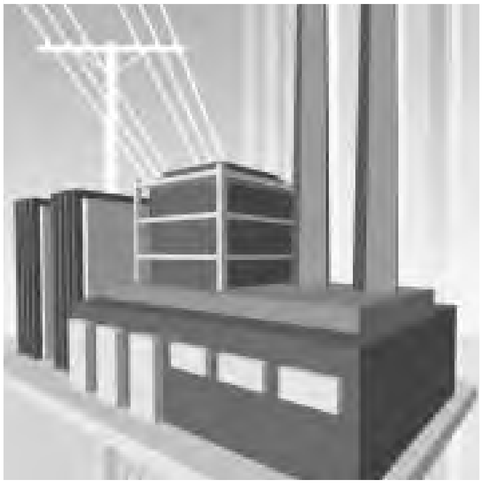
Guide for

Industrial Waste Management

Protecting
Land
Ground Water
Surface Water
Air



Building
Partnerships

EPA

EPA's Guide for Industrial Waste Management Introduction

Welcome to EPA's Guide for Industrial Waste Management. The purpose of the Guide is to provide facility managers, state and tribal regulators, and the interested public with recommendations and tools to better address the management of land-disposed, non-hazardous industrial wastes. The Guide can help facility managers make environmentally responsible decisions while working in partnership with state and tribal regulators and the public. It can serve as a handy implementation reference tool for regulators to complement existing programs and help address any gaps. The Guide can also help the public become more informed and more knowledgeable in addressing waste management issues in the community.

In the Guide, you will find:

- Considerations for siting industrial waste management units
- Methods for characterizing waste constituents
- Fact sheets and Web sites with information about individual waste constituents
- Tools to assess risks that might be posed by the wastes
- Principles for building stakeholder partnerships
- Opportunities for waste minimization
- Guidelines for safe unit design
- Procedures for monitoring surface water, air, and ground water
- Recommendations for closure and post-closure care

Each year, approximately 7.6 billion tons of industrial solid waste are generated and disposed of at a broad spectrum of American industrial facilities. State, tribal, and some local governments have regulatory responsibility for ensuring proper management of these wastes, and their programs vary considerably. In an effort to establish a common set of industrial waste management guidelines, EPA and state and tribal representatives came together in a partnership and developed the framework for this voluntary Guide. EPA also convened a focus group of industry and public interest stakeholders chartered under the Federal Advisory Committee Act to provide advice throughout the process. Now complete, we hope the Guide will complement existing regulatory programs and provide valuable assistance to anyone interested in industrial waste management.

What Are the Underlying Principles of the Guide?

When using the *Guide for Industrial Waste Management*, please keep in mind that it reflects four underlying principles:

- **Protecting human health and the environment.** The purpose of the Guide is to promote sound waste management that protects human health and the environment. It takes a multi-media approach that emphasizes surface-water, ground-water, and air protection, and presents a comprehensive framework of technologies and practices that make up an effective waste management system.
- **Tailoring management practices to risks.** There is enormous diversity in the type and nature of industrial waste and the environmental settings in which it is managed. The Guide provides conservative management recommendations and simple-to-use modeling tools to tailor management practices to waste- and location-specific risks. It also identifies in-depth analytic tools to conduct more comprehensive site-specific analyses.
- **Affirming state and tribal leadership.** States, tribes, and some local governments have primary responsibility for adopting and implementing programs to ensure proper management of industrial waste. This Guide can help states, tribes, and local governments in carrying out those programs. Individual states or tribes might have more stringent or extensive regulatory requirements based on local or regional conditions or policy considerations. The Guide complements, but does not supersede, those regulatory programs; it can help you make decisions on meeting applicable regulatory requirements and filling potential gaps. Facility managers and the public should consult with the appropriate regulatory agency throughout the process to understand regulatory requirements and how to use this Guide.
- **Fostering partnerships.** The public, facility managers, state and local governments, and tribes share a common interest in preserving quality neighborhoods, protecting the environment and public health, and enhancing the economic well-being of the community. The Guide can provide a common technical framework to facilitate discussion and help stakeholders work together to achieve meaningful environmental results.

What Can I Expect to Find in the Guide?

The *Guide for Industrial Waste Management* is available in both hard-copy and electronic versions. The hard-copy version consists of five volumes. These include the main volume and four supporting documents for the ground-water and air fate-and-transport models that were developed by EPA specifically for this Guide. The main volume presents comprehensive information and recommendations for use in the management of land-disposed, non-hazardous industrial waste that includes siting the waste management unit, characterizing the wastes that will be disposed in it, designing and constructing the unit, and safely closing it. The other four volumes are the user's manuals and background documents for the ground-water fate-and-transport model—the Industrial Waste Evaluation Model (IWEM)—and the air fate-and-transport model—the Industrial Waste Air Model (IWAIR).

The electronic version of the Guide, which can be obtained either on CD-ROM or from EPA's Web site **<www.epa.gov/epaoswer/non-hw/industd/index.htm>**, contains a large collection of additional resources. These include an audio-visual tutorial for each main topic of the Guide; the IWEM and IWAIR models developed by EPA for the Guide; other models, including the HELP (Hydrologic Evaluation of Landfill Performance) Model for calculating infiltration rates; and a large collection of reference materials to complement the information provided in each of the main chapters, including chemical fact sheets from the Agency for Toxic Substances and Disease Registry, links to Web sites, books on pertinent topics, copies of applicable rules and regulations, and lists of contacts and resources for additional information. The purpose of the audio-visual tutorials is to familiarize users with the fundamentals of industrial waste management and potentially expand the audience to include students and international users.

The IWEM and IWAIR models that come with the electronic version of the Guide are critical to its purpose. These models assess potential risks associated with constituents in wastes and make recommendations regarding unit design and control of volatile organic compounds to help mitigate those risks. To operate, the models must first be downloaded from the Web site or the CD-ROM to the user's personal computer.

What Wastes Does the Guide Address?

The *Guide for Industrial Waste Management* addresses non-hazardous industrial waste subject to Subtitle D of the Resource Conservation and Recovery Act (RCRA). The reader is referred to the existence of 40 CFR Part 257, Subparts A and B, which provide federal requirements for non-hazardous industrial waste facilities or practices. Under RCRA, a waste is defined as non-hazardous if it does not meet the definition of hazardous waste and is not subject to RCRA Subtitle C regulations. Defining a waste as non-hazardous under RCRA does not mean that the management of this waste is without risk.

This Guide is primarily intended for new industrial waste management facilities and units, such as new landfills, new waste piles, new surface impoundments, and new land application units. Chapter 7B–Designing and Installing Liners, and Chapter 4–Considering the Site, are clearly directed toward new units. Other chapters, such as Chapter 8–Operating the Waste Management System, Chapter 9–Monitoring Performance, Chapter 10–Taking Corrective Action, Chapter 11–Performing Closure and Post-Closure Care, while primarily intended for new units, can provide helpful information for existing units as well.

What Wastes Does the Guide Not Address?

The *Guide for Industrial Waste Management* is not intended to address facilities that primarily handle the following types of waste: household or municipal solid wastes, which are managed in facilities regulated by 40 CFR Part 258; hazardous wastes, which are regulated by Subtitle C of RCRA; mining and some mineral processing wastes; and oil and gas production wastes; mixed wastes, which are solid wastes mixed with radioactive wastes; construction and demolition debris; and non-hazardous wastes that are injected into the ground by the use of shallow underground injection wells (these injection wells fall under the Underground Injection Control (UIC) Program).

Furthermore, while the Guide provides many tools for assessing appropriate industrial waste management, the information provided is not intended for use as a replacement for other existing EPA programs. For example, Tier 1 ground-water risk criteria can be a useful conservative screening tool for certain industrial wastes that are to be disposed in new landfills, surface impoundments, waste piles, or land application units, as intended by the Guide. These ground-water risk criteria, however, cannot be used as a replacement for sewage sludge standards, hazardous waste identification exit criteria, hazardous waste treatment standards, MCL drinking water standards, or toxicity characteristics to identify when a waste is hazardous—all of which are legally binding and enforceable. In a similar manner, the air quality tool in this Guide does not and cannot replace Clean Air Act Title V permit conditions that may apply to industrial waste disposal units. The purpose of this Guide is to help industry, state, tribal, and environmental representatives by providing a wealth of information that relays and defers to existing legal requirements.

What is the Relationship Between This Guide and Statutory or Regulatory Provisions?

Please recognize that this is a voluntary guidance document, not a regulation, nor does it change or substitute for any statutory or regulatory provisions. This document presents technical information and recommendations based on EPA's current understanding of a range of issues and circumstances involved in waste management The statutory provisions and EPA regulations contain legally binding requirements, and to the extent any statute or regulatory provision is cited in the Guide, it is that provision, not the Guide, which is legally binding and enforceable. Thus, this Guide does not impose legally binding requirements, nor does it confer legal rights or impose legal obligations on anyone or implement any statutory or regulatory provisions. When a reference is made to a RCRA criteria, for example, EPA does not intend to convey that any recommended actions, procedures, or steps discussed in connection with the reference are required to be taken. Those using this Guide are free to use and accept other technically sound approaches. The Guide contains information and recommendations designed to be useful and helpful to the public, the regulated community, states, tribes, and local governments. The word "should" as used in the Guide is intended solely to recommend particular action and does not connote a requirements. Similarly, examples are presented as recommendations or demonstrations, not as requirements. To the extent any products, trade name, or company appears in the Guide, their mention does not constitute or imply endorsement or recommendation for use by either the U.S. Government or EPA. Interested parties are free to raise questions and objections about the appropriateness of the application of the examples presented in the Guide to a particular situation.

Part I
Getting Started

Chapter 1
Understanding Risk and Building Partnerships

Contents

Understanding Risk and Building Partnerships

This chapter will help you:

- *Understand the basic principles of risk assessment and the science behind it.*
- *Build partnerships between a company that generates and manages waste, the community within which the company lives and works, and the state agency that regulates the company in order to build trust and credibility among all parties.*

Residents located near waste management units want to understand the management activities taking place in their neighborhoods. They want to know that waste is being managed safely, without danger to public health or the environment. This requires an understanding of the basic principles of risk assessment and the science behind it. Opportunities for dialogue between facilities, states, tribes, and concerned citizens, including a discussion of risk factors, should take place before decisions are made. Remember, successful partnerships are an ongoing activity.

I. Understanding Risk Assessment

Environmental risk communication skills are critical to successful partnerships between companies, state regulators, the public, and other stakeholders. As more environmental management decisions are made on the basis of risk, it is increasingly important for all interested parties to understand the science behind risk assessment. Encouraging public participation in environmental decision-making means ensuring that all interested parties understand the basic principles of risk assessment and can converse equally on the development of assumptions that underlie the analysis.

A. Introduction to Risk Assessment

This Guide provides simple-to-use risk assessment tools that can assist in determining the appropriate waste management practices for surface impoundments, landfills, waste piles, and land application units. The tools estimate potential human health impacts from a waste management unit by modeling two possible exposure pathways: releases through volatile air emissions and contaminant migration into ground water. Although using the tools is simple, it is still essential to understand the basic concepts of risk assessment to be able to interpret the results and understand the nature of any uncertainties associated with the analysis. This section provides a general overview of the scientific principles underlying the methods for quantifying cancer and

> This chapter will help address the following questions.
>
> - What is risk and how is it assessed?
> - What are the benefits of building partnerships?
> - What methods have been successful in building partnerships?
> - What is involved in preparing a stakeholder meeting?

noncancer risk. Ultimately, understanding the scientific principles will lead to more effective use of the provided tools.

B. Types of Risk

Risk is a concept used to describe situations or circumstances that pose a hazard to people or things they value. People encounter a myriad of risks during common everyday activities, such as driving a car, investing money, and undergoing certain medical procedures. By definition, risk is comprised of two components: the probability that an adverse event will occur and the magnitude of the consequences of that adverse event. In capturing these two components, risk is typically stated in terms of the probability (e.g., one chance in one million) of a specific harmful "endpoint" (e.g., accident, fatality, cancer).

In the context of environmental management and this section in the Guide, risk is defined as the probability or likelihood that public health might be unacceptably impacted from exposure to chemicals contained in waste management units. The risk endpoints resulting from the exposure are typically grouped into two major consequence categories: cancer risk and noncancer risk.

The cancer risk category captures risks associated with exposure to chemicals that might initiate cancer. To determine a cancer risk, one must calculate the probability of an individual developing any type of cancer during his or her lifetime from exposure to carcinogenic hazards. Cancer risk is generally expressed in scientific notation; in this notation, the chance of 1 person in 1,000,000 of developing cancer would be expressed as 1×10^{-6} or 1E-6.

The noncancer risk category is essentially a catch-all category for the remaining health effects resulting from chemical exposure. Noncancer risk encompasses a diverse set of effects or endpoints, such as weight loss, enzyme changes, reproductive and developmental abnormalities, and respiratory reactions. Noncancer risk is generally assessed by comparing the exposure or average intake of a chemical with a corresponding reference (a health benchmark), thereby creating a ratio. The ratio so generated is referred to as the hazard quotient (HQ). An HQ that is greater than 1 indicates that the exposure level is above the protective level of the health benchmark, whereas, an HQ less than 1 indicates that the exposure is below the protective level established by the health benchmark.

It is important to understand that exposure to a chemical does not necessarily result in an adverse health effect. A chemical's ability to initiate a harmful health effect depends on the toxicity of the chemical as well as the route (e.g., ingestion, inhalation) and dose (the amount that a human intakes) of the exposure. Health benchmark values are used to quantify a chemical's possible toxicity and ability to induce a health effect, and are derived from toxicity data. They represent a "dose-response"[1] estimate that relates the likelihood and severity of adverse health effects to exposure and dose. The health benchmark is used in combination with an individual's exposure level to determine if there is a risk. Because individual chemicals generate different health effects at different doses, benchmarks are chemical specific; additionally, since health effects are related to the route of exposure and the timing of the exposure, health benchmarks are specific to the route and the duration (acute, subchronic, or chronic) of the exposure. The definitions of acute, subchronic, and chronic exposures vary, but acute typically implies an exposure of less than one day, subchronic generally indicates an exposure of a few weeks to a few months, and chronic exposure can span periods of several months to several years.

[1] Dose-response is the correlative relationship between the dose of a chemical received by a subject and the degree of response to that exposure.

The health benchmark for carcinogens is called the cancer slope factor. A cancer slope factor (CSF) is defined as the upper-bound[2] estimate of the probability of a response per unit intake of a chemical over a lifetime and is expressed in units of (mg/kg-d). The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular concentration of a carcinogen.

A reference dose (RfD) for oral exposure and reference concentration (RfC) for inhalation exposure are used to evaluate noncancer effects. The RfD and RfC are estimates of daily exposure levels to individuals (including sensitive populations) that are likely to be without an appreciable risk of deleterious effects during a lifetime and are expressed in units of mg/kg-d (RfD) or mg/m^3 (RfC).

Most health benchmarks reflect some degree of uncertainty because of the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, nutritionally or immunologically compromised) to the effects of hazardous substances. There is additional uncertainty because most benchmarks must be based on studies performed on animals, as relevant human studies are lacking. From time-to-time benchmark values are revised to reflect new toxicology data on a chemical. In addition, because many states have developed their own toxicology benchmarks, both the groundwater and air tools in this Guide enable a user to input alternative benchmarks to those that are provided.

There are several sources for obtaining health benchmarks, some of which are summarized in the text box on the following page. Most of these sources have toxicological profiles and fact sheets on specific chemicals that are written in a general manner and summarize the potential risks of a chemical and how it is currently regulated. One good Internet source is the Agency for Toxic Substances and Disease Registry (ATSDR) **<www.atsdr.cdc.gov>**. ATSDR provides fact sheets for many chemicals. These fact sheets are easy to understand and provide general information regarding the chemical in question. An example for cadmium is provided in the appendix at the end of this chapter. Additional Internet sites are also available such as: the Integrated Risk Information System (IRIS); EPA's Office of Air Quality Planning and Standards Hazardous Air Pollutants Fact Sheets; EPA's Office of Ground Water and Drinking Water Contaminant Fact Sheets; New Jersey's Department of Health, Right to Know Program's Hazardous Substance Fact Sheets; Environmental Defense's Chemical Scorecard; EPA's Office of Pollution Prevention and Toxics (OPPT) Chemical Fact Sheets, American Chemistry Council (ACC), and several others. Visit the Envirofacts Warehouse Chemical References Complete Index at **<www.epa.gov/enviro/html/emci/chemref/complete_index.html>** for links to these Web sites.

Example of Health Benchmarks for Acrylonitrile

Chronic:
- inhalation CSF: 0.24 (mg/kg-d)
- oral CSF: 0.54 (mg/kg-d)
- RfC: 0.002 mg/m^3
- RfD: 0.001 mg/kg-d

Subchronic:
- RfC: 0.02 mg/m^3

Acute:
- ATSDR MRL: 0.22 mg/m^3

C. Assessing Risk

Sound risk assessment involves the use of an organized process of evaluating scientific data. A risk assessment ultimately serves as

[2] Upper-bound is a number that is greater than or equal to any number in a set.

