride, BOD, etc. Provided some additional field verifications are carried out, these models could be available as a decision procedure within approximately three years. (See Table 29.) For the more complex cases, such as the migration of certain toxic trace elements or organic chemicals, additional study appears necessary, but it is estimated that appropriate models for these constituents will be available within a period of approximately 6 to 10 years.

While it is obvious that no clear picture exists as to whether a model will ever simultaneously simulate all physical and chemical processes present in the system, it is also doubtful that such a model should be used. Many situations lend themselves to analysis without needing a complete model. When certain waste/soil combinations can be identified, models can lead to relatively-accurate predictions, even if more than one ion has to be considered in the simulations.

Considerable expertise is available, but it must be integrated into a few relatively accurate, simple conceptual mathematical models. This will require the cooperation of experts in widely different fields, such as soil-physicists, soil-chemists, civil engineers, hydrogeologists, mathematicians, and computer modelers. Considerable progress in simulation technology has been obtained in the last ten years; however, much research is obviously still needed. This research will likely result in new and/or improved models, thereby continuously updating existing capabilities for simulating the behavior of proposed and operative waste disposal systems.

"Model" Decision Procedure. A "Model" Decision Procedure has been prepared by Weston as shown in Table 41. The intent of this "Model" Decision Procedure is to show the basic steps involved, which are: (1) input - specify and aquire the basic data base for waste and site characterization; (2) analysis - compile, assimilate, and evaluate these data to determine probable waste/site interactions and potential impacts; and (3) output - the decision to issue (or reject) a permit and the type of disposal operation that will be required.

This "Model" Decision Procedure is not meant to be adopted as the "standard" decision procedure, but is presented here to indicate the steps in the overall decision making process. It is also intended to show how and where the various identified decision procedures and "subroutines" fit into this overall procedure.

TABLE 41

"MODEL" DECISION PROCEDURE

INPUT - AQUIRE BASIC DATA

		Procedure
I.	Waste Characterization	Criteria Listing Criteria Ranking Matrix
	Type: Industrial SIC Plant name/location Waste stream Municipal Specify waste/ source Other Specify waste/ source	
	Amount: Volume or weight Rate of generation	
	Physical: Solid Liquid Sludge	
	Chemical: pH Toxicity Major constituents (by volume, weight or concentration) Minor constituents (by volume, weight or concentration)	
	Biological: Degradability Organic content	
II.	Site Characterization	Criteria Listing Criteria Ranking Matrix
	Location Topography Climatology Land use Soils Geology Hydrology	

TABLE 41
(continued)

ANALYSIS - ASSIMILATE AND EVALUATE DATA

	Procedure
I. Waste	
Solubility waste/water	Shaker test
Leachability waste/leachate	Standard leachate test
Toxicity index	Texas Water Quality Board Illinois State Geological Survey Other agencies
II. Site	
Water budget	Standard: $P = R + ET + GWR \pm GWS$ (Precipitation = Runoff + Evapotranspiration + ground water runoff (baseflow) ± ground water storage. (Baseflow) ± Ground Water Storage)
Water flux infiltration underflow	Moisture routing models
Permeability (cm/sec)	Field/lab procedures
Depth to water table and/or bedrock	Backhoe pits, borings
III. Interaction/Attenuation	
Soil/waste/leachate, ground water/leachate, ground water/ surface water	Shaker test column test Oakes dilution model Mathematical computer models Soil/waste interaction matrix Criteria Ranking
IV. Impacts	
Ground water, surface water	Background water quality, drinking water standards, stream standards Mathematical/computer models Criteria Ranking

TABLE 41
(continued)

OUTPUT - DECISION TO PERMIT AND TYPE OF OPERATION

	Procedure
I. Permit Disposal (Methodology)	Classification System (C.S.) (California, Texas, Illinois)
Direct land disposal	
Containment	(note: Criteria Listing inherent in C.S.; matrix and models used as "subroutines" in analysis steps above)
Attenuation	
Controlled discharge	
Uncontrolled discharge	
Pretreatment - then above	
II. Reject permit application	

SECTION VI

REGULATORY AGENCY PRACTICES

In order to assess actual waste disposal permit procedures being utilized, selected domestic and foreign regulatory agencies were visited and interviewed. Those agencies contacted were chosen on the basis of their being considered most progressive with respect to the type and comprehensiveness of their waste regulatory programs and extent of application. Emphasis was placed on selecting those regulatory agencies that have specifically addressed the problem of hazardous waste disposal.

Regulatory Agencies Contacted

The following regulatory agencies were contacted during the course of this investigation:

- Domestic:

  1. California State Water Resource Control Board (WRCB), California State Solid Waste Management Board (SWMB), and California Department of Health.

  2. Illinois Environmental Protection Agency (EPA).

  3. Minnesota Pollution Control Agency (PCA).

  4. New York State Department of Environmental Conservation (DEC).

  5. Pennsylvania Department of Environmental Resources (DER).

  6. Texas Department of Health Resources (DHR), and Texas Water Quality Board (WQB).

- <u>Foreign</u>:

7. Canada - Ontario Ministry of the Environment (OME).

8. Netherlands - The Institute for Waste Disposal (SVA).

9. United Kingdom - Department of the Environment (DOE), and The Greater London Council (GLC).

10. West Germany - Office of the State of Bavaria for Environmental Protection, and Institute for Wasser and Abfallwirtschaft.

A contact form for each of these agencies is provided in Appendix C, Regulatory Agency Contacts. Information provided in these forms and attachments to them describe the type of permit procedure utilized and the permit application review and processing procedure. A discussion is also provided covering salient points of that particular procedure, with emphasis placed on the manner in which hazardous wastes are regulated.

Copies of supporting documents for each regulatory agency contacted are provided in Appendix D, Supporting Documents for Permit Application and Processing. These documents include the following categorical items: (1) permit application forms and modules; (2) guidelines for specifications and criteria for waste disposal facility construction; and (3) other pertinent diagrams on a select basis, such as organizational flow charts for the permit review process.

Assessment of Regulatory Practices

A detailed assessment of the waste-permitting procedures for each of the regulatory agencies contacted on an individual basis is extremely difficult. This difficulty results from the fact that the existing procedures for waste disposal siting and, in particular, those for hazardous waste disposal, are either generally being developed or are undergoing further development and modification. For most of the agencies contacted, these changes are considered by them to be significant, both in content and impact, on their waste management program.

A more beneficial assessment of the regulatory procedures is considered to be provided by a discussion and comparative assessment of the various approaches taken, with emphasis on an overview perspective. Such an approach can better identify and assess areas of common approach and areas where different approaches are taken. Some salient points for each of the regulatory programs identified have been summarized, as shown in Table 42, to facilitate this overview assessment. Those points considered that could be most easily identified and specified include the following: the decision procedure utilized; the status of regulations for hazardous waste disposal; whether hazardous wastes are regulated separately, or jointly with municipal wastes; the mode of waste disposal (containment versus attenuation); the permeability required for containment; cost to acquire permits, where estimates are available; time requirements for permit review and processing; and regulatory manpower requirements to process the permits.

The mode of disposal for hazardous wastes for each of the agencies contacted is by containment, with few exceptions. Those few exceptions include the co-disposal of limited amounts of hazardous wastes with municipal refuse on a waste- and site-specific basis. This practice is permitted in Pennsylvania, New York, Canada, and the United Kingdom. Municipal wastes, on the other hand, are permitted for disposal primarily

TABLE 42

SELECTED FACTORS IN THE ASSESSMENT OF REGULATORY AGENCY PERMIT PRACTICES

Regulatory Agency[1]	Permit Procedure	Status of Regulations[2]	Regulatory Authority[3]	Mode of Disposal[4]	Containment Permeability (cm/sec)	Applicant Costs for Permit Aquisition[5]		Time Process Permits - Range and Average (months)	Regulatory Staff Processing Time (hours)	
						Technical	Hearing		Technical	Admin.
Domestic										
California Regional Water Quality Control Board[1]	Classification System	Revised December 1976	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW: $\leq 1 \times 10^{-6}$	$250,000 to	$100,000	8-18; 12	80	12
California State Solid Waste Management Board	Classification System	Revised 1976	Municipal Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW: $\leq 1 \times 10^{-6}$	800,000		8-18; 12	NA[6]	NA
California Department of Health	Classification System	Feb. 1975 Being Revised	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-8}$ MW $\leq 1 \times 10^{-6}$			8-18; 12	NA	NA
Illinois Environmental Protection Agency	Classification System	Revised-Pending Approval mid-1978	Both	Containment	HW: I-$\leq 1 \times 10^{-8}$ II-$\leq 5 \times 10^{-8}$ MW: $\leq 1 \times 10^{-7}$	25,000 to 50,000		1-3; 1½	80	16
Minnesota Pollution Control Agency	Criteria Listing	Being Provided (Draft Reg. June 1977)	Both	Containment	HW: $\leq 1 \times 10^{-7}$	25,000 to 200,000	up to 50,000	6-12; 8	320	80
New York Department of Environmental Conservation	Criteria Listing	Revised August 1977	Both separate sections	Both as specified	HW: $\leq 1 \times 10^{-7}$			3-6; 3	35	5
Pennsylvania Department of Environmental Resources	Criteria Listing	Revised June 1977	Both	Both as specified	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$, if specified	15,000+	up to 60,000	6-18; 12	280	20
Texas Department of Health Resources	Classification System	Revised April 1977	Municipal Wastes	Containment	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$			2½-16; 7	83	17
Texas Water Quality Board[1]	Classification System	Revised-Pending Approval Late 1977	Hazardous Wastes	Containment	HW: $\leq 1 \times 10^{-7}$ MW: $\leq 1 \times 10^{-7}$	50,000 to 200,000	5,000 to 10,000	6-12; 8	240	112
Foreign										
Canada - Ontario Ministry of the Environment	Criteria Listing	SW-Revised Feb. 1976 HW-Being Drafted	Both separate sections	Attenuation	not specified	50,000	20,000	8-36; 24	NA	NA
Netherlands - SVA	Criteria Listing	Being Revised	Both	Attenuation	not specified			NA		
United Kingdom - Greater London Council	Classification System	Revised 1976	Both	Attenuation	not specified	up to $2.63 million total		2-9; 3	NA	NA
West Germany - Office of State of Bavaria for Environmental Protection	Criteria Listing	SW-Revised Sept. 1976 HW-Being Drafted	Both	Containment	HW: not specified MW: $\leq 1 \times 10^{-6}$	20,000 to 90,000		6-24; 12	NA	NA

[1] *Indicates agency responsible for hazardous waste regulation.*
[2] Includes both municipal (MW) and hazardous wastes (HW) unless specified.
[3] Municipal and/or hazardous wastes.
[4] Municipal wastes only, all hazardous wastes require containment unless otherwise specified.
[5] Costs given are gross estimates generally for off-site facilities.
[6] Information not available.

by containment in California, Illinois, Texas, and West Germany. Municipal waste disposal with reliance on attenuation of waste leachates is permitted by the remaining agencies contacted, unless specified differently on an individual case basis.

Decision Procedures Utilized. The decision procedures utilized for waste disposal siting and permitting for each of those regulatory agencies contacted are the Criteria Listing or Classification System. As shown in Table 42, the Classification System is used by California, Illinois, Texas, and the United Kingdom. The Criteria Listing approach is utilized by the other agencies contacted.

A basic approach to the land disposal of wastes in the United Kingdom is outlined in Circular 39/76, published by the Department of the Environment entitled, "A Balancing of Interests between Water Protection and Waste Disposal" (see Appendix D). This circular presents the dilute and disperse approach as the most reasonable for most wastes. Factors that are to be considered in assessing the environmental risks associated with dilute and disperse are:

- The volume of the aquifer considered to be at risk, present and future uses of the water. If the usefulness of a aquifer is not great, then an alternate water supply should be made.

- Hydrogeologic characteristics of the site, including the ability to attenuate leachate.

- Volume and rate of waste to be deposited, including the possible interaction of wastes and the ability of leachate to be attenuated.

This dilute and disperse philosophy entails not only the dispersion of hazardous wastes throughout non-hazardous wastes (municipal) at a given site, but the disposal of a given hazardous waste at several different disposal sites such that the concentration of that waste is within the limits of acceptability. Attitudes of other regulatory agencies, particularly the water resource oriented agencies, and public pressure, however, are such that an increasing amount of wastes are being deposited utilizing the method of containment.

Each agency has stated that the waste/site permitting procedure is based upon: (1) an objective description and quantification of both waste and site characteristics; (2) the combined expertise of the permit review personnel; and (3) by comparison with empirical data generated from existing analagous waste/site disposal situations. In the final analysis therefore, a subjective decision is made based upon utilization of objective data and analysis to the degree that the data will permit. It is universally agreed by both regulatory and non-regulatory experts that this final decision must of necessity be subjective since no alternative procedure presently exists or is anticipated to exist within the near future which could be relied upon for a final objective decision.

This fact results from the realization that there are complex interrelationships between waste and site characteristics which are variable in space and time. Futhermore, these interrelationships are not presently sufficiently understood or expected to be sufficiently understood in the foreseeable future for such an objective decision-making procedure. This is not to say that other procedures do not exist which will prove invaluable in aiding to make the final subjective decision, but rather each waste/site situation can be taken to be somewhate unique and, therefore, judgement value and subjected decision making will always be necessary.

The following additional categories are addressed in the overview assessment of the permit procedures.

Relevancy and Completeness of Data Requirements. Each of the regulatory agencies contacted consider that the data requirements requested in their respective permit application forms and supplemental reports are both relevant and complete for the purposes of making a decision for the permitting of a specific waste disposal site or a specific waste being assigned to an existing site. The detailed Criteria Listing chart shown in Appendix D indicates those site characterization criteria required by some of the regulatory agencies contacted and, further, indicates an apparent wide range in the degree of specific detailed information requested. It should be noted, however, that each regulatory agency contacted does require a hydrogeologic report for adequate site characterization which would include most, if not all, of those individual parameters shown on the Criteria Listing.

An area of potential weakness, however, is that of "adequate or sufficient" site characterization. Some of the regulatory agencies contacted indicate that borings may be required, but in fact are not routinely required. For wastes other than truly inert, insoluble, demolition type waste, it is considered that borings are necessary to verify, at a minimum, the texture and type of soils and geologic deposits present at a given site and to quantitatively and qualitatively determine and assess the underlying groundwater conditions.

Waste characterization is required by each agency contacted. Those waste characteristics requiring definition are type, volume or amount, source, concentration of certain parameters (i.e., anions, cations heavy metals, pH), and the nature of the waste (liquid, solid, sludge). Many agencies now require a leachability test for hazardous materials to determine the degree of solubility of critical constituents. Some agencies will permit the direct disposal of liquid acid waste directly into a landfill, while others will require that waste be in a sludge form, with a minimum percentage solids specified, and that pH neutralization be provided.

Public hearings are required by most of the agencies contacted and, where not required, are becoming more commonplace due to increased public pressure. These hearings do result in additional costs which are often significant to both parties due to the general public attitude that insufficient data have been acquired to properly assess or ensure that adverse environmental impacts will not occur. Such public attitudes exist even when lined disposal sites are proposed with the provision for leachate collection and treatment.

Ease of Data Acquisition and Analysis. The ease of data gathering on the part of the permit applicant is highly variable. Generally, the more uniform the soils and geology of the proposed waste disposal site, the greater the ease in acquisition of the required data for site characterization. Obviously, larger sites with a greater natural variation of physical parameters will require more time and, accordingly, greater cost for data acquisition. Waste characterization is also variable and is dependent upon the type and complexity of the waste itself and whether it is largely a single component or mixed-waste stream. Ease of data acquisition, therefore, is largely a function of variability, i.e., the greater the waste and site variability, the greater the cost.

A side issue, which can become a major issue, is the need for mutual understanding by both the permit applicant and grantor as to what is required to adequately characterize both the waste and the disposal site and the method of disposal to be utilized. Not infrequently, there may be a lack of understanding of the adequacy of characterization on the part of the permit applicant. In addition, there may also be a "changing on the ground rules" by the regulatory agencies to require additional data or a more-sophisticated characterization of the initial data. Meetings between parties at the outset of a proposed waste disposal operation and at critical stages throughout the permit review process will minimize such difficulties. Most if not all agencies encourage this approach, but applicants may be reluctant to pursue this course of action for various reasons.

The aspect of ease of data analysis is also directly associated with the variability of both the waste and the site. More effort is required for analysis for more complex and variable waste/site situations.

The type of personnel and their level of experience and competency in the field of waste management has a significant direct bearing on the ease of data analysis on the part of both parties. A balanced team of sanitary and chemical engineers, hydrogeologists, and soil scientists at a minimum will greatly enhance the ease of data analysis. Inexperience or lack of personnel in the key disciplines mentioned above can and often does lead to extended difficulties in data analysis and timely permit processing.

Consistency of Permit Procedure. Those regulatory agencies contacted have stated that the interpretation and enactment of the permit application procedure is consistent at different sites within their area of jurisdiction. Realistically, however, there is a varying degree of stringency of application among at least some of the agencies contacted. This flexibility relates to such variables as: the need for a disposal site in that particular area; the occasional emergency situation for waste disposal due to such acts as flooding or major accidents or spills; the proximity to urban areas or, conversely, the location in an extremely remote rural area; the proximity to significant aquifers; and the degree of involvement and activity of public and environmental groups.

One specific area of variable application of the permit procedure has been identified with the New York State DEC. Landfill sites are permitted for the disposal of municipal refuse in the majority of the state except Long Island proper with reliance upon natural attenuation of waste leachates. Those sites permitted on Long Island, however, do require liners which preferably are natural clay materials for the containment of waste leachates to facilitate their collection and subsequent treatment. This more stringent control of land disposal sites on Long Island is directly related to the need to protect the underlying groundwater resources which are the sole source of water supply for that area.

The permeability required for containment of hazardous wastes ranges from $\leq 1 \times 10^{-7}$ cm/sec to $\leq 1 \times 10^{-8}$ cm/sec. The permeability requirement for containment of municipal wastes ranges from $\leq 1 \times 10^{-6}$ cm/sec to 5×10^{-8} cm/sec. There is a need to standardize the permeability requirement for both hazardous waste and municipal waste containment, particularly the former. There is also a need to standardize the minimum requirement for the depth to water below a disposal site and the thickness of the confining layer for the standardization of the specified permeability control. These needs will be addressed in the Section VII, Recommended Development Plan.

Comprehensiveness of Procedure. Each agency contacted considers that the permit procedure utilized is sufficiently comprehensive to account for variation of both waste and site characteristics. As previously stated, each waste/site disposal operation is evaluated on an individual case-by-case basis. It is felt that these procedures do provide the best assurance that waste and site variables are sufficiently identified and assessed prior to permit approval.

The Classification System, in itself, is a comprehensive procedure in that all waste types, exclusive of radioactive waste, are identified if only in a general sense. These waste types are then assigned to disposal site types with specified natural or manmade waste leachate control criteria. The Criteria Listing approach in actual operation leads to a Classification System analysis and assignment of waste or site construction criteria, although it is not inherently so structured.

Level of Confidence. Those regulatory agencies contacted also expressed a high level of confidence in the decision procedures utilized for the permitting of waste disposal operations. Since each waste/site disposal operation is handled on a case-by-case basis, decisions can be made with confidence that minimum or no adverse impacts will occur. This degree of confidence is reinforced by the increasingly stringent disposal standards which are placing greater reliance on a mode of deposition by waste containment. With this form of deposition, most of the "guess work" with respect to the adequacy of attenuation of leachates produced is removed from the decision making process, since attenuation will not be utilized except as a back-up mechanism should the containment mechanisms fail.

While certain landfills designed for leachate containment have in fact caused leachate breakouts, it is extremely difficult at best to ascribe a "failure rate" to the decision-making process. One and possibly two of the eleven permitted Class I disposal sites in California have resulted in limited leachate discharges. However, these breakouts cannot be considered a failure or shortcoming of the decision procedure. Rather, the presence of leachate breakouts is thought to be the result of a localized permeability that was higher than the specified criteria in the site design. Actual numbers were rarely available on court hearings related proposed site denials, but it was repeatedly stated by the agencies contacted that both "very few" and "no" site denials had been issued following the technical regulatory permit review and approval.

In the great majority of cases where site problems have developed, these problems can be shown to be primarily related to actual site operation and not site design or a shortcoming of the decision procedure to permit the site. Poor site management, imporper daily practices, and practices that do not conform to site design criteria are the major contributory reasons resulting in subsequent problems arising.

Permit Costs

Costs incurred by the regulation agencies in the permit review process were not available. Those costs incurred by the applicant are given in Table 38, but it must be emphasized that these are gross estimates. Cost estimates do range from a low of several thousand dollars for a demolition disposal site or a small landfill to over $1 million for a large municipal landfill or "secured landfill" for hazardous waste disposal.

Process Time

The time required for the review of the permit application and the issurance of that permit varies substantially between regulatory agencies. As shown in Table 38, the processing time required ranges from a low of 1 month (Illinois) to up to three years (Canada). The overall average processing time is approximately 9 months.

The internal time requirements for processing range from a low estimate of 40 hours (New York) to more than 330 (Texas Water Quality Board). The time required for some of the agencies contacted is given in Table 38 where it can be seen that it is a highly variable factor, if in fact it can be estimated.

Self Assessment

A detailed "self assessment" has been prepared by the staff of the Texas Department of Health Resources of their permit procedures program. This assessment relates to the municipal solid waste facilities permit program. The following self assessment has been made:

1. Assess the relevancy and completeness of information requested of permit applicants for making permit decisions:

    The "Design Criteria" section of the January 1976 "Municipal Solid Waste Management Regulations" stated that design factors to be considered should provide for safeguarding the health, welfare, and physical property of the people through consideration of geology, soil conditions, drainage, land use, zoning, adequacy of access, economic haul distances, and other conditions as the specific site indicates. Information obtained from the applicant generally addressed all design factors in sufficient detail on which to base a sound decision.

However, less than half of the applicants initially submit relevant and complete data with the application. Therefore, in more than half of the cases, additional data must be requested before the application can be processed. This problem is more prevalent with small cities, counties, and operators which are applying for permits for facilities serving less than 5,000 persons. More difficulty is experienced in obtaining data for existing sites than for proposed sites.

2. Evaluate the ease of data gathering and analysis on the part of the permit applicant and the permit grantor:

    The majority of the applicants for permits for large facilities apparently have very little trouble in obtaining the required data for a permit application. The applicants for small facility permits (less than 5,000 population served) have relatively more difficulty in obtaining data due to more limited staff and budget.

    The ease of analysis on the part of the permit grantor is directly related to the amount and quality of data submitted by the applicant. Considerable effort is frequently required to obtain necessary data from small operators.

3. Assess the consistency in interpretation and application of the permit application process at different sites within the jurisdiction:

The Department is aware that consistency is of great importance and has designed its internal procedures with that goal in mind. Because Texas contains extreme variations in population densities, rainfall, hydrogeology, and other principal design factors, a policy of consistency is sometimes difficult to follow but is generally achieved.

4. Evaluate how well the procedure accounts for both site and waste parameters, and determine the applicability of the procedure to a range of sites and waste characteristics:

   The procedure followed by this Department has worked quite well. The range of site and waste characteristics varies from small rural communities to large metropolitan areas. The Department has been able to adapt the permit procedures to both extremes and those occurring in between.

5. Identify the level of confidence in decisions made, both as to site rejection and site approval:

   There is little doubt that the proper decisions have been made. This is backed up by the fact that out of 436 permits which have been issued and 18 permits which have been denied during the past 2 1/2 years only four decisions (2 approvals and 2 denials) have been taken to court. The court upheld the decision in three cases and voided one approval on the basis of procedural error (a complete list of adjacent property owners had not been submitted by the applicant and consequently all affected persons had not been advised of the opportunity to attend the public hearing). As a result, a rehearing was held which resulted in the denial of the permit. Also, as a result of the court's ruling, the procedure of individually notifying adjacent property owners of public hearings was deleted from the regulations.

One recent approval and one denial are expected to be appealed.

6. Determine costs of obtaining the permit decision:

See case history for City of Carrollton, Permit No. 750 and City of Mesquite, Permit No. 556.

In addition to the Department's costs, other Federal, State, or local agencies incur costs as a result of reviews which those agencies must make due to jurisdictional responsibilities they may have. In some cases, up to 10 other agencies may evaluate a specific application. Their costs are probably low, but in the case of the City of Carrollton's permit application, the Texas Water Development Board estimated its costs as $1,800 inasmuch as it had to issue a formal approval, after a hearing, for construction of required levees in a floodplain.

7. Determine the time (maximum, minimum, average) required to obtain a permit.

Since the start of the program in October 1974, the Department received approximately 625 permit applications within a three (3) month period and has received approximately 500 additional permit applications since that time. Considerable difficulty has been experienced in obtaining information on existing sites. During the past

2 1/2 years, 436 permits have been issued, 18 denied, and 69 permit applications have been withdrawn during processing, mainly either because of public opposition to the site operation or the applicant found it too expensive to proceed.

(a) The maximum time to issue a permit for a proposed site has been 16 months. This was for the City of Victoria (Permit No. 120) which was opposed and involved the reopening of the hearing.

(b) Minimum programmed time to issue a permit after permit application is complete when processed on a normal basis is 4 months and 3 weeks:

2 weeks to review application	15 days
4 weeks for review agency comments	30 days
2 weeks to schedule public hearing	15 days
3 weeks for public hearing notice	20 days
60 days for final decision	60 days
	140 days

The actual minimum time to issue a permit for a proposed site has been 2 1/2 months. This was for a transfer station for Travis County (Permit No. 119).

(c) Average time to obtain a permit under this program, since its start in 1974 is 7 months (for proposed sites, which are given priority and processing of applications starts as soon as received).

8. Determine staff requirements to process permit applications (man hours by labor class per permit application) by the regulatory agency.

Engineering Supervisory Review	8 man hours
Project Engineer	36 man hours
Secretarial	12 man hours
Legal Staff	15 man hours
Legal Secretarial	4 man hours
Regional Engineer-Inspection & Review	15 man hours
Regional Secretarial	2 man hours
Staff Geologist	3 man hours
Supervisory Review	3 man hours
Court Reporter	2 man hours
	100 man hours

This is an average figure over a 2 1/2-year period although several highly-contested cases have required over 200 man hours.

Current/Future Trends

Based upon the foregoing discussion, it has become clear that three major modes of land disposal of wastes exist. The first mode of disposal places reliance on the containment of wastes and waste leachates produced to avoid adverse impacts on surface and groundwater quality. The second mode of deposition places reliance on the assimilation of waste leachates into the environment to an acceptable degree by the various mechanisms of attenuation. The third mode of deposition does not rely on containment of waste or attenuation of leachate because of the inert nature of waste.

Accordingly, three major classes of waste disposal sites have been defined with three corresponding major groupings of wastes. This Classification System is best exemplified in the California waste regulatory program. It does apply generally, however, to those Classification Systems developed elsewhere, such as Texas, Illinois, and the United Kingdom.

These Classification Systems may be most aptly summarized as follows:

Site Type	Mode of Disposal	Waste Type
Class I	Containment	Group 1 - Hazardous
Class II	Limited containment, with attenuation	Group 2 - Decomposable, non-hazardous
Class III	Few controls, no containment or attenuation	Group 3 - Inert, insoluble

It is nearly universally agreed that hazardous wastes should be deposited in a Class I type sites. Co-disposal of certain "hazardous" wastes with municipal wastes, however, is permitted on a case-by-case basis in a non-contained (Class II) site by some regulatory agencies. In addition, it is recognized that certain hazardous wastes must undergo some form of pretreatment (such as neutralization, fixation, or complexing) prior to land disposal or some other form of disposal such as incineration.

Although municipal wastes have been considered by many to represent Group 2 wastes, the current trend by an increasing number of regulatory agencies is for municipal wastes as well to be disposed of in a containment site. The third type of waste (Group 3) by virtue of these wastes being inert and insoluble require little control other than obvious site construction operation and aesthetic considerations.

The overriding element of consideration becomes one of the degree of risk associated with adverse environmental impact. The greater the unknowns for a given waste/site situation, the greater the risk factor. It is clear from the assessment of those identified pollution prediction procedures that their applicability to "real world" disposal situations is inversely proportional to the generally-accepted risk or hazard involved for a given waste/site situation. It has become equally clear that with few exceptions, pollution-prediction procedures have no application to the safe disposal of hazardous wastes given the current state of the art of prediction capabilities and economics of land disposal. The element of risk is simply too high for them to be considered, particularly in light of the "maximum site utilization" philosophy mandated by current economics. The Group 3 wastes on the other hand do not require the use of pollution-prediction procedures, since no polluting wastes or leachates are involved.

The Group 2 wastes, those that are decomposable but nonhazardous, become therefore, the prime area for concentrated application of pollution-prediction procedures. Techniques to more specifically define those wastes that can be reliable and permanently assigned to Group 1 and Group 3 wastes are needed. Concurrently, pollution prediction techniques are needed which will permit the assignment of wastes to a Group 2, Class II classification to maximize the beneficial attenuation capabilities of the environment while minimizing waste disposal costs.

The decision procedures and pollution-prediction procedures described in the next section have been recommended for further development with these objectives in mind.

SECTION VII

RECOMMENDED DEVELOPMENT PLANS

It is worth restating at this point that several types of decision procedures have been identified in the course of this state-of-the-art assessment. These procedures are as follows:

- Criteria Listing.
- Criteria Ranking.
- Matrix.
- Classification System.
- Models.

The Criteria Listing procedure provides a basis for objective site characterization data which the review personnel can use to predict the potential for pollution and upon which to formulate a decision for issuing or rejecting a site operation permit. The Criteria Listing is not structured to inherently be a predictive or decision tool, but does provide the basic data on which experienced review personnel can formulate such action. It is the most basic of the decision procedures identified and is presently utilized by over half of the regulatory agencies contacted. For this reason, it is recommended as a decision procedure for further refinement and improvement within a three-year development period. This development plan is described below.

The Criteria Ranking and the Matrix approaches are both very similar decision procedures in that both assign weighted values to various waste and site criteria within an established range. While these approaches are predictive in nature by virtue of their format, they do possess major weaknesses. The most significant weakness results from the fact that the assigned weighted values for both the range of values and the actual value assigned to a specific parameter is somewhat arbitrary. In addition, the "bottom line" number developed by the ranking or matrix analysis is then compared against some "standard" which is itself arbitrary. The lack of testing, calibration, and verification associated with these approaches is another area of significant weakness. Due to these major weaknesses and the fact that these procedures have had only extremely-limited applications, they are not being recommended for further development at this time. They are, however, useful techniques for a preliminary assessment of site suitability and particularly for comparative assessment of several candidate sites.

The Classification System approach has been identified to have undergone rather extensive on-line use (California) and to be comprehensive in the assignment of all wastes (excluding radioactive wastes) to specific types of disposal sites. Because of this comprehensive treatment of wastes, with emphasis on hazardous waste disposal, and the indication that additional regulatory agencies are utilizing this approach (i.e., Texas, Illinois), the Classification System has also been selected for further development.

The rapidly changing waste disposal technology and legislative controls for waste disposal, together with the "subroutines" such as leaching tests, shaker tests, and mathematical modeling for waste/site characterization and interaction, indicate a need for a program of continual updating and refinement. The Classification System Development Plan described below will encompass, therefore, both a short-term time frame (3 years) and a long-term time frame (ten years).

Various forms of simulation models, such as soil-leaching column studies, shaker tests, and thin layer chromatography, are useful tools for the evaluation of the pollution potential for a waste/site situation. These tools are in effect "subroutines" with respect to the larger framework necessary for a usable decision procedure for waste disposal siting. In addition, serious questions can and have been raised as to the reproducibility, representativness, and reliability of their results. For these reasons, no further concentrated effort is recommended for these approaches at this time.

Numerous mathematical models have been developed which also attempt to simulate an actual or proposed waste/site situation. Serious questions have also arisen as to the reproducibility, representativeness, and reliability of the mathematical modeling approach. However, some of these models have undergone on-line testing, calibration, and verification. The major advantages of such models is that they can be a strong predictive tool for use in the permit decision-making process. Mathematical models are recommended, therefore, for further development as described below. This development plan can be expected to encompass a long-term time frame (up to and probably exceeding 10 years).

Criteria Listing Development Plan (Short Term)

Background. Two basic modes of land deposition/treatment of waste have been identified in this state-of-the-art assessment of Pollution Prediction Techniques for Waste Disposal Siting. These approaches are as follows: (1) attenuation of waste leachates, and (2) containment of waste with collection and treatment of leachates.

The basic philosophy for the former is that leachates produced from certain wastes (generally non-hazardous) will be afforded renovation by the various mechanisms of attenuation to an acceptable degree to avoid adverse environmental impacts. Such an approach is dependent upon a proper "match up" of waste/site characterization, proper design and operation, and, perhaps most important, proper management and maintenance.

The basic philosophy for the latter approach is that leachates produced by certain wastes (generally hazardous), by virtue of their concentration, physical and chemical properties, and solubility, would result in significant adverse human or environmental impacts without containment of the waste. Such containment does entail for most regions of the country the collection and treatment of leachate to avoid the "bathtub" effect.

It has been determined that the Classification System and the Criteria Listing approaches for waste/site characterization are currently the most widely-accepted and utilized by regulatory agencies in their decision procedures for waste disposal siting.

Analysis of Development Needs. A need has been recognized to develop a comprehensive Criteria Listing for waste/site characterization in a format that will be suitable for utilization by regulatory agencies in a uniform manner for the land disposal/treatment of waste. The specific objectives of this development plan will be to:

1. Develop a Criteria Listing for use in waste/site characterization for both wastes that are: (1) amenable to attenuation of leachates produced from them; and (2) wastes that will require containment and the collection and treatment of leachates produced to avoid adverse environmental impacts. In addition, develop a matrix which will indicate which of the criteria listed will be required for every disposal/treatment site and which will be required for certain waste/site disposal situations.

2. Describe the best state-of-the-art methodology to quantify each of the criteria listed, and describe the proper utilization of such data. Finally, prepare a manual for use by regulatory agencies which presents in a uniform fashion the criteria necessary, the quantification methodology, and the use of information gathered for assessment of proper waste-disposal siting.

In order to meet the objectives of this development plan, the following tasks are to be conducted:

- Task 1 - Develop a comprehensive Criteria Listing for waste/site characterization where reliance will be placed upon the attenuation of leachates produced.

  a. Identify and list those waste/site characterization criteria required by regulatory agencies.

  b. Assimilate those criteria currently being utilized by regulatory agencies. These criteria will be obtained from the most "progressive" regulatory agencies.

  c. Assess the comprehensiveness of those criteria listed and the need for additional criteria.

  d. Develop the comprehensive list of criteria.

  The comprehensive list of criteria should include the following:

  1. Waste characterization criteria: type, amount and physical, chemical and biological properties

  2. Site characterization criteria: location, topography, climatology, land use, soils, geology and hydrology

  3. Waste behavior criteria: solubility, leachability, toxicity and hazardous properties

  4. Site suitability criteria: water flux patterns, permeability and attenuation

  5. Environmental quality criteria: ground and surface water quality standards, land use and air quality objectives

  6. Site management criteria: means of disposal, erosion and runoff control, leachate management, and site reuse.

- Task 2 - Develop a similar list for waste/site situations where containment of leachates produced from the waste would be required.

  a. See steps a through d above.

- Task 3 - Develop a matrix for Task 1 and 2 above which will specify those criteria necessary for waste/site characterization with respect to each of the following land disposal practices.

  a. Landfilling of municipal refuse.

  b. Land farming/spreading of oily wastes and municipal and industrial sludges.

  c. Spray irrigation of treated sewage effluent.

  d. Other identified land disposal/treatment practices, such as deep well disposal.

- Task 4 - Present the best state-of-the-art methodology to obtain both field and laboratory data relative to each of the criteria listed for their quantitative and qualitative assessment. For example, definition of the groundwater flow system will require depth to water measurements which can be obtained in backhoe pits, boring wells or piezometers. The need for each type should be addressed.

- Task 5 - Describe in a "how to use" fashion, data required for an assessment of site suitability, for example, utilization of a mixing zone for waste assimilation, waste application rates, or containment of waste by the use of natural site factors and/or engineered controls (liners).

- Task 6 - Prepare a manual on Utilization of the Criteria Listing Approach for Waste Disposal Siting for use by regulatory agencies. This manual will describe in a step-wise fashion the Criteria Listing necessary for waste/site characterization, the methodology to obtain quantitative and qualitative data relative to those criteria, and the assessment procedure to evaluate those criteria.

Timing, Staffing, and Funding Estimates. The development of a comprehensive Criteria Listing and a matrix for selected types of waste disposal will require the input from an interdisciplinary team. This team should be comprised of technical personnel in the following areas: environmental, civil and chemical engineering, soils science, and hydrogeology. Balanced input from these team members will be required for an estimated total four-manyear effort as shown on Table 43. These tasks should be conducted in a sequential manner as shown on Table 44 with some concurrent effort to result in an estimated total project period of 15 months.

Project funding is estimated at $200,000 based on this level of anticipated work effort.

Classification System Development Plan (Short and Long Term)

Background. Several state regulatory agencies have been identified which presently utilize a Classification System approach for waste disposal siting. California has utilized this approach for some five years, while Texas and Illinois have recently initiated a similar approach. The Classification System approach is comprehensive in that all wastes, including hazardous wastes but excluding radioactive wastes, are assigned to specific site types. These site types are defined on the basis of certain characteristics, primarily permeability requirements, for waste leachate control to avoid or minimize the risk of surface and groundwater contamination.

Analysis of Development Needs. An assessment of the identified Classification Systems has led to the recognition that: (1) certain key parameters such as the maximum permeability allowed for waste containment in a "secured landfill" vary by a least one order of magnitude; and (2) waste types are often characterized in only general and not specific terms.

TABLE 43

LEVEL OF EFFORT FOR CRITERIA LISTING DEVELOPMENT

Development Task	Level of Effort (Man Months)
1. Develop a comprehensive criteria listing for reliance on attenuation	9
2. Develop a comprehensive criteria listing for reliance on containment	9
3. Develop a matrix designating different criteria and disposal methods	3
4. Develop procedures for field and laboratory evaluation of parameters	9
5. Develop methodology for utilization of attenuation and containment practices	6
6. Prepare user manual and report	12
TOTAL	48
	(4 man years)
Total Funding, assuming $50,000 per man year	$200,000

TABLE 44

CRITERIA LISTING DEVELOPMENT SEQUENCE

Development Task	Time - Months														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Develop a comprehensive criteria listing for reliance on attenuation	—	—	—	—											
2. Develop a comprehensive criteria listing for reliance on containment	—	—	—	—											
3. Develop a matrix designating different criteria and disposal methods			—	—	—	—	—								
4. Develop procedures for field and laboratory evaluation of parameters						—	—	—	—	—					
5. Develop methodology for utilization of attenuation and containment practices									—	—	—	—			
6. Prepare user manual and report												—	—	—	—

It has become apparent, therefore, that a more detailed and uniform approach to both waste and site characterization is necessary for waste management to minimize or avoid adverse environmental impacts while at the same time maintaining associated costs at an affordable level. To meet these needs, the following overall objectives can be stated: (1) more definitive waste characterization, by uniform methods and descriptions; (2) more uniform site characterization; and (3) more specific and uniform waste management techniques, such as waste segregation, pretreatment, lift thickness and cover requirements.

The following tasks will be conducted to fulfill these stated objectives:

- Task 1 - Waste Characterization: Techniques will be identified and assessed as to their capability for more definitive and uniform waste characterization. Such techniques will include, but not be limited to:

    a. A standard leaching test.
    b. A shaker test.
    c. Thin film chromatography.

  Specific wastes will be identified which will require disposal in a Class I Type site as well as those specific waste types which are suitable for Class II and III site disposal. In addition, specific wastes will be identified which will require pretreatment prior to disposal in a Class I site or some other form of disposal such as incineration. (See task on Waste Management below.)

- Task 2 - Site Characterization: Criteria for site definition are presently designated in both the Criteria Listing and Classification System approaches to waste disposal siting. These criteria will be assessed and a uniform set of limits will be placed on such key parameters as: (1) maximum permeability required for containment (2) minimum depth to the highest measured water level and (3) minimum thickness of the low permeability confining unit.

Uniform site characterization criteria applicable to all waste classes, equivalent to Class I, II, and III of the California System, will be specified.

- Task 3 - Waste Management Requirements: A set of requirements for matching types of waste with types of sites should be developed and would cover; 1) criteria for reliance on attenuation, 2) criteria for reliance on containment, and 3) criteria for site design, operation and management.

- Task 4 - Waste Management Task Force: A Waste Management Task Force should be established to keep abreast of the rapidly-changing waste disposal program. This Task Force will be comprised of approximately 10 members with a balanced representation of governmental, industrial, consulting, and academic personnel. This Task Force will meet no less than annually to review the current waste disposal technology and current waste disposal regulations. A primary function of this Task Force will be to continually update and specify those waste management techniques most environmentally sound for specific waste types.

  Specific wastes are to be identified that: will require disposal in a Class I type site; are permissible for disposal in Class II and III type sites; will require pretreatment and the method of pretreatment prior to land disposals; and that will require a specified form of disposal other than to the land (i.e., incineration).

- Task 5 - Methodology of Using Classification System: Different methodologies for using the classification system must be developed. These will include: 1) data requirements, 2) data qualification and quantification and 3) analysis and interpretation.

- Task 6 - Prepare Manuals and Reports: A series of users manuals and reports should be prepared and updated. The task of review, modification and updating of these manuals is part of the function of the Waste Management Task Force.

Timing, Staffing, and Funding Estimates. While the Classification System approach to waste disposal siting is presently being utilized, the above described tasks readily attest to the need for refinement and continued updating with changing technology and legislation. This development plan encompasses, therefore, both a short-term and long-term timeframe. As the "subroutines" for waste characterization (i.e., leaching tests) and waste/site interactions (i.e., modeling) become more reliable, the utilization of the Classification System for waste disposal siting will likewise become more reliable and cost effective.

Due to the comprehensive nature of this development plan and the rapidly-changing waste technology and legislative controls, timing estimates for the conduct of this plan are difficult to formulate. It can be anticipated however, that short-term development (within three years) will require an estimated 5-manyear effort over the three-year period as shown on Table 45. Once a uniform Classification System is being used and the Task Force is operative, it is estimated that approximately one man-year of effort will be required for the duration of the long-term period (to 10 years). The concurrent tasks and sequence for further development of the Classification System is shown on Table 46.

TABLE 45

LEVEL OF EFFORT FOR CLASSIFICATION SYSTEM DEVELOPMENT

Development Task	Level of Effort short term	long term
1. Develop waste characterization techniques	1	*
2. Develop site characterization techniques	1	*
3. Develop waste management requirements for different waste and site classes	1	*
4. Create and support a waste management task force	1/2	7
5. Develop methodology for using classification system	1/2	*
6. Prepare user manual and update reports	1	*
TOTAL MAN YEARS	5	7
TOTAL Funding, assuming $50,000/ man year	$250,000	$350,000

* included in long term estimated for supporting task force (Task 4)

TABLE 46

CLASSIFICATION SYSTEM DEVELOPMENT SEQUENCE

Development Task	Time in Years 1	2	3	4	5	6	7	8	9	10
1. Develop waste characterization techniques	———	———	— —	— —	— —	— —	— —	— —	— —	— —
2. Develop site characterization techniques	———	———	— —	— —	— —	— —	— —	— —	— —	— —
3. Develop waste management requirements for different waste and site classes	———	———	———	— —	— —	— —	— —	— —	— —	— —
4. Create and support a waste management task force	———	———	———	— —	— —	— —	— —	— —	— —	— —
5. Develop methodology for using classification system	———	———	———	— —	— —	— —	— —	— —	— —	— —
6. Prepare user manual and update reports	———	———	———	— —	— —	— —	— —	— —	— —	— —

——— Short Term Development

— — Long Term Development

An EPA selected contractor would conduct the tasks indicated for the short term (3 year) effort and would work with EPA to create the Waste Management Task Force. Thereafter, the Waste Management Task Force would meet annually to review, modify and update the users manual, including the associated tasks that are inherent to that manual, under direct contract to the EPA.

Staffing for the contractor selected to perform the short-term work will require the input from a multi-disciplinary team as indicated in the Criteria Listing Development Plan. Staffing requirements for the Task Force should include: technical representation in environmental, civil and chemical engineering, soils science, hydrogeology, and applied computer science; industrial representation from several of the key industrial sectors; academic representation in applied waste management research; regulatory representation from a minimum of one state regulatory agency, and EPA; and legal representation at the federal level. Input from these varied personnel should be on a "balanced" basis.

Funding estimates for this development program are also extremely difficult to determine. Assuming $50,000 per manyear effort, and the assessment timing requirements stated above, a minimum cost of $250,000 will be required for the short-term period (3 year) and an additional $350,000 for the long-term period (up to 10 years).

Mathematical Model Development Plan (Long Term)

Background. The very nature of waste disposal into a physically, chemically, and biologically active environment results in such a complex of interrelated processes that a comprehensive description of the system becomes extremely difficult. Frequently, the system is too complicated for any reasonable model to include all the factors that might be considered important, thus leading to criticism, particularly from non-modeling personnel, of the model being non-representative and incomplete. On the other hand, a model which includes the major processes may be too complex to be used by average technical personnel.

It must also be realized and emphasized that detailed models do not provide absolute "yes" or "no" answers to questions of disposal-site suitability. The user of any mathematical model must make site suitability recommendations on the basis of model outputs which describe the presence of various waste constituents in the soil/water system below and down gradient from a disposal site. Perhaps the most effective application of models is that they can be used to evaluate various management schemes that will make a given waste disposal site more acceptable in terms of minimizing its impact on the environment.

During the past decade, the level of activity in modeling water and waste leachate transport through different types of porous media has increased significantly. Thus, effort has occurred in various government, educational and private sectors and has been undertaken by personnel in various technical disciplines. Many models, however, are similar in their conception of the processes which exist in a waste disposal system and how they may be described.

Analysis of Development Needs. The specific objectives of this development plan will be:

- Task 1 - Simulation Library: Develop a central library which contains existing models and their numerical solution and appropriate documentation. The concern that some individuals may misuse a model developed by another group is not sufficient justification for the general reluctance to establish a central library of available models. An interdisciplinary team of individuals capable of understanding model development and computer programming would establish guidelines for model presentation, documentation, and limitations. The material in the library should be available to anyone upon request. There will be an annual need to update the entries in the library.

- Task 2 - Test Model Sensitivity: Develop procedures to evaluate model output sensitivity to input parameters, initial and boundary conditions, and the assumptions made. Most of the available numerical models are too complex for previously-developed sensitivity analysis techniques. This capability will identify the precision with which each model parameter and variable will have to be measured in the laboratory and/or field to give reliable output from the model. Some of the available statistical procedures for conducting sensitivity tests are too costly and time consuming for general use in complex waste-leachate and soil-interaction models.

- Task 3 - Formulation and Validation of Models: Develop mathematical models (one and two dimensional) for describing water and waste constituent transport through water saturated/unsaturated porous media. The numerical treatment of complex partial differential equations for an empirical model using high-speed digital computers is very advanced and sophisticated. The major problem to date appears to center around the use of valid relationships for describing the processes occurring in the soil-waste leachate system. Therefore, it is recommended that interdisciplinary programs be used to bring experimentalists and modelers together to work on the problem of modeling waste disposal. A closer working relationship between these two groups will enhance our progress in describing the behavior and performance of given waste leachates in a specific soil environment.

- Task 4 - Model Parameters and Variables: Develop standard procedures for measuring the major parameters and variables used in models for describing the transport and interaction of single and/or multiple constituents in saturated/unsaturated porous media. This task is related to the need for better sensitivity analysis techniques for identifying the major input parameter which significantly influences the output from a model.

Processes with specific parameters that appear to be of primary importance are adsorption-desorption, ion exchange, constituent precipitation, biological decay or transformation of constituent, water transport (saturated/unsaturated), and waste leachate composition. Parameters required to describe water transport in one and two dimensions are sufficiently understood and documented at the present time. The processes which describe the chemical and biological (equilibrium and transient) behavior of waste constituents will require the greatest effort.

The product from this task should be presented in a manner similar to the "Protocol for Adsorption Tests" Federal Register (1975), 40 (123) 26881-26895, in the EPA guidelines for registering pesticides in the United States.

- Task 5 - Waste and Waste Leachate Characterization: Develop standard procedures for describing leaching characteristics of wastes under simulated environmental conditions (leaching tests and data). Without this information, it will be impossible to use the models to describe the fate of given waste constituents in a disposal site.

- Task 6 - Field Testing, Calibration, and Verification: Develop a sufficient data base from a given waste and disposal site to provide an opportunity for model comparison and verification. These data would not be used for calibration purposes, but rather for evaluating the conceptual validity of the model. The output from the model would be compared with data from the site which describes the movement and distribution of various waste constituents leaving the waste disposal area. Model verification requires that the data base be independent of that used for calibration or testing.

- Task 7 - Management Models: Develop models designated as "management models". These should be synthesized from the detailed simulation models developed by interdisciplinary research groups. These models should be simplified versions suitable for use in smaller computers. The models are not intended to provide the detail or level of sophistication associated with research or technical models, but they should help provide initial evaluations of many waste disposal sites. The management models, if process oriented, would be useful in familiarizing non-technical regulatory personnel with the use and benefits of the more detailed models.

  Such models would include calculating maximum spatial concentration maximum travel distance, and required degree of contaminant removal.

- Task 8 - Implementation Assistance: Develop a procedure for training non-technical personnel in the use of models. Write manuals which describe the major processes responsible for the mobility and attenuation of waste constituents associated with water disposal. The manuals should be written in such a manner that non-technical personnel could use and benefit from the material presented.

Time, Staffing, and Funding Estimates. The above-described tasks for model development needs indicate an obvious long-term and costly development program. This program can be broken down into certain tasks, however, which can be completed in the short term (within three years) as well as a number of tasks that can be conducted concurrently.

Due to the extremely complex nature of both the subject matter (the waste/soil interaction system) and the method to analyze that system (mathematical models and estimates of the time), staffing and funding necessary to fully develop reliable and representative models are, at best, reasonable estimates. Such reasonable estimates have been made as indicated in Tables 47, 48, and 49.

The staffing requirements reflect the interdisciplinary approach that is vital to the model development program if these models are to be representative of the complex waste/soil interactions. The staffing needs, as shown, indicate a high level of activity of an estimated 150 manyears. Using the generally acceptable rate of $50,000/manyear, the model development program is estimated to cost approximately $6 million.

TABLE 47

LEVEL OF EFFORT FOR MODELS DEVELOPMENT (MAN YEARS)

Development Activity	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Total (Man Years)
1. Simulation Library.												
• Start Compilation of Material	2											2
• Maintain Current Information		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5
2. Develop a Standardized Test Procedure for Numerical Models.	1	1	1									3
3. Mathematical Formulation and Numerical Solution.												
a. One-Dimensional Saturated/Unsaturated Model with No Adsorption or Decay of Single Constituent	2											2
b. One-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Single Constituent	1	2	1									4
c. One-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Several Constituents	1	2	2	1								6
d. Two-Dimensional Saturated/Unsaturated Model with No Adsorption or Decay of Single Constituent	2											2
e. Two-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Single Constituent	1	1	1	1								4
f. Two-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Several Constituents	1	1	1	1	1	1						6
g. Three-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Several Constituents		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5

TABLE 47
(continued)

Development Activity	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Total (Man Years)
4. Develop Methodology for Laboratory and Field Quantification of Major Model Parameters.												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent	1	2	1									4
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent	1	1	1	1	1	1						6
c. Saturated/Unsaturated Models for Adsorption and Decay of Several Constituents		1	1	1	1	1	1	1	1	1	1	10
5. Develop Methodology for Quantification of Waste Leachate for Specific Soils and Environmental Conditions.												
a. Leaching characteristics	1	1										2
b. Soil/Constituent Interaction	1	2	2	1	1							7
6. Field Testing, Calibration, and Verification.												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent	2	3	3	2								10
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent	2	3	4	4	4	3						20
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents				3	3	3	3	3	3	3	3	24

TABLE 47
(continued)

Development Activity	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Total (Man Years)
7. Develop Management Models from Detailed Models.												
a. Saturated/Unsaturated Models with No Adsorption of Decay of Single Constituent	1	1	1	1	1							5
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent				1	1	1	1	1	1	1	1	8
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents						1	1	1	1	1	1	6
8. Implementation Assistance.												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent				0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent						0.5	0.5	0.5	0.5	0.5	0.5	3
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents										1	1	2
TOTAL												150

TABLE 48

MODEL DEVELOPMENT SEQUENCE

Development Activity	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1. Simulation Library.											
Start Compilation of Material	■										
Maintain Current Information	■	■	■	■							
2. Develop a Standardized Test Procedure for Numerical Models.	■	■	■								
3. Mathematical Formulation and Numerical Solution.											
a. One-Dimensional Saturated/Unsaturated Model with No Adsorption or Decay of Single Constituent	■										
b. One-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Single Constituent	■	■	■								
c. One-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Several Constituents	■	■	■	■	■						
d. Two-Dimensional Saturated/Unsaturated Model with No Adsorption or Decay of Single Constituent	○										
e. One-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Single Constituent	■	■	■	■							
f. Two-Dimensional Saturated/Unsaturated Model for Adsorption and Decay of Several Constituents	■	■	■	■	■	■					
g. Three-Dimensional Saturated/Unsaturated Models for Adsorption and Decay of Several Constituents	■	■	■	■	■	■	■	■	■	■	■
4. Develop Methodology for Laboratory and Field Quantification of Major Model Parameters.											
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent	■	■	■								
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent	■	■	■	■	■	■					
c. Saturated/Unsaturated Models for Adsorption and Decay of Several Constituents.	■	■	■	■	■	■	■	■	■	■	■

TABLE 48
(continued)

Development Activity	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	
5. Develop Methodology for Quantification of Waste Leachate for Specific Soils and Environmental Conditions.												
a. Leaching characteristics	■	■										
b. Soil/Constituent Interaction	■	■	■	■	■							
6. Field Testing, Calibration, and Verification.												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent	■	■	■	■								
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent	■	■	■	■	■	■						
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents				■	■	■	■	■	■	■	■	→
7. Develop Management Models from Detailed Models.												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent	■	■	■	■	■							
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent				■	■	■	■	■	■	■	■	
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents						■	■	■	■	■	■	→
8. Implementation Assistance												
a. Saturated/Unsaturated Models with No Adsorption or Decay of Single Constituent				■	■	■	■	■	■	■	■	→
b. Saturated/Unsaturated Models for Adsorption and Decay of Single Constituent						■	■	■	■	■	■	→
c. Saturated/Unsaturated Models for Adsorption No Decay of Several Constituents										■	■	→

TABLE 49

STAFFING AND MANPOWER REQUIREMENTS
FOR MODEL DEVELOPMENT

Development Activity	Manyears	Breakdown of Staffing, % (1)	(2)	(3)	(4)	(5)
1. Simulation Library	7	30	20	-	20	20
2. Standardized Test Procedure for Numerical Models	3	70	10	5	10	5
3. Mathematical Formulation and Numerical Solutions	29	45	20	10	20	5
4. Methodology for Laboratory and Field Quantification of Major Model Parameters	20	10	20	30	35	5
5. Methodology for Quantification of Waste Leachate, Specific Soil, and Environmental Conditions	9	10	15	40	30	5
6. Field Testing, Calibration, and Verification	54	5	20	20	50	5
7. Management Models from Detailed Models	19	60	10	5	20	5
8. Implementation Assistance	9	20	20	15	20	5
TOTAL	150					

Type of Staff:
(1) Applied mathematician, computer scientists, programmer, etc.
(2) Environmental, chemical, civil engineer, etc.
(3) Chemist, lab technician, etc.
(4) Soil scientist, hydrogeologist, field technician, etc.
(5) Secretary/clerical, administrative, etc.

APPENDIX A

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APPENDIX B
NON-REGULATORY EXPERT CONTACTS

CONTACT FORM

Person Contacted and Affiliation:

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Type of Procedure:

Field Investigation

Discussion:

Approach Taken. This approach involved field investigation for renovating secondary sewage effluent by groundwater recharge with rapid infiltration basins. The data base will be used to develop decision and design criteria.

Ten years of experimental work in renovating secondary sewage effluent by groundwater recharge with rapid infiltration basins in the sandy and gravel materials of the salt river bed west of Phoenix, Arizona have established the following information:

The infiltration of the secondary effluent through the sands and gravel resulted in essentially complete attenuation of suspended solids, biological oxygen demand, viruses, and fecal coliform bacteria. However, the renovated water still contained about 5 mg/l of total organic carbon. Almost all of the fecal coliform bacteria were attenuated in the first two feet of the soil, but further penetration was observed for the first few days of a new flooding period following a dry period.

The total nitrogen load at the design hydraulic loading rate of 300 ft/yr was about 24,000 lb/acre. Sequences of short, frequent flooding and drying periods of several days each yielded essentially complete conversion of the nitrogen in the effluent to nitrate in the renovated water, but no attenuation of nitrogen. With flooding and drying periods of two weeks each, ammonia was adsorbed in the soil during flooding and nitrified and then partially denitrified during the drying period. This yielded renovated water with alternating low nitrogen levels and nitrate peak and a net nitrogen removal of about 30 percent. If the hydraulic loading rate was reduced to 200 ft/yr (by using 9-day flooding periods) nitrogen attenuation was increased to about 60 percent.

Phosphate attenuation was about 50 percent after 30 feet of underground travel. At least 300 feet were required to attenuate more than 90 percent of the phosphate. Phosphate gradually precipitated in the sands and gravel, probably as calcium phosphate. The phosphate removal continued to be stable after ten years of operation of the project.

Copper and zinc concentrations were attenuated about 80 percent, whereas those of cadmium and lead remained about the same as the water moved through the sands and gravels. Metal concentrations were below maximum limits for irrigation.

Results/Conclusions to Date. The project has demonstrated that a high quality renovated water suitable for unrestricted irrigation and recreation can be obtained with a rapid-infiltration system in the Salt river bed. The cost of putting the effluent underground and pumping it up as renovated water on a large scale was estimated at about $5.3/ acre-foot in 1969. This is much less than the cost of equivalent in-plant treatment to produce a renovated water of similar quality.

State of Development. The project is nearly completed with some mathematical simulations being made using the experimental data. No effort is being made at this time to develop a complete mathematical model to describe the behavior of the various constituents in the secondary sewage effluent. Experience with the system is serving as the basis for the development of additional sites for treating secondary sewage effluent. Based on the results, the City of Phoenix in 1975 installed a 40-acre rapid-infiltration system to produce renovated influent for an irrigation district.

Availability as Decision Procedure. Their data base is available immediately to design infiltration basins for secondary sewage effluent treatment in other parts of the United States.

Key Publications:

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2. Bouwer, H. Design and operation of land treatment systems for minimum contamination of ground water. Groundwater, 12:140-147, 1974.

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5. Bouwer, H. Zoning aquifers for tertiary treatment of wastewater. Groundwater, 14, 1976.

6. Gilbert, R.G., C.P. Gerba, R.C. Rice, H. Bouwer, C. Wallis, and J.L. Melnick. Virus and bacteria removal from wastewater by land treatment. Applied and Env. Microbiology, 32:333-338, 1976.

CONTACT FORM

Person Contacted and Affiliation:

Mr. John D. Bredehoeft
Acting Assistant Chief Hydrologist
for Research and Technical Coordination

- U.S. Geological Survey
Reston, Virginia 22092

Type of Procedure:

Models/Simulation - Flow and Solute Transport Models

Discussion:

Approach Taken. Mr. Bredehoeft and other U.S.G.S. researchers (e.g., Konikow and Rubin) have outstanding expertise in their respective fields. The survey is spending $6 million on research related to groundwater quality and quantity modeling, with emphasis on radioactive waste disposal sites.

Results/Conclusions to Date. The U.S.G.S. has documented and has available a program which handles solute transport, with heat and reactions in both two and three dimensions.

State of Development. The U.S.G.S. has developed, through a control to Intercomp, and documented two- and three-dimensional solute transport models with heat reaction. The survey also has in press the documentation of a two-dimensional method for a characteristics program for solute transport with first order chemical reaction. Research is in progress on transport codes with higher order chemical reactions; they should be available within the next year or two.

Availability as a Decision Procedure. Some computerized mathematical models can be made available for application as tools for pollution prediction in the near future. More sophisticated models (two- and three-dimensional, with high-order chemical reactions) could be available after research and testing is completed. A key element in the availability of these models as a universal tool for site selection depends on the extent of model testing, calibration and field verification, which requires several years of effort after model development.

Key Publications:

The key publications are numerous. See "Status of Ground-Water Modeling in the U.S. Geological Survey," Appendix D.

CONTACT FORM

Persons Contacted and Affiliation:

Dr. John Bromley
Research Manager, Chemist

Dr. Allen Parker

Dr. Ian Harrison
Geologist
Institute of Geological Sciences based at Harwell

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Chemical Engineer

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Dr. John Bromley heads up the Environmental Safety Group at the Atomic Energy Research Establishment in Harwell. This group of selected personnel is conducting extensive research for application to environmental problems with emphasis on toxic and hazardous materials. It is noteworthy that Harwell does have a well-established chemical data bank to catalogue various types of chemicals and hazardous wastes, as well as a chemical emergency center which is manned 24 hours a day for response to emergency spill situations.

Type of Procedure:

Field/Laboratory Investigations

Discussion:

Approach Taken. The major work currently underway at Harwell is a three-year investigation of some 20 landfills, with emphasis on hazardous waste landfills and the co-disposal of hazardous waste with municipal refuse. This study is being conducted cooperatively with the Water Research Centre, and is funded by the Department of the Environment at a cost of approximately $2,000,000. The final report is to be submitted to the Department on or about September 1, 1977.

Investigation is expected to be continued for an additional two years with the following scope of work proposed: (1) additional bore holes at selected landfills; (2) a continuation of leachate column studies; (3) additional analysis of leachate volume and composition from landfill wastes; and (4) additional investigation, both in the field and in the laboratory, of co-disposal of industrial and municipal waste.

Two philosophies of waste management (identified at Harwell and by others) are being persued; these philosophies include: (1) containment of wastes for the purpose of containment and concentration of leachate; and (2) assimilation of leachate into the environment at an acceptable rate utilizing dilution and dispersion.

Earlier work by Gray, Mather and Harrison in Review of Ground Water Pollution from Waste Disposal Sites in England and Wales, With Provisional Guidelines for Future Site Selection identified a waste categorization approach to site selection. Three waste categories were identified as follows:

- Category 1 - Hazardous waste.
- Category 2 - Domestic and related waste.
- Category 3 - Inert waste.

A flow diagram was proposed whereby specific waste categories were permissible for disposal, based upon avoidance of interception of the water table and the definition of permeability of both surficial deposits and bedrock. It is noteworthy, however, that additional work along these lines led to the conclusion that (as published in Waste Management Paper 4, The Licensing of Waste Disposal Sites by the Department of the Environment) unfortunately neither wastes nor sites lend themselves to such categorization, and it is necessary to produce a more generalized scheme which can be modified and adapted for local use. Site classification, however, is preserved whereby three classes of sites are recognized as follows:

Class 1. Those providing a significant element of containment for waste and leachate.

Class 2. Those allowing slow leachate migration and significant attenuation.

Class 3. Those allowing rapid leachate migration and insignificant attenuation.

A thickness of 15 meters of impermeable strata was stated as the minimum requirement of a site receiving Category 1 waste; however, this figure was admittedly arbitrary and subject to some reservation. Current thinking on the thickness of impermeable strata indicates that a maximum of 5 meters would be appropriate. Ideal attenuation would be obtained with a clayey sand to optimize both adsorption and dilution of leachate constituents. Extrapolation however remains questionable at this time due to the state of the art of prediction of pollution potential; therefore, attenuation must be addressed on a site-by-site basis.

Personnel at Harwell had been active in the mathematical modeling approach to the prediction of groundwater pollution by land disposal of waste. Models are currently reviewed with some reservation on anything other than a site-by-site basis. An earlier project by Bromley and Hebden on An Interactive Computer System for Advising on the Safety of Waste Disposal to a Landfill Site has been discontinued due to changes in project personnel and the fact that the degree of specificity for the model became unattainable due to the inability of laboratory analytical procedures to identify low concentrations of leachate constituents. One important publication relative to modeling by D.C. Wilson, entitled Mathematical Modeling of Pollution Migration from a Landfill Site to a Ground Water Abstraction Point - A Survey of the Literature in 1974, presented a summary of the significant models in existance as well as their scope and limitations.

Results/Conclusions to Date. Since the final report has not yet been submitted, printed conclusions of the 20-site study could not be obtained; however, the following major conclusions of the three-year study were verbally obtained:

1. Heavy metals have been found to be effectively tied up in the tips (landfills) primarily by the process of precipitation as metal sulfides, metal carbonates, and metal hydroxides.

2. Once the addition of leachate to the field lysimeters at Uffington ceased, the leachate front ceases migrating deeper into the soil column and the leachate discharge continues at a very slow and dilute rate.

3. The organics, particularly phenols, are the most troublesome material to deal with; however, some organics are volatilized (such as cleaning fluids), some are biodegraded, and others are adsorbed onto plastics within municipal refuse.

4. There has been a good correlation between the degree of metal precipitation and leachate front migration utilizing both rapid saturated methods in laboratory column studies and the lysimeters. Leachate was applied at twice the normal rate of flushing at the unsaturated field lysimeters.

5. Considerable emphasis is placed on the importance of the unsaturated zone for the attenuation of both municipal and many "hazardous" waste/leachate constituents.

6. Investigation of some 20 landfills in the field has indicated no evidence of significant pollution except where such would be obvious, such as disposal over abandoned mine shafts, fractured bedrock, or highly-permeable gravel.

7. A pragmatic "common sense" approach to utilize moderate permeability for dilution and dispersion is favored over either a high permeability for rapid leachate transport and contamination or a low permeability for leachate ponding and concentration which would require collection and treatment to avoid adverse impacts from concentrated leakage.

8. The United Kingdom does not experience groundwater pollution from waste disposal to any significant degree based upon this current study and an earlier desk-top study whereby only 51 sites out of 2,494 in England and Wales were assessed to represent a serious pollution risk to major or minor aquifers.

Significant conclusions of the modeling efforts are as follows:

1. Simulation models of pollutant migration from a landfill into and through the aquifer hold some promise for future development within their limitations. These are primarily computational incompetence in solving huge numbers of simultaneous equations and more particularly in a lack of detailed data input.

2. For routine site evaluation, the inescapable conclusion is that a mathematical model, even if it worked perfectly, would demand too much time and effort to be practicable.

State of Development. Emperical data and conclusions drawn from a detailed analysis and assessment of that data will serve as useful guidelines in decisions relative to waste disposal siting.

Availability as a Decision Procedure. Results of this study will be available for reference and use in late 1978.

Key Publications:

1. Harwell Laboratory (Cooperative with Water Research Centre). Programme of research on the behaviour of hazardous wastes in landfill sites. Interim Report on Progress, Sept. 1975 (Final report late 1977).

2. Gray, D.A., J.D. Mather, and I.B. Harrison. Review of groundwater pollution from waste disposal sites in England and Wales, with provisional guidelines for future site selection. Harwell Laboratory, 1974. Reprinted from The Quarterly Journal of Engineering Geology, Vol. 7, No. 2.

3. Mather, J.D. and J. Bromley. Research into leachate generation and attenuation at landfill sites. Hydrogeological Department, Institute of Geological Sciences, Hazardous Materials Service, Harwell Laboratory, Didcot. Presented at Land Reclamation Conference, Oct. 1976.

4. Wilson, D.C. Mathematical modeling of pollution migration from a landfill site to a groundwater abstraction point - a survey of the literature. Aere Harwell, Dec. 1974.

CONTACT FORM

Persons Contacted and Affiliation:

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Water Resources Program
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Types of Procedures:

Models/Simulation
Field and Laboratory Data

Discussion:

Approach Taken. As part of a large 208 project for Long Island, New York, analytical and numerical mathematical models of pollutant transport in saturated and unsaturated groundwater systems have been developed. In particular, a one-dimensional, multi-solute, multi-layer, numerical model has been constructed to simulate transient simultaneous movement of solutes and moisture in unsaturated soils. This model is being calibrated and verified with unsaturated solute/moisture field data from a wastewater recharge basin whose depth to water is approximately 25 feet.

Several multi-dimensional models for saturated water and solute transport have also been constructed including a three-dimensional finite element-Galerkin model. Four closed-form analytical solutions which describe pollutant transport in two- and three-dimensional systems subject to time-varying distributed (Gaussian and step) boundary conditions have also been developed.

The analytical solutions serve as checks on the multi-dimensional numerical models and the two and three-dimensional versions of the modular numerical model. These models have been calibrated with field data collected on a monthly basis (since October 1975) from a three-dimensional well network which has approximately 120 wells in the leachate plume of the sanitary landfill.

CONTACT FORM

Person Contacted and Affiliation:

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Type of Procedure:

Engineering Evaluation and Judgment (Non-procedural)

Discussion:

Approach Taken. Site evaluation is performed by the application of engineering principles.

Results/Conclusions to Date. Mr. Curry applies basic engineering concepts (e.g., mass balance) as a site-selection method (non-procedure). He feels that some form of Criteria Listing may be feasible as a Decision Procedure; however, the final selection or evaluation of sites will depend heavily on the judgment of the engineers and scientists evaluating or approving the site.

Key Publications:

1. Curry, N.A. Hazardous waste management and disposal, chemical and industrial. Presented at the Engineering Foundation Conference, Land Application of Residual Materials, Easton, Maryland, Sept. 26-Oct. 1, 1976.

2. Curry, N.A. Management of organic materials in landfills. Presented at 32nd Purdue Industrial Conference, May 1977.

3. Curry, N.A. PCB movement in the environment. Presented at 9th mid-Atlantic Industrial Conference, Bucknell University, Aug. 1977.

4. Curry, N.A. Aluminum sludge generation and disposal. Presented at American Water Works School Program, Lake Placid, N.Y., Sept. 1977. Journal Amer. W.W. Assoc., July 1978.

CONTACT FORM

Persons Contacted and Affiliation:

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Mr. Thomas Lindstrom
Dr. Larry Boersma

Oregon State University
Department of Chemical Engineering and
Agricultural Chemistry
Corvallis, Oregon
Phone: 503-754-4951

Type of Procedure:

Models/Simulation

Discussion:

Approach Taken. Basically, the model landfill and the soil region is divided into a simple two-dimensional grid. Each compartment of the grid has dimensions of length DELX, depth DELZ = 2 feet, and width WIDTH sufficient to encompass the contaminated zone of the landfill.