Sources for Health Benchmarks

Integrated Risk Information System (IRIS) The Integrated Risk Information System (IRIS) is the Agency's official repository of Agency-wide, consensus, chronic human health risk information. IRIS contains Agency consensus scientific positions on potential adverse human health effects that might result from chronic (or lifetime) exposure to environmental contaminants. IRIS information includes the reference dose for noncancer health effects resulting from oral exposure, the reference concentration for noncancer health effects resulting from inhalation exposure, and the carcinogen assessment for both oral and inhalation exposure. IRIS can be accessed at <**www.epa.gov/iris**>.

Health Effects Assessment Summary Tables (HEAST) HEAST is a comprehensive listing compiled by EPA consisting of risk assessment information relative to oral and inhalation routes for chemicals. HEAST benchmarks are considered secondary to those contained in IRIS. Although the entries in HEAST have undergone review and have the concurrence of individual Agency Program Offices, they have either not been reviewed as extensively as those in IRIS or they do not have as complete a data set as is required for a chemical to be listed in IRIS. HEAST can be ordered from NTIS by calling 1-800-553-IRIS or accessing their Website at <**www.ntis.gov**>.

Agency for Toxic Substances and Disease Registry (ATSDR) The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), requires that the Agency for Toxic Substances and Disease Registry (ATSDR) develop jointly with the EPA, in order of priority, a list of hazardous substances most commonly found at facilities on the CERCLA National Priorities List; prepare toxicological profiles for each substance included on the priority list of hazardous substances; ascertain significant human exposure levels (SHELs) for hazardous substances in the environment, and the associated acute, subchronic, and chronic health effects; and assure the initiation of a research program to fill identified data needs associated with the substances. The ATSDR Minimal Risk Levels (MRLs) were developed as an initial response to the mandate. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. MRLs are derived for acute (1-14 days), intermediate (15-364 days), and chronic (365 days and longer) exposure durations, for the oral and inhalation routes of exposure. ATSDR's toxicological profiles can be accessed at <**www.atsdr.cdc.gov/toxfaq.html**>.

guidance for making management decisions by providing one of the inputs to the decision making process. Risk assessment furnishes beneficial information for a variety of situations, such as determining the appropriate pollution control systems for an industrial site, predicting the appropriateness of different waste management options or alternative waste management unit configurations, or identifying exposures that might require additional attention.

The risk assessment process involves data collection activities, such as identifying and characterizing the source of the environmental pollutant, determining the transport of the pollutant once it is released into the environment, determining the pathways of human exposure, and identifying the extent of exposure for individuals or populations at risk.

Performing a risk assessment is complex and requires knowledge in a number of scientific disciplines. Experts in several areas, such as toxicology, geochemistry, environmental engineering, and meteorology, can be involved in performing a risk assessment. For the purpose of this section, and for brevity, the basic components important to consider when assessing risk are summarized in three main categories listed below. A more extensive discussion of these components can be found in the references listed at the end of this section. The three main categories are:

1. **Hazard Identification:** identifying and characterizing the source of the potential risk (e.g., chemicals managed in a waste management unit).
2. **Exposure Assessment:** determining the exposure pathways and exposure routes from the source to an individual.
3. **Risk Characterization:** integrating the results of the exposure assessment with information on who is potentially at risk (e.g., location of the person, body weights) and chemical toxicity information.

1. Hazard Identification

For the purpose of the Guide, the source of the potential risk has already been identified: waste management units. However, there must be a release of chemicals from a waste management unit for there to be exposure and risk. Chemicals can be released from waste management units by a variety of processes, including volatilization (where chemicals in vapor phase are released to the air), leaching to ground water (where chemicals travel through the ground to a groundwater aquifer), particulate emission (where chemicals attached to particulate matter are released in the air when the particulate matter becomes airborne), and runoff and erosion (where chemicals in soil water or attached to soil particles move to the surrounding area).

To consider these releases in a risk assessment, information characterizing the waste management unit is needed. Critical parameters include the size of the unit and its location. For example, larger units have the potential to produce larger releases. Units located close to the water table might produce greater releases to ground water than units located further from the water table. Units located in a hot, dry, windy climate can produce greater volatile releases than units in a cool, wet, non-windy climate.

2. Exposure Assessment: Pathways, Routes, and Estimation

Individuals and populations can come into contact with environmental pollutants by a variety of exposure mechanisms and processes. The mere presence of a hazard, such as toxic chemicals in a waste management unit, does not denote the existence of a risk. Exposure is the bridge between what is considered a hazard and what actually presents a risk. Assessing exposure involves evaluating the potential or actual pathways for and extent of human contact with toxic chemicals. The magnitude, frequency, duration, and route of exposure to a substance must be considered when collecting all of the data necessary to construct a complete exposure assessment.

The steps for performing an exposure assessment include identifying the potentially exposed population (receptors); pathways of exposure; environmental media that transport the contaminant; contaminant concentration at a receptor point; and receptor's exposure time, frequency, and duration. In a deterministic exposure assessment, single values are assigned to each exposure variable. For example, the length of time a person lives in the same residence adjacent to the facility might be assumed to be 30 years. Alternatively, in a probabilistic analysis, single values can be replaced with probability distribution functions that represent the range in real-world variability, as well as uncertainty. Using the time in residence example, it might be found that 10 percent of the people adjacent to the facility live in their home for less than three years, 50 percent less than six years, 90 percent less than 20 years, and 99 percent less than 27 years.

A probabilistic risk assessment is performed by running the equations that describe each distribution in a program in conjunction with a Monte Carlo program. The Monte Carlo program randomly selects a value from the designated distribution and mathematically treats it with numbers randomly selected from distributions for other parameters. This process is repeated a number of times (e.g., 10,000 times) to generate a distribution of theoretical values. The person assessing risk then uses his or her judgement to select the risk value (e.g., 50th or 90th percentile).

The output of the exposure assessment is a numerical estimate of exposure and intake of a chemical by an individual. The intake information is then used in concert with chemical-specific health benchmarks to quantify risks to human health.

Before gathering these data, it is important to understand what information is necessary for conducting an adequate exposure assessment and what type of work might be required. Exposures are commonly determined by using mathematical models of chemical fate and transport to determine chemical movement in the environment in conjunction with models of human activity patterns. The information required for performing the exposure assessment includes site-specific data such as soil type, meteorological conditions, ground-water pH, and location of the nearest receptor. Information must be gathered for the two components of exposure assessment: exposure pathways/routes and exposure quantification/estimation.

a. *Exposure Pathways/Routes*

An exposure pathway is the course the chemical takes from its source to the individual or population it reaches. Chemicals cycle in the environment by crossing through the different types of media which are considered exposure pathways: air, soil, ground water, surface water, and biota (Figure 1). As a result of this movement, a chemical can be present in various environmental media, and human exposure often results from multiple sources. The relative importance of an exposure pathway depends on the concentration of a chemical in the relevant medium and the rate of intake by the exposed individual. In a comprehensive risk assessment, the risk assessor identifies all possible site-specific pathways through which a chemical could move and reach a receptor. The Guide provides tools to model the transport and movement of chemicals through two environmental pathways: air and ground water.

The transport of a chemical in the environment is facilitated by natural forces: wind and water are the primary physical processes for distributing contaminants. For example, atmospheric transport is frequently caused by ambient wind. The direction and speed of the wind determine where a chemical can be found. Similarly, chemicals found in surface water and ground water are carried by water currents or sediments suspended in the water.

The chemistry of the contaminants and of the surrounding environment, often referred to as the "system," also plays a significant role in determining the ultimate distribution of pollutants in the various types of media. Physical-chemical processes, including dissolution/precipitation, volatilization, photolytic and hydrolytic degradation, sorption, and complexation, can influence the distribution of chemicals among the different environmental media and the transformation from one chemical form to another[3]. An important component of creating a conceptual model for performing a risk assessment is the identification of the relevant processes that occur in a system. These complex processes depend on the conditions at the site and specific chemical properties.

[3] Kolluru, Rao (1996).

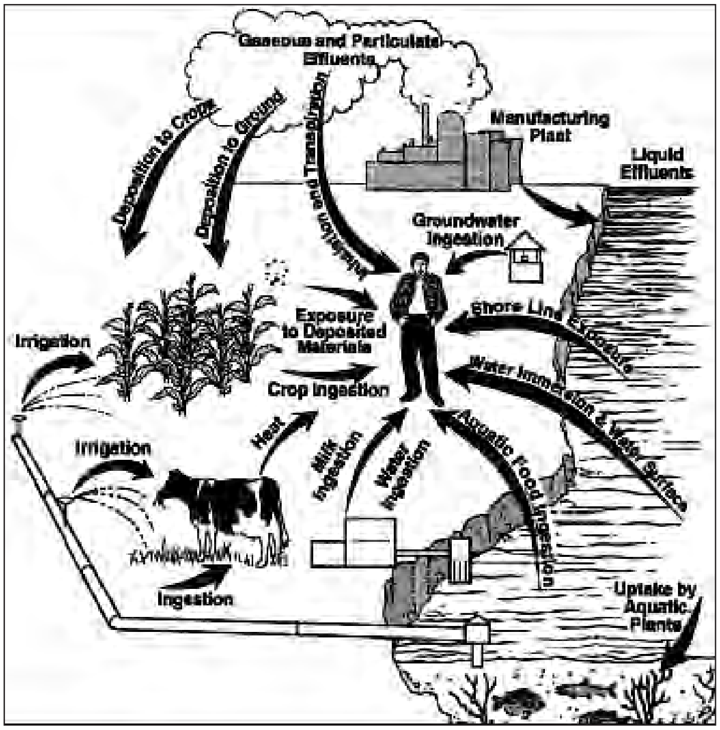


Figure 1. Multiple Exposure Pathways/Routes *(National Research Council, "Frontiers in Assesssing Human Exposure," 1991)*

Whereas the exposure pathway dictates the means by which a contaminant can reach an individual, the exposure route is the way in which that chemical comes in contact with the body. To generate a health effect, the chemical must come in contact with the body. In environmental risk assessment, three exposure routes are generally considered: ingestion, inhalation, and dermal absorption. As stated earlier, the toxicity of a chemical is specific to the dose received and its means of entry into the body. For example, a chemical that is inhaled might prove to be toxic and result in a harmful health effect, whereas the same chemical might cause no reaction if ingested, or vice-versa. This phenomenon is due to the differences in physiological response once a chemical enters the body. A chemical that is inhaled reaches the lungs and enters the blood system. A chemical that is ingested might be metabolized into a different chemical that might result in a health effect or into another chemical that is soluble and can be excreted.

Some contaminants can also be absorbed by the skin. The skin is not very permeable and usually provides a sufficient barrier against most chemicals. Some chemicals, however, can pass through the skin in sufficient quantities to induce severe health effects. An example is carbon tetrachloride, which is readily absorbed through the skin and at certain doses can cause severe liver damage. The dermal route is typically considered in worker scenarios in which the worker is actually performing activities that involve skin contact with the chemical of concern. The tools provided in the Guide do not address the dermal route of exposure.

b. Exposure Quantification/Estimation

Once appropriate fate-and-transport modeling has been performed for each pathway, providing an estimate of the concentration of a chemical at an exposure point, the chemical intake by a receptor must be quantified. Quantifying the frequency, magnitude, and duration of exposures that result from the transport of a chemical to an exposure point is critical to the overall assessment. For this step, the risk assessor calculates the chemical-specific exposures for each exposure pathway identified. Exposure estimates are expressed in terms of the mass of a substance in contact with the body per unit body weight per unit time (e.g., milligrams of a chemical per kilogram body weight per day, also expressed as mg/kg-day).

The exposure quantification process involves gathering information in two main areas: the activity patterns and the biological

Key Chemical Processes

Sorption: the partitioning of a chemical between the liquid and solid phase determined by its affinity for adhering to other solids in the system such as soils and sediment. The amount of chemical that "sorbs" to solids and does not move through the environment is dependent upon the characteristics of the chemical, the characteristics of the surrounding soils and sediments, and the quantity of the chemical. A sorption coefficient is the measure of a chemical's ability to sorb. If too much of the chemical is present, the available binding sites on soils and sediments will be filled and sorption will not continue.

Dissolution/precipitation: the taking in or coming out of solution by a substance. In dissolution a chemical is taken into solution; precipitation is the formation of an insoluble solid. These processes are a function of the nature of the chemical and its surrounding environment and are dependent on properties such as temperature and pH. A chemical's solubility is characterized by a solubility product. Chemicals that tend to volatilize rapidly are not highly soluble.

Degradation: the break down of a chemical into other substances in the environment. Some degradation processes include biodegradation, hydrolysis, and photolysis. Not all degradation products have the same risk as the "parent" compound. Although most degradation products present less risk than the parent compound, some chemicals can break down into "daughter" products that are more harmful than the parent compound. In performing a risk assessment it is important to consider what the daughter products of degradation might be.

Bioaccumulation: the take up/ingestion and storage of a substance into an organism. For substances that bioaccumulate, the concentrations of the substance in the organism can exceed the concentrations in the environment since the organism will store the substance and not excrete it.

Volatilization: the partitioning of a compound into a gaseous state. The volatility of a compound is dependent on its water solubility and vapor pressure. The extent to which a chemical can partition into air is described by one of two constants: Henry's Law or Rauolt's Law. Other factors that are important to volatility are atmospheric temperature and waste mixing.

characteristics (e.g., body weight, inhalation rate) of receptors. Activity patterns and biological characteristics dictate the amount of a constituent that a receptor can intake and the dose that is received per kilogram of body weight. Chemical intake values are calculated using equations that include variables for exposure concentration, contact rate, exposure frequency, exposure duration, body weight, and exposure averaging time. The values of some of these variables depend on the site conditions and the characteristics of the potentially exposed population. For example, the rate of oral ingestion of contaminated food is different for different subgroups of receptors, which might include adults, children, area visitors, subsistence farmers, and subsistence fishers. Children typically drink greater quantities of milk each day than adults per unit body weight. A subsistence fisher would be at a greater risk than another area resident from the ingestion of contaminated fish. Additionally, a child might have a greater rate of soil ingestion than an adult due to playing outdoors or hand-to-mouth behavior patterns. The activities of individuals also determine the duration of exposure. A resident might live in the area for 20 years and be in the area for more than 350 days each year. Conversely, a visitor or a worker will have shorter exposure times. After the intake values have been estimated, they should be organized by population as appropriate (e.g., children, adult residents) so that the results in the risk characterization can be reported for each population group. To the extent feasible, site-specific values should be used for estimating the exposures; otherwise, default values suggested by the EPA in *The Exposure Factors Handbook* (EPA, 1995) can be used.

3. *Risk Characterization*

In the risk-characterization process, the health benchmark information (i.e., cancer slope factors, reference doses, reference concentrations) and the results of the exposure assessment (estimated intake or dose by potentially exposed populations) are integrated to arrive at quantitative estimates of cancer and noncancer risks. To characterize the potential noncarcinogenic effects, comparisons are made between projected intake levels of substances and reference dose or reference concentration values. To characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime are estimated from projected intake levels and the chemical-specific cancer slope factor value. This procedure is the final calculation step. This step determines who is likely to be affected and what the likely effects are. Because of all the assumptions inherent in calculating a risk, a risk characterization cannot be considered complete unless the numerical expressions of risk are accompanied by explanatory text interpreting and qualifying the results. As shown in the text box, the risk characterization step is different for carcinogens and noncarcinogens.

Calculating Risk

Cancer Risks:

Incremental risk of cancer = average daily dose (mg/kg-day) * slope factor (mg/kg-day)

Non-Cancer Risks:

Hazard quotient = exposure or intake (mg/kg-day) or (mg/m^3)/ RfD (mg/kg-day) or RfC (mg/m^3)

Another consideration during the risk-characterization phase is the cumulative effects of multiple exposures. A given population can be exposed to multiple chemicals from several exposure routes and sources. Multiple constituents might be managed in a single waste management unit, for example, and by considering one chemical at a time, the risks associated with the waste management unit might be underestimated. The EPA has developed guidance outlined in the *Risk Assessment Guidance for Superfund, Volume I* (U.S. EPA, 1989b) to assess the overall potential for cancer and noncancer effects posed by multiple chemicals. The risk assessor, facility manager, and other interested parties should determine the appropriateness of adding the risk contribution of each chemical for each pathway to calculate a cumulative cancer risk or noncancer risk. The procedures for adding risks differ for carcinogenic and noncarcinogenic effects.

The cancer-risk equation described in the adjacent box estimates the incremental individual lifetime cancer risk for simultaneous exposure to several carcinogens and is based on EPA (1989a) guidance. The equation combines risks by summing the risks to a receptor from each of the carcinogenic chemicals.

Cancer Risk Equation for Multiple Substances

$Risk_T = \Sigma Risk_i$

where:

$Risk_T$ = the total cancer risk, expressed as a unitless probability.