SIM-1 is considered to be a two-dimensional model since calculations account for distribution of the chemical in two directions only, i.e., vertical and horizontal. (Although dispersion of the chemical in a lateral direction does occur, for the purpose of the model, it is assumed to be zero; therefore, the model tends to calculate a higher groundwater concentration.)

The elevation of the top of each landfill and soil column and the elevation of the bottom of each landfill column are specified as input data.

The model logic is based upon a chemical mass balance at each point in time and space to allow concentration estimates inside of, as well as exterior to, a landfill disposal site. The model incorporates the following important physical-chemical parameters:

1. Hydrodynamic flow velocity based upon the porosity and hydrodynamic gradient of the porous medium.

2. Variable water table.

3. Variable rainfall.

4. Reversible adsorption-desorption phenomena.

5. First-order irreversible sorption or first-order chemical reaction.

6. First-order microbial degradation kinetics.

State of Development. Basically, the model is capable in its present form to approximate the conditions within and in the adjacent vicinity of a working landfill. However, it is still a very simplified technique. Improvements have been undertaken by Canadian research personnel. The model now has capability to simulate the following parameters:

1. Variations in soil character for each cell which allows the modeling of layered soil conditions. Also included in these amendments is a water balance check.

2. Cell dimensions can be varied in both the vertical and the horizontal directions. This allows greater flexibility in choosing a cell size.

3. Time increments for each interaction of the program can be varied according to the estimated column drainage time of the site being modeled. The column drainage time is the time for a column of soil above the water table to drain to field capacity.

4. Mass transport is considered in both the horizontal and vertical directions to allow for density effects and vertical gradients.

5. The maximum number of cells below the water table is a variable according to the site characteristics. This allows a more complete modeling of the saturated layers between water table and underlying impermeable layers.

Pros and Cons. The main advantage of the Oregon model is that it represents a simple and easy-to-use procedure. The basic logic of the model can be readily understood without recourse to complex math. Input parameters are clearly identified, and the output is easy to interpret.

However, a number of the simplifying assumptions are embodied in the logic of the program which are not readily apparent to the user.

It would be valuable if these assumptions were spelled out as input requirements needing the authority of the user to specify the input. The procedure by which flow in the water table is modeled may be overly simplistic. The assumption is basically one-dimensional flow. It is not known whether an increase in the number of cells below the water table, which are capable of passing saturated flow, will in itself solve this problem.

Known Application. Basically, the model was developed for use in a study of the Brown's Island Site near Salem, Oregon. The feature of the model which simulates periodic inundation of the site is a representation of Brown's Island conditions. However, since the monitoring information available for Brown's Island was extremely limited, the application of the model to Brown's Island conditions cannot be viewed as a valid verification procedure. An evaluation of the impact of various organic pesticides upon groundwater conditions has been conducted by the Oregon Department of Environmental Quality, but it is not apparent that the results of these evaluations were in any way incorporated in landfill design requirements. No other application has been identified.

Availability as a Decision Procedure. With the provision that the required adsorption constants in biodegradation rates should be available, the model in present form could be used as a decision procedure. However, the standard methods available by which these parameters can be obtained are open to question even in single-element situations. The prospect of modeling interactive chemicals or interactive leachate flow is probably a long way off. In addition, the simplifying assumptions referred to earlier, presently require considerable finesse on the part of the user. In the present state of the art, this special ingredient will always be needed, though not necessarily in the form incorporated in this model. Further sophistication of the modeling procedure itself is probably unwise since the basic building-block approach is already an overriding simplistic assumption. Further development to overcome this simplification would lead automatically to the more sophisticated finite-element or finite-difference models.

Key Publication:

1. Elzy, E., L. Boersma, F.T. Lindstrom, and C. Wang. Disposal of environmentally hazardous waters. Task Force Report for Environmental Sciences Center, Oregon State University, Dec. 1974.

CONTACT FORM

Person Contacted and Affiliation:

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Soil Scientist

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Agricultural Research Service
Beltsville, Maryland 20705
Phone: 301-344-3163

Type of Procedure:

Field and Laboratory Analyses of Sludge Application to Land

Discussion:

Approach Taken. Dr. Epstein has authored and coauthored publications on composting and sludge application to land. Dr. Epstein was one of a project team which investigated the "Trench Incorporation of Sewage Sludge in Marginal Agricultural Land" for an experimental operation in the Beltsville, Maryland area. This investigation evaluated the effects of trench incorporation of limed, undigested (raw-limed) sewage sludge and of digested sewage sludge on groundwater quality. The de-watered sludges (20-25 percent solid) were placed in trenches that were 60-cm wide by 60-cm deep by 60-cm apart or 60 x 120 x 120 cm. Some 40 test wills were drilled to monitor groundwater quality beneath and adjacent to the entrenchment site.

Results/Conclusions to Date. The investigation entailed an evaluation of the movement of nitrate, chlorides, pathogens, and heavy metals. The major conclusions to data (September 1975) are as follows:

1. Analyses of well waters did not show increased concentrations of nitrate or ammonia nitrogen.

2. There was evidence of increasing movement of nitrogen downward from the entrenched sludge with time.

3. Greater levels of organic materials moved into the soil from the raw limed sludge than the digested entrenched sludges and provided a greater potential for dinitrification.

4. Elevated chloride concentrations and elevated conductivities were sporadically detected.

5. Movement of fecal coliform or salmonella bacteria was not detected out of the entrenched sludge into the surrounding soil or down to the groundwater.

6. Raw sludge limed to a high pH decreased tremendously the number of salmonella and fecal coliform bacteria. With a sludge pH drop, these organisms showed only a temporary increase in numbers.

7. There was essentially no movement of zinc or copper out of the entrenched raw limed sludge.

8. As the entrenched sludge became aerobic, DTPA-TDA extractable metals increased.

9. A major conclusion was that since the effects of entrenchment had been studied for a short time under limited conditions, any limited plan to use trenching and large-scale land application of sludge should include careful monitoring.

State of Development. Research is continuing to date on this method of sludge disposal. Of particular concern is the monitoring of heavy metals from the sludge into the underlying soils and groundwater.

Availability as a Decision Procedure. Data can be expected to be available within three years that would aid in the permitting of sludge application to land sites. No formal decision procedure, however, is planned as an output of this research.

Key Publications:

1. Epstein, E., J.M. Taylor, and R.L. Chaney. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. J. Environmental Quality, Vol. 5, No. 4, Oct.-Dec. 1976.

2. Walker, J.M., W.D. Burge, R.L. Chaney, E. Epstein, and J.D. Menzies. Trench incorporation of sewage sludge in marginal agricultural land. Environmental Protection Agency, EPA-600/2-75-034, Sept. 1975.

CONTACT FORM

Person Contacted and Affiliation:

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Associate Professor of Civil Engineering

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Types of Procedures:

Models/Simulation
Empirical Data, and Laboratory and Field Investigations

Discussion:

Approach Taken. Dr. Farquhar has authored and coauthored (primarily with Mr. F. Rovers) numerous papers relative to the attenuation of landfill leachate and industrial waste through soil columns, landfill leachate and gas generation and characterization, and methodologies for landfill leachate treatment. The approach taken in his investigations relative to leachate generation and attenuation shows the following evolutionary process:

1. Initial laboratory investigations to evaluate leachate flow and attenuation through soil columns.

2. Field investigations relative to leachate concentration and attenuation with distance and texture of deposits down gradient from actual landfill sites.

3. Development of a three-dimensional finite element model for the prediction of leachate concentration at given points down gradient from a landfill.

The series of landfill studies conducted to date has cost approximately $250,000. Dr. Farquhar is particularly interested in waste interactions and in the development of adsorption isotherms, assessment of biological activities, and physical chemical reactions. The approaches taken include the following:

1. Research to measure and predict contaminant removal from soil by passage of leachate applied by batch dispersal methods on both

disturbed and undisturbed soil columns. A range of soil types were investigated under both aerobic and anaerobic conditions, and the soils were described in terms of grain size, ion exchange capacity, organic carbon content, and resident ion distribution both before and following exposure to leachate.

2. Investigation of the use of dispersed soil experiments for examining soil contaminant interactions.

3. Evaluation of the attenuation of two liquid industrial wastes and soil columns typical of the environment in Ontario, Canada.

4. An assessment of leachate production, characteristics, migration into the environment, control and treatment based upon analysis of actual field case histories and certain laboratory procedures.

5. An assessment of the effect of the season on landfill leachate and gas production.

6. Development of guidelines for landfill location and management for water pollution control.

7. An assessment of the state of the art of groundwater contaminant modeling.

8. Continued evaluation of landfill leachate monitoring data generated at existing sites.

Results/Conclusions to Date. Significant results and conclusions from the numerous investigations conducted have been arrived at to date. These are as follows:

1. Dilution is an important mechanism of attenuation for all of the liquid waste contaminants in the two industrial wastes studied (steel plant liquors and alkaline cleansing wastes).

2. Desorption was exhibited by all contaminants studied and was most prominant for those which were attenuated primarily by the mechanism of dilution.

3. Attenuation data collected from the dispersed soil experimentations can be used to project soil water concentrations in a field situation by the use of a correction factor; however, this was not determined during the project.

4. The zone of influence of the disposal operation is closely related to the waste loading.

5. A soil/waste interaction matrix (see Dr. C.R. Phillips) was developed during the course of the contaminant attenuation in disperse soil investigations.

6. It was observed that the remolded soils provided more attenuation by dilution than did the undisturbed soils.

7. Removal isotherms constructed from the dispersed soil studies can be used to predict the breakthrough curves for some contaminants resulting from remolded soil column experiments.

8. The types and amounts of chemicals leached from refuse were sufficient to create a serious pollution hazard to groundwaters in a proximity of landfill sites.

9. Definitive conclusions can be drawn for gas and leachate production relative to seasonal climatic changes.

10. Once refuse attains a moisture content equal to field capacity, leachate production becomes equivalent to the net infiltration.

11. The yearly dissolved and suspended contaminant load discharge to the environment by a landfill is significantly less than that of a pollution controlled plan where both serve the same population.

12. The major factors affecting leachate composition and strength are refuse composition, rate of infiltration, and site age.

13. Most inorganics disposed of in a landfill will apparently be leached to the environment eventually.

14. A growing body of information exists on the field assessment of leachate contaminant attenuation under a variety of conditions.

15. Existing data show that, with intergranular flow, leachate attenuation is significant for fine grain soils.

16. Waste disposal sites should be located and designed in a manner that takes advantage of natural processes to minimize problems with water pollution control.

In addition, some direct personal conclusions have been derived as follows:

1. Before any meaningful prediction can be made, there is a need to define the hydrogeologic system, the fluid flux through that

system, and the contaminant flux which is a waste characterization and waste interaction.

2. To date, the most definitive approach will be to develop models for the fluid flux and contaminant soil interactions for the prediction of pollution concentration at a given point down gradient from a disposal site.

State of Development. A large empirical data base has been developed from both laboratory and field investigations which would serve as a useful decision procedure for new waste disposal operations by comparison with existing operations and their documented degree of attenuation. The three-dimensional model mentioned above is currently under development and will not be calibrated, tested, verified and made available for use for a period of approximately three years.

Availability as a Decision Procedure. It is proposed that the empirical data developed to date, coupled with a hydrologic site investigation and monitoring data of a geologically similar site, could be used now to predict the contaminant migration from a proposed disposal site. The matrix development, testing, verification, and actual use can be expected to be on line within three years.

Key Publications:

1. Farquhar, G.J. Contaminant movement from a landfill. Presented at the Ontario Pollution Control Association Meeting, Brampton, March 1973.

2. Farquhar, G.J. and F.A. Rovers. Landfill contaminant flux - surface and subsurface behaviour. 21st Industrial Waste Conference, MOE, June 1974.

3. Farquhar, G.J. Research in Canada on groundwater contamination from waste disposal in soil. Presented at the London Geological Society, Feb. 1976.

4. Farquhar, G.J. Experimental determination of leachate contaminant attenuation in soils. Presented at Eidgenossische Technische Hochschulen, EAWAG, Zurich, Switzerland, April 1976.

5. Farquhar, G.J. and F.A. Rovers. Evaluation of contaminant attenuation in the soil to improve sanitary landfill selection and design. Proceedings of the International Conference on Land for Waste Management, National Research Council of Canada, Ottawa, Oct. 1-3, 1973.

6. Farquhar, G.J. and P.M. Huck. Water quality modelling using the Box-Jenkins method. Journal of Environmental Engineering Division, 100, EE3, June 1974.

7. Farquhar, G.J. and F.A. Rovers. Leachate attenuation in undisturbed and remoulded soil. In proceedings of Symposium on Leachate and Gas Production, Rutgers Univ., Cook College, New Brunswick, N.J., March 1975.

8. Farquhar, G.J., H.M. Hill, and R.N. Farvolden. Phase I report, sanitary landfill study. Ontario Department of Health and the Grand River Conservation Authority, IRI Project 8083, March 1970.

9. Farquhar, G.J., H.M. Hill, and R.N. Farvolden. Phase II report, Sanitary landfill study. Ontario Department of Health and the Grand River Conservation Authority, IRI Project 8083, March 1971.

10. Farquhar, G.J. and F.A. Rovers. Sanitary landfill study final report, vol. I, field studies on groundwater contamination. Ontario Department of Health and the Grand River Conservation Authority, Waterloo Research Institute Project 8083, Oct. 1972.

11. Farquhar, G.J. and F.A. Rovers. Sanitary landfill study final report, vol. II, effect of season on landfill leachate and gas production. Ontario Department of Health and the Grand River Conservation Authority, Waterloo Research Institute Project 8083, Oct. 1972.

12. Farquhar, G.J. and F.A. Rovers. Monitoring contaminants from a landfill, study plan. Canada-Ontario Committee, Canada-U.S. Agreement, March 1974.

13. Farquhar, G.J. and W. Seitz. Sanitary landfill study, volume III, A mapping technique for landfill location. Ontario Ministry of the Environment, April 1975.

14. Farquhar, G.J. and F.A. Rovers. Sanitary landfill study, volume IV, Guidelines to landfill location and management for water pollution control. Ontario Ministry of the Environment, April 1975.

15. Farquhar, G.J. Liquid industrial waste attenuation in the soil. Waste Management Branch, Environmental Protection Service, Environment Canada, May 1975.

CONTACT FORM

Person Contacted and Affiliation

Dr. Allen Freeze

University of British Columbia
Department of Geological Science
Vancouver, British Columbia
Phone: 604-228-6462

Type of Procedure:

Groundwater Modeling

Discussion:

Approach Taken. In a telephone conversation with Dr. Freeze, it became apparent that his work is entirely concerned with the sophisticated quantitative modeling of groundwater movement. Dr. Freeze is of the opinion that efforts to adequately model changes in groundwater quantity are unlikely to prove useful given the present state of the art.

CONTACT FORM

Person Contacted and Affiliation:

Dr. Wallace H. Fuller

University of Arizona
Department of Soils, Water and Engineering
Tucson, Arizona 85721

Type of Procedure:

Criteria Listing

Discussion:

Approach Taken. Dr. W.H. Fuller is studying factors which attenuate contaminants in leachates from municipal solid waste landfills. Although the work is associated with municipal waste, the impact of co-disposal of municipal and hazardous waste was also considered. This project emphasizes the influences of soil and contaminant properties on constituent migration and attenuation.

The project is concerned with contaminants normally present in leachates from municipal landfills and with contaminants that are introduced or increased in concentration by co-disposal of hazardous wastes. These contaminants are: arsenic, beryllium, cadmium, chromium, copper, cyanide, iron, mercury, lead, nickel, selenium, vanadium, and zinc. Eleven soils representing seven major orders were collected and used in this study.

A landfill leachate was continuously flushed through a column of soil, and the effluent from the soil was evaluated. Two types of variables were considered for regression analysis of the results: (1) those representing soil properties--clay, sand, percent of free iron oxide, surface area, total manganese, pH, and electrical conductivity of the saturated extract; and (2) those measurements characterizing the migration and/or attenuation of the trace metals (mass absorbed per gram of soil per ml of added leachate). A mass balance for each soil column was calculated from daily measurement of the effluent from the soil and input at the soil surface.

Results/Conclusions to Date. Based on the data analysis completed to date, Dr. Fuller has concluded that clay content, surface area of soil, and content of hydrous oxides (free iron) and free lime will be the soil properties most useful in selecting safe disposal sites for municipal and hazardous waste. Data suggested that the use of clay, lime, and iron oxides should be examined as practical management tools for minimizing the movement of contaminants from landfills.

State of Development. The project is nearing completion, and the data base and regression equations should be available for use within three years. However, the application of this data to other leachates and soils has not been tested.

Availability as a Decision Procedure. A more thorough validation of the procedure must be performed before wide use is made of the procedure.

Key Publications:

1. Fuller, W.H. Some microbiological transformations in soil. Proc. of Agr. and Pollut. Seminar, U of A Engr. Exp. Sta. EES Series Rep. 35, 1971. 60 p.

2. Amoozegar-Fard, A., W.H. Fuller, and A.W. Warrick. Migration of salt from feedlot waste as affected by moisture regime and aggregate size. J. Environ. Qual., 4:468-472, 1975.

3. Korte, N.E., J.M. Skopp, E.E. Niebla, and W.H. Fuller. A baseline study of trace metal elution from diverse soil types. Water, Air, and Soil Pollu., 5:149-156, 1975.

4. Marion, G.M., D.M. Hendricks, G.R. Dutt, and W.H. Fuller. Aluminum and silica solubility in soils. Soil Sci., 121:(2)76-85, 1976.

5. Alesii, B.A. and W.H. Fuller. The mobility of three cyanide forms in soils. In Residual Management by Land Disposal. Proceedings of the Hazardous Waste Research Symposium, February 2-4, 1976. Tucson, Arizona. W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 280 p.

6. Fuller, W.H. and N. Korte. Attenuation mechanisms of pollutants through soils. In Gas and Leachate from Landfills, Formation, Collection and Treatment. Proceedings of a research symposium, March 25-26, 1975, New Brunswick, New Jersey. E.J. Genetelli and J. Cirello, eds. EPA-600/9-76-004, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 196 p.

7. Fuller, W.H., C. McCarthy, B.A. Alesii, and E. Niebla. Liners for disposal sites to retard migration of pollutants. In Residual Management by Land Disposal. Proceedings of the Hazardous Waste Research Symposium, February 2-4, 1976, Tucson, Arizona. W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 280 p.

8. Korte, N.E., W.H. Fuller, E.E. Niebla, J. Skopp, and B.A. Alesii. Trace element migration in soils: desorption of attenuated ions and effects of solution flux. In Residual Management by Land Disposal. Proceedings of the Hazardous Waste Research Symposium, February 2-4, 1976, Tucson, Arizona. W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 280 p.

9. Fuller, W.H., ed. Residual management by land disposal. Proceedings of the Hazardous Waste Research Symposium, February 2-4, 1976, Tucson, Arizona. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 280 p.

10. Fuller, W.H., N.E. Korte, E.E. Niebla, and B.A. Alesii. Contribution of the soil to the migration of certain common and trace elements. Soil Science, 122(4):223-235, 1976.

CONTACT FORM

Person Contacted and Affiliation:

James P. Gibb
Associate Engineer

Illinois State Water Survey
Water Resources Building
605 East Springfield, IL
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Type of Procedure:

Research into investigative and monitoring techniques for identifying leachate from surficial toxic waste sites.

Discussion:

Approach Taken. The vertical and horizontal migration patterns of zinc, cadmium, copper, and lead through the soil and shallow aquifer systems at two secondary zinc smelters were identified through the use of soil-coring and monitoring-well techniques. The vertical migration of these elements at a third zinc smelter was also defined. The migration of metals that occurred at the three smelters has been limited to relatively shallow depths into the soil profile by attenuation processes.

Results/Conclusions to Date. Cation exchange and precipitation of insoluble metal compounds, as a result of pH changes in the infiltrating solution, were determined to be the principal mechanisms controlling the movement of the metals through the soil. Increased metals content in the shallow groundwater system has been confined to the immediate plant sites. At a fourth site, it appeared that the glacial materials were retarding the migration of organic pollutants. Problems associated with sampling and analyses for chlorinated hydrocarbon waste products prohibited further definition of the effectiveness of the soils in retaining the pollutants from this site. No detectable organic pollutants were found in the shallow groundwater system.

Soil coring was determined to be an effective investigative tool, but was not suitable by itself for routine monitoring of waste disposal activities. However, it should be used to gather preliminary information in determining the proper horizontal and vertical locations for monitoring well design. The analysis of water samples collected in this project generally did not provide a stable reproducible pattern of results. This indicates the need for development of sampling techniques to obtain representative water samples. The failure of some well seals in a highly polluted environment also indicates the need for additional research in monitoring well construction.

Key Publication:

1. Gibb, J.P., K. Cartwright, D. Lindorff, and A. Hartley. Field verification of toxic waste renovation by soils at disposal sites. EPA Grant No. R 803216-01-3 (unpublished report).

CONTACT FORM

Person Contacted and Affiliation:

Dr. Eugene Glysson, P.E.
Professor, Civil Engineering

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Civil Engineering Department
Ann Arbor, Michigan 18109
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Type of Procedure:

Non-procedure Engineering Evaluation

Discussion:

Approach Taken. Dr. Glysson is one of many experts in the field that does not rely on specific procedures; instead, he evaluates disposal sites through the use of engineering concepts/judgments. He feels that if all waste/site elements were put into a list of criteria, this list would be of help to those people making these decisions.

CONTACT FORM

Persons Contacted and Affiliation:

Dr. R.A. Griffin
Assistant Geochemist

Dr. N.F. Shimp
Principal Chemist

Dr. K. Cartwright
Geologist

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Natural Resource Building
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Types of Procedures:

Laboratory Simulation
Criteria Ranking

Discussion:

Approach Taken. In general, the approach is derived entirely from a column leaching study with some supporting field verification. The leachate was taken from the 15-year old DuPage County Sanitary Landfill. Chemical characteristics are shown in Table B-1.

Treated clay minerals (montmorillonite, illite, kaolinite) formed the soil medium through which the "standard" leachate was run for periods of up to 10 months. Effluents were collected periodically throughout this period and were analyzed for 16 chemical constituents. The column contents were then cut into sections and analyzed to determine the vertical distribution of chemical constituents in each column. A general table of attenuation levels is suggested by the study.

The results of the tests were analyzed to determine the mechanisms of attenuation. By the use of various statistical methods comparing the results of the analysis through three different clays, it was concluded that the four chemical constituents with the highest ATN ranking (lead, zinc, cadmium, mercury) were in fact attenuated by a precipitation mechanism. Table B-2 identifies the attenuation mechanisms.

TABLE B-1

CHEMICAL CHARACTERISTICS OF LANDFILL LEACHATES

Component	Range of All Values Given by Garland and Mosher (1975) mg/L	Du Page Leachate Used in Column Study mg/L	
		Natural	Sterile
Chemical oxygen demand (COD)	40 - 89,520	1,340.	10,603.*
Biological oxygen demand (BOD)	9 - 54,610	-	-
Total organic carbon	256 - 28,000	-	-
Organic acids	-	333.	290.
Carbonyls as acetophenone	-	57.6	90.1
Carbohydrates as dextrose	-	12.	11.
pH	4 - 9	6.9	7.2
Eh (oxidation potential) (mv)	-	+7.	+75.
Total dissolved solids	0 - 42,276	5,120	5,280
Electrical conductivity (mmhos/cm)	3 - 17	10.20	10.42
Alkalinity ($CaCO_3$)	0 - 20,850	-	-
Hardness ($CaCO_3$)	0 - 22,800	-	-
Total phosphorus	0 - 154	0.1	0.1
Ortho-phosphate	6 - 85	-	-
NH_4-nitrogen	0 - 1,106	862.	773.
NO_3+NO_2-nitrogen	0 - 1,300	-	-

TABLE B-1
(continued)

Component	Range of All Values Given by Garland and Mosher (1975) mg/L	Du Page Leachate Used in Column Study mg/L	
		Natural	Sterile
Aluminum	-	0.1	0.1
Arsenic	-	0.11	0.14
Boron	-	29.9	28.5
Calcium	5 - 4,080	46.8	43.2
Chloride	34 - 2,800	3,484.	3,311.
Sodium	0 - 7,700	748.	744.
Potassium	3 - 3,770	501.	491.
Sulfate	1 - 1,826	0.01	0.01
Manganese	0 - 1,400	0.01	0.1
Magnesium	16 - 15,600	233.	230.
Iron	0 - 5,500	4.2	3.0
Chromium	-	0.1	0.1
Mercury	-	0.0008	0.87*
Nickel	-	0.3	0.3
Silicon	-	14.9	15.0
Zinc	0 - 1,000	18.8	16.3
Copper	0 - 10	0.1	0.1
Cadmium	0 - 17	1.95	1.88
Lead	0 - 5	4.46	4.26

*Added as a result of sterilization maintenance.

TABLE B-2

RANK OF CHEMICAL CONSTITUENTS IN MUNICIPAL LEACHATE ACCORDING TO RELATIVE MOBILITY THROUGH CLAY MINERAL COLUMNS

Chemical Constituent	Mean Attenuation Number	Qualitative Grouping	Principal Attenuation Mechanism
Pd	99.8		Precipitation/exchange
Zn	97.2		Precipitation/exchange
Cd	97.0	High	Precipitation/exchange
Hg	96.8		Precipitation/exchange
Fe	58.4		Anaerobic reduction
Si	54.7		--
K	38.2	Moderate	Cation exchange
NH_4	37.1		Cation exchange
Mg	29.3		Cation exchange
COD	21.3		Microbial degradation
Na	15.4	Low	Cation exchange
Cl	10.7		Dispersion
B	-11.8		Artifact
Mn	-95.4	Negative	Elution from clay
Ca	-656.7	(elution)	Desorbed from clay

However, in discussions with Keros, Cartwright, and Bob Griffin, the point was made that the exchange mechanism can only be considered a long-term storage system since adsorption and desorption are taking place continuously.

A significant determinant of exchangeability is the sorption isotherm for the particular material. For any given solution, sorption may be expressed as the ratio of the quantity of material sorbed to the equilibrium concentration of the material:

$$\text{Sorption} = \frac{\text{Quantity sorbed}}{\text{Equilibrium concentration}}$$

A complete isotherm is a curve representing this ratio for a variety of equilibrium concentrations (at fixed temperatures and pH conditions).

In general, adsorption of the cationic heavy metals (Pb, Cd, Zn, Cu, and Cr+3) was found to increase as the pH increased. Adsorption of the anionic heavy metals (Cr+6, As, and Se) decreased as the pH increased.

It was concluded that removal of the heavy metal cations from solution is primarily a cation-exchange adsorption phenomenon that is affected by pH and ionic competition.

Results/Conclusions to Date. Griffin has developed a pollution hazard factor which uses the ATN number generated by the column tests.

To overcome objection to a formula developed by EPA for determination of a pollution hazard index for municipal leachates, the ranking equation was changed to read as follows:

$$R = (Q)\ (HI)$$

where R and Q are as previously defined and HI is the pollution hazard index for the waste. The pollution hazard index (HI) is a toxicity index for the element within a given leachate, multiplied by a mobility index for the element in a particular leachate-clay system.

The pollution hazard for the whole leachate is that for the constituent with the highest hazard within the particular leachate.

$$HI = \left(\frac{C}{DWS}\right)\ (100 - ATN)$$

where:

C = The effective concentration of the chemical constituent.
DWS = The drinking water standard (U.S. EPA, 1973b).
ATN = the attenuation number for the given element.

The effective concentration is defined as the concentration of the chemical constituent in the leachate plus the concentration of the constituent that may be leached from the soil or clay. When attenuation is occurring, the effective concentration is merely the concentration of the constituent in the influent leachate. When elution from the columns is occurring, as it did for the three elements B, Ca, and MN, the effective concentration is the leachate concentration plus the concentration eluted from the column.

State of Development. The proposed system of ranking pollution hazards in municipal leachates overcomes the objections posed for the CP component of the Priority Ranking System. The toxicity index can, in most cases, be readily computed from a chemical analysis of the leachate.

The evaluation of the toxicity index is flexible in that drinking water standards need not be the criteria. LD_{50} (lethal dose of 50 percent of the population) values, or some other toxicity evaluation, can be used in place of drinking water standards. What is important is the computation of the ratio of the actual waste concentration relative to whichever toxicity evaluator is used. The mobility index, however, must be determined experimentally or be estimated from the data presented in the paper. The results of this study indicate that the mobility index will be function of: the CEC of the earth material, the cations initially present on the exchange complex, the chemical composition of the leachate, and the pH of the leachate.

Ultimately, the value of this or any other procedure rests entirely on the accuracy of the analytical procedure used. In the case of Griffin's work, long-term column tests were used. Shaker tests and TLC methods have also been used, but no specific standard method has evolved. There seem to be limitations in the use of each method depending upon the nature of the leached material under test.

Availability as a Decision Procedure. There is no further specific development of the formula presently contemplated, although further research into attenuation (or retardation) mechanisms continues.

Key Publications:

1. Griffin, R.A. and R.G. Burau. Kinetic and equilibrium studies of boron desorption from soil. Soil Science Society of America Proceedings, v. 38, 1974. p. 892-897.

2. Griffin, R.A. and N.F. Shimp. Attenuation of pollutants in municipal landfill leachate by clay minerals. Final report for contract 68-03-0211, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976.

3. Griffin, R.A., K. Cartwright, N.F. Shimp, J.D. Steele, R.R. Ruch, W.A. White, G.M. Hughes, and R.H. Gilkeson. Attenuation of pollutants in municipal landfill leachate by clay minerals, part 1-column leaching and field verification. Illinois State Geological Survey, Environmental Geology Note 78, 1976. 34 p.

4. Griffin, R.A., R.R. Frost, A.K. Au, G.D. Robinson, and N.F. Shimp. Attenuation of pollutants in municipal landfill leachate by clay minerals, part 2-heavy-metal adsorption. Illinois State Geological Survey, Environmental Geology Note 79, April 1977.

CONTENT FORM

Person Contacted and Affiliation:

Dr. D. Joseph Hagerty
Associate Professor

University of Louisville
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Louisville, Kentucky 40208
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Type of Procedure

Criteria Ranking

Discussion:

Approach Taken. The criteria ranking procedure developed by Pavoni, Hagerty, and Lee in 1971-1972 was intended to serve as a decision making tool to determine:

1. The hazardousness of various waste substances.

2. The suitability of various land sites to contain waste substances.

3. The feasibility of disposing of a waste substance at a specific site.

The development of this procedure was undertaken as a master's thesis by Robert E. Lee from September 1971 to May 1972 and was not funded.

The procedure basically encompasses two ranking formulas: one for waste products, and one for landfill sites. The waste ranking consists of five quantified parameters: human toxicity, groundwater toxicity, disease transmission potential, biological persistence, and waste mobility. The total waste ranking is correlated with the hazardousness of wastes as follows:

Rank	Hazardousness
0 - 30	Nonhazardous
31 - 60	Slightly hazardous
61 - 80	Moderately hazardous
> 80	Hazardous

The site ranking consists of ten qualified parameters: infiltration potential, bottom leakage potential, organic content, filtering capacity, adsorptive capacity, buffering capacity, potential travel distance, groundwater velocity, prevailing wind direction, and population factor. Again, the total site ranking is correlated with the suitability of the site for waste disposal.

Results/Conclusions to Date. The ranking system developed was intended to serve as a first step in waste and site evaluation which would be verified and upgraded by others. Unfortunately, that was not the case.

Hagerty's major comment with regard to the Decision Procedures study was that it would be a major mistake to publish a "cookbook" on site evaluation and/or selection. His suggested approach was:

1. Planning should be conducted initially to determine, in general, what areas of a state or region are amenable to waste disposal. This general planning could be done with a crude approach similar to LeGrand's.

2. Wastes should be classified with a system similar to that used in California or the waste ranking developed by Pavoni, Hagerty, and Lee. This would enable planners to develop site-waste match-ups, i.e., which wastes could be deposited in what general areas.

3. When two or three specific sites are chosen from a general area, then a more-sophisticated, site-evaluation approach is needed in which competent soils-hydrogeologist professionals must be involved.

Hagerty's comments of Phillips' work are as follows:

1. The chemical persistence factor is really biological in nature, and should be combined with the biological persistence factor or be omitted.

2. Chemical persistence is also related to the leachate flushing characteristics of the site.

3. Weighting of groundwater gradient toward an existing water supply is a bad assumption.

4. The viscosity factor is not important and should be omitted.

5. The pH factor is debatable. It depends to a large extent on flow and soils characteristics of site. Decrease in importance or omit.

6. The waste application rate should be related to infiltration characteristics of the site, since acceptable "rates" could vary drastically from site to site.

7. Hagerty disagrees with Phillips' comment that ranking sites is more difficult than ranking wastes. He feels just the opposite.

8. Any site or waste rankings should be multiplied (not summed) to emphasize poor rankings.

9. Disease transmission is weighted too low in Phillips' approach.

10. Phillips' soil-site approach is over simplified and, in some cases, is incorrect. Approach is qualitative and broad-brush. It neglects important factors such as containment layer thickness and incorrectly defines clay as an unconsolidated granular material.

Availability as a Decision Procedure. Could be available within 3 years with testing and validation.

Key Publications:

1. Pavoni, J.L., D.J. Hagerty, and R.E. Lee. Environmental impact evaluation of hazardous waste disposal in land. Water Resources Bulletin, Vol. 8, No. 6, Dec. 1972.

2. Hagerty, D.J., J.L. Pavoni, and J.E. Heer, Jr. Solid waste management. Van Nostrand Reinhold, New York, NY, 1973.

CONTACT FORM

Person Contacted and Affiliation:

Dr. Robert K. Ham
Associate Professor of Civil
and Environmental Engineering

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Type of Procedure:

Development of a Standard Leaching Test

Discussion:

Approach Taken. Under contract to the Environmental Protection Agency, Dr. Ham is engaged in the development of a Standard Leaching Test which could be used to predict the leachate from any known waste.

A wide variety of complex wastes is being tested, including milled refuse, paint sludge, paper mill sludge, fly ash, wastewater treatment sludge, and copper oxide/sodium sulfate slurry. The aim is to develop a laboratory procedure which would be standard repeatable and be applicable for a variety of waste types not specifically limited to hazardous wastes.

This "leach test" should not be confused with leachate tests which are typically laboratory procedures used to determine changes in leachate concentration after passage through a soil column.

Results/Conclusions to Date. The results and conclusions are not available at this time.

Key Publications:

1. Ham, R.K. and R. Karnauskas. Leachate production from milled and unprocessed refuse. ISWA Bulletin No. 14/15:3-16, Dec. 1974.

2. Reinhardt, J.J. and R.K. Ham. Final report on a demonstration project at Madison, Wisconsin to investigate milling of solid wastes between 1966 and 1972 - vol. 1. U.S. Environmental Protection Agency, Washington, D.C., 1973. p. 48-63.

3. Ham, R.K. The generation, movement and attenuation of leachates from solid waste land disposal sites. Waste Age, June 1975.

CONTACT FORM

Person Contacted and Affiliation:

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Research Scientist

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Phone: 801-522-5417

Type of Procedure:

Laboratory Simulation

Discussion:

Approach Taken. Experimental evaluation of leachate composition from various industrial wastes and of the movement of these leachates through selected soils is being conducted. The data being collected will be used as a data base to develop mathematical models or decision tools.

The potential increase in hazard resulting from the co-disposal of industrial wastes with municipal refuse was tested using wastes from several different industries, namely, electroplating waste, inorganic pigment waste, and nickel-cadmium battery production waste. Known weights of each waste were mixed with municipal landfill leachate and water. The samples were extracted for 24 and 72 hours, filtered, and the filtrates were analyzed for cadmium, chromium, copper, and nickel by atomic absorption spectrophotometry. The wastes were recovered, mixed with fresh aliquots of municipal landfill leachate or water, and were re-extracted. This serial batch extraction was carried out seven times.