$\Sigma Risk_i$ = the sum of the risk estimates for all of the chemical risks.

Assessing cumulative effects from noncarcinogens is more difficult and contains a greater amount of uncertainty than an assessment for carcinogens. As discussed earlier, noncarcinogenic risk covers a diverse set of health effects and different chemicals will have different effects. To assess the overall potential for noncarcinogenic effects posed by more than one chemical, EPA developed a hazard index (HI) approach. The approach assumes that the magnitude of an adverse health effect is proportional to the sum of the hazard quotients of each of the chemicals investigated. In keeping with EPA's *Risk Assessment Guidance*, hazard quotients should only be added for chemicals that have the same critical effect (e.g., both chemicals affect the liver or both initiate respiratory distress). As a result, an extensive knowledge of toxicology is needed to sum the hazard quotients to produce a hazard index. Segregation of hazard indices by effect and mechanism of action can be complex, time-consuming, and will have some degree of uncertainty associated with it. This analysis is not simple and should be performed by a toxicologist.

4. *Tiers for Assessing Risk*

As part of the Guide, EPA has used a 3-tiered approach for assessing risk associated with air and water releases from waste management units. Under this approach, an acceptable level of protection is provided across all tiers, but with each progressive tier the level of uncertainty in the risk analysis is reduced. Reducing the level of uncertainty in the risk analysis might reduce the level of control required by a waste management unit (if appropriate for the site), while maintaining an acceptable level of protection. The facility performing the risk assessment accepts the higher costs associated with a more complex risk assessment in return for greater certainty and potentially reduced construction and operating costs.

The advantages and relative costs of each tier are outlined below.

Tier 1 Evaluation

- Allows for a rapid but conservative assessment.
- Lower cost.
- Requires minimal site data.
- Contaminant fate-and-transport and exposure assumptions are developed using conservative, non-site specific assumptions provided by EPA. The values are provided in "look-up tables" that serve as a quick and straightforward means for assessing risk. These values are calculated to be protective over a broad range of conditions and situations and are by design very conservative.

Tier 2 Evaluation

- Represents a higher level of complexity.
- Moderate cost.
- Provides the ability to input some site-specific data into the risk assessment and thus provides a more accurate representation of site risk.
- Uses relatively simplistic fate and transport models.

Tier 3 Evaluation

- Provides a sophisticated risk assessment.
- Higher cost.
- Provides the maximum use of site-specific data and thus provides the most accurate representation of site risk.
- Uses more complex fate-and-transport models and analyses.

D. Results

The results of a risk assessment provide a basis for making decisions but are only one element of input into the process of designing a waste management unit. The risk assessment does not constitute the only basis for management action. Other factors are also important, such as technical feasibility of options, public values, and economics. Understanding and interpreting the results for the purpose of making decisions also requires a thorough knowledge of the assumptions that were applied during the risk assessment. Ample documentation should be assembled to describe the scenarios that were evaluated for the risk assessment and any uncertainty associated with the estimate. Information that should be considered for inclusion in the risk assessment documentation include: a description of the contaminants that were evaluated; a description of the risks that are present (i.e., cancer, noncancer); the level of confidence in the information used in the assessment; the major factors driving the site risks; and the characteristics of the exposed population. The results of a risk assessment are essentially meaningless without the information on how they were generated.

II. Information on Environmental Releases

There are several available sources of information that citizens can review to understand chemical risk better and to review potential environmental release from waste management units in their communities. The Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 provides one such resource. EPCRA created the Toxic Release Inventory (TRI) reporting program which requires facilities in designated Standard Industry Codes (see 40 CFR §372.22) with more than 10 employees that manufacture or process more than 25,000 pounds, or otherwise use more than 10,000 pounds, of a TRI- listed chemical to report their environmental releases annually to EPA and state governments. Environmental releases include the disposal of wastes in landfills, surface impoundments, land application units, and waste piles. EPA compiles these data in the TRI database and release this information to the public annually. Facility operators might wish to include TRI data in the facility's information repository. TRI data, however, are merely raw data. When estimating risk, other considerations need to be examined and understood too, such as the nature and characteristics of the specific facility and surrounding community.

In 1999, EPA promulgated a final rule that established alternate thresholds for several persistent, bioaccumulative, and toxic (PBT) chemicals (see 64 FR 58665; October 29, 1999). In this rule, EPA has added seven chemicals to the EPCRA Section 313 list of TRI chemicals and lowered the reporting thresholds for another 18 PBT chemicals and chemical categories. For these 18 chemicals, the alternate thresholds are significantly lower than the standard reporting thresholds of 25,000 pounds manufactured or processed, and 10,000 pounds otherwise used.

EPCRA is based on the belief that citizens have a right to know about potential environmental risks caused by facility operations in their communities, including those posed as a result of waste management. TRI data, therefore, provide yet another way for residents to learn about the waste management activities taking place in their neighborhood and to take a more active role in decisions that potentially affect their health and environment. More information on TRI and access to TRI data can be obtained from EPA's Web site **<www.epa.gov/tri>**.

III. Building Partnerships

Building partnerships between all stakeholders—the community, the facility, and the regulators—can provide benefits to all parties, such as:

- Better understanding of waste management activities at an industrial facility.
- Better understanding of facility, state, and community issues.
- Greater support of industry procedures and state policies.
- Reduced delays and costs associated with opposition and litigation.
- A positive image for a company and relationship with the state and community.

Regardless of the size or type of a facility's waste management unit, facilities, states, and local communities can all follow similar principles in the process of building partnerships. These principles are described in various state public involvement guidance documents, various EPA publications, and state requirements for waste facilities. These principles embody sound business practices and common sense and can go beyond state requirements that call for public participation during the issuance of a permit. The Guide recommends principles that can be adopted throughout the operating life of a facility, not just during the permitting process. Following these principles will help all involved consider the full range of activities possible to give partners an active voice in the decision-making process, and in so doing, will result in a positive working relationship.

A. Develop a Partnership Plan

The key to effective involvement is good planning. Developing a plan for how and when to involve all parties in making decisions will help make partnership activities run smoothly and achieve the best results. Developing a partnership plan also helps identify concerns and determine which involvement activities best address those concerns.

The first step in developing a partnership plan is to work with the state agency to understand what involvement requirements exist. Existing state requirements dealing with partnership plans must be followed. (Internet sites for all state environmental agencies are available from **<www.astswmo.org/links.htm>**.) After this step, you should assess the level of community interest generated by a facility's waste management activities. Several criteria influence the amount of public interest, including implications for public health and welfare, current relationships between the facility and community members, and the community's political and economic climate. Even if a facility has not generated much public interest in the past, involving the public is a good idea. Interest in a facility can increase suddenly when changes to existing activities are proposed or when residents' attitudes and a community's political or economic climate change.

To gauge public interest in a facility's waste management activities and to identify the community's major concerns, facility representatives should conduct interviews with community members. They can first talk with members of community groups, such as civic leagues, religious organizations, and business associations. If interest in the facility's waste management activities seems high, facility representatives can consider conducting a more comprehensive set of community interviews. Other individuals to interview include the facility's immediate neighbors, representatives from other agencies and environmental organizations, and any individuals in the community who have expressed interest in the facility's operations.

Using the information gathered during the interviews, facility representatives can develop a list of the community's concerns regarding the facility's waste management activities. They can then begin to engage the community in discussions about how to address those concerns. These discussions can form the basis of a partnership plan.

B. Inform the State and Public About New Facilities or Significant Changes in Facility Operating Plans

A facility's decision to change its operations provides a valuable opportunity for involvement. Notifying the state and public of new units and proposed changes at existing facilities gives these groups the opportunity to identify applicable state requirements and comment on matters that apply to them.

What are examples of effective methods for notifying the public?

Table 1 presents examples of effective methods for public notification and associated advantages and disadvantages. The method used at a particular facility, and within a particular community, will depend on the type of information or issues that need to be communicated and addressed. Public notices usually provide the name and address of the facility representative and a brief description of the change being considered. After a public notice is issued, a facility can develop informative fact sheets to explain proposed changes in more detail. Fact sheets and public notices can include the name and telephone number of a contact person who is available within the facility to answer questions.

What is involved in preparing a meeting with industry, community, and state representatives?

Meetings can be an effective means of giving and receiving comments and addressing concerns. To publicize a meeting, the date, time, and location of the meeting should be placed in a local newspaper and/or advertised on the radio. To help ensure a successful dialogue, meetings should be at times convenient for members of the community, such as early in the evenings during the week, or on weekends. An interpreter might need to be obtained if the local community includes residents whose primary language is not English.

Prior to a meeting, the facility representative should develop a waste management plan or come to the meeting prepared to describe how the industrial waste from the facility will be managed. A waste management plan provides a starting point for public comment and input. Keep data presentations simple and provide information relevant to the audience. Public speakers should be able to respond to both general and technical questions. Also, the facility representative should review and be familiar with the concerns of groups or citizens who have previously expressed an interest in the facility's operations. In addition, it is important to anticipate questions and plan how best to respond to these questions at a meeting.

Table 1
Effective Methods for Public Notification

Methods	Features	Advantages	Disadvantages
Briefings	Personal visit or phone call to key officials or group leaders to announce a decision, provide background information, or answer questions.	Provides background information. Determines reactions before an issue "goes public." Alerts key people to issues that might affect them.	Requires time.
Mailing of key technical reports or environmental documents	Mailing technical studies or environmental reports to other agencies, leaders of organized groups, or other interested parties.	Provides full and detailed information to people who are most interested. Often increases the credibility of studies because they are fully visible.	Costs money to print and mail. Some people might not read the reports.
News conferences	Brief presentation to reporters, followed by a question-and-answer period, often accompanied by handouts of presenter's comments.	Stimulates media interest in a story. Direct quotations often appear in television and radio. Might draw attention to an announcement or generate interest in public meetings.	Reporters will only come if the announcement or presentation is newsworthy. Cannot control how the story is presented, although some direct quotations are likely.
Newsletters	Brief description of what is going on, usually issued at key intervals for all people who have shown interest.	Provides more information than can be presented through the media to those who are most interested. Often used to provide information prior to public meetings or key decision points. Helps to maintain visibility during extended technical studies.	Requires staff time. Costs money to prepare, print, and mail. Stories must be objective and credible, or people will react to the newsletters as if they were propaganda.
Newspaper inserts	Much like a newsletter, but distributed as an insert in a newspaper.	Reaches the entire community with important information. Is one of the few mechanisms for reaching everyone in the community through which you can tell the story your way.	Requires staff time to prepare the insert, and distribution costs money. Must be prepared to newspaper's layout specifications.
Paid advertisements	Advertising space purchased in newspapers or on the radio or television.	Effective for announcing meetings or key decisions or as background material for future media stories.	Advertising space can be costly. Radio and television can entail expensive production costs to prepare the ad.
News releases	A short announcement or news story issued to the media to get interest in media coverage of the story.	Might stimulate interest from the media. Useful for announcing meetings or major decisions or as background material for future media stories.	Might be ignored or not read. Cannot control how the information is used.
Presentations to civic and technical groups	Deliver presentations, enhanced with slides or overheads, to key community groups.	Stimulates communication with key community groups. Can also provide in-depth responses.	Few disadvantages, except some groups can be hostile.
Press kits	A packet of information distributed to reporters.	Stimulates media interest in the story. Provides background information that reporters can use for future stories.	Few disadvantages, except cannot control how the information is used and might not be read.
Advisory groups and task forces	A group of representatives of key interested parties is established. Possibly a policy, technical, or citizen advisory group.	Promotes communication between key constituencies. Anticipates public reaction to publications or decisions. Provides a forum for reaching consensus.	Potential for controversy exists if "advisory" recommendations are not followed. Requires substantial commitment of staff time to provide support to committees.

Table 1
Effective Methods for Public Notification (cont.)

Methods	Features	Advantages	Disadvantages
Focus groups	Small discussion groups established to give "typical" reactions of the public. Conducted by a professional facilitator. Several sessions can be conducted with different groups.	Provides in-depth reaction to ideas or decisions. Good for predicting emotional reactions	Gets reactions, but no knowledge of how many people share those reactions. Might be perceived as an effort to manipulate the public.
Telephone line	Widely advertised phone number that handles questions or provides centralized source of information.	Gives people a sense that they know whom to call. Provides a one-step service of information. Can handle two-way communication.	Is only as effective as the person answering the telephone. Can be expensive.
Meetings	Less formal meetings for people to present positions, ask questions, and so forth.	Highly legitimate forum for the public to be heard on issues. Can be structured to permit small group interaction— anyone can speak.	Unless a small-group discussion format is used, it permits only limited dialogue. Can get exaggerated positions or grandstanding. Requires staff time to prepare for meetings.

U.S. EPA 1990. *Sites for Our Solid Waste: A Guidebook for Effective Public Involvement.*

State representatives also should anticipate and be prepared to answer questions raised during the meeting. State representatives should be prepared to answer questions on specific regulatory or compliance issues, as well as to address how the facility has been working in cooperation with the state agency. The following are some questions that are often asked at meetings.

- What are the risks to me associated with the operations?
- Who should I contact at the facility if I have a question or concern?
- How will having the facility nearby benefit the area?
- Will there be any noticeable day-to-day effects on the community?
- Which processes generate industrial waste, and what types of waste are generated?
- How will the waste streams be treated or managed?
- What are the construction plans for any proposed containment facilities?
- What are the intended methods for monitoring and detecting emissions or potential releases?
- What are the plans to address accidental releases of chemicals or wastes at the site?
- What are the plans for financial assurance, closure, and post-closure care?
- What are the applicable state regulations?
- How long will it take to issue the permit?
- How will the permit be issued?
- Who should I contact at the state agency if I have questions or concerns about the facility?

At the meeting, the facility representative should invite public and state comments on the proposed change(s), and tell community members where, and to whom, they should send written comments. A facility can choose to respond to comments in several ways. For example, telephone calls, additional fact sheets, or additional meetings can all be used to address comments. Responding promptly to residents' comments and concerns demonstrates an honest attempt to address them.

C. Make Knowledgeable and Responsible People Available for Sharing Information

Having a facility representative available to answer the public's questions and provide information helps assure citizens that the facility is actively listening to their concerns. Having a state contact available to address the public's concerns about the facility can also make sure that concerns are being heard and addressed.

In addition to identifying a contact person, facilities and states should consider setting up a telephone line staffed by employees for citizens to call and obtain information promptly about the facility. Opportunities for face-to-face interaction between community members and facility representatives include onsite information offices, open houses, workshops, or briefings. Information offices function similarly to information repositories, except that an employee is present to answer questions. Open houses are informal meetings on site where residents can talk to company officials one-to-one. Similarly, workshops and briefings enable community members, state officials, and facility representatives to interact, ask questions, and learn about the activities at the facility. Web sites can also serve as a useful tool for facility, state, and community representatives to share information and ask questions.

D. Provide Information About Facility Operations

Providing information about facility operations is an invaluable way to help the public understand waste management activities. Methods of informing communities include conducting facility tours; maintaining a publicly accessible information repository on site or at a convenient offsite public building such as a library; developing exhibits to explain operations; and distributing information through the publications of established organizations. Examples of public involvement activities are presented in the following pages.

Conduct facility tours. Scheduled facility tours allow community members and state representatives to visit the facility and ask questions about how it operates. By seeing a facility first-hand, residents learn how waste is managed and can become more confident that it is being managed safely. Individual citizens, local officials, interest groups, students, and the media might want to take advantage of facility tours. In planning tours, determine the maximum number of people that can be taken through the facility safely and think of ways to involve tour participants in what they are seeing, such as providing hands-on demonstrations. It is also a good idea to have facility representatives available to answer technical questions in an easy-to-understand manner.

Maintain a publicly accessible information repository. An information repository is simply a collection of documents describing the facility and its activities. It can include background information on the facility, the partnership plan (if developed), permits to manage waste on site, fact sheets, and copies of relevant guidance and regulations. The repository should be in a convenient, publicly accessible place. Repositories are often maintained on site in a public "reading room" or off site at a public library, town hall, or public health office. Facilities should publicize the existence, location, and hours of the repository and update the information regularly.

Develop exhibits that explain facility operations. Exhibits are visual displays, such as maps, charts, diagrams, or photographs, accompanied by brief text. They can provide technical information in an easily understandable way and an opportunity to illustrate creatively and informatively issues of concern. When developing exhibits, identify the target audience, clarify which issue or aspect of the facility's operations will be the exhibit's focus, and determine where the exhibit will be displayed. Public libraries, convention halls, community events, and shopping centers are all good, highly visible locations for an exhibit.

Use publications and mailing lists of established local organizations. Existing groups and publications often provide access to established communication networks. Take advantage of these networks to minimize the time and expense required to develop mailing lists and organize meetings. Civic or environmental groups, rotary clubs, religious organizations, and local trade associations might have regular meetings, newsletters, newspapers, magazines, or mailing lists that could be useful in reaching interested members of the community.