Results/Conclusions to Date. Results of this study show that the migration of hazardous materials in soils is largely controlled by the physical and chemical composition of the soil. However, differences in waste composition cause large differences in the migration of specific elements or compounds through soils. This is demonstrated by comparing the migration of cadmium from four different industrial wastes through one soil type. The wastes were: nickel-cadmium battery, electrical plating, water-base paint, and inorganic pigment waste. The distribution of cadmium in the soil was related to differences in the water.

The concentrations of cadmium, cooper, and nickel in the municipal landfill leachate extracts were much higher than was found in water extracts. Depending on the waste, metal, and extraction number, the increase in solubilization of the metals by the municipal landfill leachate ranged from approximately 100 to 3,000 times higher than with water. Chromium was the only exception. The concentration of Cr metal in both solvent extracts was approximately the same (or slightly greater in the water extracts). These findings dramatically demonstrate the potential hazard that may result from the disposal of certain industrial wastes together with municipal refuse. This raises the serious question as to the advisability of co-disposal in general.

State of Development. The results of this study give insight into waste leachate composition and the importance of this composition on the mobility of a given constituent in the waste. These experiments have been underway for a short period of time, and the data have not been analyzed or used to develop regression equations to define the mobility and attenuation of given waste constituents.

Availability as a Decision Procedure. The results of these experiments are at least 5 to 10 years away from being used for management decisions involving waste and site selection.

Key Publication:

1. Houle, M.J., D. Long, R. Bell, J. Soyland, and R. Grabbe. Effect of municipal landfill leachate on the release of toxic metals from industrial wastes. Chemical Laboratory Division, U.S. Army Dugway Proving Ground, Dugway, Utah.

CONTACT FORM

Persons Contacted and Affiliation:

Dr. Lenny Konikow
Mr. David Grove

U.S. Geological Survey
Department of the Interior
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Denver Federal Center
Denver, Colorado 80225
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Type of Procedure:

Models/Simulation

Discussion:

Approach Taken. Lenny Konikow has been involved with solute transport modeling for the U.S.G.S. for the last three years. His modeling work is based mainly on the logic developed by Pinder and Bredehoeft (1968).

Like Pinder, he is chiefly concerned with the solution of: (1) the equation of flow; and (2) the solute-transport equation.

Flow Equation. By following the derivation of Pinder and Bredehoeft (1968), the equation describing the transient two-dimensional flow of a homogeneous compressible fluid through a non-homogeneous anisotropic aquifer may be written in cartesian tensor notation as:

$$\frac{\partial}{\partial x_i}\left(T_{ij}\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \quad i, j = 1,2$$

where:

T_{ij} = is the transmissivity tensor, L^2/T;
h = is the hydraulic head in the aquifer, L;
S = is the storage coefficient, L^0;
t = is the time, T; and
W = is the volume flux per unit area, L/T.*

Solute Transport Equation. The equation used to describe the two-dimensional transport and dispersion of a given dissolved chemical

*See Key Publication for complete discussion.

species in flowing groundwater was derived by Reddell and Sunada (1970), Bear (1972), and Bredehoeft and Pinder (1973), and may be written as:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(C\,V_i) - \frac{C'W}{nb} + \sum_{K=1}^{s} R_k \quad i,j = 1,2$$

where:

- C = is the concentration of the dissolved chemical species, M/L^3;
- D_{ij} = is the dispersion tensor, L^2/T;
- b = is the saturated thickness of the aquifer, L;
- C' = is the concentration of the dissolved chemical in a source or sink fluid, M/L^3; and
- R_k = is the rate of production of the chemical species in reaction k of s different reactions, M/L^3T.*

Methods of Solving These Equations. Three general classes of numerical methods have been used to solve the solute-transport equation: finite-difference methods, finite-element methods, and the method of characteristics. Each method has some advantages, disadvantages, and special limitations for applications to field problems. Each method also requires that the area of interest be subdivided by a grid into a number of smaller subareas.

The method of characteristics was orginally developed to solve hyperbolic equations. If solute-transport is dominated by convective transport, as is common in many field problems, then this equation may closely approximate a hyperbolic equation and be highly compatible with the method of characteristics. Although it is difficult to present a rigorous mathematical proof for this numerical scheme, it has been successfully applied to a variety of field problems. The development and application of this technique to problems of flow through porous media have been presented by Garder and others (1964), Pinder and Cooper (1970), Reddell and Sunada (1970), and Bredehoeft and Pinder (1973).

The numerical solution is achieved by introducing a set of moving points that are traced with reference to the stationary co-ordinates of a finite-difference grid. Each point has a concentration associated with it and is moved through the flow field in proportion to the flow velocity at its location. The moving points simulate convective transport because the concentration at each node of the grid changes as different points enter and leave its area of influence. The additional change in concentration

*Op. Cit.

due to dispersion, fluid sources, and chemical reactions is computed with an explicit finite-difference equation. This method has generally been coupled with finite-difference solutions to the flow equations. Because the movement of points is analogous to the flow of small volumes of water, it is relatively easy to visualize the relation of the model to the field problem.

Finite-difference methods solve an equation that is approximately equivalent to the partial differential equation. Problems of numerical dispersion, overshoot, and undershoot may induce significant errors for some problems; however, these problems can be solved by selecting proper finite-difference grid sizes to satisfy the convergence criteria. In general, the finite-difference methods are the simplest mathematically and the easiest to program for a digital computer. Lantz and others (1976) describe a three-dimensional, transient, finite-difference model that simultaneously solves the pressure, energy, and mass-transport equations.

Finite-element methods use assumed functions of the dependent variables and parameters to evaluate equivalent integral formulations of the partial differential equations. Recent articles by Pinder (1973), Segol and Pinder (1976), and Gupta and others (1975) have indicated that Galerkin's procedure is well suited to solve solute-transport problems. These methods generally require the use of more sophisticated mathematics than the previous two methods, but for many problems may be more accurate numerically and more efficient computationally than the other two methods. A major advantage of the finite-element methods is the flexibility of the finite-element grid, which allows a close spatial approximation of irregular boundaries of parameter zones. However, Gupta and others (1975) report that, in problems dominated by convection, the finite-element methods may also have difficulties.

The selection of a numerical method for a particular problem depends on several factors, such as accuracy, efficiency/cost, and usability. The first two factors are related primarily to the nature of the field problem, availability of data, and scope or intensity of the investigation. A trade-off between accuracy and cost is frequently required. The usability of a method may depend more on the availability of a documented program and on the mathematical background of the modeler. Greater efficiency is usually attainable if the modeler can modify a selected program for adaption to the specific field problem of interest.*

Results/Conclusions to Date. One of the most impressive features of the work Konikow has been doing is the number of practical field applications of his model. The two most significant are the Arkansas River Valley and the Rocky Mountain Arsenal. More recently, the model was applied to a brine disposal problem in Indiana.

*Substantial portions of this discussion have been excerpted from the Key Publication.

In each case, the movement of conservative chlorides has been very accurately modeled. The model generates isopleths of dissolved-solids concentration over time, and these compare very closely with monitored data in both studies.

Unfortunately, in spite of the accuracy of this type of modeling, there are at least two major drawbacks: (1) extensive data needs; and (2) only conservative species in the saturated environment area are modeled. The former of these drawbacks is difficult to analyze since many such models are set so that extensive data needs seem to follow automatically.

There is much discussion in the U.S.G.S. at present over the second drawback of modeling, and an effort is currently under way to model the interactive processes attendant upon non-conservative solute-transport.

State of Development. The model is verified for conservative ions only.

Availability as a Decision Procedure. Currently, the sophistication of the model far exceeds the sophistication of the data available to run it. This is true for conservative substances; for non-conservative substances, the problems are greater.

As a decision procedure, development within a time frame of 10+ years offers some promise.

Key Publication:

1. Konikow, L.F. Modeling chloride movement in the alluvial aquifer at the Rocky Mountain Arsenal, Colorado. Geological Survey Water Supply Paper 2044, United States Government Printing Office, Washington, 1977.

CONTACT FORM

Person Contacted and Affiliation:

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Type of Procedure:

Empirical Data

Discussion:

Approach Taken. Soils of loamy sand on weathered, sandy dolomite were cored from 6 holes up to 70 feet beneath a municipal waste landfill in Central Pennsylvania. Total and less than 15 m soil samples were analyzed for Mn, Fe, Ni, Co, Cu, Zn, Cd, Pb, and Ag.

Results/Conclusions to Date. Soil extractable Co, Ni, Cu, and Zn could be predicted from the Mn extracted. Based in part on factor analysis of the data, Mn-rich oxides had at least 10-fold higher heavy-metal percentages than Fe-rich oxides, thus reflecting their greater co-precipitation potential. Because of this potential and because of the generally higher solubility of Mn than Fe oxides, more heavy metals may be released from Mn-rich than from Fe-rich soils by disposal of organic-bearing waste. Leaching of the moisture-unsaturated soils in situ, however, is rarely severe enough to completely dissolve both Mn and Fe oxides. Based on the Mn content, Cd, Cu and Pb were depleted in soil moisture beneath the landfill relative to their amount in the soil. This depletion may reflect factors including: heterogeneity in metal content of the soil oxides; preferential resorption of these metals; and removal of the Cd, Cu and Pb as organic precipitates or as inorganic precipitates such as carbonates.

Availability as a Decision Procedure. These empirical data will be useful in assessment of attenuation of metals from municipal landfill leachate; however, no formal decision procedure process will result from this and associated landfill research at Penn State.

Key Publications:

1. Suarez, D.L. and D. Langmuir. Heavy metal relationships in a Pennsylvania soil. 1976. Geochim. et Cosmochim. Acta, v. 40, pp. 589-598.

2. Apgar, M.A. and D. Langmuir. Ground water pollution potential of a landfill above the water table. Groundwater, v. 9, No. 6, 1971. p. 76-96. Proc. Natl. Ground Water Quality Symposium, Denver, Colo., Aug. 25-27, 1971. U.S. Environmental Protection Agency, Water Pollution Control Research Ser. 16060, p. 76-96.

CONTACT FORM

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Type of Procedure:

Criteria Ranking - Numerical Rating System, 1977
(Updates Point Count System, 1964)

Discussion:

Approach Taken. A Numerical Rating System has been established (which replaces the 1964 Point Count System by LeGrand) which weighs four geologic and hydrogeologic characteristics to evaluate the ground water contamination potential from waste disposal sources and other contamination sites at the land surface. The four factors are as follows:

1. Distance from a contamination source to the nearest well or point of water use.

2. Depth to the water table.

3. Gradient of the water table.

4. Permeability and adsorption capacity of the subsurface materials. (note that permeability and adsorption were separate factors in the earlier point count system.)

The rating system was developed by assigning a 0 rating for the least favorable setting for each factor and a 9 rating (5 in one case) for the most favorable setting for each factor. For each site the estimated numerical or point value for each of the four factors is added and the total expressed is a number between 0 and 32 that characterizes the site. A full presentation of this approach is given in the section of "Criteria Ranking".

Results/Conclusions to Date. The rating and expression of these key characteristics is performed in five steps with the first four steps involving the recording of estimated values for each of the four key hydrogeological parameters and the fifth step that of adding the separate point count values determined in the first four steps and describing the site in relative descriptive terms on a scale from poor to excellent. These descriptive terms are an expression of the site hydrogeology relative to those conditions for all possible sites and do not relate to a site in terms of these specific waste or contamination characteristics.

Two apparent problems with the system are the need for good data and the skill required to use the system.

State of Development. The Numerical Rating System has been expanded from the earlier point count system to include a more refined and detailed point value breakdown for the thickness of unconsolidated material over bedrock in 10-foot increments from 0 to greater than 100 feet. Descriptive categories of very poor to poor, fair, good, very good and excellent constitutes step 5 on a basis of the summation of the point counts derived in the assessment of the four key factors described above. Examples of the Numerical Rating System as applied to various waste disposal site and wastes types are given. These waste types include septic tank systems, sanitary landfills, surface impoundments, spills and leaks, stock piles of highway salt, mining wastes, selected burial grounds, pipe line and sewer line breaks, agricultural and waste - broadcast operations and disposal through wells. These examples include a numerical point count assessment of these types of facilities in different hydrogeologic settings. It is noteworthy that a statement is made that "the complexities of sanitary landfill requirements emphasize that the total point value of a site may be only slightly helpful and does not include specific information that is needed. The sequential listing of the total value followed by the specific value for each variable, however, indicates the positive and negative features, as well as the compromises and trade-offs.

It must be emphasized that the Numerical Rating System is designed to provide a quick, first-round approximation of all sites but is not intended to be adequate or substitute for more advanced detailed studies that may be required for certain critical contamination potential situations. The rating system was developed to provide a standardized method of evaluation of sites.

Availability as a Pollution Prediction Technique. This procedure is available now for use in assessment of waste disposal situations.

<u>Key Publications</u>:

1. LeGrand, H.E. and Brown, H.S., Evaluation of ground water contamination potential from waste disposal sources. Prepared for Office of Water and Hazardous Materials, EPA, Washington, D.C. Contract #68-01-4405.

2. LeGrand, H.E. System for evaluation of contamination potential of some waste disposal sites. <u>Journal American Water Works Association</u>, 56(8): 959-974, Aug. 1964.

3. LeGrand, H.E. Environmental framework of ground-water contamination. <u>Groundwater</u>. 3(2): 11-15, Apr. 1965.

4. LeGrand, H.E. Management aspects of groundwater contamination. <u>Journal Water Pollution Control Federation</u>, 36(9): 1133-1145, Sept. 1964.

5. LeGrand, H.E. Patterns of contaminated zones of water in the ground. <u>Water Resources Research</u>, 1(1): 83-95, First Quarter 1965.

CONTACT FORM

Person Contacted and Affiliation:

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Types of Procedures:

Criteria Listing
Criteria Ranking

Discussion:

Approach Taken. Using the available data base, Dr. Overcash and his colleagues have developed what they believe to be the best alternatives for industrial waste disposal. This information has been compiled into a manual which is used for teaching a course on landspreading of industrial wastes. The course is taught on request through the American Society of Chemical Engineering.

The book and course describe what is necessary to establish land application rates for various industrial waste constituents. Actual land area requirements are defined by waste generation rate and waste loading capacity. The process and typical constraints to be utilized in defining the land application rate include: (1) the plant-soil system design, (2) environmental and groundwater constraints, (3) securing relevant local data on geoclimatic and associated factors, and (4) the established land assimilative capacity for certain prevalent industrial constituents. These design stages are discussed in the book with examples cited for certain typical industrial effluent parameters.

State of Development. The procedure and its validation are in the initial stages of development. Although the book has been used as a text, the soundness of the approach has not been validated. The approach appears sound, but considerable management is involved.

Availability as a Decision Procedure. The procedure is available immediately, but requires that the user be knowledgeable regarding the behavior of waste constituents in soils. The procedure also requires large land areas for the disposal of large quantities of industrial waste, although it is still often the most cost-effective with respect to BAT and toxic substances regulations.

Key Publications:

1. Overcash, M.R., J.C. Lamb, and D. Pal. Industrial waste land application, 1977.

CONTACT FORM

Person Contacted and Affiliation:

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Type of Procedure:

Criteria Listing

Discussion:

Approach Taken. Emphasis is on containment of wastes with low permeability deposits and, to a lesser extent, utilization of artificial liners.

Results/Conclusions to Date. Leachate generation is basically understood but not adequately applied in a moisture-routing approach. There is a general lack of a sufficiently-detailed geotechnical model. Attenuation is a valid concept; however, site management and controls are necessary. We are just beginning to understand the aspects of waste loading and attenuation capacity.

CONTACT FORM

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Types of Procedures:

Laboratory Simulation
Field Investigation

Discussion:

Approach Taken. Laboratory and field experiments are being conducted on the mobility and attenuation of trace and heavy metals. This data is being used to illustrate the effectiveness of the soil to attenuate contaminants from municipal and industrial waste. No modeling effort is being made at this time, except perhaps to develop a Criteria Listing.

This group has measured plant uptake of trace and heavy metals from soils treated with municipal and industrial wastes. In conjunction with these studies, they have also measured the concentration distribution of various contaminants in the soil below waste disposal sites. Concentration distributions below sewage disposal ponds have also been considered. Concentration distributions of metals were greater under disposal ponds than when the waste was spread on the soil surface. Metal enrichment was evident to depths as great as three meters under some ponds. The depth and degree of the metal enrichment depended upon pond type and composition of the waste.

Results/Conclusions to Date. This research group readily concludes that the soil has a great capacity to attenuate trace and heavy metals applied to it with time. Much of this work has been conducted in the arid regions of the United States, and it is not well known how the wastes would have behaved under more humid conditions. The experience in this laboratory is sufficient to make qualitative recommendations about western U.S. sites and wastes.

State of Development. A well defined decision procedure is at least ten years away in this laboratory.

Key Publications:

1. Garcia-Miragaya, J. and A.L. Page. Influence of ionic strength and inorganic complex formation on the sorption of trace amounts of Cd by montmorellonite. Soil Sci. Soc. Am. J., 1976 (in press).

2. Page, A.L. and P.F. Pratt. Effects of sewage sludge on effluent application to soil on the movement of nitrogen, phosphorus, soluble salts and trace metals to groundwaters. Proceedings: Second National Conference on Municipal Sludge Management and Disposal. Information Transfer Inc., Rockville, Ma., 1975. p. 179188.

3. Pratt, P.F., A.C. Chang, J.P. Martin, A.L. Page, and C.F. Kleine. Removal of biological and chemical contaminants by soil systems with groundwater recharge by spreading or infection of treated municipal wastewater. In State of the art review of health aspects of wastewater reclamation for groundwater recharge. State Water Resources Control Board, 1975. p. iv-3 to iv-92.

4. Lund, L.J., A.L. Page, and C.O. Nelson. Movement of heavy metals below sewage disposal ponds. J. Environ. Quality, 5:330-334, 1976.

5. Page, A.L. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. Environmental Protection Technology Series, EPA 670/2-74-005, 1974. 96 p.

6. Page, A.L. Trace metals in soils. McGraw-Hill Yearbook of Science and Technology, 1974. p. 381-382.

CONTACT FORM

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Types of Procedures:

Criteria Listing
Matrix

Discussion:

Approach Taken. The decision procedure study was performed by Dr. Phillips and a graduate student in his Department, Jatin Nathwani, through a consulting firm (Chemical Engineering Research Consultants, Ltd.) composed of approximately 30 professors in the Department of Chemical Engineering and Applied Chemistry at the University of Toronto. This study was funded for $10,750 by the Solid Waste Management Branch, Environmental Conservation Directorate, Environment Canada -- Mr. Hans Mooij, Project Director. The time period of the study was June 1975 to April 1976.

This study was intended to provide guidance for the land disposal of hazardous (industrial) wastes in Canada. Another study is currently underway by Environment Canada to develop a procedure for selecting municipal waste disposal sites and is anticipated to take into account economic and political criteria in addition to technical criteria.

It should be noted that the soil-waste interaction matrix presented by Phillips does not entail the development of a "new" procedure. His approach basically combines soil and waste ranking systems that had previously been developed with little, if any, revision. The site ranking portion of Phillips' system was developed by LeGrand in 1964, whereas the waste ranking portion of Phillips' system (with minor revision) was basically developed by Pavoni, Hagerty, and Lee in 1972. A full discussion of this procedure is given in the section entitled Matrix.

Results/Conclusions to Date. Concise technical comments regarding Phillips' system discussed during the interview follow:

1. The system is not time dependent; however, it was not determined whether or not this is a detriment.

2. The matrix is intended as a tool to determine best site for industrial waste disposal.

3. Parameters of both the waste and site should be incorporated in such a procedure.

4. The system allows for site-independent versus site-dependent analysis.

5. The system should be verified.

6. The system does not consider capacity of site to contain leachate from a given quantity of refuse. Whether or not this can be done is debatable.

7. Multiple sites or wastes are considered in the system by adding or multiplying rankings for individual sites or wastes. Phillips agreed that this approach could not be justified, but did not have any thoughts on an alternate approach.

8. When industrial wastes are combined in landfills, a negative impact (less detrimental) usually results; however, Phillips admitted combinations of wastes were very difficult to quantify.

9. The system includes both a biological persistence factor and a chemical persistence factor. However, the chemical persistence factor is basically biological in nature. It is recommended that the biological persistence factor be removed from the system and that the chemical persistence factor be renamed "persistence".

10. The system takes into account whether or not groundwater gradient is toward an existing water supply. This is a bad assumption since the purpose of the system should be to protect all groundwater and not just groundwater that moves toward existing water supplies. This parameter could be omitted.

11. The viscosity factor which is included in the system is probably not a significant parameter and could be omitted.

12. pH of waste is taken into account instead of buffering capacity. The significance of pH in a ranking system is debatable.

13. Capacity rate (Co) is improperly defined; however, the capacity rate is an important factor.

14. LeGrand's approach to one layer versus two layer soil media may not be viable.

15. An application rate factor is not included in the system, but should be included in future systems if possible.

16. The major contribution of Phillips' system was redefining the "sorption" term.

17. Too little emphasis was placed on disease transmission potential by Phillips.

State of Development. It should be noted that this matrix was recently applied to various industrial waste disposal sites in Canada. The results of the application, however, are not presently available.

Availability as a Decision Procedure. If the system proves to be reliable following verification in Canada, it could be usable as a decision procedure within three years. However, it should be stressed that this system is not intended to evaluate the attenuation potential of sites.

Key Publications:

1. Phillips, C.R. Soil-waste interactions: a state-of-the-art review. Solid Waste Management Report EPS 3-EC-76-14, Environmental Conservation Directorate, Oct. 1976.

2. Phillips, C.R. Development of a soil-waste interaction matrix. Solid Waste Management Report EPS 4-EC-76-10, Environmental Conservation Directorate, Oct. 1976.

CONTACT FORM

Persons Contacted and Affiliation:

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Type of Procedure:

Models/Simulation

Discussion:

Approach Taken. These studies involved simulation of contaminant transport processes.

Results/Conclusions to Date. Several one- and two-dimensional transport models have been developed. A one-dimensional transient, saturated/unsaturated multi-ion transport model is currently being tested using experimental leachate quality data obtained from several (laboratory and field) experimental landfills. This has been done to determine if the ability exists to describe mathematically the migration of adsorbing chemicals in multi-ion systems. A two-dimensional, saturated/unsaturated cross-sectional finite element model has been developed and is presently being tested on an existing landfill in Pennsylvania.

State of Development. Models are being tested, and some field verifications are being carried out.

Availability as a Decision Procedure. Drs. Pinder and van Genuchten believe that, if appropriate funding were made available and a concentrated effort made, a sufficiently-tested transport model could be operational as a Decision Procedure for general use within three years. The model would be perfected in ten years.

Key Publications:

1. van Genuchten, M. Th., G.F. Pinder, and W.P. Saukin. Modeling of leachate and soil interactions in an aquifer. Management of Gas and Leachate in Landfills, S.K. Baniyi (ed). Third Annual Municipal Solid Waste Research Symposium, U.S. EPA, Cincinnati, Ohio 45268. EPA-600/9-77-026 (1977). pp. 95-103.

2. Pinder, G.F. A Galerkin-finite element simulation of groundwater contamination on Long Island, New York. Water Resour. Res., 9(6):1657-1670, 1973.

3. Pinder, G.F., W.P. Saukin, and M.Th. van Genuchten. Use of simulation for characterizing transport in soils adjacent to land disposal sites. Research Report 76-WR-6, Water Resources Program, Dept. of Civil Engineering, Princeton University, Princeton, N.J., 1976.

4. van Genuchten, M.Th., G.F. Pinder, and E.O. Frind. Simulation of two-dimensional contaminant transport with isoparametric Hermitian finite elements. Water Resour. Res., 1977

CONTACT FORM

Persons Contacted and Affiliation:

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Discussion:

Approach Taken. There has been a variety of research studies conducted during the last 3 to 4 years at Georgia Tech under Dr. Fred Pohland. These studies have dealt with leachate generation, characterization, and treatment. Almost all this work has been supported with U.S. EPA grants.

The significant comments received during the interview were:

1. The Decision Procedures project is not feasible at this time.

2. The current state-of-the-art is not even to the point where leachate characterization and/or generation information is reliable.

3. Information regarding the mass loading of leachate from a given amount of refuse is not available.

4. Rainfall is a very important parameter in the consideration of a Decision Procedure.

Key Publications:

1. Pohland, F.G. Sanitary landfill stabilization with leachate recycle and residual treatment. Environmental Protection Technology Series, EPA-600/2-75-043, Oct. 1975.

2. Chaw-Ming Mao, M. and F.G. Pohland. Continuing investigations on leachate stabilization with leachate recirculation, neutralization, and seeding. Special Progress Report, Georgia Institute of Technology, Sept. 1973.

3. Pohland, F.G. Accelerated solid waste stabilization and leachate treatment by leachate recycle through sanitary landfills. Progress in Water Technology, Vol. 7, No. 3/4, p. 753-765.

CONTACT FORM

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Type of Procedure:

Groundwater Modeling

Discussion:

Mr. Prickett is a member of the International SCOPE Groundwater Modeling Steering Committee and is well versed in the field of groundwater modeling.

To date, no specific in-house pollution prediction model has been developed in the Water Survey. Work is continuing on several aspects of groundwater modeling, with particular interest in the development of a model which would be useful from a practical standpoint.

In partnership with C.G. Lonnquist, Mr. Prickett has coauthored a number of important papers on the subject of groundwater modeling. In particular he coauthored "Selected Digital Computer Techniques for Ground Water Resource Evaluation" - which is an invaluable summary of the principal groundwater modeling procedures available at the time of writing in 1971.

Key Publications:

1. Comparison between analog and digital simulation techniques for aquifer evaluation. IWSR114.

2. Aquifer simulation program listing using alternating direction implicit method.

3. Aquifer simulation model for use on disc supported small computer systems. IWSR114.

CONTACT FORM

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Types of Procedures:

Criteria Listing
Matrix
Models/Simulation
Empirical Data from Laboratory and Field Investigations

Discussion:

Approach Taken. Mr. Rovers has coauthored (primarily with Dr. G. Farquhar) numerous papers dealing directly with the attenuation of contaminants, with migration through laboratory soil columns and in-place field soils. Those contaminants investigated include leachate from municipal and industrial refuse and liquid industrial waste. Several approaches have been taken in the extensive research conducted. These approaches include the following:

1. Research to measure and predict contaminant removal from soil by passage of leachate applied by batch dispersal methods on both disturbed and undisturbed soil columns. A range of soil types were investigated under both aerobic and anaerobic conditions, and the soils were described in terms of grain size, ion-exchange capacity, organic-carbon content, and resident-ion distribution both before and following exposure to leachate.

2. Investigation of the use of dispersed soil experiments for examining soil-contaminant interactions.

3. Evaluation of the attenuation of two liquid industrial wastes and soil columns typical of the environment in Ontario, Canada.

4. An assessment of leachate production, characteristics, migration into the environment, control and treatment based upon analysis of actual field case histories, and certain laboratory procedures.

5. An assessment of the effect of the season on landfill leachate and gas production.

6. Development of guidelines for landfill location and management for water pollution control.

7. An assessment of the state of the art of groundwater contaminant modeling.

8. Continued evaluation of landfill leachate monitoring data generated at existing sites.

Results/Conclusions to Date. A number of definitive conclusions have been reached relative to the above research and various approaches taken. The primary conclusions reached in these investigations are as follows:

1. Dilution is an important mechanism of attenuation for all of the liquid waste contaminants in the two industrial wastes studied (steel plant liquors and alkaline cleansing wastes).

2. Desorption was exhibited by all contaminants studied and was most prominant for those which were attenuated primarily by the mechanism of dilution.

3. Attenuation data collected from the dispersed soil experimentations can be used to project soil water concentrations in a field situation by the use of a correction factor; however, this was not determined during the project.

4. The zone of influence of the disposal operation is closely related to the waste loading.

5. It was observed that the remolded soils provided more attenuation by dilution than did the undisturbed soils.

6. Removal isotherms constructed from the dispersed soil studies can be used to predict the breakthrough curves for some contaminants resulting from remolded soil column experiments.

7. The types and amounts of chemicals leached from refuse were sufficient to create a serious pollution hazard to groundwaters in near proximity of landfill sites.

8. The yearly dissolved and suspended contaminant load discharge to the environment by a landfill is significantly less than that of a pollution controlled plan where both serve the same population.

9. A growing body of information exists on the field assessment of leachate contaminant attenuation under a variety of conditions.

10. Existing data show that, with intergranular flow, leachate attenuation is significant for fine grain soils.

11. Waste disposal sites should be located and designed in a manner that takes advantage of natural processes to minimize problems with water pollution control.

The following personal opinions relate to waste attenuation and management:

1. The most valid approach for present use relative to decision procedures for waste disposal siting would be to evaluate groundwater quality data from existing landfills and waste disposal sites for assessment and feedback as to the degree of attenuation and renovation to be expected from various types of soils and geologic materials.

2. Smaller waste disposal operations would be favored so as not to overload the system, particularly with respect to the assimulative capacity whereby dilution and distance of travel are major factors in the attenuation of those wastes to acceptable limits.

State of Development. A significant empirical data base has been generated relative to leachate production and attenuation with distance from various landfills and laboratory investigations. This information provides a useful check by affording a comparison of actual leachate concentrations in various textured materials at distance from the landfill with proposed sites. In addition, a matrix is being developed similar to the one developed by C.R. Phillips for industrial wastes, which will identify a procedure for the siting of municipal refuse landfill sites.

Availability as a Decision Procedure. It is proposed that the empirical data developed to date, coupled with a hydrologic site investigation and monitoring data of a geologically-similar site, could be used now to predict the contaminant migration from a proposed disposal site. The matrix development, testing, verification, and actual use can be expected to be on line within three years.

Key Publications:

1. Farquhar, G.F. and F.A. Rovers. Landfill contaminant flux - surface and subsurface behavior. 21st Industrial Waste Conference, MOE, June 1974.

2. Farquhar, G.F. and F.A. Rovers. Evaluation of contaminant attenuation in the soil to improve sanitary landfill selection and design. Proceedings of the International Conference on Land for Waste Management, National Research Council of Canada, Ottawa, Oct. 1-3, 1973.

3. Farquhar, G.F. and F.A. Rovers. Leachate attenuation in undisturbed and remoulded soil. In Proceedings of Symposium on Leachate and Gas Production, Rutgers University, Cook College, New Brunswick, N.J., Mar. 1975.

4. Farquhar, G.F. and F.A. Rovers. Sanitary landfill study final report, volume I, field studies on groundwater contamination. Ontario Department of Health and the Grand River Conservation Authority Waterloo Research Institute Project 8083, Oct. 1972.

5. Farquhar, G.F. and F.A. Rovers. Sanitary landfill study final report, volume II, effect of season on landfill leachate and gas production. Ontario Department of Health and the Grand River Conservation Authority, Waterloo Research Institute Project 8083, Oct. 1972.

6. Farquhar, G.F. and F.A. Rovers. Monitoring contaminants from a landfill, study plan. Canada-Ontario Committee, Canada-U.S. Agreement, Mar. 1974.

7. Farquhar, G.F. and F.A. Rovers. Sanitary landfill study, volume IV, guidelines to landfill location and management for water pollution control. Ontario Ministry of the Environment, April 1975.

CONTACT FORM

Persons Contacted and Affiliation:

Dr. Dwight A. Sangrey
Associate Professor of Civil Engineering

Mr. Kevin J. Roberts
Graduate Student

● Cornell Univeristy
School of Civil and Environmental Engineering
Hollister Hall
Ithaca, New York 14853
Phone: 607-256-3506

Types of Procedures:

Criteria Listing
Models/Simulation

Discussion:

Approach Taken. Natural soils which had been in contact with leachate from actual refuse disposal sites were sampled in the field and tested in the laboratory with two major objectives in mind: (1) determine the maximum assimilative capacity for various leachate constituents by different soils in New York state; and (2) define in more detail the time and space variation in leachate attenuation by soils.

The overall objective of the four-year study is to define better ways to engineer landfill sites by the development of a rational approach such that assimilative capacity of soils can be defined and utilized to reduce the undesirable impact of leachate. In addition, a two-dimensional finite-element model is currently being developed by Keith Wheeler.

Results/Conclusions to Date. Key conclusions drawn to date from the first two years of research are as follows:

1. Chemical and physical interactions of landfill leachate with soil are very complex.

2. Effective leachate saturation on a chemical-reduction environment and on contaminated soils is a very significant influence on the type of chemical interactions which occur.

3. It is an unreasonable simplification to assume that there will be predictable, simple reactions when adding landfill leachate to soil.

4. A large number of different mechanisms may be responsible for attenuation of leachate as it flows through soil. Some are highly resistant to displacement or decomposition (such as precipitation and certain adsorption reactions), while others are reversible (such as cation exchange).

5. Precipitation, dissolution, complex-ion formation, and hydrous-oxide sorption are the most significant mechanisms affecting trace-metal attenuation.

6. Three zones, with the attenuation of trace metals different for each zone, are possible within the soil system. They depend primarily on the oxidation potential: Zone I - an oxidized zone furthest from the disposal site; Zone II - a moderately-reduced zone; and Zone III - a strongly-reduced zone nearest the disposal site.

7. Trace metals are very effectively removed from leachate in strongly-reduced zones (Zone III). Favorable conditions for Zone III are: low permeability (less than 10^{-3} cm/sec), moderately high to high clay content (greater than 25 percent), and moderate to high available moisture content (greater than 0.12 cm water per 1.0 cm of soil).

8. Impermeable liners should be placed beneath landfills overlying coarse-textured deposits to protect groundwater resources with regard to trace metals.

9. The relative potential of different soils in New York state to attenuate contaminants in landfill leachate varies over a wide range.

10. Data are now available however for ranking different soils of New York state in terms of their potential leachate contaminant/ assimilation capacities.

State of Development. The second year of research has been completed and published as indicated below. The model which is currently under development is not expected to be on line for a period of approximately three years.

Availability as a Decision Procedure. The large empirical base generated by this research would be available now for use as a decision procedure to compare the concentration of leachate which has traveled through various textured soils from existing landfills with proposed new sites. The model currently under development is not expected to be on line, tested, and validated for a period of approximately three years.

Key Publications:

1. Roberts, K.J., G.W. Olson, and D.A. Sangrey. Attenuation of sanitary landfill leachate in soils of New York State. Department of Agronomy and School of Civil and Environmental Engineering, Cornell University, 1976.

2. Roberts, K.J. and D.A. Sangrey. Attenuation of inorganic landfill leachate constituents in soils of New York. School of Civil and Environmental Engineering, Geotechnical Engineering Report 77-2, Cornell University, 1977.

CONTACT FORM

Persons Contacted and Affiliation:

Mr. Michael J. Stiff
Chemist

Mr. P.J. Maris
Chemist

Mr. Chris Young
Geologist (Medmenham Laboratory at Marlow)

Water Research Centre
Stevenage Laboratory
Elder Way
Stevenage, Hertfordshire SG1-1TH
United Kingdom
Phone: 0438-2444

Types of Procedures:

Field/Laboratory Investigations
Idealized Models

Discussion:

Approach Taken. The Water Research Centre (WRC) is conducting a landfill investigation cooperatively with the people at Harwell Laboratory for the Department of the Environment (DOE) at a cost of approximately $2 million. Twenty sites are being investigated (9 by WRC), and the final report will be completed in 1977. The approach taken was to sample leachate and surface breakouts, sample existing wells, and sample additional bore holes drilled on a grid basis. Some undisturbed sampling was also done.

In a second investigation, six pilot-scale (concrete tanks of 5.0 m^2 size) and six small-scale (PVC pipes of 0.071 m^2 size) experimental landfills were operated at Stevenage over a three-year period (Nov. 1973 to Nov. 1976) to study the leaching of three industrial wastes: an aqueous oil emulsion, a cyanide heat-treatment waste, and a metal-hydroxide sludge containing nickel and chromium when mixed with domestic waste under aerobic and anaerobic conditions. The pilot-scale experiments were leached by natural rainfall for much of the time; in the small-scale experiments, an artificially high leaching rate (four times the natural rate) was used, thus making them less representative of typical landfill conditions.

A third investigation used an idealized model to predict the dilution of tip percolates (leachate) in groundwater. This approach considered both dilution/dispersion and pollutant travel times with respect to groundwater flow and discharge to streams.

Results/Conclusions to Date. Interpretation of the results of the landfill study will be in the final report to DOE; however, one major conclusion thus far is that there is no real problem with heavy metals since there has been no metal migration. Leachate plums were present, but were not found to have migrated to the extent anticipated. For example, in a worst-case condition, chromium wastes were placed in a mined-out dike area and were diluted to acceptable limits in groundwater within 250 meters. The metals are felt to be very effectively tied up by precipitation as metal sulfides, carbonates, and hydroxides. Solid organics including PCBs were readily tied up by actually being soaked up in the municipal refuse. Soluble organics such as phenols are the biggest problem; however, it was felt that phenols could be biodegraded with domestic waste.

Major conclusions of the lysimeter investigation were:

1. Decomposition of the domestic waste gave rise to a typical leachate whose composition varied between different experiments, but was not obviously affected by the presence of the industrial waste except in the case of the small-scale cyanide experiments.

2. The major effect of allowing access of air to the base of the landfill was that the leachates from the aerobic experiments typically contained considerably-lower concentrations of organic carbon and were of higher pH value than those from the anaerobic experiments. The only clear effect of aerobic conditions on the concentrations of the industrial wastes in the leachate was a small reduction in the concentrations of metals.

3. The quantity of oil leached in 2½ years was less than two percent of that added, and the maximum concentration in leachate was 300 mg/l. The data are consistent with the hypothesis that the oil was retained on the domestic waste, although the quantity of oil added was small in relation to that already present in the waste.

4. The quantity of cyanide leached in 3 years was less than three percent of that added. The maximum concentration in leachate was 270 mg/l, but this may have been a consequence of the artificially-high leaching rate used in the small-scale experiments. Under conditions of leaching by natural rainfall, no concentrations exceeding 7 mg/l were measured.

5. The quantities of nickel and chromium leached in 2½ years were less than 0.2 percent of the weights added as metal hydroxides. Over a 2½-year period, the increase in mean concentration in leachate over background values caused by the presence of the sludge was no more than sixfold for nickel and twofold for chromium.

Significant conclusions of the dilution model approach are as follows:

1. Pollutant travel times through the saturated zone are rapid in comparison to those in the unsaturated zone, and more research must be done to evaluate the role of solute diffusion processes in saturated flow.

2. The results show a wide range of variation even for a single aquifer and, consequantly, must be used with care.

State of Development. The empirical data developed from the current 20-site field and laboratory landfill investigation should be available in final report form by late 1977. Data from the lysimeter study is available now, and additional data will be forthcoming. The dilution model is developed for typical hydrogeologic settings, but has not yet been calibrated or verified for a specific field situation.

Availability as a Decision Procedure. The results of the field and laboratory studies and the assessment of the empirical data generated are available for immediate use to substantiate the judgment value decision-making process.

Key Publications:

1. Water Research Centre (Cooperative with Harwell Laboratory). Programme of research on the behaviour of hazardous wastes in landfill sites. Interim Report on Progress, Sept. 1975 (Final report late 1977).

2. Newton, J.R. Pilot-scale studies of the leaching of industrial wastes in simulated landfills. Water Research Centre, Stevenage Laboratory, Feb. 1977.

3. Oakes, D.B. Dilution of tip percolates in groundwater. Water Research Centre, Medmenham Laboratory, Medmenham, Marlow, Bucks, United Kingdom, WLR 53, Jan. 1976.

4. Oakes, D.B. Use of idealised models in predicting the pollution of water supplies due to leachate from landfill sites. Water Research Centre, Paper 16.

CONTACT FORM

Person Contacted and Affiliation:

Mr. William H. Walker
Director, Midwest Operations

- Geraghty & Miller, Inc.
Groundwater Hydrologists & Geologists
501 South 6th Street
Suite 201
Champaign, Illinois 61820
Phone: 217-352-0101

Type of Procedure:

Empirical Studies

Discussion:

Mr. Walker initiated the core studies which have recently been completed for the Illinois Water Survey and Geological Survey. He has a wealth of experience in this area and remains skeptical of the real practical values of modeling the attenuative mechanisms. His years in the field prompt the suggestion that the natural system is too varied and complex to model, and any approximations possible are unlikely to be applicable to more than one site.

He is the author of several important papers on the subject of hazardous wastes. In particular he authored "Monitoring Toxic Chemicals in Land Disposal Sites", Pollution Engineering, September 1974, in which he proposed that in fine-grained sediments of low permeability core sampling might be an appropriate supplemental technique for location of the optimum water sampling point in the vertical sequence.

Mr. Walker is a seasoned and pragmatic professional with a considerable amount of practical experience in the vagaries of land and natural systems.

Key Publication:

1. Walker, W.H. Monitoring toxic chemicals in land disposal sites. Pollution Engineering, Sept. 1974.

2. Walker, W.H. Field verification of hazardous waste migration from land disposal sites. Solid and Hazardous Waste Research Laboratory, National Environmental Research Center, Cincinnati, Ohio 45268. U.S. EPA R-803216-01-2. Fall, 1977.

CONTACT FORM

Person Contacted and Affiliation:

Dr. Raul Zaltzman
Professor, Civil Engineering

West Virginia University
Morgantown, West Virginia 26506

Types of Procedures:

Matrix - Simplified Matrix Analysis
Models/Simulation-Analog Computer

Discussion:

Approach Taken. Dr. Zaltzman evaluates landfills using a set of criteria arranged in a matrix.

Results/Conclusions to Date. Although no formal conclusions have been developed, Dr. Zaltzman recognizes the need for developing a set of decision precedures. He feels that both predictive tools (such as models) and non-predictive tools (such as Matrix or Criteria Listing/Ranking) could be used. However, he sees such procedures used only as tools to assist qualified scientists and engineers in making decisions regarding site suitability for disposal.

State of Development. Experimental, not fully developed.

Availability as a Decision Procedure. None of the specific procedures used are documented in a manner that makes it usable as a standard Decision Procedure.

APPENDIX C
REGULATORY AGENCY CONTACTS

CONTACT FORM

Agency:	Persons Contacted:
California Regional Water Quality Control Board Los Angeles Region 107 South Broadway Room 4027 Los Angeles, CA Phone: 213-620-4460	Mr. Hank Yacoub Water Quality Control Engineer
State Solid Waste Management Board 1709 11th Street Sacramento, CA Phone: 916-322-2684	Peter L. Huff, Chief Technical Assistant and Training Section
California State Department of Health 744 P Street Sacramento, CA Phone: 916-322-2337	James L. Stahler, P.E. Consultant

Type of Procedure:

Classification System

Permit Procedure:

The procedure utilized to make application for a permit for all waste disposal operations (hazardous or non-hazardous) is as follows:

This procedure is to be applied only to new solid waste disposal sites and transfer stations proposed to be placed in operation prior to Board approval of the applicable county plan.

1. Filing a Notice of Intent:

    a. Persons planning to commence operation of a new solid waste disposal site or transfer station which has been granted land-use approval by a city or county shall notify the Board of their intent.

    b. Persons proposing to place a waste processing facility in operation must inform the Board of such a proposal and submit to the Board adequate information to permit the Board to determine if the facility is governed by these procedures.

2. Information to be submitted with Notice of Intent. Information to be submitted shall include:

   a. County map showing: site location of proposed facility, existing transfer stations and disposal sites; the service area of proposed facility; and communities within and immediately adjacent to the service area.

   b. Facility information such as: acreage, projected site life, and type and volume of wastes handled.

   c. Certification of local land-use approval, including evidence of CEQA compliance (EIR or Negative Declaration).

   d. Statement on justification of public need and necessity by the project proponent.

3. The local entity granting land-use approval shall submit a statement of any information relative to public need and necessity as identified at the local level.

4. The agency of the county responsible for development of the county solid waste management plan shall:

   a. Comment on the relationship of the proposed facility to the proposed county plan.

   b. Determination that the distance from the facility (disposal site) to the nearest residential structures is in compliance with the Minimum Standards for Solid Waste Handling and Disposal, and especially that the distance of residences from the site is sufficient to permit adequate control of noise levels, odor nuisances, traffic congestion, litter nuisances, and vectors as required by Government Code Section 66784.1.

5. Review by the Board. Within 30 days of receipt of the Notice of Intent, the Board shall review the Notice of Intent and inform the project proponent of any additional information needed.

6. Determination of Findings by the Board. Within forty-five (45) days after the receipt of complete information, the Board at a public meeting shall make a finding for or against the need of the facility to protect the public health or because of public need and necessity. The project proponent, the local government and, where applicable, the Regional Water Quality Control Board shall be notified of the Board's action.

7. Exemptions. Any facility is exempt from these requirements if prior to August 28, 1974, either an environmental impact report notice of completion was filed with the State or land-use approval was issued for the facility by a city or county.

This procedure is to be applied to new solid waste disposal sites, transfer stations, waste processing or resource recovery facilities proposed to be established and operated after completion and Board approval of the county solid waste management plan.

1. Filing a Notice of Intent:

   Persons planning to establish or operate a new solid waste disposal site, transfer station, waste processing or resource recovery facility shall notify the Board of their intent at least 45 days prior to the scheduled commencement of construction of the facility. A copy of the notice shall be submitted to the local agency that has been selected to maintain the solid waste management plan of the county in which the proposed facility is to be located.

2. Information to be submitted with the Notice of Intent shall include:

   a. County map showing site location of proposed facility, existing transfer stations and disposal sites, the service area of proposed facility, the communities within and immediately adjacent to the service area of the proposed facility.

   b. Facility information such as: owner, operator, acreage, projected site life, and type and volume of wastes to be handled.

   c. Evidence of CEQA Compliance (EIR or Negative Declaration).

d. Reference to page or pages in the approved county solid waste management plan where the facility is discussed.

3. Evaluation by County:

Within 15 days after receipt of the notification from the project proponent or at the request of the Board, the local agency that has been selected to maintain the county solid waste management plan shall inform the Board of their:

a. evaluation of whether the proposed facility conforms or does not conform with the county plan.

b. Determination that the distance from the facility (disposal site only) to the nearest residential structures is in compliance with the Minimum Standards for Solid Waste Handling and Disposal, and especially that the distance of residences from the site is sufficient to permit adequate control of noise levels, odor nuisances, traffic congestion, litter nuisances and vectors as required by Government Code Section 66784.1.

4. Determination of Findings by the Board:

Within forty-five (45) days after the receipt of a notification of a proposed facility, the Board at a public meeting shall make a finding of conformance or non-conformance with the county plan. The Board may extend the time period to obtain additional information if necessary.

5. Determination of Non-Conformance:

If after a review of the necessary information the Board determines the proposed facility to not be in conformance with the county plan, the Board may, after public hearing, inform the county and the project proponent that:

a. The proposed facility is not in conformance with the county solid waste management plan and cannot be implemented.

b. An amendment to the plan can be submitted to the Board to include the proposed facility. Any amendment to a county solid waste management plan shall be subject to the requirements of Section 66780 of the Government Code and Title 14, Division 7, Chapter 2, Articles 1 through 7 of the Administrative Code.

Discussion:

The Classification System approach to waste management has been in effect on an informal basis in California for some 20 years. Formal regulations for "Waste Discharge Requirements for Waste Disposal to Land-Disposal Site Design and Operational Criteria" were adopted in December 1972 by the California State Water Resource Control Board. These requirements were last revised in December 1976 and are included in Appendix D. Nine regional water quality control boards assist the State board in carrying out its responsibility in water quality controls. The regional boards are responsible for regulating all liquid and solid waste disposal sites for protection of water quality. All waste disposal sites are subject to waste discharge requirements and criteria established by the regional boards. This Board sets statewide policy, enforces PL 92-500, and is concerned primarily with the protection of surface and ground waters. The California Department of Health and the Solid Waste Management Board are concerned with other waste management aspects such as overall resource recovery and the overall operation of disposal sites.

The Solid Waste Management Board either issues waste disposal permits directly for all waste disposal sites including transfer stations, or designates the appropriate state department or county agency to issue a facility permit. Waste discharge requirements issued by the regional water quality control board are prerequisite to facility permits.

The Department of Health established new guidelines for handling, storage, transportation, and disposal of hazardous and extremely hazardous wastes, set forth in "Hazardous Waste Regulations" (adopted Fall, 1977), a copy of which is included in Appendix D.

The California Classification System represents the earliest formalized procedure for waste disposal siting that has been identified and has, by far, the longest history of on-line utilization. This system establishes criteria to define both site classifications and waste groupings. Class I, II-1, II-2, III sites and Group 1, 2 and 3 wastes have been defined as shown in Table C-1.

As indicated in the table, the mode of deposition for hazardous wastes is that of containment by utilizing natural deposits with a permeability of 1×10^{-8} cm/sec or less. Municipal wastes generally rely on containment of waste leachates with a required permeability of

TABLE C-1

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD
DISPOSAL SITE DESIGN REQUIREMNTS

Site Type	Site Classification	Waste Classification	Permeability cm/sec	Soils	% Passing a No. 200 Sieve	Liquid Limit	Plasticity Index
Class I	Complete protection is provided for all time for the quality of ground and surface water. Geological conditions are naturally capable of preventing vertical and lateral hydraulic continuity between liquids and gases from the waste in the site and usable surface and ground waters. The disposal area can be modified to prevent lateral continuity. Underlain by usable ground water only under exceptional circumstances.	Group 1 Consisting of or containing toxic substances and substances which could significantly impair the quality of usable waters. Also accepts Group 2 and 3 wastes.	$\leq 1 \times 10^{-8}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
Class II	Protection is provided to water quality from Group 2 and Group 3 wastes.	Group 2 Consisting of or containing chemically or biologically decomposable material which does not include toxic substances or those capable of significantly impairing the quality of usable water. Also accepts Group 3 Wastes.					
II-1	Overlying usable ground water and geologic conditions are either naturally capable of preventing lateral and vertical hydraulic continuity or site has been modified to achieve such capability.		$\leq 1 \times 10^{-6}$	CL, CH or OH	Not less than 30	Not less than 30	Not less than 30
II-2	Having vertical and lateral hydraulic continuity with usable ground water but geological and hydraulic features and other factors assure protection of water quality.		Not specified	Not specified	Not specified	Not specified	Not specified
Class III	Protection is provided from Group 3 wastes by location, construction and operation which prevent erosion of deposited material.	Group 3 Consist entirely of non-water soluble, non-decomposable inert solids.	-	-	-	-	-

1 x 10^{-6} cm/sec or less. Attenuation is utilized to some extent for a Class II-1 situation however, since a permeability of 10^{-6} cm/sec will permit the slow migration of waste leachates. In addition, the definition of a Class II-2 site strongly implies that some attenuation will take place. Assured protection of water quality is required even though vertical and lateral hydraulic continuity may exist.

Examples of waste discharge requirements for Class I, limited Class I, Class II-1, Class II-2, and Class III disposal sites are given in pages 37-63 of the Waste Disposal Design and Operational Criteria. (See Appendix E.) Copies of sample permit application forms issued by the Regional Water Quality Control Board, the County Planning Department (Ventura Co.) including an Environmental Assessment Application, and a City Planning Commission (Oxnard) are also included in Appendix E. A copy of "Revised Waste Discharge Requirements for Palos Verdes Landfill in Los Angeles County" is also included. Finally, a flow chart for the waste permit application review and processing procedure is included in Appendix D.

CONTACT FORM

Agency:

Illinois Environmental Protection Agency
Division of Land/Noise Pollution Control
2200 Churchill Road
Springfield, Illinois 62706
Phone: 217-782-6760

Persons Contacted:

Thomas E. Cavanagh, Jr.
Civil Engineer
Manager, Land Permit Section

Michael W. Rapps
Engineer
Land Technical Operations Section
Permit Section

Thomas P. Clark
Hydrogeologist
Environmental Protection Specialist
Land Technical Operations Section
Technical Support Unit

Types of Procedure:

Criteria Listing (current)
Classification System (expected enactment by mid-1978)

Permit Procedure:

The Illinois EPA is currently processing waste disposal permit applications under the Illinois Pollution Control Board Rules and Regulations (Chapter 7, Solid Waste) adopted 27 July 1973. These rules and regulations require site and waste characterization that utilize a Criteria Listing approach. A draft set of guidelines has been developed for land disposal criteria for special wastes (liquids, sludges, and hazardous or potentially hazardous waste) which are to some extent also currently being utilized. These draft guidelines are expected to be enacted and operative by mid-1978. A copy of these guidelines is included in Appendix D.

A flow diagram for the site permitting procedure showing the review process, the agencies involved and the timing is given in Figure C-1. The following steps are taken:

1. An applicant may submit an informal request for review by the EPA and/or Illinois State Geologic Survey (IGS) prior to full formal submittal in order to obtain a positive decision prior to the expenditure of considerable funds.

2. The applicant must submit a general solid waste application form for concurrent review by the Division of Water Pollution Control, Division of Noise Pollution Control, Division of Public Water Supply, and the Illinois State Geologic Survey. The IGS will provide a technical review and the first three agencies mentioned will assess whether that location would have adverse effects on existing or future land-use activities. Proper notification of adjacent landowners and public officials is required as well as a land-use assessment analysis.

3. The Illinois EPA is mandated to provide a decision by 90 days unless extended due to hearing. No action within 90 days would result in a permit being issued by the State.

4. A technical review which entails geology, engineering, and land use is made by the Central Office staff only. The Regional Office will review the development and site preparation including monitoring wells to see that there is conformance between designed and implemented facilities.

5. A permit is then issued, following that field inspection. If there are deficiencies, they must be corrected prior to permit issuance. Subsequent activities are at the Regional level with inspection of operations performed on a monthly or bimonthly basis. Central Office staff becomes involved again only when there is a major problem. Once permitted, the permit is good for the life of the site unless there are modifications or unless there are violations which are in need of correction.

6. The present system does not provide automatically for a public hearing at each and every site. Once the Illinois EPA has issued a permit, the citizens may contest the same with a hearing before the Pollution Control Board or the Circuit Court. It can be appealed higher to the Appellate Court and eventually to the State Supreme Court. A very important aspect of the permitting procedure is that, by ruling of the State Supreme Court in October 1975 based upon the Carlson vs. Worth case, local zoning cannot overrule an EPA decision to issue a permit to a site. There is no zoning for landfills in Illinois, however, and

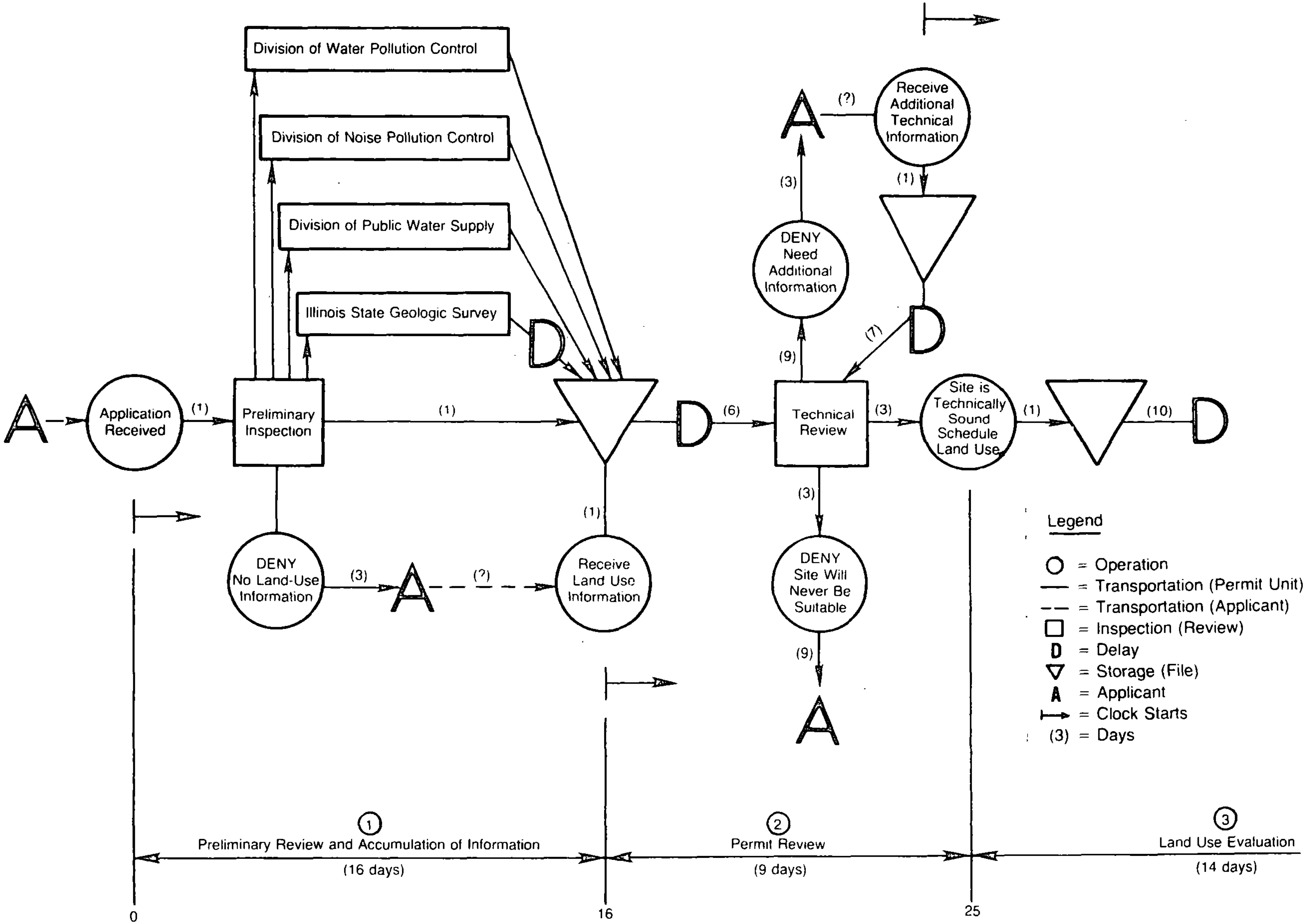
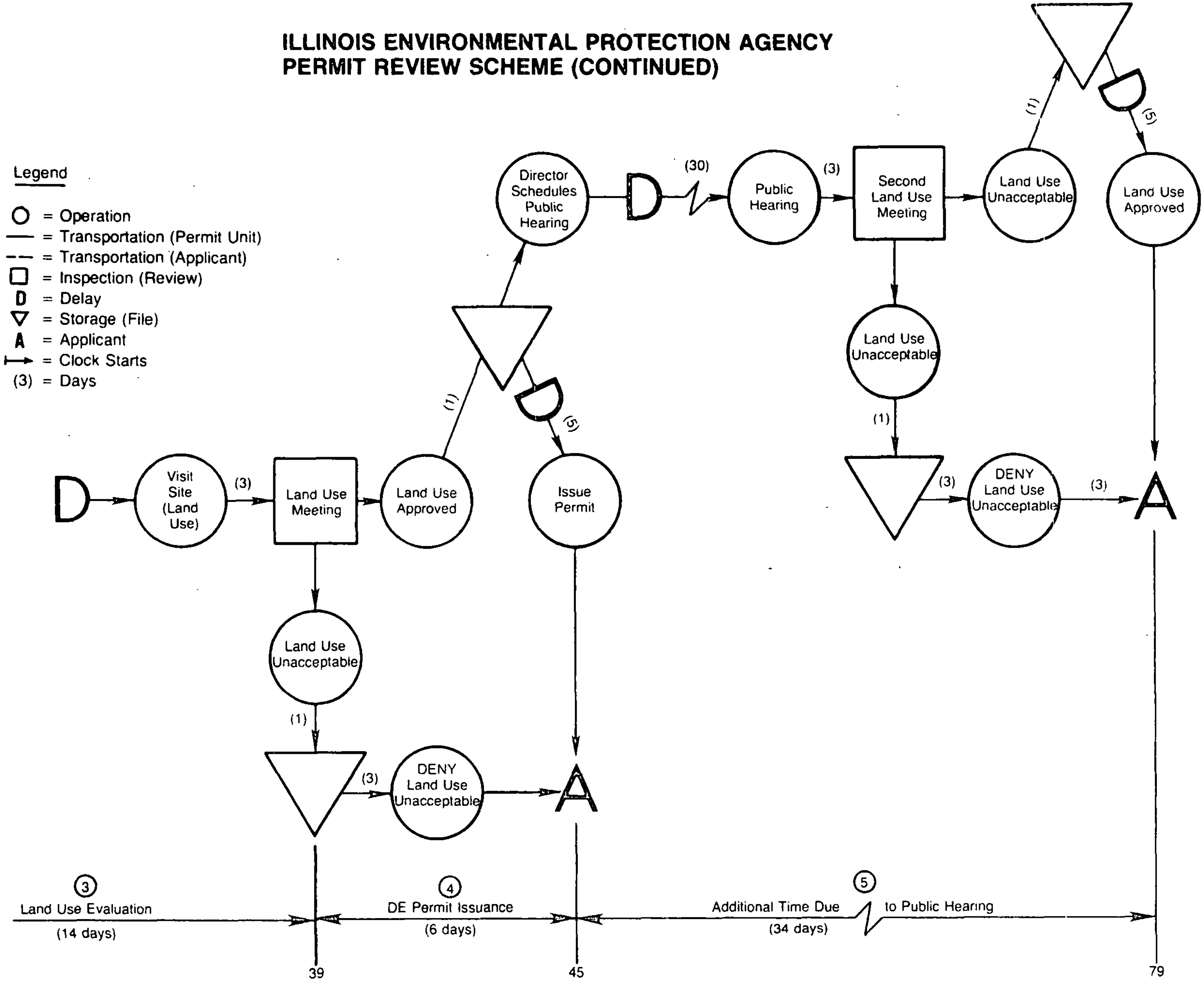


FIGURE C-1 ILLINOIS ENVIRONMENTAL PROTECTION AGENCY PERMIT REVIEW SCHEME

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
PERMIT REVIEW SCHEME (CONTINUED)



emphasis is placed on compatible land use. The Illinois EPA expects this ruling to be changed in the near future, but it does offer them, at present, extensive power in the permitting of sites.

Discussion:

A complete package of that information required by the Illinois EPA as well as supporting documents and information is contained in the booklet "Sanitary Landfill Management", issued December 1973. Copies of the permit application form are found on pages 39 through 53 of that document, and it is also included in Appendix D. The pending draft guidelines list and describe the land disposal criteria for special wastes. Once adopted the following modules will be required:

Module A & B - Development Permit;

Module C - Operation Permit;

Module D or E - Supplemental Permit -- D is for site modifications, E is waste specific for a change to or addition of waste types;

Module F - Intra Agency Permit;

Module G - Class 5 Site Development and Operation.

A copy of Module E and instructions for its use is also included in Appendix D. It must be emphasized, however, that revisions will be made including the proposed procedure for a leaching test.

A table of site types and suitable methods of disposal for wastes of varying properties is given in Table C-1.

There is generally no distinction made between municipal and industrial waste except that general municipal refuse is accepted at Class III sites. Class I sites accept all waste excluding radioactive waste and are the main repository for hazardous wastes. A Class I site must meet all the physical criteria, including a naturally low permeability of 10-8 cm/sec. Engineered site characteristics are permitted for Class III sites and lower which accept no hazardous wastes. There are two groups of site types: Class I, II and III sites form one group and Class IV and V sites form the other. The wastes that are disposed of in the first group are those that pose a potential for contamination while the wastes that are disposed of in Class IV and V sites are those that pose virtually no environmental threat.

TABLE C-2
ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
SOLID WASTE MANAGEMENT SITE
GUIDELINES
(APPROVAL PENDING)

Site	Maximum Permeability	Thickness of Confining Layer	Depth to Aquifer	Flood Frequency	Theoretical Confinement Time	Monitoring	Site Pollution Potential	Waste	Module
Class I	$1x10^{-8}$ cm/sec natural	10'	10'	100 yr. line or maximum known elevation. No marginal lands.	500 yrs	Yes	Very low	All wastes excluding radioactive	E A,B,C F
Class II	$5x10^{-8}$ natural	10'	10'	100 yr. line or maximum known elevation. No marginal lands.	250 yrs.	Yes	Low	General putrescible, special, specified hazardous wastes, all Class III, IV and V.	E A,B,C F
Class III	$1x10^{-7}$ natural or engineered	10'	10'	100 yr. line or maximum known elevation. No marginal lands.	150 yrs.	Usually yes	Low to Moderate	General municipal, certain special, all Class IV and V.	E A,B,C F
Class IV	$5x10^{-7}$ natural or engineered	5'	0'	No marginal lands	-	May	Moderate	Demolition and construction, bulky, landscape wastes and inert, insoluble materials. All Class V.	A,B,C F
Class V	Little or no confinement, or sufficient site information to determine the pollution potential of the site has not been provided.	-	-	-	-	-	-	Inert, noncombustible material.	G

The Illinois EPA relies very little on attenuation of waste leachates even though the existing "Sanitary Landfill Management" guidelines discuss attenuation. Rather, they favor, and in fact require, containment of both municipal and hazardous wastes by reliance on deposits with a natural low permeability. They do not favor the use of synthetic liners due to their unknown long-term integrity, and, for that matter, their short-term integrity.

CONTACT FORM

Agency:

Minnesota Pollution Control Agency
Hazardous Waste Management Section
1935 West County Road, B2
Roseville, MN 55113
Phone: 612-296-7317

Person Contacted:

Mr. James Kinsey, Chief
Hazardous Waste Management Section

Type of Procedure:

Criteria Listing

Permit Procedure:

The following steps comprise the permit procedure:

1. A contact between the person interested in permitting a site and the agency often results in an appointment with the MPCA staff to discuss the permitting procedure.

2. A pre-application conference is held with the MPCA staff to discuss the following:

   a. The concept of disposal
   b. Environmental control
   c. Permitting procedure
   d. Local agency's involvement
   e. Timing and schedules, etc.

3. A preliminary application is then submitted to the agency for review. This application includes:

   a. Hydrogeologic report for the site
   b. Conceptual design of the proposed facility
   c. General discussion of environmental concerns and controls

4. After review of the preliminary application, and the receiving of an indication of site acceptability to the agency, a final application is prepared. This application includes a complete engineering design package, operational plan, proposed monitoring, etc. Details of such package are found in Appendix D.

5. An Environmental Impact Statement may be required for major or critical waste disposal projects. When required, the applicant is notified at early phases of permit processing; however, the EIS could be presented at an advanced phase of the review.

6. When required by citizens or by the agency a public hearing(s) may be scheduled. This is only required for major and/or critical waste disposal facilities.

7. Local agencies' input is a part of the state permit requirements and permit review process. County permits, land disposal facilities, zoning, etc., must be obtained by the applicant prior to receiving final approval from MPCA.

Discussion:

In June, 1977, the Minnesota Pollution Control Agency published a draft of rules and regulations for hazardous waste management. The provisions of these regulations govern the identification, classification, storage, labeling, transportation, treatment, processing and disposal of hazardous waste and the issuance of permits for construction, operation and closure of a hazardous waste facility.

Key definitions in the proposed regulations are the following:

1. Corrosive material: a material that has any one of the following properties:

   a. a pH that is greater than 12 or less than 3 for a liquid, semisolid, sludge, or saturated aqueous solution of a solid or gas;

   b. the ability to cause a visible destruction or irreversible alteration of skin tissues at the site of contact following an exposure period of four hours or less when tested by the technique described in 16 C.F.R. #1,500.41 (1977);

   c. a corrosion rate of 0.250 inch per year or more on Society of Automotive Engineers' 1020 Steel when tested in accordance with the minimum requirements described in the National Association of Engineers' Standard TM-01-69, at a test temperature of 130°F (54.4°C).

2. Flammable material: any material that:

   a. has a flash point below 200°F (93.3°C), except the following:

1) a material comprised of miscible components having one or more components with a flash point of 200°F (93.3°C), or higher, that make up at least 99 percent of the total volume of the mixture;

2) a material that has a flash point greater than 100°F (37.8°C) and that when heated to 200°F (93.3°C) will not support combustion beyond the flash;

3) an explosive material;

b. may ignite without application of a flame or spark including, but not limited to, nitro cellulose, certain metal hydrides, alkali metals, some oily fabrics, processed meals, and acidic anhydrides.

3. Explosive material: a material that has the property either to evolve large volumes of gas that are dissipated in a shock wave or to heat the surrounding air so as to cause a high pressure gas that is dissipated in a shock wave. Explosive materials include, but are not limited to, explosives as defined in 49 C.F.R. #173,300 (1976).

4. Irritative material: a noncorrosive material which has the property to cause a local reversible injury to a biological membrane at the site of contact as determined by either of the following:

a. Practical experience with the waste where short term exposures have caused first degree burns and where long term exposures may cause second degree burns;

b. Skin irritation of an empirical score of five or more as determined pursuant to 16 C.F.R. #1,500.41 (1977).

5. Oxidative material: any material with the property to readily supply oxygen to a reaction in the absence of air. Oxidation materials include, but are not limited to, oxides, organic and inorganic peroxides, permanganates, perrhenates, chlorates, perchlorates, persulfates, nitric acid, organic and inorganic nitrates, iodates, periodates, bromates, perselenates, perbromates, chromates, dischromates, ozone, and perborates. Bromine, chlorine, fluorine, and iodine react similarly to oxygen under some conditions and are therefore also considered oxidative materials.

6. Toxic material: a material with any one of the following properties:

   a. An oral LD_{50} less than 500 milligrams of material per kilogram of body weight of test animal.

   b. A dermal LD_{50} less than 1,000 milligrams of material per kilogram of body weight of test animal.

   c. An inhalation LC_{50} (when the material or a component is in a form that may be inhaled) less than:

      1. 2,000 milligrams of material as dust or mist per cubic meter of air, or

      2. 1,000 parts per million of material as gas or vapor.

   d. An aquatic LC_{50} less than 100 milligrams of material per liter of water.

7. Median lethal concentration (LC_{50}): the calculated concentration at which a material kills 50 percent of a group of test animals within a specified time.

   a. Aquatic LC_{50}: the LC_{50} determined by a test in which the specified time is 96 hours, the test animals are at least 10 fathead minnows, and the route of administration follows accepted static or flow-through bioassay techniques.

   b. Inhalation LC_{50}: the LC_{50} determined by a test in which the specified time is 14 days, the group of the test animals is at least ten white laboratory rats of 200 to 300 grams each, half of which are male and half of which are female, and the route of administration is continuous respiratory exposure for a period of one hour.