American Chemistry Council's Responsible Care®

To address citizens' concerns about the manufacture, transport, use, and disposal of chemical products, the American Chemistry Council (ACC) launched its Responsible Care® program in 1988. To maintain their membership in ACC, companies must participate in the Responsible Care® program. One of the key components of the program is recognizing and responding to community concerns about chemicals and facility operations.

ACC member are committed to fostering an open dialogue with residents of the communities in which they are located. To do this, member companies are required to address community concerns in two ways: (1) by developing and maintaining community outreach programs, and (2) by assuring that each facility has an emergency response program in place. For example, member companies provide information about their waste minimization and emissions reduction activities, as well as provide convenient ways for citizens to become familiar with the facility, such as tours. Many companies also set up Community Advisory Panels. These panels provide a mechanism for dialogue on issues between plants and local communities. Companies must also develop written emergency response plans that include information about how to communicate with members of the public and consider their needs after an emergency.

Responsible Care® is just one example of how public involvement principles can be incorporated into everyday business practices. The program also shows how involving the public makes good business sense. For more information about Responsible Care®, contact ACC at 703 741-5000.

AF&PA's Sustainable Forestry Initiative

Public concern about the future of America's forests coupled with the American Forest & Paper Association's (AF&PA's) belief that "sound environmental policy and sound business practice go hand in hand" fueled the establishment of the Sustainable Forestry Initiative (SFI). Established in 1995, the SFI outlines principles and objectives for environmental stewardship with which all AF&PA members must comply in order to retain membership. SFI encourages protecting wildlife habitat and water quality, reforesting harvested land, and conserving ecologically sensitive forest land. SFI recognizes that continuous public involvement is crucial to its ultimate goal of "ensuring that future generations of Americans will have the same abundant forests that we enjoy today."

The SFI stresses the importance of reaching out to the public through toll-free information lines, environmental education, private and public sector technical assistance programs, workshops, videos, and other means. To help keep the public informed of achievements in sustainable forestry, members report annually on their progress, and AF&PA distributes the resulting publication to interested parties. In addition, AF&PA runs two national forums a year, which bring together loggers, landowners, and senior industry representatives to review progress toward SFI objectives.

Many AF&PA state chapters have developed additional activities to inform the public about the SFI. For example, in New Hampshire, AF&PA published a brochure about sustainable forestry and used it to brief local sawmill officials and the media. In Vermont, a 2-hour interactive television session allowed representatives from industry, public agencies, environmental organizations, the academic community, and private citizens to share their views on sustainable forestry. Furthermore, in West Virginia, AF&PA formed a Woodland Owner Education Committee to reach out to nonindustrial private landowners.

For more information about the SFI, contact AF&PA at 800 878-8878, or visit the Web site **<www.afandpa.org>**.

Understanding Risk and Building Partnerships Activity List

You should consider the following activities in understanding risk and building partnerships between facilities, states, and community members when addressing potential waste management practices.

- ❑ Understand the definition of risk.
- ❑ Review sources for obtaining health benchmarks.
- ❑ Understand the risk assessment process including the pathways and routes of potential exposure and how to quantify or estimate exposure.
- ❑ Be familiar with the risk assessment process for cancer risks and non-cancer risks.
- ❑ Develop exhibits that provide a better understanding of facility operations.
- ❑ Identify potentially interested/affected people.
- ❑ Notify the state and public about new facilities or significant changes in facility operating plans.
- ❑ Set up a public meeting for input from the community.
- ❑ Provide interpreters for public meetings.
- ❑ Make knowledgeable and responsible people available for sharing information.
- ❑ Develop a partnership plan based on information gathered in previous steps.
- ❑ Provide tours of the facility and information about its operations.
- ❑ Maintain a publicly accessible information repository or onsite reading room.
- ❑ Develop environmental risk communication skills.

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Appendix

ATSDR

CADMIUM

CAS # 7440-43-9

Agency for Toxic Substances and Disease Registry ToxFAQs **June 1999**

This fact sheet answers the most frequently asked health questions (FAQs) about cadmium. For more information, call the ATSDR Information Center at 1-888-422-8737. This fact sheet is one in a series of summaries about hazardous substances and their health effects. It's important you understand this information because this substance may harm you. The effects of exposure to any hazardous substance depend on the dose, the duration, how you are exposed, personal traits and habits, and whether other chemicals are present.

HIGHLIGHTS: Exposure to cadmium happens mostly in the workplace where cadmium products are made. The general population is exposed from breathing cigarette smoke or eating cadmium contaminated foods. Cadmium damages the lungs, can cause kidney disease, and may irritate the digestive tract. This substance has been found in at least 776 of the 1,467 National Priorities List sites identified by the Environmental Protection Agency (EPA).

What is cadmium?

(Pronounced kăd′mē-əm)

Cadmium is a natural element in the earth's crust. It is usually found as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide).

All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Most cadmium used in the United States is extracted during the production of other metals like zinc, lead, and copper. Cadmium does not corrode easily and has many uses, including batteries, pigments, metal coatings, and plastics.

What happens to cadmium when it enters the environment?

- Cadmium enters air from mining, industry, and burning coal and household wastes.
- Cadmium particles in air can travel long distances before falling to the ground or water.
- It enters water and soil from waste disposal and spills or leaks at hazardous waste sites.
- It binds strongly to soil particles.
- Some cadmium dissolves in water.
- It doesn't break down in the environment, but can change forms.
- Fish, plants, and animals take up cadmium from the environment.
- Cadmium stays in the body a very long time and can build up from many years of exposure to low levels.

How might I be exposed to cadmium?

- Breathing contaminated workplace air (battery manufacturing, metal soldering or welding).
- Eating foods containing it; low levels in all foods (highest in shellfish, liver, and kidney meats).
- Breathing cadmium in cigarette smoke (doubles the average daily intake).
- Drinking contaminated water.
- Breathing contaminated air near the burning of fossil fuels or municipal waste.

How can cadmium affect my health?

Breathing high levels of cadmium severely damages the lungs and can cause death. Eating food or drinking water with very high levels severely irritates the stomach, leading to vomiting and diarrhea. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease.

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Public Health Service
Agency for Toxic Substances and Disease Registry

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CADMIUM
CAS # 7740-43-9

ToxFAQs Internet address via WWW is http://www.atsdr.cdc.gov/toxfaq.html

Other long-term effects are lung damage and fragile bones. Animals given cadmium in food or water had high blood pressure, iron-poor blood, liver disease, and nerve or brain damage.

We don't know if humans get any of these diseases from eating or drinking cadmium. Skin contact with cadmium is not known to cause health effects in humans or animals.

How likely is cadmium to cause cancer?

The Department of Health and Human Services (DHHS) has determined that cadmium and cadmium compounds may reasonably be anticipated to be carcinogens.

How can cadmium affect children?

The health effects in children are expected to be similar to those in adults (kidney, lung and intestinal damage).

We don't know if cadmium causes birth defects in people. Cadmium does not readily go from a pregnant woman's body into the developing child, but some portion can cross the placenta. It can also be found in breast milk. The babies of animals exposed to high levels of cadmium during pregnancy had changes in behavior and learning ability. Cadmium may also affect birth weight and the skeleton in developing animals.

Animal studies also indicate that more cadmium is absorbed into the body if the diet is low in calcium, protein, or iron, or is high in fat. A few studies show that younger animals absorb more cadmium and are more likely to lose bone and bone strength than adults.

How can families reduce the risk of exposure to cadmium?

In the home, store substances that contain cadmium safely, and keep nickel-cadmium batteries out of reach of young children. If you work with cadmium, use all safety precautions to avoid carrying cadmium-containing dust home from work on your clothing, skin, hair, or tools.

A balanced diet can reduce the amount of cadmium taken into the body from food and drink.

Is there a medical test to show whether I've been exposed to cadmium?

Tests are available in some medical laboratories that measure cadmium in blood, urine, hair, or nails. Blood levels show recent exposure to cadmium, and urine levels show both recent and earlier exposure. The reliability of tests for cadmium levels in hair or nails is unknown.

Has the federal government made recommendations to protect human health?

The EPA has set a limit of 5 parts of cadmium per billion parts of drinking water (5 ppb). EPA doesn't allow cadmium in pesticides.

The Food and Drug Administration (FDA) limits the amount of cadmium in food colors to 15 parts per million (15 ppm).

The Occupational Safety and Health Administration (OSHA) limits workplace air to 100 micrograms cadmium per cubic meter (100 $\mu g/m^3$) as cadmium fumes and 200 μg cadmium/m^3 as cadmium dust.

Source of Information

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for cadmium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Where can I get more information? For more information, contact the Agency for Toxic Substances and Disease Registry, Division of Toxicology, 1600 Clifton Road NE, Mailstop E-29, Atlanta, GA 30333. Phone: 1-888-422-8737, FAX: 404-639-6359. ToxFAQs Internet address via WWW is http://www.atsdr.cdc.gov/toxfaq.html ATSDR can tell you where to find occupational and environmental health clinics. Their specialists can recognize, evaluate, and treat illnesses resulting from exposure to hazardous substances. You can also contact your community or state health or environmental quality department if you have any more questions or concerns.

Part I
Getting Started

Chapter 2
Characterizing Waste

Contents

Characterizing Waste

This chapter will help you:

- *Understand the industrial processes that generate a waste.*
- *Determine the waste's physical and chemical properties.*
- *Estimate constituent leaching to facilitate ground-water risk analysis.*
- *Quantify total constituent concentrations to facilitate air emissions analysis.*

Understanding the physical and chemical properties of a waste using sampling and analysis techniques is the cornerstone upon which subsequent steps in the Guide are built. It is necessary for gauging what risks a waste might pose to surface water, ground water, and air and drives waste management unit design and operating decisions. Knowing the composition of the waste is also necessary when determining the constituents for which to test. And, as discussed in Chapter 3–Integrating Pollution Prevention, knowledge of the physical and chemical properties of the waste is crucial in identifying pollution prevention opportunities.

In many instances, you can use knowledge of waste generation processes, analytical testing, or some combination of the two to estimate waste generation rates and waste constituent concentrations. To the extent that the waste is not highly variable, the use of process knowledge can be a sound approach to waste characterization and can prove more reasonable and cost effective than frequent sampling of the waste. It is important to note, however, that owners or operators using process knowledge to characterize a waste in lieu of testing are still responsible for the accuracy of their determinations. No matter what approach is used in characterizing a waste, the goal is to maximize the available knowledge that is necessary to make the important decisions described in later chapters of the Guide. Also, as changes are made to the industrial processes or waste management practices, it might be necessary to recharacterize a waste in order to accurately make waste management decisions and evaluate risk.

In considering the use of process knowledge or analytical testing, it is important to note that the ground water and air emissions models that accompany the Guide use constituent concentrations to estimate risk. Input requires specific concentrations which cannot be precisely estimated solely by knowledge of the processes that generate the waste. Further, when wastes are placed in a waste management unit, such as a landfill or surface

This chapter will help you address the following questions:

- How can process knowledge be used to characterize a waste?
- Which constituent concentrations should be quantified?
- Which type of leachate test should be used?

impoundment, they are subjected to various physical, chemical, and biological processes that can result in the creation of new compounds in the waste, changes in the mass and volume of the waste, and the creation of different phases within the waste and within the landfill or impoundment. In order to accurately predict the concentration of the contaminants in the leachate, these changes must be accounted for.

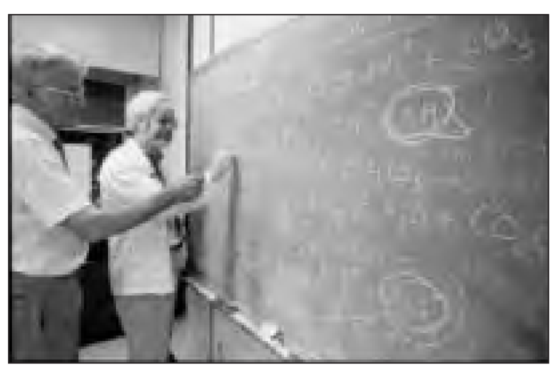
Accurate waste management unit constituent characterization is also necessary for input to the modeling tools provided in the Guide. Because model input requires specific data, model output will be based on the accuracy of the data input. Process knowledge alone (unless based on previous testing) might not be sufficiently accurate to yield reliable results. Leachate testing (discussed later in this chapter), for example, will likely give you a more precise assessment of waste constituent concentrations than process knowledge. Also note that whether you are using process knowledge, testing, or a combination of both, sources of model input data must be well documented so that an individual evaluating the modeling results understands the background supporting the assessment.

I. Waste Characterization Through Process Knowledge

A waste characterization begins with an understanding of the industrial processes that generate a waste. You must obtain enough information about the process to enable proper characterization of the waste, for example, by reviewing process flow diagrams or plans and determining all inputs and outputs. You should also be familiar with other waste characteristics such as the physical state of the waste, the volume of waste produced, and the general composition of the waste. In addition, many industries have thoroughly tested and characterized their wastes over time, therefore it might be beneficial to contact your trade association to determine if waste characterizations have already been performed and are available for processes similar to yours. Additional resources can assist in waste characterization by providing information on waste constituents and potential concentrations. Some examples include:

- Chemical engineering designs or plans for the process, showing process input chemicals, expected primary and secondary chemical reactions, and products.
- Material Safety Data Sheets (MSDSs) for materials involved. (Note that not all MSDSs contain information on all constituents found in a product.)
- Manufacturer's literature.
- Previous waste analyses.
- Literature on similar processes.
- Preliminary testing results, if available.

A material balance exercise using process knowledge can be useful in understanding where wastes are generated within a process and in estimating concentrations of waste constituents particularly where analytical test data



are limited. In a material balance, all input streams, such as raw materials fed into the processes, and all output streams, such as products produced and waste generated, are calculated. Flow diagrams can be used to identify important process steps and sources where wastes are generated. Characterizing wastes using material balances can require considerable effort and expense, but can help you to develop a more complete picture of the waste generation process(es) involved.

Note that a thorough assessment of your production processes can also serve as the starting point for facility-wide waste reduction, recycling, or pollution prevention efforts. Such an assessment will provide the information base to explore many opportunities to reduce or recycle the volume or toxicity of wastes. Refer to Chapter 3–Integrating Pollution Prevention for ideas, tools, and references on how to proceed.

While the use of process knowledge is attractive because of the cost savings associated with using existing information, you must ensure that this information accurately characterizes your wastes. If using process descriptions, published data, and documented studies to determine waste characteristics, the data should be scrutinized carefully to determine if there are any differences between the processes in the studies and the waste generating process at your facility, that the studies are acceptable and accurate (i.e., based on valid sampling and analytical techniques), and that the information is current.

If there are discrepancies, or if you begin a new process or change any of the existing processes at your facility (so that the documented studies and published data are no longer applicable), you are encouraged to consider performing additional sampling and laboratory analysis to accurately characterize the waste and ensure proper management. Also, if process knowledge is used in addition to, or in place of, sampling and analysis, you should clearly document the information used in your characterization assessment to demonstrate to regulatory agencies, the public, and other interested parties that the information accurately and completely characterizes the waste. The source of this information should be clearly documented.

What is process knowledge?

Process knowledge refers to detailed information on processes that generate wastes. It can be used to partly, or in many cases completely, characterize waste to ensure proper management. Process knowledge includes:

- Existing published or documented waste analysis data or studies conducted on wastes generated by processes similar to that which generated the waste.
- Waste analysis data obtained from other facilities in the same industry.
- Facility's records of previously performed analyses.

II. Waste Characterization Through Leachate Testing

Although sampling and laboratory analysis is not as economical and might not be as convenient as using process knowledge, it does have advantages. The resulting data usually provide the most accurate information available on constituent concentration levels.

Incomplete or mis-characterization of waste can lead to improper waste management, inaccurate modeling outputs, or erroneous decisions concerning the type of unit to be used, liner selection, or choice of land application methods. Note that process knowledge allows you to eliminate unnecessary or redundant waste testing by helping you focus on which constituents to measure in the waste. Again, thorough documentation of both the process knowledge used (e.g., studies, published data), as well as the analytical data is important.

The intent of leachate and extraction testing is to estimate the leaching potential of constituents of concern to water sources. It is important to estimate leaching potential in order to accurately estimate the quantity of chemicals that could potentially reach ground- or surface-water resources (e.g., drinking water supply wells, waters used for recreation). The Industrial Waste Management Evaluation Model (IWEM) developed for the Guide uses expected leachate concentrations for the waste management units as the basis for liner system design recommendations. Leachate tests will allow you to accurately quantify the input terms for modeling.

If the total concentration of all the constituents in a waste has been estimated using process knowledge (which could include previous testing data on wastes known to be very similar), estimates of the maximum possible concentration of these constituents in leachate can be made using the dilution ratio of the leachate test to be performed.