8. Median lethal dose (LD_{50}): the calculated dose at which a material kills 50 percent of a group of test animals within a specified time.

   a. Oral LD_{50}: the LD_{50} determined by a test in which the specified time is 14 days, the group of test animals is at least ten white laboratory rats of 200 to 300 grams each, half of which are male and half of which are female, and the route of administration is a single oral dose.

b. Dermal LD_{50}: the LD_{50} determined by a test in which the specified time is 14 days, the group of test animals is ten or more white rabbits, half of which are male and half of which are female, and the route of administration is a 24-hour exposure with continuous contact on bare skin.

Generators of Hazardous Waste are required to disclose all types of hazardous waste and submit a report to the MPCA. Generators are also responsible for management and disposal of waste. Shipping papers prepared by the generator track waste to disposal. Generators are required to properly prepare and label all hazardous waste shipments.

Location, Operation and Closure for the Hazardous Waste facility has to be in accordance with MPCA regulations. These include locating facilities in a hydrogeologically suitable area and in a computable environment. Storage and disposal must be in areas with liners having permeability no greater than 10-7 cm/sec. The regulations require keeping records and procedures for reporting to MPCA and proper closing of hazardous waste facilities after termination of operation.

The draft regulations outline permit requirements for all hazardous waste facilities, including submission, granting and reissuance, review and general or special conditions and exceptions of permits. The contents of hazardous waste permit applications include: 1) preliminary application documenting, soils and hydrogeologic conditions, 2) description of surface and ground water resources, 3) utilities at site vicinity, and 4) general environment conditions and support information.

In addition to the above requirements, reports on land disposal facilities include: 1) logs and borings, 2) plot plans delineating surface and ground waters, 3) placement of monitoring wells, 4) cross sections showing soil profile, ground water aquifers, etc. 5) a comparison of the findings of the field investigation with previous literature and research, 6) water balance, 7) a section that addresses seasonal fluctuations of ground water levels, and 8) a section on ground water quality, both present and anticipated after operation of the facility.

All land disposal facility applications must be also supported by an engineering report that conceptually addresses the following: 1) type of waste, 2) treatment processes, 3) plot plans, 4) liner specifications and leachate collection, treatment and disposal facilities, 5) discussion of the operation of the proposed facility, and 6) a report on impact of vapor gas and dust and the potential of their migration.

Most interestingly, these regulations require inclusion in the interim report of a section that addresses the porosity and permeability of major soil types that were encountered in the field investigation, including a description of the procedures used in the testing of the major soil types. The section shall discuss:

1. The ability of the soil to attenuate the hazardous waste and the leachate thereof through ion exchange, adsorption, adsorption, precipitation, and other such mechanisms.

2. A review of the anticipated products from such mechanisms including both final and intermediate biochemical metabolites and chemical degradation products.

3. An assessment of how effective the soil attenuation processes will be in providing treatment to the hazardous waste and leachate thereof.

After review and acceptance of the preliminary permit, the facility owner submits a final application which includes: 1) response to comments on the preliminary application, 2) an engineering report including plans and specifications for the construction of the facility, 3) operations and management plans, and 4) a site closure manual and other support materials.

CONTACT FORM

Agency:

New York State Department of Environmental Conservation
Division of Solid Waste Management
50 Wolf Road
Albany, NY 12201
Phone: 518-457-6607

Persons Contacted:

G. David Knowles, P.E.
Sanitary Engineer
Division of Solid Waste Management

Charles N. Goddard, Chief
Hazardous Wastes Section

Type of Procedure:

Criteria Listing

Permit Procedure:

The permit procedure is described in detail on pages 6-11 of Part 360, "Solid Waste Management Facilities", which became effective 28 August 1977. A copy of these rules and regulations is included in Appendix D.

The following steps highlight the permit procedure:

1. The operator of any solid waste management facility in operation on the effective date of this Part for which a currently effective approval was issued by this Department, pursuant to regulations of the Department in effect from September 1973 until repealed hereby, shall submit an application for an operation permit on forms provided by the Department not later than eighteen months after the effective date of this Part unless otherwise notified in writing by the Department.

2. The operator of any solid waste management facility in operation on the effective date of this Part for which no approval as aforesaid was issued shall submit an application for an operation permit on forms provided by the Department not later than six months after the effective date of this Part unless otherwise notified in writing by the Department.

3. A complete application, timely submitted pursuant to this Subdivision, shall be deemed a permit until such application is acted upon.

4. If an application submitted pursuant to this Subdivision is determined by the Department to be incomplete, the Department shall notify the applicant in writing concerning the respects in which the application is incomplete. Unless the applicant completes the application, consistent with such notice, within 30 days after the date of notice, the application shall be denied.

5. Every application pursuant to this Subdivision shall, in addition to complying with Subdivision (d) of this Section, include a detailed report describing the plan of operation and a contingency plan setting forth in detail the applicant's proposal for corrective or remedial action to be taken in the event of equipment breakdowns, ground or surface water or air contamination attributable to the facility's operation, fires, and spills or releases of hazardous or toxic materials. In addition, every application to this Subdivision shall reasonably demonstrate that the subject solid waste management facility meets the standards of operation.

6. Proposed facilities. Any person proposing to construct a solid waste management facility shall submit to the Department, on forms provided by the Department, not less than 90 days in advance of the date on which it is proposed to commence such construction, a complete application for a construction permit.

7. Proposed modifications to existing facilities. Any person proposing to modify the use of a solid waste management facility in a manner which is not reflected in either a construction permit or operation permit issued pursuant to this Part, or its predecessors, shall submit to the Department, on forms provided by the Department, not less than 90 days in advance of the date on which it is proposed to so modify, a complete application for a construction permit reflecting such proposed modification.

8. Applications submitted pursuant to this Part shall be accompanied by such data as the Department may reasonably require for the purpose of fulfilling its responsibilities under the ECL and this Part in accordance with guidelines furnished by the Department.

9. If an application submitted pursuant to this Section (excepting Subdivision (b) hereof) is determined by the Department to be incomplete, the Department shall notify the applicant in writing concerning the respects in which the application is incomplete. The effective date of application shall be the time at which the applicant completes the application consistent with such notice.

10. Within 90 days following receipt of a complete application pursuant to this Part, or such longer period as may be agreed upon in writing by the Department and the applicant, the Department shall either approve the application and issue the appropriate permit or disapprove the application or may proceed to a public hearing. If an application for a construction or operation permit is disapproved, the Department shall notify the applicant in writing of the reasons therefor.

11. Any permit holder who intends to continue construction or operation beyond the period of time covered in such permit must file for reissuance of such permit at least 30 days prior to its expiration. Filing for reissuance shall be made by the permit holder on forms authorized by the Department. The provisions of this Part relative to submittal and processing of initial applications shall apply to reissuance applications under this Section to the extent indicated by the Department in instructions accompanying reissuance application forms.

12. After notice and opportunity for a hearing, any permit issued pursuant to this Part may be modified, suspended, or revoked in whole or in part during its term for causes stated on p. 11. The Department may revise or modify a schedule of compliance or other terms in an issued permit if it determines good cause exists for such revision.

Discussion:

The Solid Waste Management Facility "Content" and "Guidelines for Plans and Specifications" have been prepared in draft form to aid the applicant in satisfying the requirements of Part 360. Copies of these two documents as well as the following application forms are included in Appendix D:

1. Application for Approval to Construct a Solid Waste Management Facility.

2. Application for Approval to Operate a Solid Waste Management Facility.

3. Application for Variance from 6NYCRR360.

4. Application for Use of a Construction and Demolition Debris Disposal Site.

The newly-written guidelines contain procedures applicable to all facilities as well as those specific to sanitary landfills, resource recovery and processing facilities, and hazardous wastes and special wastes (sewage sludge and power plant wastes) facilities. A list of hazardous substances is included in Appendix G of the "Guidelines". Note, however, that this is a working draft and not for publication. An industrial and hazardous waste disposal application form and a leaching potential test reporting form are also included in these "Guidelines" at the end of Section 5, Industrial and Hazardous Waste Disposal. The leaching potential test is required only if requested by the Department.

The following procedure should be used to evaluate a waste for its potential to readily leach deleterious substances. Triplicate samples of the wastes should be analyzed to obtain representative results.

1. A representative sample of the waste should be taken according to ASTM Standard Methods.

2. Any free liquid associated with the sample should be removed by decanting or filtering. Such free liquid should be analyzed in accordance with 3. below and the "dry" material in accordance with 4. below.

3. A qualitative and quantitative analysis of any associated free liquid should be performed in accordance with accepted standard methods. Suspended particulate matter should be removed before analysis by filtering the supernatant solution through a 0.45-micron glass filter.

4. The following procedure should be used on the residual "dry" material:

    a. A 250-gram sample of the "dry" residual should be mixed with one liter of distilled or deionized water.

    b. The mixture should be agitated for 48 hours by shaking or slow stirring.

    c. The sample container should be stoppered and the sample allowed to settle for at least three days.

    d. The supernatant water should be decanted and filtered through a 0.45-micron glass filter.

e. A qualitative and quantitative analysis of the supernatant should be performed by standard methods.

Paragraph 360.8(a)(17) states that "hazardous wastes shall be accepted only at facilities which have been specifically approved by the Department for the processing or disposal of the specific wastes". Paragraph 360.8(b)(1)(xi) goes on to state that "No hazardous or industrial wastes nor materials which when combined together will produce hazardous wastes shall be disposed of in a sanitary landfill except pursuant to specific operation permit authorization".

"Guidelines for Plans and Specifications" provides information regarding on-site data. Such items as soil description, soil boring identification and location (Unified Soil Classification), groundwater depth and flow directions, and estimates of leachate formation are included. Permeability is considered an important parameter; specific requirements are determined on a case-by-case basis. Municipal wastes are not classified. There are separate sections on industrial and hazardous waste disposal and/or special wastes. The form includes criteria for identifying hazardous substances, the list of hazardous substances, and the leaching potential test. The latter includes sewage and septic waste treatment and disposal, waste lagoon, ground spreading, and injection into the land.

Wastes classified as hazardous may be required to be disposed of in a "Secure landburial facility". The site requirements for such a facility are more detailed and more stringent than for a sanitary landfill. The requirements are shown on Table C-3. Permeability of 1×10^{-7} cm/sec is required for a site liner; a thickness is not specified. An impermeable cover is also required for the facility in order to prevent infiltration of rain water. The combined effect of the two impermeable barriers is to provide total containment of waste and hydrologic isolation.

It is noteworthy that two modes of deposition of municipal solid wastes exist within New York State. Waste deposition with reliance on the natural attenuation of leachate is generally permitted in those areas of the State except on Long Island. Waste containment with subsequent leachate collection and treatment is generally required on Long Island to ensure protection of the "sole source" groundwater supply present in the underlying permeable sand and gravel aquifers. Liners are required which preferably are clays with a natural low permeability rather than synthetic liners for waste/leachate containment.

TABLE C-3

NEW YORK DEC SITE CRITERIA

Site Characteristics	Hazardous Waste	Other Wastes
Permeability of liner	$\leq 1 \times 10^{-7}$ cm/sec	Site - specific requirements may be indicated
Impermeable cap	Required	Final cover such to minimize ponding, erosion, and infiltration.
Leachate collection and treatment	Required	Site - specific requirements may be indicated
Surface drainage	Collection and treatment	Designed to minimize ponding, erosion, and infiltration.
On-site soil permeability	$\leq 1 \times 10^{-5}$ cm/sec	Not specified
Depth to groundwater or bedrock	$\geq$ 10 feet	$\geq$ 5 feet
Proximity to surface water	Site - specific requirements may be indicated	Site - specific requirements may be indicated
Groundwater monitor wells	min 3 - 2 downgradient	Same

CONTACT FORM

Agency:

Pennsylvania Department of Environmental Resources
Bureau of Land Protection
Division of Solid Waste Management
P.O. Box 2063
Harrisburg, PA 17120
Phone: 717-787-7381

Persons Contacted:

John Rosso, Chief
Program Development Section

Gary Merritt, Geologist
Program Development Section

Gary Galida
Program Development Section

Dwight Worley
Operations and Compliance Section

Type of Procedure:

Criteria Listing

Waste management including hazardous waste is regulated by Chapter 75, Solid Waste Management Rules and Regulations. These Rules and Regulations were recently revised to include standards for sanitary landfill liners, standards for hazardous solid waste management, and general standards for industrial and hazardous waste disposal sites. These and other modifications became effective 27 June 1977.

Permit Procedure:

1. The applicant notifies DER of his intent to open a new landfill site. DER encourages the applicant to meet with the State at an early date to discuss his proposed plan and concept of operation and to obtain suggestions by DER personnel for site utilization in an environmentally-acceptable manner. DER also encourages local involvement, particularly with local zoning and local planning offices. This initial meeting may be held in the DER Regional Offices; in many cases, however, the meeting is held with the Central Office staff in Harrisburg.

2. A formal application is submitted to the Regional Office and includes the following items: an Application for Permit for Solid Waste Disposal and/or Processing Facilities; a Solid Waste Disposal and/or Processing Site Application Module, Phase I; and Module 5A - Phase I, Supplementary Geology and Ground Water Information.

3. Technical review is provided in the Regional Office with input from the Central Office technical staff as required in the soils and geology areas. All review comments are compiled by the Regional Solid Waste Program Manager; he also reviews comments by additional agencies such as the Bureau of Water Quality Management, the Bureau of Air Quality and Noise Control and Radiological Health (if such comments are appropriate). This coordinated review is made at the Phase I level and, in many cases, the applicant is informed by DER that certain changes will be required prior to submittal of the Phase II application. The Bureau of Water Quality Management must review and permit those operations where leachate collection facilities are provided with a point discharge. The Bureau of Air Quality and Noise Control provides input for those wastes generated by air pollution control measures such as stack precipitators and the ensuing ash.

4. A formal Phase II submittal then follows; it involves completion of the solid waste disposal and/or processing site application module, Phase II and the groundwater module, Phase II monitoring points. Technical review is provided by soil scientists, geologists, and engineers with their comments coordinated by the Regional Program Manager and, if necessary, a letter is submitted by him to the applicant with deficiencies that need resolution. Following their resolution, the Phase II submittal is returned to the Operations and Compliance Section for processing and assurance that all items are completed. The final and formal permit is prepared by the Operations and Compliance unit for the Bureau Director's signature and is then issued.

5. A public hearing is not required; however notification of the intended action must be published in the Pennsylvania Bulletin on two occassions:

   When the permit application is made.
   When the permit has been approved for issuance.

   If considerable protest arises prior to the issuance of the permit and a written request is made, an informal (non-legal) fact-finding hearing will be held by a DER hearing examiner who will make recommendations on the course of action. Following the DER advertisement of permit issuance, there is a 15-day period in which complaints may be filed to the hearing board. Formal hearings, if required, are held by the Environmental Hearing Board within 30 days of permit issuance. Following acquisition of expert testimony, the hearing board will render a decision which may be appealed (by either the applicant or by citizens groups) to the Commonwealth Court and, if not resolved there, the appeal may be taken to the State Supreme Court.

Discussion:

The philosophy of waste management and waste site permitting currently in effect is that the waste leachates must not adversely affect groundwater quality. DER does not necessarily advocate containment of waste and collection and treatment of leachates, but the trend is definitely in that direction; attenuation is considered on a site-by-site basis. Waste/site permitting is conducted on a case-by-case basis for both hazardous and non-hazardous wastes. Certain industrial waste may be given approval if the waste type remains constant for the life of that waste being generated and deposited in a specific approved site. Where the unit process changes frequently, wastes are permitted on a "load-by-load" basis as long as the waste characteristics remain the same. When the waste type does change, the landfill operator must acquire an amendment to the permit to accept that type of waste.

DER provides the applicant with an array of modules, rules and regulations, guidelines, and applications according to the waste type proposed for disposal. A listing of these items is as follows: Application for Permit for Solid Waste Disposal and/or Processing Facilities; Solid Waste Disposal and/or Processing Site Application Module, Phases I and II; Module 5A-Phase I, Supplementary Geology and Groundwater Information; Ground Water Module, Phase II Monitoring Points; Module for Sewage Sludge and Septic Tank or Holding Tank Waste; Interim Guidelines for Sewage, Septic Tank, and Holding Tank Waste on Agricultural Lands; a Spray Irrigation Manual (which is administered by the Bureau of Water Quality Management); and Coal Refuse Disposal Application for Permit. (Copies of these forms are included in Appendix E.)

With respect to hazardous waste, there is no standardized form for waste characterization; however, specific information is required relative to the volume and nature of the waste to be disposed. A chemical analysis of the waste must be provided, as well as a leaching analysis using methods approved by the department. A waste leachate analysis procedure has been established by the department and is attached. This procedure has been in use for more than five years.

Based upon the waste characterization and leaching analysis, DER determines the manner in which the waste is to be handled. Waste handling methodologies include landfilling, isolation within the landfill by containerization, physical separation or lime encapsulation, chemical stabilization, and incineration. It is noteworthy that there is no site designated within Pennsylvania specifically and solely for the disposal of hazardous waste. Hazardous waste being disposed of are either incorporated in existing approved landfills, are treated and disposed of by using other methodologies, or are exported from the State. There is no formal waste site classification with the exception of three classes of waste (I, II, III) for construction and demolition wastes.

Disposal site characterization is provided by an extensive listing of soils, geology, and surface and groundwater criteria that must be defined to adequately describe the physical site conditions. This site characterization is well defined in Module 5A and in various sections of Chapter 75, Solid Waste Management Rules and Regulations. A one-to-one ratio of refuse to unsaturated thickness of soil deposits is required where attenuation is relied upon for renovation of leachates produced from the waste. As stated above, however, the trend is definitely toward the collection and treatment of leachates generated by municipal waste and, in most cases, hazardous waste. The utilization of man-made and natural liners, particularly the former, is becoming more commonplace. Synthetic liners of the membrane type must have a minimum thickness of 20 mils and a natural permeability of 1×10^{-7} cm/sec or less. If natural deposits are used, they must have a uniform thickness of greater than 2 feet and must have a permeability of less than 1×10^{-7} cm/sec. If the uniform thickness is greater than 4 feet and there is an upward groundwater flow, the permeability may be increased to 1×10^{-6} cm/sec or less.

CONTACT FORM

Agency:

Texas State Department of Health Resources
Division of Solid Waste Management
1100 W. 29th Street
Austin, Texas 78756
Phone: 512-458-7271

Persons Contacted:

Mr. Jack C. Carmichael Director	Hector H. Mendieta Chief, Facilities Evaluation Branch
Mr. Lou B. Griffith, Jr. Chief, Technical and Regulatory Branch	George King Geologist

Types of Procedure:

Criteria Listing
Classification System

The Department of Health Resources (DHR) has undergone an 18-month program and has published new regulations for municipal solid waste management that became effective 20 April 1977. (A copy of these "Municipal Solid Waste Management" regulations is included in Appendix E.)

Permit Procedure:

A flow chart illustrating the review process, the agencies involved, and the timing is presented in Figure C-2. A detailed description of this permit review process is as follows:

> Upon receipt of an application, the Department will make a preliminary evaluation to determine if the application is administratively and technically complete. If additional information is required, it will be requested of the applicant before continuing with the processing of the application.

1. Application Processing

    a. Following receipt of all required information, the Department will provide copies of the application to those

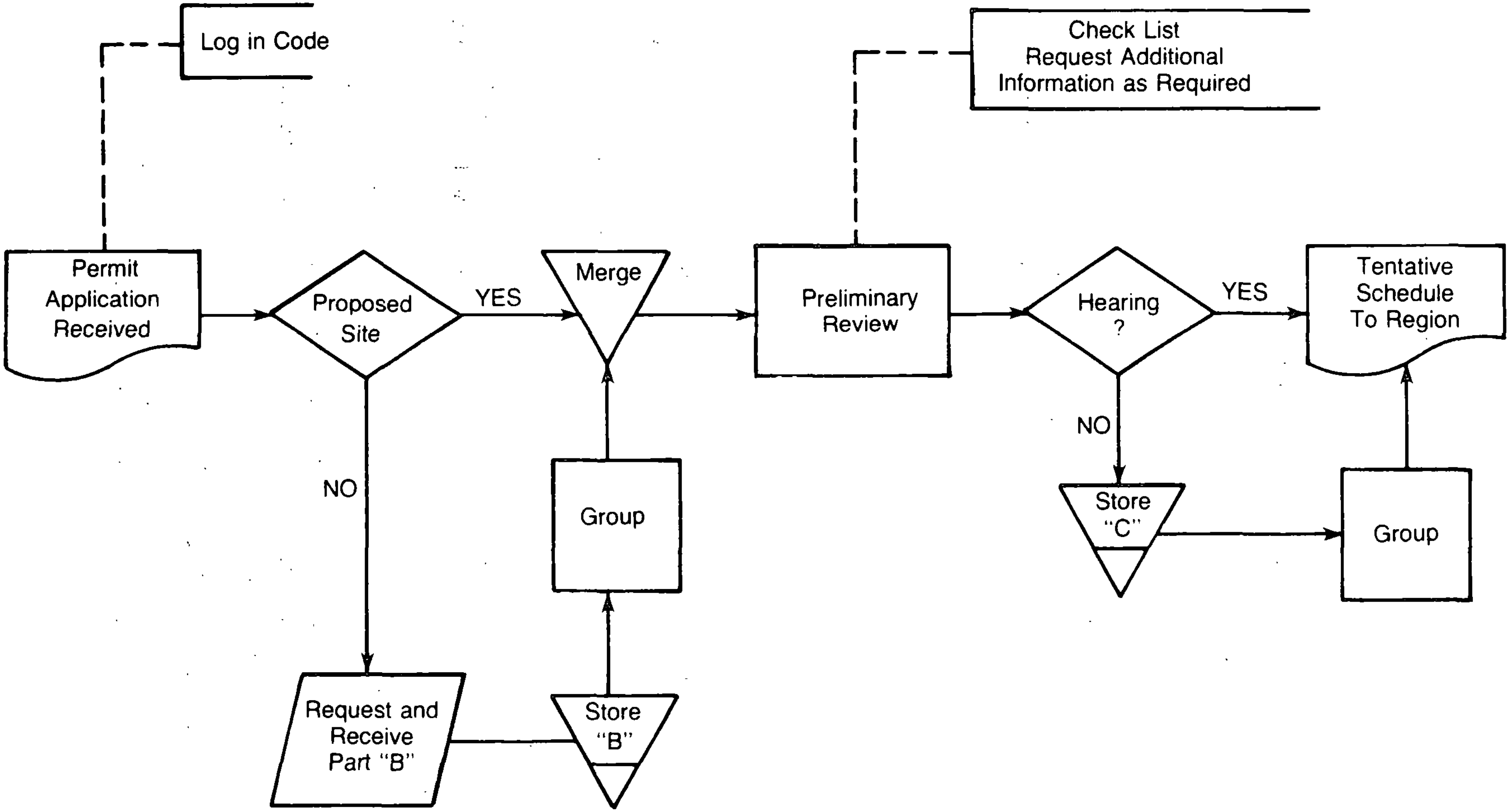
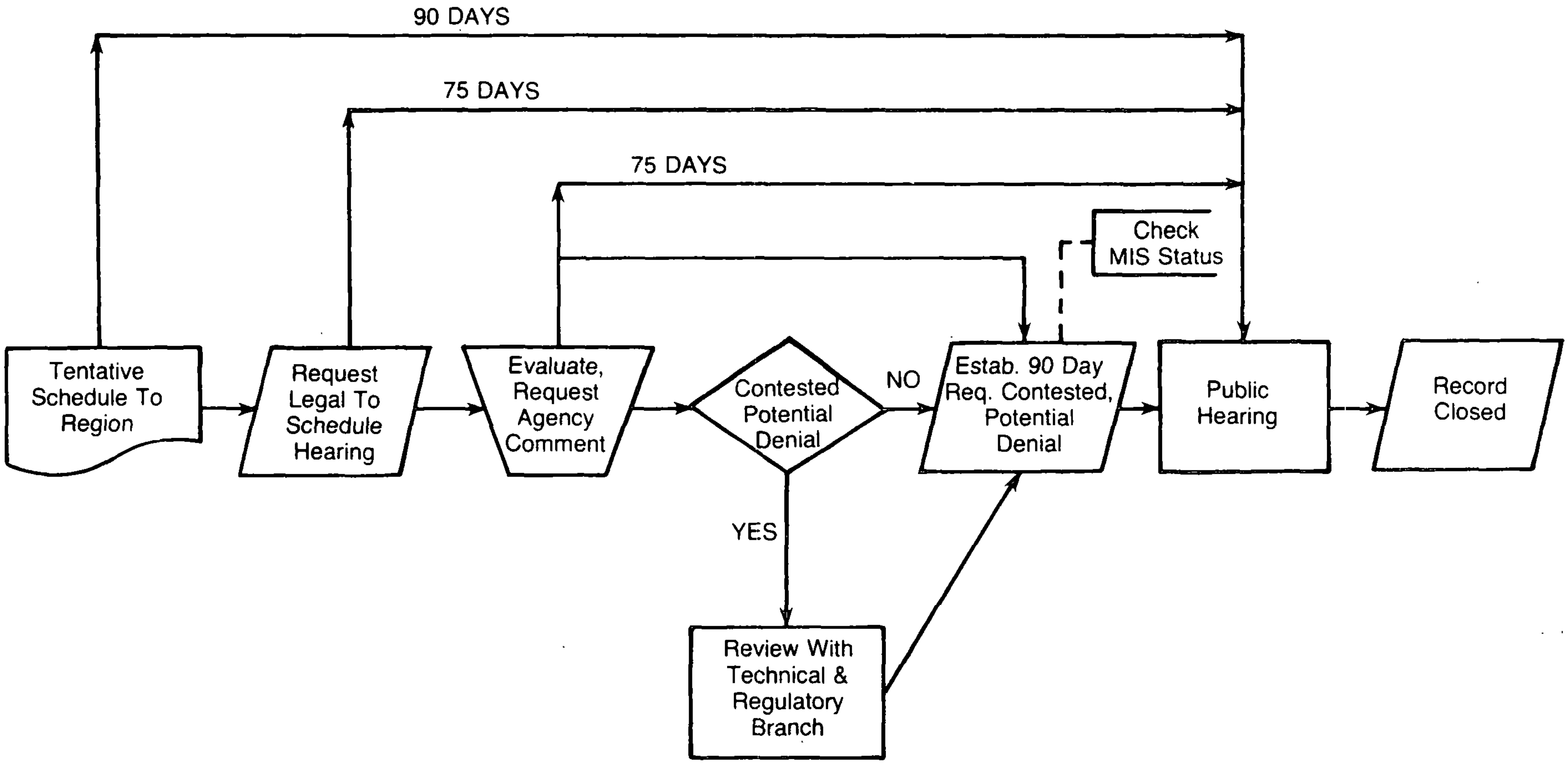
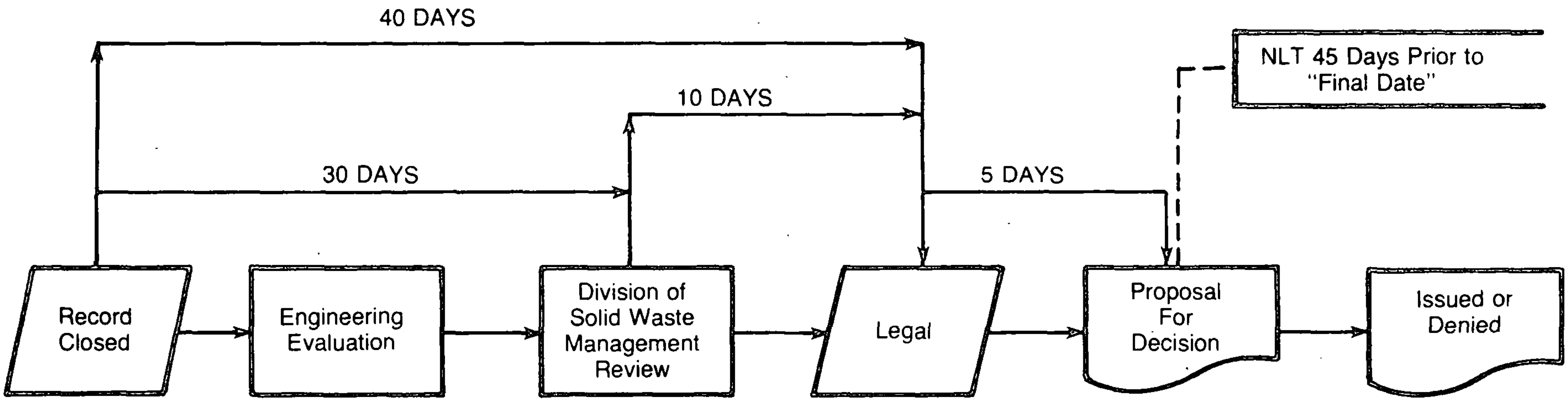


FIGURE C-2 PERMIT APPLICATION REVIEW PROCEDURE USED BY THE TEXAS DEPARTMENT OF HEALTH RESOURCES



PERMIT APPLICATION REVIEW PROCEDURE USED BY THE TEXAS DEPARTMENT OF HEALTH RESOURCES (continued)



PERMIT APPLICATION REVIEW PROCEDURE USED BY THE TEXAS DEPARTMENT OF HEALTH RESOURCES (continued)

agencies which have or may have a jurisdictional interest in the case and request their comments or recommendations. The agencies include:

1) Texas Water Quality Board.

2) Texas Air Control Board (A separate permit may be required).

3) Texas Water Development Board (A separate permit may be required).

4) State Department of Highways and Public Transportation.

5) Federal Aviation Administration.

6) U.S. Army Corps of Engineers (A separate permit may be required).

7) Mayor of the city in whose territorial or extraterritorial jurisdiction the site is located.

8) Health authority of the city in whose territorial or extraterritorial jurisdiction the site is located.

9) County Judge of the county in which the site is located.

10) Health authority of the county in which the site is located.

11) Others as determined appropriate by the Department.

b. Additionally, a copy of the application is provided to the appropriate Regional Engineer of the Department for his conduct of a site evaluation, verifying insofar as possible the data submitted and technical feasibility of the proposed operation. In submitting his comments and recommendations, the Regional Engineer will consider the past operating record and current status of an existing site. The site operator's ability or lack of ability to comply with the Department's regulations will also be discussed at the public hearing.

c. Normally, the entities to whom copies of the application are mailed shall have thirty (30) days to present comments and recommendations on the permit application. If any of the review agencies or the Department requires additional data in order to conduct a proper evaluation, the additional data will be requested by the Department. Following receipt of comments and recommendations from the various review agencies, a professional engineer from the Department will make a detailed engineering evaluation of the application taking into consideration all comments received from the review agencies. The Department will give consideration to any recommendation or action taken by the governing body of a city or county within whose jurisdiction the proposed site is to be located concerning implications of the application with respect to public health welfare and physical property, including proper land use, reasonable projection of growth and development, and any other pertinent considerations.

2. <u>Scheduling and Preparation for a Public Hearing</u>

a. Upon completion of the evaluation of the permit application, the Department will normally make arrangements with the applicant for a time and place for the conduct of the required public hearing.

b. The Department will provide the applicant with a public hearing notice announcing the time, place and purpose of the public hearing, and advising all citizens of their right to present comments for or against the issuance of a permit. The applicant shall be responsible for ensuring that such notice of the public hearing is published at least once in a newspaper regularly published or circulated in the county in which the disposal site is located. The applicant shall be responsible for paying for and publishing the hearing notice. The Department, at its option in any individual case, may require that publication of the notice be made in additional newspapers in the county or other counties. Publication shall not be less than twenty (20) days before the date of the hearing. The applicant shall provide the Department with proof that the publication was timely by submitting prior to the date of the hearing an affidavit of the publisher which shows the date of publication. The affidavit shall be accompanied by a copy of the published notice.

3. <u>Conduct of the Public Hearing</u>

a. The public hearing will be conducted by a Hearing Examiner from the Department's legal staff and a professional engineer from the Division of Solid Waste Management.

b. The applicant or his duly-authorized representative will be present at the public hearing to present the application and answer any questions that may arise during the hearing or to clarify any of the information previously submitted. In view of the possibility that legal questions may arise, the applicant should be accompanied by his legal counsel. If a professional engineer prepared the engineering plan for the site, he should also be present at the hearing to answer any technical questions. Failure of an applicant to be present at the public hearing, or to be properly represented, could result in the denial of a permit.

c. All hearings held by the Department on solid waste permit applications are conducted in accordance with the "Administrative Procedure and Texas Register Act", which requires that evidence submitted by legally admissible (as opposed to hearsay) if such evidence is to be used as a basis for a final decision. Because this statute requires that administrative hearings follow the same rules of evidence as those used in non-jury District Court cases, applicants are advised to seek assistance from their attorneys in preparing for a hearing and, although not required, it is advisable that the applicant's attorney actually participate in the hearing, particularly if there is opposition to the permit application.

d. The hearing record may be closed by the Hearing Examiner upon conclusion of the public hearing, or he may keep the record open for a specified period of time to receive specific documents or additional information not available during the hearing.

4. <u>Final Determination on Application</u>

a. <u>Unopposed Cases</u>

After the record is closed, the Department will complete the engineering and legal evaluation of all data submitted prior to and during the hearing and before the closing of the record, including comments received from the various review agencies. The Director of the Department reviews the findings and recommendations and either approves or denies the issuance of a permit. Normally the final decision will be made within 60 days after the closing of the hearing record, but this may be extended by the Hearing Examiner at the public hearing up to 90 days when required by circumstances. The applicant will be advised by the Department of the Director's final decision by letter.

b. Design Adjustments

1) If during the public hearing additional engineering or design data are considered necessary as a result of questions raised or introduction of conflicting data by opponents, the Department will request the data to resolve such conflicts. Any data thus received at the public hearing or subsequent thereto and prior to the closing of the hearing record will be made a part of the application and be subject to consideration during the final evaluation.

2) Any data received at, or as a result of, the public hearing will be provided to those designated as parties to the action or review agencies who have an apparent interest and whose original comments could be influenced by the additional data.

3) Following the receipt of comments on the supplemental data, the Department reevaluates all data and prepares a Proposal for Decision in opposed cases or in such cases when an intended decision may be detrimental to the applicant. The Proposal for Decision may contain special requirements that could necessitate a redesign of the facility or a revision in operating procedures.

c. Opposed Cases

In opposed cases in which the departmental Director neither hears the evidence nor reads the complete record, a Proposal for Decision shall be provided to all parties to the action after the closing of the record. All parties to the action will be provided with a specified period of time to file exceptions and briefs to such Proposal for Decision. Notice of this time limitation will be provided to all parties in each case. Following his review of the Proposal for Decision, exceptions and briefs to such Proposal, and the staff recommendations, the Department Director shall issue a final decision in the form of either a permit, with special provisions attached thereto, or a denial order, containing the grounds for such denial. Subsequent to this final decision by the Director, a Motion for Rehearing may be filed by any person affected by the decision. This must be filed within fifteen (15) days of the Director's decision, and persons opposing or otherwise responding to the Motion for Rehearing will be provided an opportunity to file a reply to the Motion. The Director shall have forty-five (45) days from the time of the final decision (i.e., the issuance of the permit or denial order) to rule on the Motions for Rehearing, unless such time is extended by the Director by written order. Anyone who has filed a Motion for Rehearing may appeal the Agency's final decision to a District Court in Travis County within thirty (30) days after a Motion for Rehearing has been overruled either by written Order of the Director or by operations of law. Time limitations for the filing of Motions, responses, exceptions and briefs shall be governed by the provisions of the "Administrative Procedure and Texas Register Act", Article 6252-13a, Texas Civil Statutes.

Discussion:

The responsibility for disposal of solid waste is divided between the Texas Water Quality Board (WQB) which is responsible for industrial waste and the Texas State Department of Health Resources (DHR) which is responsible for municipal waste. When wastes are combined, the DHR has responsibility. The two agencies differ somewhat in their approach, and the regulations for the two waste types are different. DHR uses a site type classification system for municipal waste. The various site types have specific physical criteria which must be met but, as seen in Table C-4, the site types are primarily distinguished by the population served by the site and the frequency of covering. The site criteria are then applied according to the population. Type I (which serves the highest population) has the strictest criteria and is considered to be the standard for disposal of municipal solid waste.

The site type classification system makes a distinction not only on the basis of population served, but also on the basis of waste type. The Department does not regulate the acceptability of industrial or

TABLE C-4

Texas Department of Health Resources
Requirements for Municipal Solid Waste Disposal*

		Minimum Acceptable Ground Water Protection						
Site Type	Site Classification	Soil Thickness	Permeability cm/sec	Liquid Limit	Plasticity Index	Drinking Water Protection	Flood Protection	Frequency of Compaction and Cover
Sanitary Landfills Site Type I	Considered to be the standard sanitary landfill for disposal of municipal solid waste and is encouraged in all cases. Required in a county with a population >100,000 or sites serving >5,000 persons, or the same population equivalent.	3'**	$\leq 1 \times 10^{-7}$**	Not less than 30	Not less than 15	Not within 500' of drinking water supply well, intake of a water treatment plant, or raw water intake which furnishes water to a public water sy-system for human consumption. If closer than 500', engineering data shall be presented to show that adequate protection to drinking water sources is provided.	Levees constructed to provide protection from a 50 yr. frequency flood.	All solid waste shall be compacted and covered at least daily except for areas designated to receive only brush and/or construction-demolition wastes which shall be covered at least monthly.
Sanitary Landfills Site Type II	May be authorized by the Department for a site survey serving <5,000 or same population equivalent when relevant factors indicate a frequency of less than daily compaction and cover will not result in any significant health problems.	"	"	"	"	"	"	Up to seven (7) days.
Sanitary Landfills Site Type III	May be authorized by the Department for a site serving <1,500 persons or same population equivalent using the same considerations as applicable to a site Type II operation.	"	"	"	"	"	"	Up to thirty (30) days.
Sanitary Landfills Type IV	For disposal of brush and construction-demolition wastes that are free from other solid wastes.	"	"	"	"	"	"	As necessary.

* Minor amounts (5% or less by weight or volume) of Class I industrial solid waste may be accepted under certain conditions, at Type I sites which have a permit from or have filed a permit application with the Texas Department of Health Resources without special Department approval.

** or equivalent (e.g., liner equivalent degree of impermeability).

municipal solid waste by its point of origin. Municipal, agricultural, or industrial waste can contain hazardous material and, therefore, the Department regulates such wastes in relationship to the degree of hazard the waste will create in specific municipal solid waste collection, handling, storage, or disposal activities. Class I industrial solid waste may be accepted at a municipal solid waste site only if special provisions for such disposal and special handling procedures are approved by the Department.

Minor amounts of Class I industrial solid wastes (an estimated 5 percent or less by weight or volume) may be accepted at Type I sites which have a permit from or have filed a permit application with the Texas Department of Health Resources without special Department approval if certain conditions are met. Significant amounts of Class I industrial solid wastes, which are in excess of an estimated 5 percent by weight or volume of the total combined waste during any phase of collection, handling, storage, transportation or disposal shall not be accepted by or deposited in a municipal solid waste disposal site unless prior written approval has been obtained from the Texas Department of Health Resources. Requests for approval to accept Class I industrial solid wastes shall be submitted to the Texas Department of Health Resources by the municipal solid waste disposal site operator.

Furthermore, Class I industrial solid wastes shall not be accepted for disposal at a Type II or III site without written approval from the Department and hazardous wastes shall not be accepted for disposal at any solid waste facility without prior written approval of the Department.

The specific conditions and requirements for co-disposal of municipal and industrial wastes are found on pages 71-75 of the Regulations.

All municipal waste basically undergoes a mode of deposition relying upon containment and not attenuation, since a permeability of 1×10^{-7} cm/sec or less is required. A variance may be issued which is site specific, whereby a greater permeability may be approved due to such factors as size of site, amount and types of waste received, isolation of the site, depth of water table, or lack of usable water. Relative to liners, natural clays, either on-site or transported in and reworked, are favored. There has been one permitted artificial liner, an asphalt liner; however, the DHR does not favor the use of synthetic liners.

Even though site types are specified, as shown in the table, an extensive Criteria listing is required for site characterization. The specific site definition criteria are stated on pages 38 through 55 of the Regulations.

Pertinent documents relative to the permit process are included in the regulations booklet. Specifically they include: "Application for a Permit to Operate a Municipal Solid Waste Facility, Part A - General Data (3 pages, Appendix A); Part B - Technical Data (5 pages, Appendix B); Notice of Appointment, relative to submission of engineering plans (Appendix C); and Affidavit to the Public, relative to the land owner/operator (Appendix D).

A "self assessment" of the Municipal Solid Waste Management regulatory program has been completed by the DHR staff as follows:

1. Assess the relevancy and completeness of information requested of permit applicants for making permit decisions:

   The "Design Criteria" section of the January 1976 "Municipal Solid Waste Management Regulations" stated that design factors to be considered should provide for safe-guarding the health, welfare, and physical property of the people through consideration of geology, soil conditions, drainage, land use, zoning, adequacy of access, economic haul distances, and other conditions as the specific site indicates. Information obtained from the applicant generally addressed all design factors in sufficient detail on which to base a sound decision. However, less than half of the applicants initially submit relevant and complete data with the application. Therefore, in more than half of the cases, additional data must be requested before the application can be processed. This problem is more prevalent with small cities, counties, and operators which are applying for permits for facilities serving less than 5,000 persons. More difficulty is experienced in obtaining data for existing sites than for proposed sites.

2. Evaluate the ease of data gathering and analysis on the part of the permit applicant and the permit grantor:

   The majority of the applicants for permits for large facilities apparently have very little trouble in obtaining the required data for a permit application. The applicants for small facility permits (less than 5,000 population served) have relatively more difficulty in obtaining data due to more limited staff and budget.

   The ease of analysis on the part of the permit grantor is directly related to the amount and quality of data submitted by the applicant. Considerable effort is frequently required to obtain necessary data from small operators.

3. Assess the consistency in interpretation and application of the permit application process at different sites within the jurisdiction:

   The Department is aware that consistency is of great importance and has designed its internal procedures with that goal in mind. Because Texas contains extreme variations in population densities, rainfall, hydrogeology, and other principal design factors, a policy of consistency is sometimes difficult to follow, but is generally achieved.

4. Evaluate how well the procedure accounts for both site and waste parameters, and determine the applicability of the procedure to a range of sites and waste characteristics:

   The procedure followed by this Department has worked quite well. The range of site and waste characteristics varies from small rural communities to large metropolitan areas. The Department has been able to adapt the permit procedures to both extremes and those occurring in between.

5. Identify the level of confidence in decisions made, both as to site rejection and site approval:

   There is little doubt that the proper decisions have been made. This is backed up by the fact that, out of 436 permits which have been issued and 18 permits which have been denied during the past 2 1/2 years, only four decisions (2 approvals and 2 denials) have been taken to court. The court upheld the decision in three cases and voided one approval on the basis of procedural error (a complete list of adjacent property owners had not been submitted by the applicant and, consequently, all affected persons had not been advised of the opportunity to attend the public hearing). As a result, a rehearing was held which resulted in the denial of the permit. Also, as a result of the court's ruling, the procedure of individually notifying adjacent property owners of public hearings was deleted from the regulations.

   One recent approval and one denial are expected to be appealed.

6. Determine costs of obtaining the permit decision:

   See case history for City of Carrollton, Permit No. 750 and City of Mesquite, Permit No. 556.

In addition to the Department's costs, other Federal, State, or local agencies incur costs as a result of reviews which those agencies must make due to jurisdictional responsibilities they may have. (See Table C-5.) In some cases, up to 10 other agencies may evaluate a specific application. Their costs are probably low, but, in the case of the City of Carrollton's permit application, the Texas Water Development Board estimated its costs as $1,800 inasmuch as it had to issue a formal approval, after a hearing, for construction of required levees in a floodplain.

7. Determine the time (maximum, minimum, average) required to obtain a permit:

   Since the start of the program in October 1974, the Department received approximately 625 permit applications within a three (3) month period and has received approximately 500 additional permit applications since that time. Considerable difficulty has been experienced in obtaining information on existing sites. During the past 2 1/2 years, 436 permits have been issued, 18 denied, and 69 permit applications have been withdrawn during processing, mainly either because of public opposition to the site operation or the applicant found it too expensive to proceed.

   a. The maximum time to issue a permit for a proposed site has been 16 months. This was for the City of Victoria (Permit No. 120) which was opposed and involved the reopening of the hearing.

   b. Minimum programmed time to issue a permit after permit application is complete when processed on a normal basis is 4 months and 3 weeks:

2 weeks to review application	15 days
4 weeks for review agency comments	30 days
2 weeks to schedule public hearing	15 days
3 weeks for public hearing notice	20 days
60 days for final decision	60 days
	140 days

   The actual minimum time to issue a permit for a proposed site has been 2 1/2 months. This was for a transfer station for Travis County (Permit No. 119).

   c. Average time to obtain a permit under this program, since its start in 1974 is 7 months (for proposed sites, which are given priority and processing of applications starts as soon as received).

TABLE C-5

TEXAS DEPARTMENT OF HEALTH RESOURCES
PERMIT APPLICATION REVIEW AGENCIES

PERMIT
Copies of DENIAL No. ________ were mailed to the following review agencies and individuals:

REVIEW AGENCIES AND MISC.

____ Region ____, TDHR
____ TWQB
____ TACB
____ TWDB
____ SDHPT
____ Mayor of ________________
____ County Judge
____ City-County Health Department
____ City Health Department
____ County Health Department
____ City Health Officer
____ County Health Officer
____ FAA
____ USACE
____ Trinity River Authority (N)
____ Texas Pollution Report
____ The Process Company, Inc.
____ Legal, TDHR
____ Permit File (By Date Issued)
____ Permit File (By PA Number)
____ File Folder
____ Gulf Coast Waste Disposal Authority (Chambers, Galveston, & Harris Counties)

INDIVIDUALS REQUESTED BY LEGAL

____ ______________________________
____
____
____ ______________________________
____
____
____ ______________________________
____
____
____ ______________________________
____
____

OTHER INDIVIDUALS

Senator -
____ ______________________________
____
____

Representative -
____ ______________________________
____
____
____ ______________________________
____
____
____ ______________________________
____
____

Mailed by: ________________ Checked by: ________________

Date: ________________ Date: ________________

TDHR - Division of Solid Waste Management

8. Determine staff requirements to process permit applications (man hours by labor class per permit application) by the regulatory agency:

Engineering Supervisory Review	8 manhours
Project Engineer	36 manhours
Secretarial	12 manhours
Legal Staff	15 manhours
Legal Secretarial	4 manhours
Regional Engineer-Inspection and Review	15 manhours
Regional Secretarial	2 manhours
Staff Geologist	3 manhours
Supervisory Review	3 manhours
Court Reporter	2 manhours
	100 manhours

This is an average figure over a 2 1/2-year period although several highly-contested cases have required over 200 manhours.

Several excellently documented case histories which both describe and highlight the permit procedure utilized by DHR have been prepared by their staff. The case history for the City of Carrollton, Permit No. 750 (Appendix E) was considered a typical contested case which did result in the issuance of a permit.

CONTACT FORM

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Acting Chief, Industrial Engineer
Industrial Solid Waste Branch

Chesley Blevins
Assistant Director
Hearings Division

J.C. Newell
Assistant Director
Central Operations Division

Greg Tipple
Geologist/Clay
Mineralogist

Rod Kimbro
Chemist

Types of Procedures:

Criteria Listing
Classification System

Permit Procedure:

1. Initially, there is a request from a proposed disposal operation to discuss a need for a site and how best to proceed.

2. A pre-application conference is held with the proposed operator and WQB staff with some direction on where to look, the advisability of the hiring of consultants, and preliminary assessment of office data. There is a possibility of a second pre-application conference if some limited amount of data is gathered and recommendations can then be made whether to proceed further or not. The State may visit the site for recommendations on a "go/no go" situation prior to spending considerable dollars and will encourage this approach. Existing soils and geologic maps are used in the assessment process; however, a field visit is generally made unless it is obvious that, based on existing mapping, the site is not suitable.

3. Certain parameters are evaluated such as access, permeability, land use in the area, proximity to streams, and groundwater use.

4. A detailed site definition is performed including engineering plans, detailed operational manual, staffing, waste characterization, and proposed monitoring.

5. Technical review is conducted by the State, and a second site visit may be made. A permit is written based upon the application and any modifications made to it, if necessary, on a site-by-site basis. This generally entails a resubmittal. There is no time limitation on the application review. A public hearing is required for both municipal and industrial landfill permits, and a date of action by the Water Quality Board on the application is set at that hearing, generally at 60 days. Copies of the draft report are sent to the District Office and the following other state agencies for in-house review: the Health Department; the Water Development Board, which will write a report on the groundwater water-quality impacts; and the Parks and Wildlife agency.

6. Local notification of the public hearing is set 20 days prior to the hearing. The public hearing is held before a hearing examiner who is a staff attorney of the Board. The hearing examiner hears all the evidence, summarizes the proceedings in a report, and makes a recommendation which is then mailed to all pertinent parties attending the hearing at least 10 days prior to the Board meeting. The Board meeting is public and the Board makes the final decision needing the majority of votes (4) for permit approval. If there is disagreement between the applicant and the technical review of that application by the technical staff, the hearing examiner may get third party advice.

A flow chart showing the agencies involved in the permit review process is included in Appendix D.

A series of nine Technical Guidelines has been prepared by the WQB relative to the regulation of wastes, exclusive of municipal refuse. These Technical Guidelines are as follows:

Number	Topic
1	Waste Evaluation/Classification
2	Site Selection and Evaluation
3	Landfills
4	Ponds and Lagoons
5	Landfarming
6	Monitoring/Leachate Collection Systems
7	Supporting Facilities
8	Records
9	Non-Compatible Wastes

Technical Guideline No. 1 has been revised several times and the latest draft copy (August 1977) is included in Appendix D. This copy is expected to be distributed for use after 1 October 1977. The other eight Guidelines will undergo some modification in the near future.

Discussion:

The Texas Water Quality Board regulates and permits the disposal of industrial solid wastes unless they become mixed with municipal wastes. When the wastes are mixed, the Texas Department of Health Resources assumes responsibility. (See Discussion Section for this agency.)

As with municipal waste disposal sites, industrial waste disposal sites rely upon containment of wastes rather than attenuation of waste leachates. A permeability of 1 x 10^{-7} cm/sec or less is required for containment.

Waste characterization is required. A solid waste evaluation leachate test is required (a copy is included at the end of this section). A hazardous index (HI) has also been developed by the WQB. Two methods to calculate the HI have been devised: one which is non-analytical, for organic materials; and one that is analytical for inorganic materials. A copy of these two methods is also attached.

Industrial solid waste is classified by the Water Quality Board (WQB) on the basis of the hazardous potential of the waste. Site criteria have also been assigned to each of the three waste classes. (See Table C-6.) The following definitions of waste classes have been established:

> "Class III - Essentially inert and essentially insoluble industrial solid waste, usually including materials such as rock, brick, glass, dirt, certain plastics, rubber, etc., that are not readily decomposable.
>
> Class II - Any industrial solid waste or combination of industrial solid wastes which cannot be described as Class I or Class III as defined in this regulation.
>
> Class I - Any industrial solid waste or mixture of wastes, which because of its concentration, or physical or chemical characteristics, is toxic, corrosive, flammable, a strong sensitizer or irritant, generates sudden pressure by decomposition, heat or other means and may pose a substantial present or potential danger to human health or the environment when improperly treated, stored, transported or disposed of or otherwise managed; including hazardous wastes identified by the administration of the United States Environmental Protection Agency pursuant to the Federal Solid Waste Disposal Act."

TABLE C-6

Texas Water Quality Board
Industrial Solid Waste Management
Draft Site Guidelines for Landfills for Industrial Solid Waste

Waste Class	Wastes Included	Implace Soil Thickness	Compacted Soil Liner Thickness	Permeability cm/sec	% Passing No. 200 Sieve	Liquid Limit	Plasticity Index	Monitor Wells	Leachate Collection	Depth to Water Table*	Flood Protection
I	Any industrial solid waste or mixture of industrial solid wastes, which, because of its concentration, or physical or chemical characteristics, is toxic, corrosive, flammable, a strong sensitizer or irritant, generates sudden pressure by decomposition, heat or other means, and may pose substantial present or potential danger to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed; including hazardous wastes identified or listed by the administrator of the Environmental Protection Agency pursuant to the Federal Solid Waste Disposal Act.	4'	3'	$\leq 1 \times 10^{-7}$	≥ 30	≥ 30	≥ 15	Yes	Yes	50'	Below 50 yr. flood - diversion dikes 2' above 50 yr. flood elevation around perimeter of site. Above 50 yr. flood - structure for diverting all surface water runoff from 24 hr., 25 yr. storm.
II	Any industrial solid waste or combination of industrial solid waste which cannot be described as Class I or Class III as defined in this regulation.	3'	2'	$\leq 1 \times 10^{-7}$	≥ 30	≥ 30	≥ 15	Yes	-	10'	Above 50 yr. flood - structure for diverting all surface water runoff from 24 hr., 25 yr. storm.
III	Essentially inert and essentially insoluble industrial solid wastes, usually including brick, rock, glass, dirt, certain plastics, rubber, etc. not readily decomposable	-	-	-	-	-	-	-	-	-	-

* Depends on permeability and thickness of material at site.

Class I contains those wastes with the highest potential for environmental damage and Class III contains wastes that have virtually no potential for environmental damage. Class II wastes are intermediate, but do not include any hazardous waste. The primary differences between Class I and Class II waste sites are thickness of the confining layer, depth to water table, and flood protection. The permeability of the lining soil does not change. Class I sites have leachate collection systems whereby leachate is either recycled or taken to a disposal well. On Class I sites, encapsulation is strived for by using low permeability cover material as well as lining material. Criteria have also been established for a reclassification of wastes if it can be shown that they are less toxic than presumed and could be disposed of under less stringent standards.

Guidelines for site selection and evaluation using a Criteria Listing approach are given in Technical Guidelines No. 2 Attachment B in that report presents a discussion on "Geologic Formations Suitable for Disposal Site Locations". Copies of each of the Technical Guidelines and the permit application forms are given in Appendix D. In addition, an alphabetic "Waste Classification Code Report" is also included in Appendix D.

A detailed case history for the Conservation Services, Inc., Class I, II, III waste disposal site is included in Appendix E.

Solid Waste Evaluation Leachate Test - Texas WQB

1. A 250 gm (dry weight) representative sample of the waste material should be taken and placed in a 1,500-ml Erlenmeyer flask.

2. One liter of deionized or distilled water should be added to the flask and the material stirred mechanically at a low speed for five (5) minutes.

3. Stopper the flask and allow to stand for seven (7) days.

4. Filter the supernatant solution through an 0.45-micron filter.

5. The filtered leachate from (2) should be subjected to a quantitative analysis for those component or ionic species determined to be present in the analysis of the waste itself.

Note: Triplicate samples of the waste should be leached in order to obtain a representative leachate.

Hazardous Index - Texas WQB

The Hazardous Index (HI) of a material is a parameter developed by the Texas Water Quality Board by which a material's possible environmental impact from improper disposal may be calculated based on the materials solubility and toxicity.

The parameter HI may be defined by either of the following equations.

$$1)\quad HI = \frac{50}{\frac{S_w}{Tox_w}} \qquad \text{or} \qquad 2)\quad HI = \frac{50}{\sum_{1}^{N} \frac{C_i}{Tox_i}}$$

where S_w = the solubility of the waste in milligrams per liter

Tox_w = the toxicity of the waste as Oral LD_{50} in milligrams per kilogram

C_i = the concentration of component i in a liquid waste or the leachate from a dry solid waste

Tox_i = the toxicity of component i expressed as Oral LD_{50}, Oral LDL_o or Oral TDL_o

Oral LD_{50} = a calculated dose of a chemical substance which is expected to cause the death of 50 percent of an entire population of an experimental animal species, as determined by exposure to the substance by an oral route of a significant number of that population

Oral LDL_o = the lowest dose of a substance other than the LD_{50} introduced by an oral route over any given period of time and reported to have caused death in man or the lowest single dose introduced orally in one or more divided portions and reported to have caused death in animals

Oral TDL_o = the lowest dose of a substance, introduced by an oral route over any given period of time and reported to produce any toxic effect in man or to produce carcinogenic, teratogenic, mutagenic or neoplastigenic effects in humans or animals

The HI equation was derived through a rearrangement of Finney's mathematical model for additive joint toxicity, which predicts the reciprocal of the composite LD_{50} to be equal to the sum of the proportion of each constituent divided by its characteristic LD_{50} value, or

$$\frac{1}{LD_{50}} \text{ waste} = \sum_{x=1}^{N} \frac{P_x}{LD_{50x}}$$

where P_x is the fraction of constituent x in the waste. The factor of 50 which appears in the numerator is present to correlate the effect of the component concentrations on an average human with a body weight of 50 kg (110 lbs). The rearrangement, in terms of units or measurement, gives the parameter HI in liters of waste orleachate which would necessarily have to be ingested orally to deliver toxic or lethal dose to a human.

CONTACT FORM

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Municipal and Private Approvals Section
Waste Management Approvals Unit

George M. Hughes, Ph.D.
Chief, Ground Water Protection
Hydrology and Monitoring Sections
Water Resources Branch

G. Martin Wood
Head, Solid Waste Unit
Pollution Control Branch

Type of Procedure:

Criteria Listing

Procedure:

The following Waste Management Systems must be approved by this Ministry.

1. Municipal Waste Management Systems.
2. Private Waste Management Systems.
3. Hauled liquid and hazardous waste collection systems.
4. Organic Waste Management Systems.

All the preceding, with the exception of the organic waste management system, are applied for on the standard "Application for a Certificate of Approval for a Waste Management System" which is supported by a Standard "Supporting Information Form". All such applications involve approval of sites, and it is the procedure to certify the site separately. If an application is made which involves a new site, both forms are to be completed. The Organic Waste Management System will be dealt with later.

1. The applications for waste disposal sites and waste management systems under part V of the Environmental Protection Act are submitted to the Municipal and Private Abatement Section of The Regional District Office. The Environmental Officer (E.O.) receives the applications, reviews them from the Central Region point of view, attends public hearings, and presents the Central Region's position on the application. The E.O. may draw on the staff of the Technical Support Section and hydrogeologists with the Water Resources Assessment Unit, Central Region. The hydrogeologists help the E.O. review the hydrogeological setting of the landfilling sites and any monitoring program that may be required.

2. After an application and supporting documents are reviewed by the Regional Staff, the package is forwarded to the Environmental Approvals Branch, Municipal and Private Approvals Section, together with a recommendation for approval or rejection of the application as well as a recommendation as to whether a public hearing of the Environmental Assessment Board should or should not be held.

3. A decision is then made by the Director of the Environmental Approvals Branch on the recommendation of his staff (in some instances with the assistance of the Legal Services Branch) whether a hearing should or should not be held.

4. If a hearing is mandatory or if it is decided by the Director that a hearing is required, then the application together with the appropriate supporting documents is forwarded through the Waste Management Approvals Unit to the Board together with a memorandum from the Director to the Board Secretary, Environmental Assessment Board instructing the Board to hold a hearing under the appropriate sections of the Environmental Protection Act. The hearing is attended by the Regional staff Environmental Officer who assembled and reviewed the documents. On the more major and complex applications, these may be coordinated by a working group (e.g., the Maple site) composed of Head Office and District Staff.

5. The Environmental Assessment Board Report is forwarded to the Director by the Board Chairman for his consideration. It is then forwarded by the Waste Management Approvals Unit to the Regional Staff, usually the District Officer, for review with particular emphasis on any recommendations made by the Environmental Assessment Board. The Regional Staff would then discuss the Board report with the applicant and resolve how any recommendations are to be dealt with.

6. The revised support documents are then forwarded to the Municipal and Private Approvals Section by the District Staff together with the Regional recommendation on what basis the application is to be approved or in some instances rejected. There may also be further documents submitted to the Director of the Environmental Approvals Branch by interested parties. These are usually reviewed by the Municipal and Private Approvals Section; where hydrogeology is involved these documents are reviewed either with the District hydrogeologists or the Chief, Ground Water Protection Section, Water Resources Branch.

7. A Certificate or Provisional Certificate of Approval is then prepared by the Municipal and Private Approvals Section. The conditions, if any, and reasons are checked with the Legal Services Branch and the documents are signed by the Director, Environmental Approvals Branch. Formal Notice of Appeal is included with any conditional certificate or Notice of Refusal.

8. In the event that the conditions on a refusal are appealed, the Municipal and Private Approvals Section co-ordinates the appeal through the Environmental Appeal Board, but the Ministry is represented by the Regional Staff at the Appeal Board hearing.

9. The Environmental Appeal Board report is forwarded by the Board Secretary to the Director, Environmental Approvals Branch, and the Certificate or Provisional Certificate of Approval is ammended in accordance with the Board's Order.

10. The Applicant after receipt of the decision of the Board, can appeal on a question of law to the county court. The final appeal may be made to the Minister.

A flow diagram showing the review process and agencies involved is given in Figure C-3.

Discussion:

The regulation of both municipal and industrial wastes are handled in a similar manner by the above-stated agencies following the procedural

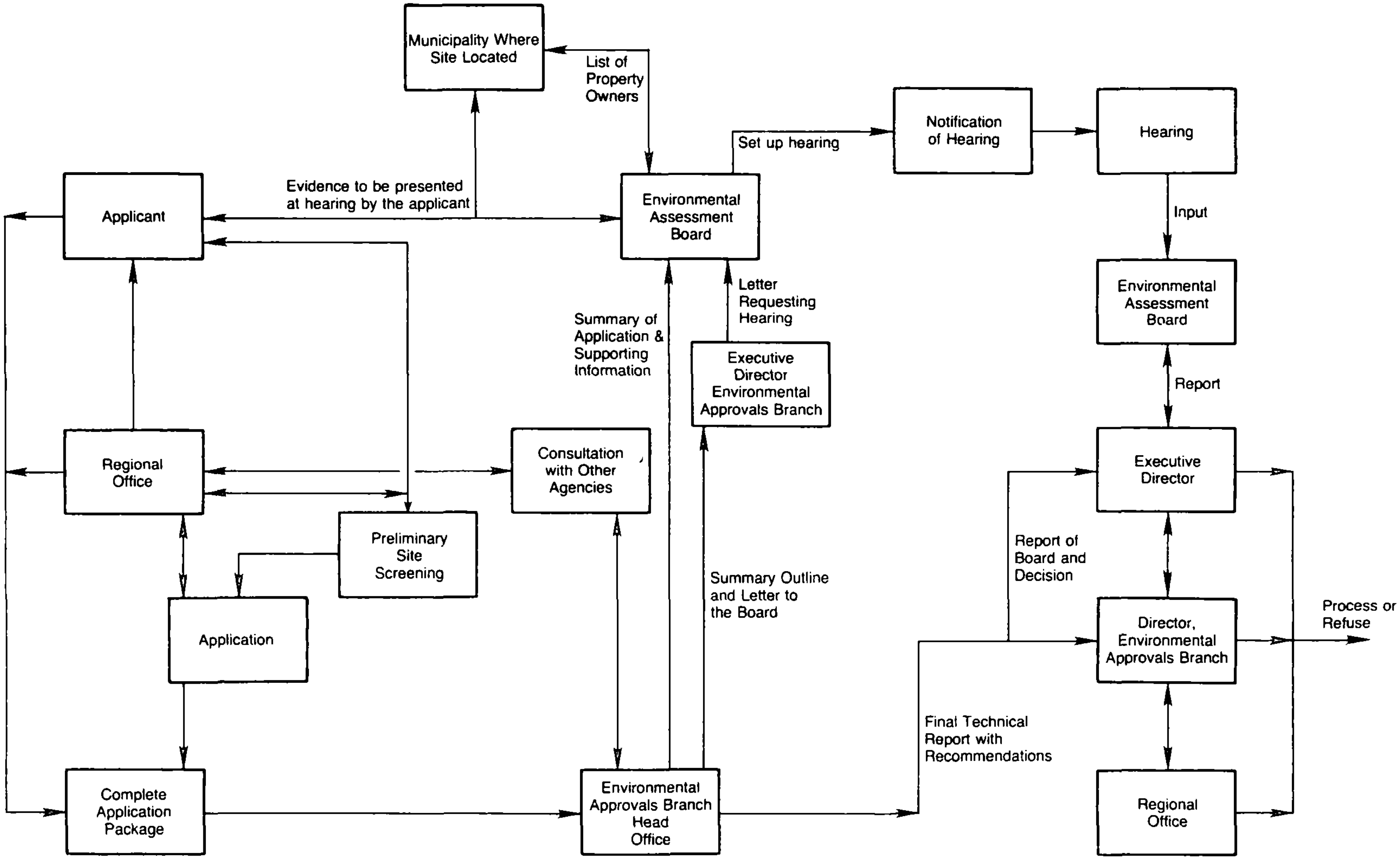

FIGURE C-3 ONTARIO MINISTRY OF THE ENVIRONMENT APPLICATION PROCESS FLOW SHEET

format described. There are no set criteria for either waste or site characterization. Disposal of industrial and hazardous materials utilizes the same "General Guidelines for Landfill Site Selection" as are used for municipal wastes. These guidelines were prepared by the Water Resources Branch and are included in Appendix D. The guidelines are general and flexible in nature and contain no specific requirements relative to site characterization. Rather, they are highly dependent on such factors as the size, location, potential for contamination, and significance of effects associated with the specific site/waste situation.

It is noteworthy that the permit approval places almost total reliance on the natural attenuation of waste leachate rather than waste containment with associated leachate collection and treatment. Several key sections of the Guidelines are as follows:

> "Under certain hydrogeologic conditions, there is little hazard of polluting ground and surface waters. These include:
>
> a. the absence of significant aquifers;
>
> b. the presence of thick, fine-grained overburden materials and a thick, unsaturated zone;
>
> c. location near, but not within, a ground water discharge zone;
>
> d. slight to moderately permeable deposits to allow some infiltration of the leachate, stabilization during percolation and reduction of ponding or excessive surface runoff.
>
> "The presence of a major potable aquifer near a site should preclude its use without engineering works to collect and treat leachate. There should be no users of ground water between the site and the discharge zone for ground water moving beneath the site that will be adversely affected by leachate migration. Alternate, adequate sources of water supply must be available for downgradient water users in the event that the prediction model for pollution migration fails."

Containment utilizing naturally low permeability deposits or artificial liners is being considered. There is presently only one site utilizing a liner.

Copies of the following items are included in Appendix D: the General Guidelines; Application for a Certificate of Approval for a Waste Management System; Supporting Information to an Application for a Waste Management System; a completed Recommendation of the District Office; Provisional Certificate of Approval for a Waste Disposal Site, with conditions; and supporting letters stating reasons for the imposition of the conditions on the Provisional Certificate.

CONTACT FORM

Agency:

SVA (Stichting Verwijdering Afvalstoffen--
The Institute for Waste Disposal)
Natriumweg 7
Postbus 184
Amersfoort
Netherlands
Phone: 033-12904

Persons Contacted:

Ir. E.J. Mesu	Ir. F. Van Veen
Soil Scientist, Hydrogeologist	Chemist

Type of Procedure:

Criteria Listing

Permit Procedure:

The legislation for land disposal of waste is as follows:

- Chemical Waste Act - Expected to be effective in January 1978.
- Waste Disposal Act - Currently in parliament, with passage expected soon.
- Soil Protection Act - In the development stage.

At present then, none of these regulations are in force.

The SVA is a semi-governmental agency which provides advice to federal and provincial governments, municipalities, and industry. It has no regulatory functions, but will review licensing applications and will write the guidelines for disposal practices. Each of the 11 provinces has an Inspector for Environmental Health who reviews applications for site licensing.

Discussion:

The approach to land disposal of waste in the Netherlands, at present, is relatively informal. Permits are required for landfilling, but soils and specific hydrogeologic information are not required. There is also no requirement for monitoring wells, however, new regulations are being drafted to require a ditch around the site to control and monitor drainage. Recommendations have been drafted to require a soils and hydrogeologic report as part of the permitting procedure. (A report, written in Dutch entitled "Recommendations for the Design, Installation and Executing of Landfills", is included in Appendix D.)

At present, the following requirements generally apply to landfill siting:

- No sites in a residential area.

- A distance of 2 kilometers between the landfill and a municipal well or point of water use as established by the Institute for Drinking Water.

- Not in parks or historical areas.

- 20 to 30 cm above the average highest ground water table; this requirement is being rewritten to state 20 to 30 cm above the highest groundwater table in 10 years.

The emphasis is placed on limiting the amount of water that enters a landfill. This is accomplished in several ways by:

- Encouraging tips (above ground disposal) rather than fills.

- Requiring disposal above the water table. It is also considered advantageous to have a fairly shallow water table to allow for ready removal of contaminated water.

- Using slopes of 1:50 on the top surface to encourage runoff.

- Using impermeable covers to limit the infiltration of precipitation.

Containment is not practiced. An ideal site is considered to have a permeability of 10^{-3} cm/sec in order to allow for release and attenuation of leachate. Containment is considered to result in a more-concentrated leachate which is more likely to pollute.