For example, the Toxicity Characteristic Leachate Procedure (TCLP) allows for a total constituent analysis in lieu of performing the test for some wastes. If a waste is 100 percent solid, as defined by the TCLP method, then the results of the total compositional analysis may be divided by twenty to convert the total results into the maximum leachable concentration[1]. This factor is derived from the 20:1 liquid to solid ratio employed in the TCLP. This is a conservative approach to estimating leachate concentrations and does not factor in environmental influences, such as rainfall. If a waste has filterable liquid, then the concentration of each phase (liquid and solid) must be determined. The following equation may be used to calculate this value:[2]

$$\frac{(V_1)(C_1) + (V_2)(C_2)}{V_1 + 20V_2}$$

Where:

V_1 = Volume of the first phase (L)

C_1 = Concentration of the analyte of concern in the first phase (mg/L)

V_2 = Volume of the second phase (L)

C_2 = Concentration of the analyte of concern in the second phase (mg/L)

Because this is only a screening method for identifying an upper-bound TCLP leachate concentration, you should consult with your state or local regulatory agency to determine whether process knowledge can be used to accurately estimate maximum risk in lieu of leachate testing.

A. Sampling and Analysis Plan

One of the more critical elements in proper waste characterization is the plan for sampling and analyzing the waste. The sampling plan is usually a written document that describes the objectives and details of the individual tasks of

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1 This method is only appropriate for estimating maximum constituent concentration in leachate for non-liquid wastes (e.g., those wastes not discharged to a surface impoundment). For surface impoundments, the influent concentration of heavy metals can be assumed to be the maximum theoretical concentration of metals in the leachate for purposes of input to the ground-water modeling tool that accompanies this document. To estimate the leachate concentration of organic constituents in liquid wastes for modeling input, you will need to account for losses occurring within the surface impoundment before you can estimate the concentration in the leachate (i.e., an effluent concentration must be determined for organics).

2 Source: Office of Solid Waste Web site at **<www.epa.gov/sw-846/sw846.htm>**.

a sampling effort and how they will be performed. This plan should be carefully thought out, well in advance of sampling. The more detailed the sampling plan, the less opportunity for error or misunderstanding during sampling, analysis, and data interpretation.

To ensure that the sampling plan is designed properly, a wide range of personnel should be consulted. It is important that the following individuals are involved in the development of the sampling plan to ensure that the results of the sampling effort are precise and accurate enough to properly characterize the waste:

- An engineer who understands the manufacturing processes.
- An experienced member of the sampling team.
- The end user of the data.
- A senior analytical chemist.
- A statistician.
- A quality assurance representative.

It is also advisable that you consult the analytical laboratory to be used when developing your sampling plan.

Background information on the processes that generate the waste and the type and characteristics of the waste management unit is essential for developing a sound sampling plan. Knowledge of the unit location and situation (e.g., geology, exposure of the waste to the elements, local climatic conditions) will assist in determining correct sample size and sampling method. Sampling plan design will depend on whether you are sampling a waste prior to disposal in a waste management unit or whether you are sampling waste from an existing unit. When obtaining samples from an existing unit, care should be taken to avoid endangering the individuals collecting the samples and to prevent damaging the unit itself. Reasons for obtaining samples from an existing unit include, characterizing the waste in the unit to determine if the new waste being added is compatible, checking to see if the composition of the waste is changing over time due to various chemical and biological breakdown processes, or characterizing the waste in the unit or the leachate from the unit to give an indication of expected concentrations in leachate from a new unit.

The sampling plan must be correctly defined and organized in order to get an accurate estimation of the characteristics of the waste. Both an appropriate sample size and proper sampling techniques are necessary. If the sampling process is carried out correctly, the sample will be representative and the estimates it generates will be useful for making decisions concerning proper management of the waste and for assessing risk.

In developing a sampling plan, accuracy is of primary concern. The goal of sampling is to get an accurate estimate of the waste's characteristics from measuring the sample's characteristics. The main controlling factor in deciding whether the estimates will be accurate is how representative the sample is (discussed in the following section). Using a small sample increases the possibility that the sample will not be representative, but a sample that is larger than the minimum calculated sample size does not necessarily increase the probability of getting a representative sample.

As you are developing the sampling plan, you should address the following considerations:

- Data quality objectives.
- Determination of a representative sample.
- Statistical methods to be employed in the analyses.
- Waste generation and handling processes.

- Constituents/parameters to be sampled.
- Physical and chemical properties of the waste.
- Accessibility of the unit.
- Sampling equipment, methods, and sample containers.
- Quality assurance and quality control (e.g., sample preservation and handling requirements).
- Chain-of-custody.
- Health and safety of employees.

Many of these considerations are discussed below. Additional information on data quality objectives and quality assurance and quality control can be found in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846* (U.S. EPA, 1996e), *Guidance for the Data Quality Objectives Process* (U.S. EPA, 1996b), *Guidance on Quality Assurance Project Plans* (U.S. EPA, 1998a), and *Guidance for the Data Quality Assessment: Practical Methods for Data Analysis* (U.S. EPA, 1996a).[3]

A determination as to the constituents that will be measured can be based on process knowledge to narrow the focus and expense of performing the analyses. Analyses should be performed for those constituents that are reasonably expected to be in the waste at detectable levels (i.e., test method detection levels). Note that the Industrial Waste Management Evaluation Model (IWEM) that accompanies this document recommends liner system designs, if necessary, or the appropriateness of land application based on calculated protective leachate thresholds (Leachate Concentration Threshold Values or LCTVs) for various constituents that are likely to be found in industrial waste and pose hazards at certain levels to people and the environment. The constituents that are evaluated are listed in Table 1.2 of the *Industrial Waste Management Evaluation Model Technical Background Document* (U.S. EPA 2002). The LCTV tables also are included in the *IWEM Technical Background Document* and the model on the CD-ROM version of this Guide, and can be used as a starting point to help you determine which constituents to measure. It is not recommended that you sample for all of the organic chemicals and metals listed in the tables, but rather use these tables as a guide in conjunction with knowledge concerning the waste generating practices to determine which constituents to measure.

1. Representative Waste Sampling

The first step in any analytical testing process is to obtain a sample that is representative of the physical and chemical composition of a waste. The term “representative sample” is commonly used to denote a sample that has the same properties and composition in the same proportions as the population from which it was collected. Finding one sample which is representative of the entire waste can be difficult unless you are dealing with a homogenous waste. Because most industrial wastes are not homogeneous, many different factors should be considered in obtaining samples. Examples of some of the factors that should be considered include:

- **Physical state of the waste.** The physical state of the waste affects most aspects of a sampling effort. The sampling device will vary according to whether the sample is liquid, solid, gas, or multiphasic. It will also vary according to whether the liquid is viscous or free-flowing, or whether the solid is hard, soft, powdery, monolithic, or clay-like.
- **Composition of the waste.** The samples should represent the average concentration and variability of the waste in time or over space.

[3] These and other EPA publications can be found at the National Environmental Publications Internet site (NEPIS) at **<www.epa.gov/ncepihom/nepishom/>**.

- **Waste generation and handling processes.** Processes to consider include: if the waste is generated in batches; if there is a change in the raw materials used in a manufacturing process; if waste composition can vary substantially as a function of process temperatures or pressures; and if storage time affects the waste's characteristics/composition.
- **Transitory events.** Start-up, shut-down, slow-down, and maintenance transients can result in the generation of a waste that is not representative of the normal waste stream. If a sample was unknowingly collected at one of these intervals, incorrect conclusions could be drawn.

You should consult with your state or local regulatory agency to identify any legal requirements or preferences before initiating sampling efforts. Refer to Chapter 9 of the EPA's SW-846 test methods document (see side bar) for detailed guidance on planning, implementing, and assessing sampling events.

To ensure that the chemical information obtained from waste sampling efforts is accurate, it must be unbiased and sufficiently precise. Accuracy is usually achieved by incorporating some form of randomness into the sample selection process and by selecting an appropriate number of samples. Since most industrial wastes are heterogeneous in terms of their chemical properties, unbiased samples and appropriate precision can usually be achieved by simple random sampling. In this type of sampling, all units in the population (essentially all locations

More information on Test Methods for Evaluating Solid Waste, Physical/ Chemical Methods—SW-846

EPA has begun replacing requirements mandating the use of specific measurement methods or technologies with a performance-based measurement system (PBMS). The goal of PBMS is to reduce regulatory burden and foster the use of innovative and emerging technologies or methods. The PBMS establishes what needs to be accomplished, but does not prescribe specifically how to do it. In a sampling situation, for example, PBMS would establish the data needs, the level of uncertainty acceptable for making decisions, and the required supporting documentation; a specific test method would not be prescribed. This approach allows the analyst the flexibility to select the most appropriate and cost effective test methods or technologies to comply with the criteria. Under PBMS, the analyst is required to demonstrate the accuracy of the measurement method using the specific matrix that is being analyzed. SW-846 serves only as a guidance document and starting point for determining which test method to use.

SW-846 provides state-of-the-art analytical test methods for a wide array of inorganic and organic constituents, as well as procedures for field and laboratory quality control, sampling, and characteristics testing. The methods are intended to promote accuracy, sensitivity, specificity, precision, and comparability of analyses and test results.

For assistance with the methods described in SW-846, call the EPA Method Information Communication Exchange (MICE) Hotline at 703 676-4690 or send an e-mail to mice@cpmx.saic.com.

The text of SW-846 is available online at: **<www.epa.gov/sw-846/main.htm>**. A hard copy or CD-ROM version of SW-846 can be purchased by calling the National Technical Information Service (NTIS) at 800 553-6847.

or points in all batches of waste from which a sample could be collected) are identified, and a suitable number of samples is randomly selected from the population.

The appropriate number of samples to employ in a waste characterization is at least the minimum number of samples required to generate a precise estimate of the true mean concentration of a chemical contaminant in a waste. A number of mathematical formulas exist for determining the appropriate number of samples depending on the statistical precision required. Further information on sampling designs and methods for calculating required sample sizes and optimal distribution of samples can be found in Gilbert (1987), Winer (1971), and Cochran (1977) and Chapter 9 of EPA SW-846.

The type of sampling plan developed will vary depending on the sampling location. Solid wastes contained in a landfill or waste pile can be best sampled using a three-dimensional random sampling strategy. This involves establishing an imaginary three-dimensional grid or sampling points in the waste and then using random-number tables or random-number generators to select points for sampling. Hollow-stem augers combined with split-spoon samplers are frequently appropriate for sampling landfills.

If the distribution of waste components is known or assumed for liquid or semi-solid wastes in surface impoundments, then a two-dimensional simple random sampling strategy might be appropriate. In this strategy, the top surface of the waste is divided into an imaginary grid and grid sections are selected using random-number tables or random-number generators. Each selected grid point is then sampled in a vertical manner along the entire length from top to bottom using a sampling device such as a weighted bottle, a drum thief, or Coliwasa.

If sampling is restricted, the sampling strategy should, at a minimum, take sufficient samples to address the potential vertical variations in the waste in order to be considered representative. This is because contained wastes tend to display vertical, rather than horizontal, non-random heterogeneity due to settling or the layering of solids and denser liquid phases. Also, care should be taken when performing representative sampling of a landfill, waste pile, or surface impoundment to minimize any potential to create hazardous conditions. (It is possible that the improper use of intrusive sampling techniques, such as the use of augers, could accelerate leaching by creating pathways or tunnels that can accelerate leachate movement to ground water.)

To facilitate characterization efforts, consult with state and local regulatory agencies and a qualified professional to select a sampling plan and determine the appropriate number of samples, before beginning sampling efforts. You should also consider conducting a detailed waste-stream specific characterization so that the information can be used to conduct waste reduction and waste minimization activities.

Additional information concerning sampling plans, strategies, methods, equipment, and sampling quality assurance and quality control is available in Chapters 9 and 10 of the SW-846 test methods document. Electronic versions of these chapters have been included on the CD-ROM version of the Guide.

2. Representative Waste Analysis

After a representative sample has been collected, it must be properly preserved to maintain the physical and chemical properties that it possessed at the time of collection. Sample types, sample containers, container preparation, and sample preservation methods are critical for maintaining the integrity of the sample and obtaining accurate results. Preservation and holding times are also important factors to consider and will vary depending on the type of constituents being measured (e.g., VOCs, heavy metals, hydrocarbons) and the waste matrix (e.g., solid, liquid, semi-solid).

The analytical chemist then develops an analytical plan which is appropriate for the sample to be analyzed, the constituents to be analyzed, and the end use of the information required. The laboratory should have standard operating procedures available for review for the various types of analyses to be performed and for all associated methods needed to complete each analysis, such as instrument maintenance procedures, sample handling procedures, and sample documentation procedures. In addition, the laboratory should have a laboratory quality assurance/quality control statement available for review which includes all key personnel qualifications.

The SW-846 document contains information on analytical plans and methods. Another useful source of information regarding the selection of analytical methods and quality assurance/quality control procedures for various compounds is the Office of Solid Waste Methods Team home page at **<www.epa.gov/sw-846/index.htm>**.

B. Leachate Test Selection

Leaching tests are used to estimate potential concentration or amount of waste constituents that can leach from a waste to ground water. Typical leaching tests use a specified leaching fluid mixed with the solid portion of a waste for a specified time. Solids are then separated from the leaching solution and the solution is tested for waste constituent concentrations. The type of leaching test performed can vary depending on the chemical, biological, and physical characteristics of the waste; the environment in which the waste will be placed; as well as the recommendations or requirements of your state and local regulatory agencies.

When selecting the most appropriate analytical tests, consider at a minimum the physical state of the sample, the constituents to be analyzed, detection limits, and the specified holding times of the analytical methods.[4] It might not be cost-effective or useful to conduct a test with detection limits at or greater than the constituent concentrations in a waste. Process knowledge can help you predict whether the concentrations of certain constituents are likely to fall below the detection limits for anticipated methods.

After assessing the state of the waste, assess the environment of the waste management unit in which the waste will be placed. For example, an acidic environment might require a different test than a non-acidic environment in order to best reflect the conditions under which the waste will actually leach. If the waste management unit is a monofill, then the characteristics of the waste will determine most of the unit's conditions. Conversely, if many different wastes are being co-disposed, then the conditions created by

Which leaching test is appropriate?

Selecting an appropriate leachate test can be summarized in the following four steps:

1. Assess the physical state of the waste using process knowledge.
2. Assess the environment in which the waste will be placed.
3. Consult with your state and/or local regulatory agency.
4. Select an appropriate leachate test based on the above information.

[4] There are several general categories of phases in which samples can be categorized: solids, aqueous, sludges, multiphase samples, ground water, and oil and organic liquid. You should select a test that is designed for the specific sample type.

the co-disposed wastes must be considered, including the constituents that can be leached by the subject waste.

A qualified laboratory should always be used when conducting analytical testing. The laboratory can be in-house or independent. When using independent laboratories, ensure that they are qualified and competent to perform the required tests. Some laboratories might be proficient in one test but not another. You should consult with the laboratory before finalizing your test selection to make certain that the test can be performed. When using analytical tests that are not frequently performed, additional quality assurance and quality control practices might need to be implemented to ensure that the tests are conducted correctly and that the results are accurate.

A brief summary of the TCLP and three other commonly used leachate tests is provided below (procedures for the EPA test methods are included in SW-846 and for the ASTM method in the *Annual Book of ASTM Standards*). These summaries are provided as background and are not meant to imply that these are the only tests that can be used to accurately predict leachate potential. Other leachate tests have been developed and might be suitable for testing your waste. The table in the appendix at the end of this chapter provides a summary of over 20 leachate tests that have been designed to estimate the potential for contaminant release, including several developed by ASTM.[5] You should consult with state and local regulatory agencies and/or a laboratory that is familiar with leachate testing methods to identify the most appropriate test and test method procedures for your waste and sample type.

1. Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP[6] is the test method used to determine whether a waste is hazardous due to its characteristics as defined in the Resource Conservation and Recovery Act (RCRA), 40 CFR Part 261. The TCLP estimates the leachability of certain toxicity characteristic hazardous constituents from solid waste under a defined set of laboratory conditions. It evaluates the leaching of metals, volatile and semi-volatile organic compounds, and pesticides from wastes. The TCLP was developed to simulate the leaching of constituents into ground water under conditions found in municipal solid waste (MSW) landfills. The TCLP does not simulate the release of contaminants to non-ground water pathways. The TCLP is most commonly used by EPA, state, and local agencies to classify waste. It is also used to determine compliance with some land disposal restrictions (LDRs) for hazardous wastes. The TCLP can be found as EPA Method 1311 in SW-846.[7] A copy of Method 1311 has been included on the CD-ROM version of the Guide.

For liquid wastes, (i.e., those containing less than 0.5 percent dry solid material) the waste after filtration through a glass fiber fil-

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[5] EPA has only reviewed and evaluated those test methods found in SW-846. The EPA has not reviewed or evaluated the other test methods and cannot recommend use of any test methods other than those found in SW-846.