Land disposal is discouraged for chemical wastes as described in The Chemical Waste Act. This act deliberately avoids an exact definition of chemical waste because such a definition is considered to have a subjective and changing meaning. A draft list of chemical components in relation to concentration is available. Four concentration levels have been established: 50 mg/kg, 5,000 mg/kg, 20,000 mg/kg and 50,000 mg/kg. The most hazardous components fall into the 50-mg/kg limit (arsenic, mercury, cadmium, etc.). Heavy metals such as lead, copper and organics fall into

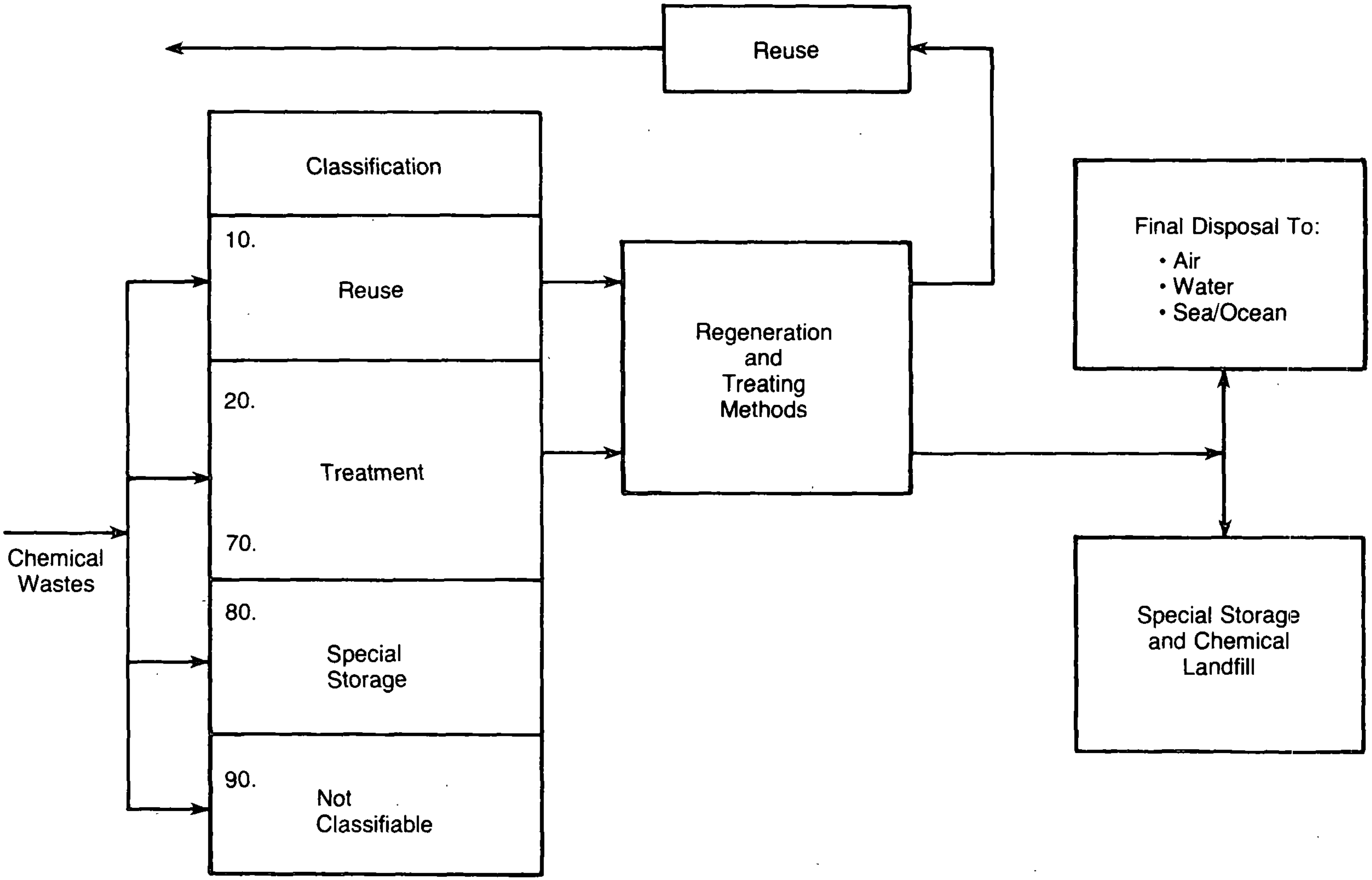

FIGURE C-4 REVIEW OF THE DISPOSAL OF CHEMICAL WASTES IS INDICATED FOR THE NETHERLANDS

the 5,000-mg/kg limit. The hazardous materials such as aliphatic hydrocarbons are in the 20,000- and 50,000-mg/kg groups. There is also a list of exceptions which includes residuals of municipal waste. This is one of the few attempts that have been made by a regulatory agency to characterize waste on the basis of concentration.

Chemical wastes are considered for reuse and/or treatment before land disposal. Land disposal is permitted only under exceptional cases. The requirements for such exceptions have not yet been defined, but will probably require that no emissions occur, i.e., a contained site. Discussions are taking place regarding the use of double liners at chemical waste disposal sites. Figure C-4 (adapted from SVA) shows the types of disposal considered for chemical waste. The waste classification shown is divided into subgroups with assigned treatment codes. The wastes that are included in the subgroups are not identified.

A standard leaching procedure is being developed and tested using both a partial extraction shake test and a continual extraction column. Various types of waste are being analyzed in this $40,000 study. Solubility of the waste is considered the most important characteristic. (A full description of this test is included in Appendix D.)

The entire process of waste disposal permitting in the Netherlands is in its infancy. The present lack of regulation is being changed, but, at present, land disposal is to uncontrolled landfills, and no licensed sites yet exist.

The present practice of treatment shows an actual reuse of chemical waste of 15 percent and an actual landfill practice of 25 percent. Since no chemical landfills presently exist, this 25 percent figure is practiced under uncontrolled conditions.

The purpose of the proposed Chemical Waste Act is to prevent pollution of the environment by chemical wastes. Because of the special situation in the Netherlands with respect to tipping and landfilling, the Act is designed for a prohibition to dispose of chemical wastes by deposition in or on the soil. Only in exceptional cases will permission be granted.

In order to obtain an exact delimitation of its juridical scope, the Act refrains from defining the term "chemical wastes", because it has a subjective and changing meaning.

Industries generating chemical wastes can dispose of these wastes by: treating under their own control, or by transferring to specialized disposal industries.

All plants used for the treatment, whether under their own control or by special industries, are controlled by other acts such as the Public Nuisance Act, the Air Pollution Act, and the Pollution of Surface Waters Act.

Transfer of chemical wastes, as collection and treatment of the wastes, will be tied to a notification and a license system. In order to handle chemical wastes, it will be necessary to connect the wastes with the corresponding treatment and disposal methods. The desirable procedure is divided into three important groups: regeneration and reuse, treatment, and storage and landfill.

The aim of treating is to transform chemical wastes into a number of components which can either be reused, or which are not considered to be chemical waste anymore. The most important treating methods are: incineration; detoxification, neutralisation, and dewatering; treating of emulsions; and special methods, e.g., for mercury-containing waste.

In the preliminary stage, each of these disposal methods will cause certain environmental emissions at a substantial level. However, when more knowledge is available about the nature and background of the wastes, these emissions can be decreased to an acceptable level. Each disposal method has its own specific residuals; generally, it is not possible to treat or reuse these residuals in a way which conforms to the environmental requirements.

When it proves impossible to avoid the generation of these residuals (for example, by change of process), "special storage" is the only possible alternative. The term "special storage" includes several techniques, such as chemical landfill and storage in abandoned salt mines, a practice in West Germany. In the Chemical Waste Act, chemical landfill is not considered to be an efficient disposal method and therefore is prohibited. Only in exceptional cases will exceptions be granted. The requirements for exceptions are not yet known, but it is very likely that a chemical landfill will only be allowed when no emissions occur and under specific conditions.

For certain types of wastes which cannot be treated or reused, the possibility exists for temporary storage. Because of the economics (very expensive) and uncertainty for recycling and other available alternatives, temporary storage can be expected to be an inappropriate and inefficient method.

CONTACT FORM

Agency Contacted:

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Greater London Council
Department of Public Health Engineering
Solid Waste Branch
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London SW1P 3AB
United Kingdom
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Persons Contacted:

Mr. Raymond G.D. Osmond
Superintendent
Toxic Waste Section
Waste Division
Water Engineering Directorate

Mr. Derrick Bond
Chemist

Peter Jarrett
Assistant Division Engineer
Division Solid Waste, Design and Development

Anthony Marchant
Project Engineer

Ray Carpenter
Chemist

Type of Procedure:

Criteria Listing

Permit Procedure:

The procedure adopted by the GLC Licensing Unit is as follows:

1. Original enquiry from the prospective applicant.
2. Dispatch of application forms comprising Parts I, II and III.
3. Part I is completed by the applicant and gives rudimentary facts about the waste disposal/handling facility.
4. Site visit by Site Licensing Unit Officers (proficient in Chemistry, Civil Engineering, Geology and waste disposal techniques) for assessment of the site and discussion over the completion of Parts II and III of the License application by the applicant.

5. Receipt of Part II and III by the Site Licensing Unit.

6. Formulation of a draft disposal license by the Site Licensing Unit using guidelines given by the Department of the Environment.

7. The whole application (Parts I, II and III) and the draft disposal License are sent for consultation with various authorities:-

   a. Water Authority

   b. Health and Safety Executive

   c. Local Authority including Planning, Environmental Health and Waste Collection departments

   d. Institute of Geological Sciences if disposal is by deep well injection or into disused mines.

   e. Fire Brigade

   Each Authority is invited to give observations within 21 days of receiving the documents.

8. Observations received by SLU.

9. Discussion where necessary with Authorities that highlight problems arising from particular sites, e.g., Water Authority may envisage possible pollution to groundwater or surface drainage. The Fire Brigade may request further fire prevention measures, etc.

10. Issue or refusal of license by GLC Committee.

11. Possible Appeal to the Secretary of State for the Environment against a refusal to grant a Waste Disposal License or to conditions included within the License. The Secretary of State then has the final decision.

Discussion:

The permitting (licensing) of waste disposal sites in the United Kingdom was provided for by the Control of Pollution Act of 1974. According to the provisions of the Act as of 14 June 1976, the deposit of controlled waste on land will, with certain specified exceptions, be punishable offences except when carried out in accordance with a valid disposal license. Sites in operation for six months or more prior to that date are not required to be licensed until 14 June 1977.

The license granting agency is the Waste Disposal Authority (WDA) which is a local agency. Each WDA has jurisdiction over a designated area (counties in England). The WDA for the Greater London Metropolitan Area is part of the Greater London Council. Although licensing application is made to the WDA which is the decision-making body, the WDA is required to consult with other agencies before issuing the license. In order to issue a license, the WDA and the relevant Water Authority must reach agreement on the license and on the conditions applied to that license. When agreement cannot be reached, either agency may refer the matter to the Secretary of State. In exceptional cases where agreement is not reached, the Department of the Environment makes the final decision.

The other agency that has a major role in the licensing procedure is the Local Planning Commission. In order for a license to be issued, planning permission must be obtained. Once such permission has been obtained, the WDA can refuse a license only when the Authority is satisfied that rejection is necessary for preventing pollution of water or danger to public health. For example, the fact that a site is not compatible with the Authority's waste disposal plan is not sufficient reason for rejection. In effect, planning considerations and technical considerations are kept separate in the licensing procedures.

Public hearings are not required for licensing; however, when one is held, it is chaired by the Planning Inspector. The Department of the Environment is only part of the decision procedure in the event of a deadlock as described above. The function of the Department is to establish policy for waste disposal and waste management.

Guidelines for completion of the Disposal License Application Form are given in Waste Management Paper No. 4, "The Licensing of Waste Disposal Sites." (A copy of this paper and the application form are included in Appendix D.)

The Disposal License Application Form that is used is standard in the United Kingdom. Application is made in writing to the relevant Waste Disposal Authority. The information required by the form is of a general nature, but the WDA may request additional information (such as a geologic report) judged to be appropriate to the site in question. The form is divided into three parts. Part I deals with general information on site location, ownership, type, and brief description of the waste to be accepted. Part II addresses the waste types, quantities, and sources in more detail. Part III is a separate submission in that it is not part of the form as such; it includes the site location plan and the working/operational plan for the facility. It is strongly suggested by the Department of the Environment (DOE) that Part I of the application be filled out and submitted prior to completion of Parts II and III. Part

I can then be used as the basis for informal discussion between the applicant and the WDA. The data that can be required of an applicant are not specified and presumably would be clarified on a case-by-case basis after the submission of Part I.

The decision procedure that is used in considering a site licensing application is that of criteria listing applied on a case-by-case basis. Criteria that are used are described in Waste Management Paper No. 4, but the criteria are not quantified. Table C-7 is a brief summary of the factors that are considered to be related to waste characteristics and site conditions. Planning considerations and legislative interaction are not shown in this table. It is notable that most of the items in the table are considered in balance, and not as absolute values; the monetary or other cost is considered in conjunction with the risk associated with the alternative action. The lack of quantification of criteria is intentional because the philosophy of the Department of the Environment is to allow enough leeway for the balance to be achieved. They do not want extensive quantification because they do not want to be bound by numbers. The emphasis is on subjective evaluation based upon: waste and site specific data, experience at similar disposal sites, and professional judgment.

The DOE has developed a site classification scheme (Table C-8) for the selection of landfill sites indicative of the non-quantified approach. The generality of the classification scheme is justified in the following:

> "At first sight it might be thought that the way to deal with the selection of landfill sites was to categorize wastes on the basis of their pollution potential and sites on the basis of their ability to contain wastes. Particular categories of waste could then be linked with particular categories of sites to produce a series of definitive recommendations. Unfortunately neither wastes nor sites lend themselves to such categorization and it is necessary to produce a more generalized scheme which can be modified and adapted for local use."

Class 2 sites appear to be considered the least likely to cause pollution if the site is properly selected and managed. According to DOE, the majority of pollution form domestic landfills involve surface water resources rather than groundwater resources. At Class 1 sites, leachate cannot move away from the site, and saturated conditions result. In time, the leachate overflows the impermeable base of the landfill to form a polluting surface discharge. Impermeable linings are recommended only where there is a shortage of potential disposal sites, and a site must be located so close to water supply wells that pollution would almost certainly occur.

TABLE C-7

CRITERIA USED FOR WASTE DISPOSAL SITE LICENSING
(DEPARTMENT OF THE ENVIRONMENT, UNITED KINGDOM)

Criteria	Description
I. Site Characteristics	
a. Past History	Existing site near end of completion may be allowed to continue even with undesirable features particularly if features have no lasting ill effects and would be unduly expensive to correct.
b. Hydrogeology	Geology of the underlying rock types, their permeability and ability to attenuate leachate, depth of the unsaturated zone, and the direction of groundwater flow are of major importance.
c. Aquifers	Whether the water is used at present or is likely to be used in the future, and the type of use are weighed against the risk from the site.
d. Rainfall	Quantity of residual rainfall must be taken into account as it affects leachate percolation and site stability. Net transmission of rainfall within the site must be considered when liquid waste is deposited.
e. Site Works	The cost of control of drainage into the site must be assessed against the reduction of pollution risks thereby achieved.
f. Wet Sites	As a general rule, only inert wastes should be deposited.
II. Waste Characteristics	
a. Type of Waste	Whether the waste is biodegradable or capable of reacting with other waste, and its behavior are to be considered.
b. Quantity of Waste	It should be determined that the proposed quantity of waste does not exceed the physical or operational site capacity.
c. Mix of Waste	Positive and negative effects of waste interaction should be considered.

TABLE C-8

CLASSIFICATION OF LANDFILL SITES
(DEPARTMENT OF THE ENVIRONMENT, UNITED KINGDOM)

Site	Class	Generalized Description	Wastes Suitable
Class 1	Sites providing a significant element of containment	Located on impermeable or relatively impermeable strata which contain wastes and leachates within landfill or immediate vicinity. Strata include fine grained compact rocks of low permeability such as slates, shales, and mudstones as well as soft clay and marls. Thickness required is computed by: $Q/A = K \times i$ Poor permeable material is used for daily cover.	Suitable for solid wastes but not recommended for large volumes of liquid waste because of build-up of head in landfill and potential for surface water contamination when completely saturated.
Class 2	Sites allowing slow leachate migration	Sites which do not provide containment but allow leachate to migrate at slow rates so that attenuation and dilution can occur before leachate reaches potential or developed groundwater resources. Major points in site characteristics are the presence of a thick unsaturated zone and large distance from groundwater withdrawal points. Sites on fissured rock are generally not suitable. Ideal site characteristics are: pit in silt or fine sand, permeability of 10^{-1} m/day, and underlain at depth by impermeable clay to protect deeper aquifers.	Suitable for readily degradable materials such as domestic waste and many industrial wastes, particularly those whose leachates are comparable to those from domestic waste; suitable for liquid waste where liquids can be degraded, dispersed and diluted before reaching groundwater resources which are so limited that some pollution would cuase no problems.
Class 3	Sites allowing rapid leachate movement	Sites having insignificant attenuation. They are located in a variety of settings; examples are river terraces with high water table and limestone with solution enlarged fractures.	Normally suitable only for relatively inert materials unless site is insensitive to contamination or there is a large dilution factor.

A basic approach to land disposal of wastes in the United Kingdom is outlined in Circular 39/76 published by the Department of the Environment, entitled "The Balancing of Interests between Water Protection and Waste Disposal". (See Appendix D.) This circular presents the dilute and disperse approach as the most reasonable for most wastes. Factors that are to be considered in assessing the environmental risk associated with dilute and disperse are:

- The volume of the aquifer considered to be at risk, and the present and future uses of the water. If the usefulness of an aquifer is not great, the provision of an alternate water supply should be made.

- Hydrogeologic characteristics of the site including the ability to attenuate leachates.

- Type, volume, and rate of waste to be disposited including the possible interaction of wastes and the ability of leachate to be attenuated.

According to a recent (January 27, 1977) article in New Civil Engineer, the dilute and disperse approach, as outlined in Circular 39/76, has not as yet been accepted by water authorities who are not convinced that water supplies can be adequately protected. Again according to the same article, the water authorities are using their advisory role to

> "...preserve total separation of potentially harmful discharges from any present or planned water resources. That generally means vetoing license applications unless there is a guarantee that the site is completely impermeable - the 'contain and concentrate' philosophy."

Although is is not possible to determine how many applications are actually vetoed by water authorities, it is interesting that most present landfill sites rely on containment, with leachate collected and hauled to a local sewage treatment plant.

It seems clear that attitudes toward land disposal of hazardous waste in the United Kingdom are now in the process of changing. Despite the controversy that is associated with the "dilute and disperse" approach, it is apparent that this approach is the one that is favored by the Department of the Environment and the Waste Disposal Authorities.

Recent guidelines prepared by the Department of the Environment (Waste Management Paper No. 4, "The Licensing of Waste Disposal Sites", 1976) considers two facets of dilute and disperse. One facet is the obvious approach of allowing some seepage of leachate from a site and is dependent on attenuation mechanisms and isolation to prevent ground water contamination.

The other facet considered relates to the disposal of very hazardous wastes.

> "The risk of long-term environmental problems can sometimes be minimized by dividing the waste to be disposed of between a number of sites so that the quantity going to each is within the limits of acceptability. This is one facet of the so-called 'dilute and disperse' approach to waste disposal which the Department considers is in most cases preferable to that of concentration and containment, and should be adopted where there are not good reasons for acting otherwise."

This form of industrial waste disposal is rather common in the United Kingdom. The number of sites taking solely toxic wastes is presently less than 25 with some of them relying upon waste containment.

CONTACT FORM

Agency:

Office of the State of Bavaria
for Environmental Protection
Bayerisches Landesamt
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Rosenkavalierplatz 2
8000 Munich 81
West Germany
Phone: 089-9214-2551

Landesanstalt für Umwelt
Institut für Wasser
and Abfallwirtschaft
State of Baden-Wurttemberg
Hirschstrabe 12-14
7500 Karlsruhe
West Germany
Phone: 0721-13-523-41

Persons Contacted:

Mr. Wolfgang Knorr
Engineer and Assistant Manager
Department of Solid Wastes

Dr. B. Matthes
Chemist

Mr. Gerhard Kreischer
Chemist

Type of Procedure:

Criteria Listing.

Permit Procedure:

Each state has its own government and procedures (Bavaria is a state.) Technical review and approval comes from the State Office; however, the formal approval comes from each District Office and is issued by the lawyer in charge. Review and approval must also come from the Water Office and from the Office of Security and Safety. The District Office summarizes each agency evaluation and makes the final decision for approval. Legal hearings are held if there is a split decision. Public hearings are required by law in all of Germany prior to final approval. Inspection and enforcement is conducted from the Central Office.

Discussion:

The licensing procedure involves a listing with required definition of waste and site characteristics. The decision is a subjective one based on assessment of these characteristics and on empirical data from existing sites. There is an aversion to using specific numbers, with a preference for using working guidelines which allow for flexibility to assess each site and waste on a case-by-case basis.

The approach to land disposal in West Germany emphasizes containment rather than attenuation and/or dilution. There are some variations in the approach within West Germany since each state has its own procedures. The States of Bavaria and Baden-Wurttemberg both have guidelines for waste disposal. The guidelines for Bavaria, however, are not written. They require containment with a permeability of 10^{-8} m/sec (10^{-6} cm/sec). Although this is a low permeability, it does not ensure complete containment.

Leachate collection and underdrain systems are generally required; it is discharged either to a river if there is adequate dilution or to a sewage treatment plant. Leachate from hazardous waste may require pretreatment before discharge to the sewage treatment plant.

Although there are no specified site criteria for depth to bedrock/water table and discharge to surface water or wells, site definition is required. A description of on-site soils, geology, depth to groundwater, direction of groundwater flow, and an environmental analysis must be included in the site report. Borings are required for hazardous waste sites and most municipal waste sites. Additional site requirements include a thickness of one meter of clay, either in place or imported and compacted. An artificial liner is in use in at least one landfill.

Monitoring wells and drainage control are required at disposal sites. State Office personnel perform sample analyses twice each year. The analyses are performed in their own laboratory. A copy of "Guidelines for Designing, Erecting, and Operating Dumps for Household Refuse and Materials Similar to Household Refuse" is included in Appendix D.

Waste characteristics must be defined including analysis of the waste itself; 100 grams of waste are mixed with 1 liter of water and mechanically agitated for 8 hours. The liquid is then filtered and analyzed for the components characteristic of that type of waste. The critical factors include: the volume of waste, its concentration, and the solubility of its constituents. Liquids are either solidified or incinerated; they are not put directly into landfills. Sludges and solid waste are accepted, but only with a pH greater than 7; acid wastes must be neutralized first. The biggest problem of landfills is the treatment of various wastes coming in as a mixed waste stream, and not necessarily the individual types of wastes.

There is a detailed waste catalogue which indicates a code number, the name of the waste, a category, and the products of that waste. The category numbers range from I to V; I is the most difficult to dispose of, not necessarily toxic, and V is the least difficult to dispose. The breakdown is arbitrary and qualitative; it is not a quantitative system. The wastes are catalogued into the following general categories:

organic wastes, metals and minerals, chemicals-synthetics (the newer technology), radioactive, and municipal and other wastes. There are nine series in all, with Series 2, 4, 6 and 8 presently omitted to allow for the system to be expanded and greater detail to be added.

A decision tree approach has been developed to aid industry in evaluating whether a waste can be co-disposed with municipal waste, recycled, or disposed of at an industrial site. This approach is attached as Figure C-5.

The guidelines that have been published by the State of Baden-Wurttemberg are similar to those in use in most of the country. They address leachate collection, treatment and disposal, and subsurface conditions and drainage control; these guidelines require a permeability of 10^{-8} m/sec (10^{-6} cm/sec) as do the unwritten guidelines for Bavaria. A map (not included in this document) has been prepared which shows those areas in Baden-Wurttemberg where landfills are not permitted, based on groundwater use and sensitive areas such as wetlands and flood plains.

Wastes are assessed as they are in Bavaria; special or hazardous wastes are separated, with certain wastes requiring incineration or pretreatment. Centrally-located waste collection points exist within 50 kilometers of any industry in order to facilitate waste handling.

A basic part of the approach in West Germany is cooperation with industry. The agencies work with industry to minimize waste quantities and to develop in-house processes to change waste characteristics for easier disposal. Also, 30 percent of the funding for District Offices is supplied by industry.

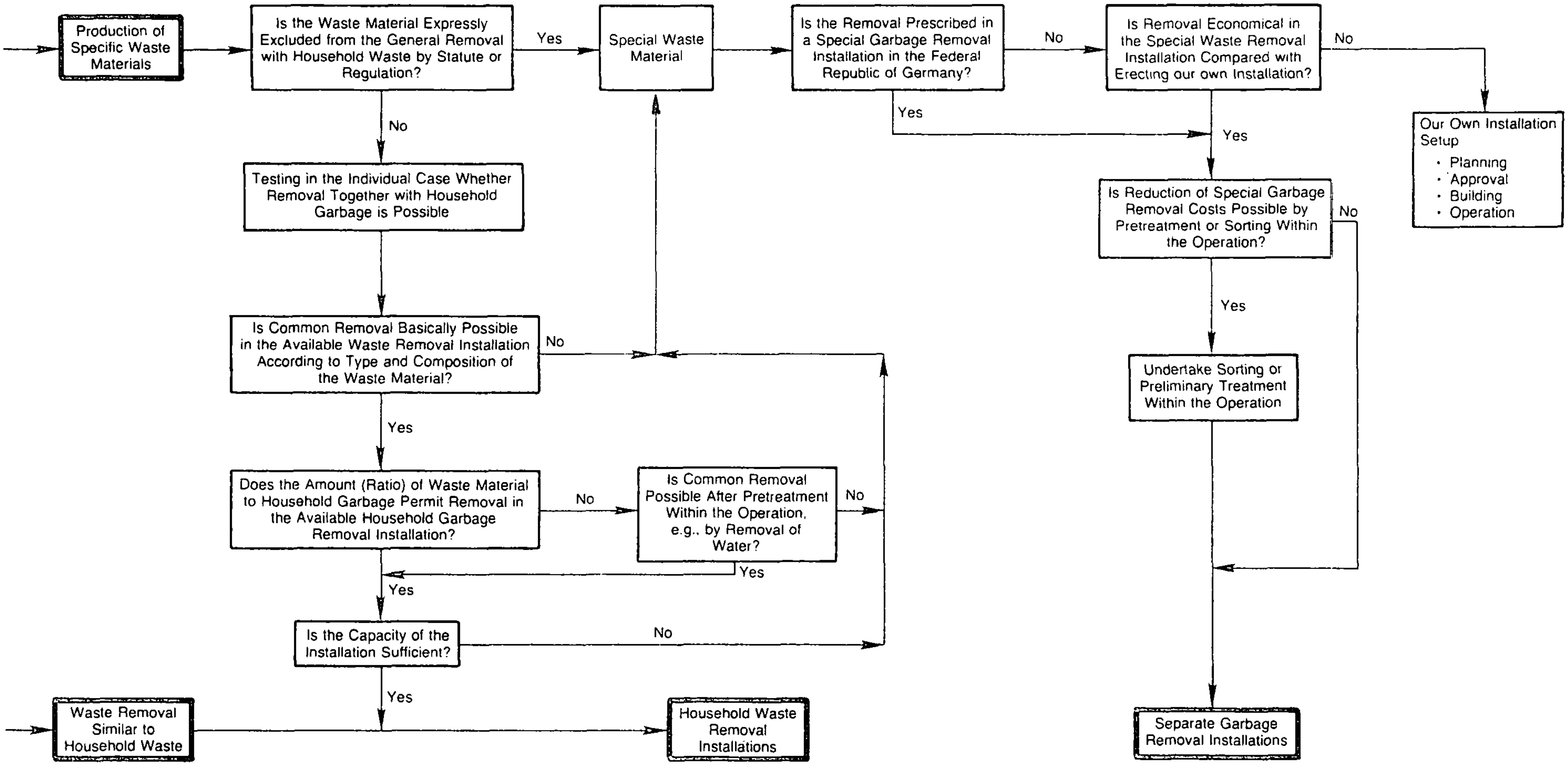

FIGURE C-5 SEQUENCE OF DECISIONS IS SHOWN FOR GROUPING THE RESIDUAL MATERIALS OCCURRING IN THE OPERATION WITH REGARD TO RE-USE AND REMOVAL

APPENDIX D*

CALIFORNIA

Applications

State Solid Waste Management Board

1. Solid Waste Facility Permit Application
2. Preparation of Report on Disposal Site Information
3. Preparation of Report on Station Information and Plan of Operation for Small Volume Transfer Stations
4. Report of Waste Discharge
5. Procedure for Implementing SB 1797 (1977) Section 66784 of the Government Code
6. Procedure for Implementing SB 1797 (1974) Section 66783.1 of the Government Code
7. Application for Rubbish Dump Permit Form #LE-34
8. Appendix B Sample Permit Application c/o Ventura County Planning Dept.
9. City of Oxnard - Environmental Impact Report Questionnaire
10. South Central Coast Regional Commission Application for Permit

Regulations and Guidelines

C.S.W.M.B. Disposal of Environmentally Dangerous Wastes in California, August, 1976

California Department of Health

1. Hazardous Waste Management
2. Law, Regulations and Guidelines for the Handling of Industrial Waste

California State Water Resources Control Board

1. Waste Discharge Requirements for Non-Sewerable Waste Disposal to Land, "Disposal Site Design and Operation Information", December 1976 (latest)

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*Separate Document--Available at Office of Solid Waste, Hazardous Waste Management Division, Washington, D.C.

ILLINOIS

Environmental Protection Agency
Division of Land/Noise Pollution Control

Applications (i.e., Solid Waste Management Site Application)

1. Application for Permit to Allow the Disposal of Special and/or Hazardous Waste at an IEPA Permitted Disposal Site - Module E

2. Application for Permit to Develop and/or Operate a Solid Waste Management Site (pp. 39 - 53 in Sanitary Landfill Management)

Regulations and Guidelines

1. Special and/or Hazardous Waste; Permit Information Instructions Module E

2. Special Waste - Land Disposal Criteria

3. Sanitary Landfill Management

MINNESOTA

Pollution Control Agency

Applications

1. "Sanitary Landfill Permit Applications" - Soil Boring

2. Permit Application for Construction of a Solid Waste Disposal System

3. Form #MPCA 651 "Preliminary Site Investigation of Proposed Sanitary Landfill"

Regulations and Guidelines

HW-1 - General Applicability, Definitions, Abbreviations, Incorporations, Severability and Variances

HW-2 - Classifications, Evaluation, and Certification on Waste

HW-3 - Generation of Hazardous Waste

HW-4 - Location, Operation and Closure of a Hazardous Waste Facility

HW-5 - Transportation of Hazardous Waste

HW-6 - The Hazardous Waste Facility Permit Program

HW-7 - Contents of Hazardous Waste Facility Permit

HW-8 - Hazardous Waste Shipping Papers Applications

HW-9 - County Regulation of Hazardous Waste Management

HW-10 - Spillages and Leakages of Hazardous Waste

NEW YORK STATE

Department of Environmental Conservation

Applications

1. #SW-7 (11/73)
   Application for Approval to Construct a Solid Waste Management Facility

2. #47-19-4 (6/77) Formerly SW-22
   Application for Approval to Operate a Solid Waste Management Facility

3. #47-19-5 (6/77) Formerly SW-23
   Application for Variance from 6 NYCRR 360

4. #47-19-6 (6/77) Formerly SW-24
   Application for Use of a Construction and Demolition Debris Disposal Site

Guidelines and Regulations

1. Application for Construction of Solid Waste Management Facility Content Guidelines and Specifications

2. Part 360, Solid Waste Management Facilities Approved by Environmental Review Board May 17, 1977, Effective August 28, 1977

PENNSYLVANIA

Department of environmental REsources

Applications

1. Application for Permit for Solid Waste Disposal and/or Processing Facility Form #ER-BLP-10 Rev. 1/74

2. Solid Waste Disposal and/or Processing Site Application Module - Phase I Form #H712.122 Rev. 1/71

3. Solid Waste Disposal and/or Processing Site Application Module - Phase II Form #ER-BLP-25 3/75

4. Module 5A - Phase I Supplementary Geology and Groundwater Information Form #ER-BLP-189.5A1 3/75

5. Ground Water Module - Phase II, Monitoring Points

6. Permit for Solid Waste Disposal and/or Processing Facility Form #ER-BLP-23 Rev. 8/74

7. Module for Sewage Sludge and Septic Tank or Holding Tank Waste Form # Module 75.32

8. Land Disposal Inspection Report Form #ER-BLP-09 Rev. 3/74

Regulations and Guidelines

1. Chapter 75 - Solid Waste Management Rules and Regulations

2. Spray Irrigation Manual Bureau of Water Quality Management Publication #31

3. Laboratory Procedure for the Conduct of a Leachate Analysis

4. Interim Guidelines for Sewage, Septic Tank, and Holding Tank Water Use on Agricultural Lands

5. Title 25
   Part 1 - D.E.R.
   Article III - Air Resources
   Chapter 125 - Coal Refuse Disposal Areas

TEXAS

Department of Health Resources

Applications

Application for a Permit to Operate a Municipal Solid Waste Facility - Appendix A in Municipal Solid Waste Management Regulations

Regulations and Guidelines

1. Municipal Solid Waste Management Regulations
   April 1977

TEXAS

Water Quality Board

Applications

1. Permit Application for Commercial Industrial Solid Waste Management Sites

   #WQB 90 (Rev. 3-76)

2. Technical Questionnaire for Non-Commercial Industrial Solid Waste Management Sites

   #WQB 90A (Rev. 3-76)

Guidelines and Regulations

Industrial Solid Waste Management Regulations
Supplemental Technical Guidelines

1. Waste Evaluation
2. Site Selection and Evaluation
3. Landfills
4. Ponds and Lagoons
5. Land Farming
6. Monitoring/Leachate Collection Systems
7. Supporting Facilities
8. Records
9. Non-Compatible Wastes
10. Texas Water Qaulity Board Waste Code Catalogue
11. Alphabetic Waste Classification Code Report (Computer Print-out) Form 030807

ONTARIO, CANADA

Ministry of the Environment

Applications

1. Application for a Certificate of Approval for a Waste Disposal Site. MOE - 14203 - 7/74

2. Supporting Information to an Application for Approval of a Landfill Disposal Site. MOE - 14202 - 7/74

3. Application for a Certificate of Approval for a Waste Management System

4. Supporting Information to an Application for a Waste Management System MOE - 14305 - 9/73

Guidelines and Procedures

1. Guidelines and Criteria for Water Quality Management in Ontario

2. General Guidelines for Landfill Site Selection

3. Procedures for the Certification Process (Paper presented at West Central Region Waste Management Seminar)

4. Guidelines for Sewage Sludge Utilization on Agricultural Lands

GREATER LONDON COUNCIL

Department of Public Health Engineering
Solid Waste Branch

Applications

1. Disposal License Application Form

    Form HE 1 SWIL.1
    Part I, Part II, Part III

Regulations and Guidelines

1. Department of the Environment
    Waste Management Paper No. 4 - The Licensing of Waste Disposal Sites.

2. Department of the Environment
    The Balancing of Interests Between Water Protection and Waste Disposal Circular 39/76

WEST GERMANY

Applications

None

Guidelines and Regulations

1. Guidelines for Designing, Erecting, and Operating Disposal Sites for Household Refuse and Material Similar to Household Refuse.

2. New Waste Removal Law (in German, Table of Contents in English is attached)

APPENDIX E*

Table E-1

Summary of Selected Case Histories

	Agency	Decision Procedures	Facility Type	Facility Location	Waste Type	Application Process Time (months)	Permit Granted Denied	Special Provisions	Remarks
1.	California Regional Water Quality Board	Classification System	Landfill	Los Angeles County	Group I and 2	15	Granted	Leachate collection wells. Low permeability barrier wall at station of site boundary	Case history is of application to upgrade one parcel of existing landfill to accept Group I waste
2.	New York State Department of Environmental Conservation	Criteria Listing	Landfill serving 42,000 persons	Columbia County	Municipal Solid waste	22 months +	Pending	Special screening from nearby historic site	There is considerable opposition to site use by citizens groups. Permit is now being delayed due to questions of compliance with new regulations.
3.	Pennsylvania Department of Environmental Resources	Criteria Listing	Regional Landfill	Allenwood Prison Camp.	Solid waste	?	Granted	Two natural liners and one artifical (30 mil PVC) liner	Considerable opposition from citizens groups delayed permit aquisition.
4.	Texas Department of Environmental Resources	Criteria Listing Classification System	Type I	Dallas County Texas	Municipal Solid waste	5 months	Granted	Change in design to preserve a stand of virgin hardwood	There was only minimal public opposition
5.	Texas Water Quality Board, Industrial Solid Waste Branch	Criteria Listing Classification System	Industrial Landfill	Jefferson County, Texas	Class I and II	2 months	Granted	Collection and spray irrigation of surface water	Although the site is approved for Class I waste, each time a new type of Class I waste is proposed for disposal, special permission must be obtained.
6.	Ontario Ministry of the Environment	Criteria Listing	Municipal Landfill	Municipality of Halton	primarily municipal solid waste	N.A.	Application to quash was granted	Municipality can proceed with necessary preliminary work.	The procedure occurred prior to permit application.

*Separate Document--Available at Office of Solid Waste, Hazardous Waste Management Division, Washington, D.C.