[6] EPA is undertaking a review of the TCLP test and how it is used to evaluate waste leaching (described in the Phase IV Land Disposal Restrictions rulemaking, 62 Federal Register 25997; May 26, 1998). EPA anticipates that this review will examine the effects of a number of factors on leaching and on approaches to estimating the likely leaching of a waste in the environment. These factors include pH, liquid to solid ratios, matrix effects and physical form of the waste, effects of non-hazardous salts on the leachability of hazardous metal salts, and others. The effects of these factors on leaching might or might not be well reflected in the leaching tests currently available. At the conclusion of the TCLP review, EPA is likely to issue revisions to this guidance that reflect a more complete understanding of waste constituent leaching under a variety of management conditions.

[7] The TCLP was developed to replace the Extraction Procedure Toxicity Test method which is designated as EPA Method 1310 in SW-846.

ter is defined as the TCLP extractant. The concentrations of constituents in the liquid extract are then determined.

For wastes containing greater than or equal to 0.5 percent solids, the liquid, if any, is separated from the solid phase and stored for later analysis. The solids must then be reduced to particle size, if necessary. The solids are extracted with an acetate buffer solution. A liquid-to-solid ratio of 20:1 by weight is used for an extraction period of 18 ± 2 hours. After extraction, the solids are filtered from the liquid through a glass fiber filter and the liquid extract is combined with any original liquid fraction of the wastes. Analyses are then conducted on the liquid filtrate/leachate to determine the constituent concentrations.

To determine if a waste is hazardous because it exhibits the toxicity characteristic (TC), the TCLP method is used to generate leachate under controlled conditions as discussed above. If the TCLP liquid extract contains any of the constituents listed in Table 1 of 40 CFR Part 261 at a concentration equal to or greater than the respective value in the table, the waste is considered to be a TC hazardous waste, unless exempted or excluded under Part 261. Although the TCLP test was designed to determine if a waste is hazardous, the importance of its use for waste characterization as discussed in this chapter is to understand the parameters to be considered in properly managing the wastes.

You should check with state and local regulatory agencies to determine whether the TCLP is likely to be the best test for evaluating the leaching potential of a waste or if another test might better predict leaching under the anticipated waste management conditions. Because the test was developed by EPA to determine if a waste is hazardous (according to 40 CFR 261.24) and focused on simulating leaching of solid wastes placed in a municipal landfill, this test might not be appropriate for your waste because the leaching potential for the same chemical can be quite different depending on a number of factors. These factors include the characteristics of the leaching fluid, the form of the chemical in the solids, the waste matrix, and the disposal conditions.

Although the TCLP is the most commonly used leachate test for estimating the actual leaching potential of wastes, you should not automatically default to it in all situations or conditions and for all types of wastes. While the TCLP test might be conservative under some conditions (i.e., overestimates leaching potential), it might underestimate leaching under other extreme conditions. In a landfill that has primarily alkaline conditions, the TCLP is not likely to be the optimal method because the TCLP is designed to replicate leaching in an acidic environment. For materials that pose their greatest hazard when exposed to alkaline conditions (e.g., metals such as arsenic and antimony), use of the TCLP might underestimate the leaching potential. When the conditions of your waste management unit are very different from the conditions that the TCLP test simulates, another test might be more appropriate. Further, the TCLP might not be appropriate for analyzing oily wastes. Oil phases can be difficult to separate (e.g., it might be impossible to separate solids from oil), oily material can obstruct the filter (often resulting in an underestimation of constituents in the leachate), and oily materials can yield both oil and aqueous leachate which must be analyzed separately.[8]

2. *Synthetic Precipitation Leaching Procedure (SPLP)*

The SPLP (designated as EPA Method 1312 in SW-846) is currently used by several state agencies to evaluate the leaching of con-

[8] SW-846 specifies several procedures that should be followed when analyzing oily wastes.

stituents from wastes. The SPLP was designed to estimate the leachability of both organic and inorganic analytes present in liquids, soils, and wastes. The SPLP was originally designed to assess how clean a soil was under EPA's Clean Closure Program. Even though the federal hazardous waste program, did not adopt it for use, the test can still estimate releases from wastes placed in a landfill and subject to acid rain. There might be, however, important differences between soil as a constituent matrix (for which the SPLP is primarily used) and the matrix of a generated industrial waste. A copy of Method 1312 has been included on the CD-ROM version of the Guide.

The SPLP is very similar to the TCLP Method 1311. Waste samples containing solids and liquids are handled by separating the liquids from the solid phase, and then reducing solids to particle size. The solids are then extracted with a dilute sulfuric acid/nitric acid solution. A liquid-to-solid ratio of 20:1 by weight is used for an extraction period of 18±2 hours. After extraction, the solids are filtered from the liquid extract and the liquid extract is combined with any original liquid fraction of the wastes. Analyses are then conducted on the liquid filtrate/leachate to determine the constituent concentrations.

The sulfuric acid/nitric acid extraction solution used in the SPLP was selected to simulate leachate generation, in part, from acid rain. Also note that in both the SPLP and TCLP, some paint and oily wastes might clog the filters used to separate the liquid extract from the solids prior to analysis, resulting in under reporting of the extractable constituent concentrations.

3. *Multiple Extraction Procedure (MEP)*

The MEP (designated as EPA Method 1320 in SW-846) was designed to simulate the leaching that a waste will undergo from repetitive precipitation of acid rain on a landfill to determine the highest concentration of each constituent that is likely to leach in a real world environment. Currently, the MEP is used in EPA's hazardous waste delisting program. A copy of Method 1320 has been included on the CD-ROM version of the Guide.

The MEP can be used to evaluate liquid, solid, and multiphase samples. Waste samples are extracted according to the Extraction Procedure (EP) Toxicity Test (Method 1310 of SW-846). The EP test is also very similar to the TCLP Method 1311. A copy of Method 1310 has been included on the CD- ROM version of the Guide.

In the MEP, liquid wastes are filtered through a glass fiber filter prior to testing. Waste samples containing both solids and liquids are handled by separating the liquids from the solid phase, and then reducing the solids to particle size. The solids are then extracted using an acetic acid solution. A liquid- to-solid ratio of 16:1 by weight is used for an extraction period of 24 hours. After extraction, the solids are filtered from the liquid extract, and the liquid extract is combined with any original liquid fraction of the waste.

The solids portion of the sample that remains after application of Method 1310 are then re-extracted using a dilute sulfuric acid/nitric acid solution. As in the SPLP, this acidic solution was selected to simulate leachate generation, in part, from acid rain. This time a liquid-to-solid ratio of 20:1 by weight is used for an extraction period of 24 hours. After extraction, the solids are once again filtered from the liquid extract, and the liquid extract is combined with any original liquid fraction of the waste.

These four steps are repeated eight additional times. If the concentration of any constituent of concern increases from the 7th or 8th extraction to the 9th extraction, the procedure is repeated until these concentrations decrease.

The MEP is intended to simulate 1,000 years of freeze and thaw cycles and prolonged exposure to a leaching medium. One advantage of the MEP over the TCLP is that the MEP gradually removes excess alkalinity in the waste. Thus, the leaching behavior of metal contaminants can be evaluated as a function of decreasing pH, which increases the solubility of most metals.

4. Shake Extraction of Solid Waste with Water or Neutral Leaching Procedure

The Shake Extraction of Solid Waste with Water, or the Neutral Leaching Procedure, was developed by the American Society for Testing and Materials (ASTM) to assess the leaching potential of solid waste and has been designated as ASTM D-3987-85. This test method provides for the shaking of an extractant (e.g., water) and a known weight of waste of specified composition to obtain an aqueous phase for analysis after separation. The intent of this test method is for the final pH of the extract to reflect the interaction of the liquid extractant with the buffering capacity of the solid waste.

The shake test is performed by mixing the solid sample with test water and agitating continuously for 18±0.25 hours. A liquid-to-solid ratio of 20:1 by weight is used. After agitation the solids are filtered from the liquid extract, and the liquid is analyzed.

The water extraction is meant to simulate conditions where the solid waste is the dominant factor in determining the pH of the extract. This test, however, has only been approved for certain inorganic constituents, and is not applicable to organic substances and volatile organic compounds (VOCs). A copy of this procedure can be ordered by calling ASTM at 610 832-9585 or online at **<www.astm.org>**.

III. Waste Characterization of Volatile Organic Emissions

To determine whether volatile organic emissions are of concern at a waste management unit, determine the concentration of the VOCs that are reasonably expected to be emitted. Process knowledge is likely to be less accurate for determining VOCs than measured values. As discussed earlier in this chapter, modeling results for waste management units will only be as accurate as the input data. Therefore, sampling and analytical testing might be necessary if organic concentrations cannot be estimated confidently using process knowledge.

Table 2 in Chapter 5–Protecting Air Quality can be used as a starting point to help you determine which air emissions constituents to measure. It is not recommended that you sample for all of the volatile organics listed in Table 2, but rather use Table 2 as a guide in conjunction with process knowledge to narrow the sampling effort and thereby minimize unnecessary sampling costs. A thorough understanding of process knowledge can help you determine what is reasonably expected to be in the waste, so that it is not necessary to sample for unspecified constituents.

Many tests have been developed for quantitatively extracting volatile and semi-volatile organic constituents from various sample matrices. These tests tend to be highly dependent upon the physical characteristics of the sample. You should consult with state and local regulatory agencies before implementing testing. You can refer to SW-846 Method 3500B for guidance on the selection of methods for quantitative extraction or dilution of samples for analysis by one of the volatile or semi-volatile determinative methods. After performing the appropriate extraction procedure, further cleanup of the sample extract might be necessary if analysis of the extract is prevented due to interferences coextracted from the sample. Method 3600 of SW-846 provides additional guidance on cleanup procedures.

Following sample preparation, a sample is ready for further analysis. Most analytical methods use either gas chromatography (GC), high performance liquid chromatography (HPLC), gas chromatography/mass spectrometry (GC/MS), or high performance liquid chromatography/mass spectrometry (HPLC/MS). SW-846 is designed to allow the methods to be mixed and matched, so that sample preparation, sample cleanup, and analytical methods can be properly sequenced for the particular analyte and matrix. Again, you should consult with state and local regulatory agencies before finalizing the selected methodology.

Waste Characterization Activity List

To determine constituent concentrations in a waste you should:

- ❑ Assess the physical state of the waste using process knowledge.
- ❑ Use process knowledge to identify constituents for further analysis.
- ❑ Assess the environment in which the waste will be placed.
- ❑ Consult with state and local regulatory agencies to determine any specific testing requirements.
- ❑ Select an appropriate leachate test or organic constituent analysis based on the above information.

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Appendix: Example Extraction Tests (Draft 9/30/97)

Test Method	Leaching Fluid	Liquid:Solid Ratio	Maximum Particle Size	Number of Extractions	Time of Extractions	Comments
I. Static Tests						
A. Agitated Extraction Tests						
Toxicity Characteristic Leaching Procedure (1311)	0.1 N acetic acid solution, pH 2.9, for alkaline wastes 0.1 N sodium acetate buffer solution, pH 5.0, for non-alkaline wastes	20:1	9.5 mm	1	18 ±2 hours	Co-disposal scenario might not be appropriate; no allowance for structural integrity testing of monolithic samples
Extraction Procedure Toxicity Test (1310)	0.5 N acetic acid (pH-5.0)	16:1 during extraction 20:1 final dilution	9.5 mm	1	24 hours	High alkalinity samples can result in variable data
ASTM D3987-85 Shake Extraction of Solid Waste with Water	ASTM IV reagent water	20:1	As in environment (as received)	1	18 hours	Not validated for organics
California WET	0.2 M sodium citrate (pH- 5.0)	10:1	2.0 mm	1	48 hours	Similar to EP, but sodium citrate makes test more aggressive
Ultrasonic Agitation Method for Accelerating Batch Leaching Test[9]	Distilled water	4:1	Ground	1	30 minutes	New—little performance data
Alternative TCLP for Construction, Demolition and Lead Paint Abatement Debris[10]	TCLP acetic acid solutions	20:1	<9.5	1	8 hours	Uses heat to decrease extraction time
Extraction Procedure for Oily Waste (1330)	Soxhlet with THF and toluene EP on remaining solids	100g:300mL 20:1	9.5 mm	3	24 hours (EP)	
Synthetic Precipitation Leaching Procedure (1312)	#1 Reagent water to pH 4.2 with nitric and sulfuric acids (60/40) #2 Regent water to pH 5.0 with nitric and sulfuric acids (60/40)	20:1	9.5 mm	1	18±2 hours	ZHE option for organics
Equilibrium Leach Test	Distilled water	4:1	150 mm	1	7 days	Determines contaminants that have been insolubilized by solidification

[9] Bisson, D.L.; Jackson D.R.; Williams K.R.; and Grube W.E. J. Air Waste Manage. Assoc., 41: 1348-1354.

[10] Olcrest, R. A Representative Sampling and Alternative Analytical Toxic Characteristic Leachate Procedure Method for Construction, Demolition, and Lead Paint Abatement Debris Suspected of Containing Leachable Lead, Appl. *Occup. Environ. Hyg.* 11(1), January 1996.

Test Method	Leaching Fluid	Liquid:Solid Ratio	Maximum Particle Size	Number of Extractions	Time of Extractions	Comments
			B. Non-Agitated Extraction Tests			
Static Leach Test Method (material characteristic centre- 1)	Can be site specific, 3 standard leachates: water, brine, silicate/bicarbonate	VOL/surface 10 cm	40 mm^2 surface area	1	>7 days	Series of optional steps increasing complexity of analysis
High Temperature Static Leach Tests Method (material characterization centre-2)	Same as MCC-1 (conducted at 100°C)	VOL/Surface 10 cm	40 mm^2 Surface Area	1	>7 Days	Series of optional steps increasing complexity of analysis
			C. Sequential Chemical Extraction Tests			
Sequential Extraction Tests	0.04 m acetic acid	50:1	9.5 mm	15	24 hours per extraction	
			D. Concentration Build-Up Test			
Sequential Chemical Extraction	5 leaching solutions of increasing acidity	Varies from 16.1 to 40.1	150 mm	5	Varies 3 or 14 days	Examines partitioning of metals into different fractions or chemicals forms
Standard Leach Test, Procedure C (Wisconsin)	DI water SYN Landfill	10:1, 5:1, 7.5:1	As in environment	3	3 or 14 days	Sample discarded after each leach, new sample added to existing leachate
			II. Dynamic Tests (Leaching Fluid Renewed)			
			A. Serial Batch (Particle)			
Multiple Extraction Procedure (1320)	Same as EP TOX, then with synthetic acid rain (sulfuric acid, nitric acid in 60:40% mixture)	20:1	9.5 mm	9 (or more)	24 hours per extraction	
Monofill Waste Extraction Procedures	Distilled/deionized water or other for specific site	10:1 per extraction	9.5 mm or monolith	4	18 hours per extraction	
Graded Serial Batch (U.S. Army)	Distilled water	Increases from 2:1 to 96:1	N/A	>7	Until steady state	
Sequential Batch Ext. of Waste with Water ASTM D-4793-93	Type IV reagent water	20:1	As in environment	10	18 hours	

Test Method	Leaching Fluid	Liquid:Solid Ratio	Maximum Particle Size	Number of Extractions	Time of Extractions	Comments
Use of Chelating Agent to Determine the Metal Availability for Leaching Soils and Wastes[11]	Demineralized water with EDTA, sample to a final pH of 7±0.5	50 or 100	<300 µm	1	18, 24, or 48 hours	Experimental test based on Method 7341
			B. Flow Around Tests			
IAEA Dynamic Leach Test (International Atomic Energy Agency)	DI water/site water	N/A	One face prepared	>19	>6 months	
Leaching Tests on Solidified Products[12]	0.1N acetic acid	20:1 (Procedure A) 2:1 (6 hrs.) & 10:1 (18 hrs.) (Procedure B)	0.6 µm-70µm	1	24 hours	S/S technologies most valid when applied to wastes contaminated by inorganic pollutants
DLT	DI water	N/A	Surface washing	18	196 days	
			C. Flow Through Tests			
ASTM D4874-95 Column Test	Type IV reagent water	One void volume	10 mm	1	24 hours	
			III. Other Tests			
MCC-5s Soxhlet Test (material characteristic center)	DI/site water	100:1	Out and washed	1	0.2 ml/min	
ASTM C1308-95 Accelerated Leach Test[13]						Only applicable if diffusion is dominant leaching mechanism
Generalized Acid Neutralization Capacity Test[14]	Acetic acid	20:1	Able to pass through an ASTM No. 40 sieve	1	48 hours	Quantifies the alkalinity of binder and characterizes buffering chemistry
Acid Neutralization Capacity	HNO_3, solutions of increasing strength	3:1	150 mm	1	48 hours per extraction	

[11] Garrabrants, A.C. and Koson, D.S.; Use of Chelating Agent to Determine the Metal Availability for Leaching from Soils and Wastes, unpublished.

[12] Leaching Tests on Solidified Products; Gavasci, R., Lombardi, F., Polettine, A., and Sirini, P.

[13] C1308-95 Accelerated Leach Test for Diffusive Releases from Solidified Waste and a Computer Program to Model Diffusive, Fractional Leaching from Cylindrical Wastes.

[14] Generalized Acid Neutralization capacity Test; Isenburg, J. and Moore, M.

Part I
Getting Started

Chapter 3
Integrating Pollution Prevention

Contents

Integrating Pollution Prevention

This chapter will help you:

- *Consider pollution prevention options when designing a waste management system. Pollution prevention will reduce waste disposal needs and can minimize impacts across all environmental media. Pollution prevention can also reduce the volume and toxicity of waste. Lastly, pollution prevention can ease some of the burdens, risks, and liabilities of waste management.*

Pollution prevention describes a variety of practices that go beyond traditional environmental compliance or single media permits for water, air, or land disposal and begin to address the concept of sustainability in the use and reuse of natural resources. Adopting pollution prevention policies and integrating pollution prevention into operations provide opportunities to reduce the volume and toxicity of wastes, reduce waste disposal needs, and recycle and reuse materials formerly handled as wastes. In addition to potential savings on waste management costs, pollution prevention can help improve the interactions among industry, the public, and regulatory agencies. It can also reduce liabilities and risks associated with releases from waste management units and closure and post-closure care of waste management units.

> This chapter will help address the following questions.
>
> - What are some of the benefits of pollution prevention?
> - Where can assistance in identifying and implementing specific pollution prevention options be obtained?

Pollution prevention is comprehensive. It emphasizes a life-cycle approach to assessing a facility's physical plant, production processes, and products to identify the best opportunities to minimize environmental impacts across all media. This approach also ensures that actions taken in one area will not increase environmental problems in another area, such as reducing wastewater discharges but increasing airborne emissions of volatile organic compounds. Pollution prevention requires creative problem solving by a broad cross section of employees to help achieve environmental goals. In addition to the environmental benefits, implementing pollution prevention can often benefit a company in many other ways. For example, redesigning production processes or finding alternative material inputs can also improve product quality, increase efficiency, and conserve raw materials. Some common examples of pollution prevention activities include: redesigning processes or products to reduce raw material needs and the volume of waste generated; replacing solvent based cleaners with aqueous based cleaners or mechanical cleaning systems; and instituting a reverse distribution system where shipping packaging is returned to the supplier for reuse rather than discard.

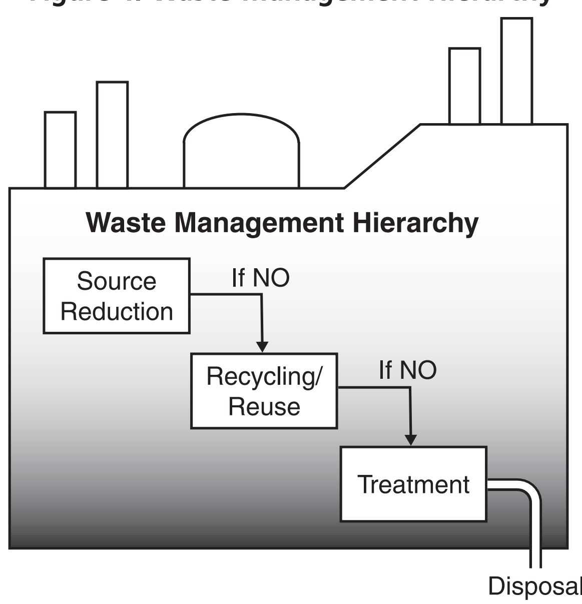
The Pollution Prevention Act of 1990 established a national policy to first, prevent or reduce waste at the point of generation (source reduction); second, recycle or reuse waste materials; third, treat waste; and finally, dispose of remaining waste in an environmentally protective manner (see Figure 1). Some states and many local governments have adopted similar policies, often with more specific and measurable goals.

Source Reduction means any practice which (i) reduces the amount of any substance, pollutant, or contaminant entering any wastestream or otherwise released into the environment, prior to recycling, treatment, or disposal; and (ii) reduces the risks to public health and the environment associated with the release of such substances, pollutants, or contaminants.

Recycling requires an examination of waste streams and production processes to identify opportunities. Recycling and beneficially reusing wastes can help reduce disposal costs, while using or reusing recycled materials as substitutes for feedstocks can reduce raw materials costs. Materials exchange programs can assist in finding uses for recycled materials and in identifying effective substitutes for raw materials. Recycling not only helps reduce the overall amount of waste sent for disposal, but also helps conserve natural resources by replacing the need for virgin materials.

Treatment can reduce the volume and toxicity of a waste. Reducing a waste's volume and toxicity prior to final disposal can result in long-term cost savings. There are a considerable number of levels and types of treatment from which to choose. Selecting the right treatment option can help simplify disposal options and limit future liability.

Figure 1. Waste Management Hierarchy



Over the past 10 years, interest in all aspects of pollution prevention has blossomed, and governments, businesses, academic and research institutions, and individual citizens have dedicated greater resources to it. Many industries are adapting pollution prevention practices to fit their individual operations. Pollution prevention can be successful when flexible problem-solving approaches and solutions are implemented. Fitting these steps into your operation's business and environmental goals will help ensure your program's success.

Throughout the Guide several key steps are highlighted that are ideal points for implementing pollution prevention to help reduce waste management costs, increase options, or reduce potential liabilities by reducing risks that the wastes might pose. For example:

Waste characterization is a key component of the Guide. It is also a key component of a pollution prevention opportunity assessment. An opportunity assessment, however, is more comprehensive since it also covers material inputs, production processes, operating practices, and potentially other areas such as inventory control. When characterizing a waste, consider expanding the opportunity assessment to cover these aspects of the business. An opportunity assessment can help identify the most efficient, cost-effective, and environmentally friendly combination of options, especially when planning new products, new or changed waste management practices, or facility expansions.

Land application of waste might be a preferred waste management option because land application units can manage wastes with high liquid content, treat wastes through biodegradation, and improve soils due to the organic material in the waste. Concentrations of constituents might limit the ability to take full advantage of land application. Reducing the concentrations of constituents in the waste before it is generated or treating the waste prior to land application can provide the flexibility to use land application and ensure that the practice will be protective of human health and the environment and limit future liabilities.

I. Benefits of Pollution Prevention

Pollution prevention activities benefit industry, states, and the public by protecting the environment and reducing health risks, and also provide businesses with financial and strategic benefits.

Protecting human health and the environment. By reducing the amount of contaminants released into the environment and the volume of waste requiring disposal, pollution prevention activities protect human health and the environment. Decreasing the volume or toxicity of process materials and wastes can reduce worker exposure to potentially harmful constituents. Preventing the release and disposal of waste constituents to the environment also reduces human and wildlife exposure and habitat degradation. Reduced consumption of raw materials and energy conserves precious natural resources. Finally reducing the volume of waste generated decreases the need for construction of new waste management facilities, preserving land for other uses such as recreation or wildlife habitat.

Cost savings. Many pollution prevention activities make industrial processes and equipment more resource-efficient. This increased production efficiency saves raw material and labor costs, lowers maintenance costs due to newer equipment, and potentially lowers oversight costs due to process simplification. When planning pollution prevention activities, consider the cost of the initial investment for audits, equipment, and labor. This cost will

vary depending on the size and complexity of waste reduction activities. In addition, consider the payback time for the investment. Prioritize pollution prevention activities to maximize cost savings and health and environmental benefits.

Simpler design and operating conditions. Reducing the risks associated with wastes can allow wastes to be managed under less stringent design and operating conditions. For example, the ground-water tool in Chapter 7, Section A – Assessing Risk might indicate that a composite liner is recommended for a specific waste stream. A pollution prevention opportunity assessment also might imply that by implementing a pollution prevention activity that lowers the concentrations of one or two problematic waste constituents in that waste stream, a compacted clay liner can provide sufficient protection. When the risks associated with waste disposal are reduced, the long-term costs of closure and post-closure care can also be reduced.

Improved worker safety. Processes involving less toxic and less physically dangerous materials can improve worker safety by reducing work-related injuries and illnesses. In addition to strengthening morale, improved worker safety also reduces health-related costs from lost work days, health insurance, and disability payments.

Lower liability. A well-operated unit minimizes releases, accidents, and unsafe waste-handling practices. Reducing the volume and toxicity of waste decreases the impact of these events if they occur. Reducing potential liabilities decreases the likelihood of litigation and cleanup costs.

Higher product quality. Many corporations have found that higher product quality results from some pollution prevention efforts. A significant part of the waste in some operations consists of products that fail quality inspections, so minimizing waste in those cases is inextricably linked with process changes that improve quality. Often, managers do not realize how easy or technically feasible such changes are until the drive for waste reduction leads to exploration of the possibilities.

Building community relations. Honesty and openness can strengthen credibility between industries, communities, and regulatory agencies. If you are implementing a pollution prevention program, make people aware of it. Environmental protection and economic growth can be compatible objectives. Additionally, dialogue among all parties in the development of pollution prevention plans can help identify and address concerns.

II. Implementing Pollution Prevention

When implementing pollution prevention, consider a combination of options that best fits your facility and its products. There are a number of steps common to implementing any facility-wide pollution prevention effort. An essential starting point is to make a clear commitment to identifying and taking advantage of pollution prevention opportunities. Seek the participation of interested partners, develop a policy statement committing the industrial operation to pollution prevention, and organize a team to take responsibility for it. As a next step, conduct a thorough pollution prevention opportunity assessment. Such an assessment will help set priorities according to which options are the most promising. Another feature common to many pollution prevention programs is measuring the program's progress.

The actual pollution prevention practices implemented are the core of a program. The following sections give a brief overview of these core activities: source reduction, recycling, and treatment. To find out more, contact some of the organizations listed throughout this chapter.

A. Source Reduction

As defined in the Pollution Prevention Act of 1990, source reduction means any practice which (i) reduces the amount of any hazardous substance, pollutant, or contaminant entering any wastestream or otherwise released into the environment, prior to recycling, treatment, or disposal; and (ii) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. The term includes equipment or technology modifications; process or procedure modifications; reformulations or redesign of products; substitution of raw materials; and improvements in housekeeping, maintenance, training, or inventory control.

Reformulation or redesign of products. One source reduction option is to reformulate or redesign products and processes to incorporate materials more likely to produce lower-risk wastes. Some of the most common practices include eliminating metals from inks, dyes, and paints; reformulating paints, inks, and adhesives to eliminate synthetic organic solvents; and replacing chemical-based cleaning solvents with water-based or citrus-based products. Using raw materials free from even trace quantities of contaminants, whenever possible, can also help reduce waste at the source.

When substituting materials in an industrial process, it is important to examine the effect on the entire waste stream to ensure that the overall risk is being reduced. Some changes can shift contaminants to another medium rather than actually reduce waste generation. Switching from solvent-based to water-based cleaners, for example, will reduce solvent volume and disposal cost, but is likely to dramatically increase wastewater volume. Look at the impact of wastewater generation on effluent limits and wastewater treatment sludge production.

Technological modifications. Newer process technologies often include better waste reduction features than older ones. For industrial processes that predate consideration of waste and risk reduction, adopting new procedures or upgrading equipment can reduce waste volume, toxicity, and management costs. Some examples include redesigning equipment to cut losses during batch changes or during cleaning and maintenance, changing to mechanical cleaning devices to avoid solvent use, and installing more energy- and material-efficient equipment. State technical assistance centers, trade associations, and other organizations listed in this chapter can help evaluate the potential advantages and savings of such improvements.

In-process recycling (reuse). In-process recycling involves the reuse of materials, such as cutting scraps, as inputs to the same process from which they came, or uses them in other processes or for other uses in the facility. This furthers waste reduction goals by reducing the need for treatment or disposal and by conserving energy and resources. A common example of in-process recycling is the reuse of wastewater.

Good housekeeping procedures. Some of the easiest, most cost-effective, and most widely used waste reduction techniques are simple improvements in housekeeping. Accidents and spills generate avoidable disposal hazards and expenses. They are less likely to occur in clean, neatly organized facilities.

Good housekeeping techniques that reduce the likelihood of accidents and spills include training employees to manage waste and materials properly; keeping aisles wide and free of obstructions; clearly labeling containers with content, handling, storage, expiration, and health and safety information; spacing stored materials to allow easy access; surrounding storage areas with containment berms to control leaks or spills; and segregating stored materials to avoid cross-contamination, mixing of incompatible materials, and unwanted reactions. Proper employee training is crucial to implementing a successful waste reduction program, especially one featuring good housekeeping procedures. Case study data indicate that effective employee training programs can reduce waste disposal volumes by 10 to 40 percent.[1]

Regularly scheduled maintenance and plant inspections are also useful. Maintenance helps avoid the large cleanups and disposal operations that can result from equipment failure. Routine maintenance also ensures that equipment is operating at peak efficiency, saving energy, time, and materials. Regularly scheduled or random, unscheduled plant inspections help identify potential problems before they cause waste management problems. They also help identify areas where improving the efficiency of materials management and handling practices is possible. If possible, plant inspections, periodically performed by outside inspectors who are less familiar with day-to-day plant operations, can bring attention to areas for improvement that are overlooked by employees accustomed to the plant's routine practices.

Storing large volumes of raw materials increases the risk of an accidental spill and the likelihood that the materials will not be used due to changes in production schedules, new product formulations, or material degradation. Companies are sometimes forced to dispose of materials whose expiration dates have passed or that are no longer needed. Efficient inventory control allows a facility to avoid stocking materials in excess of its ability to use them, thereby decreasing disposal volume and cost. Many companies have successfully implemented "just-in-time" manufacturing systems to avoid the costs and risks associated with maintaining a large onsite inventory. In a "just-in-time" manufacturing system, raw materials arrive as they are needed and only minimal inventories are maintained on site.

[1] Freeman, Harry. 1995. *Industrial Pollution Prevention Handbook*. McGraw-Hill, Inc. p. 13.

Segregating waste streams is another good housekeeping procedure that enables a facility to avoid contaminating lower risk wastes with hazardous constituents from another source. Based on a waste characterization study, it might be more efficient and cost-effective to manage wastes separately by recycling some, and treating or disposing of others. Waste segregation can also help reduce the risks associated with handling waste. Separating waste streams allows some materials to be reused, resulting in additional cost savings. Emerging markets for recovered industrial waste materials are creating new economic incentives to segregate waste streams. Recovered materials are more attractive to potential buyers if it can be ensured that they are not tainted with other waste materials. For example, if wastes from metal-finishing facilities are segregated by type, metal-specific-bearing sludge can be recovered more economically and the segregated solvents and waste oils can be recycled.

B. Recycling

Recycling involves collecting, processing, and reusing materials that would otherwise be handled as wastes. The following discussion highlights a few of the ways to begin this process.

Materials exchange programs. Many local governments and states have established materials exchange programs to facilitate transactions between waste generators and industries that can use wastes as raw materials. Materials exchanges are an effective and inexpensive way to find new users and uses for a waste. Most are publicly funded, nonprofit organizations, although some charge a nominal fee to be listed with them or to access their online databases. Some actively work to promote exchanges between generators and users, while others simply publish lists of generators, materials, and buyers. Some waste exchanges also sponsor workshops and conferences to discuss waste-related regulations and to exchange information. More than 60 waste and materials exchanges operate in North America. Below are four examples of national, state, and local exchange programs. Each program's Web site also provides links to other regional, national, and international materials exchange networks.

- EPA's Jobs Through Recycling (JTR) Web site **<www.epa.gov/jtr/comm/exchange.htm>** provides descriptions of and links to international, national, and state-specific materials exchange programs and organizations.
- Recycler's World **<www.recycle.net/exch/index.html>** is a world-wide materials trading site with links to dozens of state and regional exchange networks.
- CalMAX (California Materials Exchange) **<www.ciwmb.ca.gov/calmax>** is maintained by the California Integrated Waste Management Board and facilitates waste exchanges in California and provides links to other local and national exchange programs.
- King County, Washington's IMEX **<www.metrokc.gov/hazwaste/imex/exchanges.html/>** is a local industrial materials exchange program that also provides an extensive list of state, regional, national, and international exchange programs.

Beneficial use. Beneficial use involves substituting a waste material for another material with similar properties. Utility companies, for example, often use coal combustion ash as a construction material, road base, or soil stabilizer. The ash replaces other, nonrecycled materials, such as fill or Portland cement, not only avoiding disposal costs but also generating revenue. Other examples of beneficial use include using wastewaters and sludges as soil amendments (see Chapter 7, Section C–Designing a Land Application Program) and using foundry sand in asphalt, concrete, and roadbed construction.

Many regulatory agencies require approval of planned beneficial use activities and may require testing of the materials to be reused. Others may allow certain wastes to be designated for beneficial use, as long as the required analyses are completed. Pennsylvania, for example, allows application of a "coproduct" designation to, and exemption from waste regulations for "materials which are essentially equivalent to and used in place of an intentionally manufactured product or produced raw material and... [which present] no greater risk to the public or the environment." Generally, regulatory agencies want to ensure that any beneficially used materials are free from significantly increased levels of constituents that might pose a greater risk than the materials they are replacing. Consult with the state agency for criteria and regulations governing beneficial use.

In a continuing effort to promote the use of materials recovered from solid waste, the Environmental Protection Agency (EPA) has instituted the Comprehensive Procurement Guideline (CPG) program. Using recycled-content products ensures that materials collected in recycling programs will be used again in the manufacture of new products. The CPG program is authorized by Congress under Section 6002 of the Resource Conservation and Recovery Act (RCRA) and Executive Order 13101. Under the CPG program, EPA is required to designate products that are or can be made with recovered materials and to recommend practices for buying these products. Once a product is designated, procuring agencies are required to purchase it with the highest recovered material content level practicable. As of January 2001, EPA has designated 54 items within eight product categories including items such as retread tires, cement and concrete containing coal fly ash and ground granulated blast furnace slag, traffic barricades, playground surfaces, landscaping products, and nonpaper office products like binders and toner cartridges. While directed primarily at federal, state, and local procuring agencies, CPG information is helpful to everyone interested in purchasing recycled-content products. For further information on the CPG program, visit: **<www.epa.gov/cpg>**.

C. Treatment

Treatment of non-hazardous industrial waste is not a federal requirement, however, it can help to reduce the volume and toxicity of waste prior to disposal. Treatment can also make a waste amenable for reuse or recycling. Consequently, a facility managing non-hazardous industrial waste might elect to apply treatment. For example, treatment might be incorporated to address volatile organic compound (VOC) emissions from a waste managment unit, or a facility might elect to treat a waste so that a less stringent waste management system design could be used. Treatment involves changing a waste's physical, chemical, or biological character or composition through designed techniques or processes. There are three primary categories of treatment—physical, chemical, and biological.

Physical treatment involves changing the waste's physical properties such as its size, shape, density, or state (i.e., gas, liquid, solid). Physical treatment does not change a waste's chemical composition. One form of physical treatment, immobilization, involves encapsulating waste in other materials, such as plastic, resin, or cement, to prevent constituents from volatilizing or leaching. Listed below are a few examples of physical treatment.

- Immobilization:
  Encapsulation
  Thermoplastic binding
- Carbon absorption:
  Granular activated carbon (GAC)
  Powdered activated carbon (PAC)
- Distillation:
  Batch distillation
  Fractionation
  Thin film extraction
  Steam stripping
  Thermal drying
- Filtration
- Evaporation/volatilization
- Grinding
- Shredding
- Compacting
- Solidification/addition of absorbent material

Chemical treatment involves altering a waste's chemical composition, structure, and properties through chemical reactions. Chemical treatment can consist of mixing the waste with other materials (reagents), heating the waste to high temperatures, or a combination of both. Through chemical treatment, waste constituents can be recovered or destroyed. Listed below are a few examples of chemical treatment.

- Neutralization
- Oxidation
- Reduction
- Precipitation
- Acid leaching
- Ion exchange
- Incineration
- Thermal desorption
- Stabilization
- Vitrification
- Extraction:
  Solvent extraction
  Critical extraction
- High temperature metal recovery (HTMR)

Biological treatment can be divided into two categories–aerobic and anaerobic. Aerobic biological treatment uses oxygen-requiring microorganisms to decompose organic and non-metallic constituents into carbon dioxide, water, nitrates, sulfates, simpler organic products, and cellular biomass (i.e., cellular growth and reproduction). Anaerobic biological treatment uses microorganisms, in the absence of oxygen, to transform organic constituents and nitrogen-containing compounds into oxygen and methane gas ($CH_4(g)$). Anaerobic biological treatment typically is performed in an enclosed digestor unit. Listed below are a few examples of biological treatment.

- Aerobic:
  Activated sludge
  Aerated lagoon
  Trickling filter
  Rotating biological contactor (RBC)
- Anaerobic digestion

The range of treatment methods from which to choose is as diverse as the range of wastes to be treated. More advanced treatment will generally be more expensive, but by reducing the quantity and risk level of the waste, costs might be reduced in the long run. Savings could come from not only lower disposal costs, but also lower closure and post-closure care costs. Treatment and post-treatment waste management methods can be selected to minimize both total cost and environmental impact, keeping in mind that treatment residuals, such as sludges, are wastes themselves that will need to be managed.

III. Where to Find Out More: Technical and Financial Assistance

There is a wealth of information available to help integrate pollution prevention into an operation. As a starting point, a list of references to technical and financial resources is included in this section. The Internet can be an excellent source of background information on the various resources to help begin the search for assistance. Waste reduction information and technologies are constantly changing. To follow new developments you should maintain technical and financial contacts and continue to use these resources even after beginning waste reduction activities. Eventually, you can build a network of contacts to support all your various technical needs.

Where Can Assistance Be Obtained?

Several types of organizations offer assistance. These include offices in regulatory agencies, university departments, nonprofit foundations, and trade associations. Additionally, the National Institute of Standards and Technology (NIST) Manufacturing Extension Partnerships (MEPs)

<www.mep.nist.gov> also provide waste reduction information. Look for waste reduction staff within the media programs (air, water, solid/hazardous waste) of regulatory agencies or in the state commissioner's office, special projects division, or pollution prevention division. Some states also provide technical assistance for waste reduction activities, such as recycling, through a business advocate or small business technical assistance program. EPA's U.S. State & Local Gateway Web site **<www.epa.gov/epapages/statelocal/envrolst.htm>** is a helpful tool for locating your state environmental agency.

The listings below identify some primary sources for technical assistance that might prove helpful. This list serves as a starting point only and is by no means exhaustive. There are many additional organizations that offer pollution prevention assistance on regional, state, and local levels.

- **American Forest and Paper Association (AF&PA)** is the national trade association of the forest, paper, and wood products industries. It offers documents that might help you find buyers for wood and paper wastes. **<www.afandpa.org>** Phone: 800 878-8878 e-mail: INFO@afandpa.ccmail.compuserve.com
- **California Integrated Waste Management Board.** This Web site contains general waste prevention background and business waste reduction program overviews, fact sheets, and information about market development for recycled materials and waste reduction training. **<www.ciwmb.ca.gov/WPW>**
- **Center for Environmental Research Information (CERI)** provides technical guides and manuals on waste reduction, summaries of pollution prevention opportunity assessments,

and waste reduction alternatives for specific industry sectors. **<www.epa.gov/ttbnrmrl/ttmat.htm>** Phone: 513-569-7562 e-mail: ord.ceri@epamail.epa.gov

- **Enviroene**, part of the U.S. EPA's Web site, provides a single repository for pollution prevention, compliance assurance, and enforcement information and data bases. Its search engine searches multiple Web sites (inside and outside the EPA), and offers assistance in preparing a search. **<es.epa.gov>**
- **National Pollution Prevention Roundtable (NPPR)** promotes the development, implementation, and evaluation of pollution prevention. NPPR's Web site provides an abridged online version of *The Pollution Prevention Yellow Pages* **<www.p2.org/inforesources/nppr_yps.html>**, a listing of local, state, regional and national organizations, including state and local government programs, federal agencies, EPA pollution prevention coordinators, and non-profit groups that work on pollution prevention. **<www.p2.org>** Phone: 202 466-P2P2
- **P2 GEMS.** This site, an Internet search tool operated by the Massachusetts Toxics Use Reduction Institute, can help facility planners, engineers, and managers locate process and materials management information over the Web. It includes information on over 550 sites valuable for toxics use reduction planning and pollution prevention. **<www.edu/p2gems.org>**
- **Pollution Prevention Information Clearinghouse (PPIC).** PPIC maintains a collection of EPA non-regulatory documents related to waste reduction. **<www.epa.gov/opptintr/library/libppic.htm>** Phone: 202 260-1023 e-mail: ppic@epamail.epa.gov
- **U.S. Department of Energy (DOE) Industrial Assessment Centers (IACs).** DOE's Office of Industrial Technologies sponsors free industrial assessments for small and medium-sized manufacturers. Teams of engineering students from the centers conduct energy audits or industrial assessments and provide recommendations to manufacturers to help them identify opportunities to improve productivity, reduce waste, and save energy. **<www.oit.doe.gov/iac>**

What Types of Technical Assistance Are Available?

Many state and local governments have technical assistance programs that are distinct from regulatory offices. In addition, non-governmental organizations conduct a wide range of activities to educate businesses about the value of pollution prevention. These efforts range from providing onsite technical assistance and sharing industry-specific experiences to conducting research and developing education and outreach materials on waste reduction topics. The following examples illustrate what services are available:

- **NIST technical centers.** There are NIST-sponsored Manufacturing Technology Centers throughout the country as part of the grassroots Manufacturing Extension Partnership (MEP) program. The MEP program helps small and medium-sized companies adopt new waste reduction technologies by providing technical information, financing, training, and other services. The NIST Web site **<www.nist.gov>** has a locator that can help you find the nearest center.

- **Trade associations.** Trade associations provide industry-specific assistance through publications, workshops, field research, and consulting services. EPA's WasteWise program **<www.ergweb.com/wwta /intro.asp>** provides an online resources directory which can help you locate specific trade associations. The National Trade and Professional Associations of the Unites States' *Directory of Trade Associations* (Washington, DC: Columbia Books, Inc., 2000) is another useful resource.

- **Onsite technical assistance audits.** These audits are for small (and sometimes larger) businesses. The assessments, which take place outside of the regulatory environment and on a strictly voluntary basis, provide businesses with information on how to save money, increase efficiency, and improve community relations. DOE's Office of Industrial Technologies **<www.oit.doe.gov/iac>** provides such assessments for small and medium-sized manufacturers.

- **Information clearinghouses.** Many organizations maintain repositories of waste reduction information and serve as starting points to help businesses access this information. EPA's Pollution Prevention Information Center (PPIC) **<www.epa.gov/oppt-intr/library/libppic.htm>** is one example.

- **Facility planning assistance.** A number of organizations can help businesses develop, review, or evaluate facility waste reduction plans. State waste reduction programs frequently prepare model plans designed to demonstrate activities a business can implement to minimize waste.

- **Research and collaborative projects.** Academic institutions, state agencies and other organizations frequently participate in research and collaborative projects with industry to foster development of waste reduction technologies and management strategies. Laboratory and field research activities include studies, surveys, database development, data collection, and analysis.

- **Hotlines.** Some states operate telephone assistance services to provide technical waste reduction information to industry and the general public. Hotline staff typically answer questions, provide referrals, and distribute printed technical materials on request.

- **Computer searches and the Internet.** The Internet brings many pollution prevention resources to a user's fingertips. The wide range of resources available electronically can provide information about innovative waste-reducing technologies, efficient industrial processes, current state and federal regulations, and many other pertinent topics. Independent searches can be done on the Internet, and some states perform computer searches to provide industry with information about waste reduction. EPA and many state agencies have Web sites dedicated to these topics, with case studies, technical explanations, legal information, and links to other sites for more information.

- **Workshops, seminars, and training.** State agencies, trade associations, and other organizations conduct workshops, seminars, and technical training on waste reduction. These events provide information, identify resources, and facilitate networking.
- **Grants and loans.** A number of states distribute funds to independent groups that conduct waste reduction activities. These groups often use such support to fund research and to run demonstration and pilot projects.

Integrating Pollution Prevention Activity List

To address pollution prevention you should:

- ❑ Make waste management decisions by considering the priorities set by the full range of pollution prevention options—first, source reduction; second, reuse and recycling; third, treatment; last, disposal.
- ❑ Explore the cost savings and other benefits available through activities that integrate pollution prevention.
- ❑ Develop a waste reduction policy.
- ❑ Conduct a pollution prevention opportunity assessment of facility processes.
- ❑ Research potential pollution prevention activities.
- ❑ Consult with public and private agencies and organizations providing technical and financial assistance for pollution prevention activities.
- ❑ Plan and implement activities that integrate pollution prevention.

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Part I
Getting Started

Chapter 4
Considering the Site

Contents

Considering the Site

This chapter will help you:

- *Become familiar with environmental, geological, and manmade features that influence siting decisions.*
- *Identify nearby areas or land uses that merit buffer zones and place your unit an appropriate distance from them.*
- *Comply with local land use and zoning restrictions, including any amendments occurring during consideration of potential sites.*
- *Understand existing environmental justice issues as you consider a new site.*
- *Avoid siting a unit in hydrologic or geologic problem areas, without first designing the unit to address conditions in those areas.*

Many hydrologic and geologic settings can be effectively utilized for protective waste management. There are, however, some hydrologic and geologic conditions that are best avoided all together if possible. If they cannot be avoided, special design and construction precautions can minimize risks. Floodplains, earthquake zones, unstable soils, and areas at risk for subsurface movement need to be taken into account just as they would be when siting and constructing a manufacturing plant or home. Catastrophic events associated with these locations could seriously damage or destroy a waste management unit, release contaminants into the environment, and add substantial expenses for cleanup, repair, or reconstruction. If problematic site conditions cannot be avoided, engineering design and construction techniques can address some of the concerns raised by locating a unit in these areas.

> This chapter will help address the following questions:
>
> - What types of sites need special consideration?
> - How will I know whether my waste management unit is in an area requiring special consideration?
> - Why should I be concerned about siting a waste management unit in such areas?
> - What actions can I take if I plan to site a unit in these areas?

Many state, local, and tribal governments require buffer zones between waste management units and other nearby land uses. Even if buffer zones are not required, they can still provide benefits now and in the future. Buffer zones provide time and space to contain and remediate accidental releases before they reach sensitive environments or sensitive populations. Buffer zones also help maintain good community relations by reducing disruptions associated with noise, traffic, and wind-blown dust, often the source of serious neighborhood concerns.

In considering impacts on the surrounding community, it is important to understand whether the community, especially one with a large minority and low income population, already faces significant environmental impacts from existing industrial activities. You should develop an understanding of the community's current environmental problems and work together to develop plans that can improve and benefit the environment, the community, the state, and the company.

How should a waste management unit site assessment begin?

In considering whether to site a new waste management unit or laterally expand an existing unit, certain factors will influence the siting process. These factors include land availability, distance from waste generation points, ease of access, local climatic conditions, economics, environmental considerations, local zoning requirements, and potential impacts on the community. As prospective sites are identified, you should become familiar with the siting considerations raised in this chapter. Determine how to address concerns at each site to minimize a unit's adverse impacts on the environment in addition to the environment's adverse impacts on the unit. You should choose the site that best balances protection of human health and the environment with operational goals. In addition to considering the issues raised in this chapter, you should check with state and local regulatory agencies early in the siting process to identify other issues and applicable restrictions.

Another factor to consider is whether there are any previous or current contamination problems at the site. It is recommended that potential sites for new waste management units be free of any contamination problems. An environmental site assessment (ESA) may be required prior to the disturbance of any land area or before property titles are transferred. An ESA is the process of determining whether contamination is present on a parcel of property. You should check with the EPA regional office and state or local authorities to determine if there are any ESA requirements prior to siting a new unit or expanding an existing unit. If there are no requirements, you might want to consider performing an ESA in order to ensure that there are no contamination problems at the site.

Many companies specialize in site screening, characterization, and sampling of different environmental media (i.e., air, water, soil) for potential contamination. A basic ESA (often referred to as the Phase I Environmental Site Assessment process) typically involves researching prior land use, deciding if sampling of environmental media is necessary based on the prior activities, and determining contaminate fate and transport if contamination has occurred. Liability issues can arise if the site had contamination problems prior to construction or expansion of the waste management unit. Information on the extent of contamination is needed to quantify cleanup costs and determine the cleanup approach. Cleanup costs can represent an additional, possibly significant, project cost when siting a waste management unit.

As discussed later in this chapter, you will also need to consider other federal laws and regulations that could affect siting. For example, the Endangered Species Act (16 USC Sections 1531 et seq.) provides for the designation and protection of threatened or endangered wildlife, fish, and plant species, and ensures the conservation of the ecosystems on which such species depend. It is the responsibility of the facility manager to check with and obtain a Section 10 permit from the Secretary of the Interior if the construction or operation of a waste management unit might potentially impact any endangered or threatened species or its critical habitat. Thus, you might not be able to site a new waste management unit in an area where endangered or threatened species live, or expand an existing unit into such an area. As another example, the National Historic Preservation Act (16 USC Sections 470 et seq.) protects historic sites and archaeological resources. The facility manager of a waste management unit should be aware of the properties listed on the National Register of Historic Properties. The facility manager should consult with the state historic preservation office to ensure that the property to be used for a new unit or lateral expansion of an existing unit will not impact listed historic properties, or sites with archeological significance. Other federal laws or statutes might also require consideration. It is the ultimate responsibility of the facility owner or manager to comply with the requirements of all applicable federal and state statutes when siting a waste management unit.

Additional factors, such as proximity to other activities or sites that affect the environment, also might influence siting decisions. To determine your unit's proximity to other facilities or industrial sites, you can utilize EPA's Envirofacts Warehouse. The Envirofacts Web site at <**www.epa.gov/enviro/index_java.html**> provides users with access to several EPA databases that will provide you with information about various environmental activities including toxic chemical releases, water discharges, hazardous waste handling processes, Superfund status, and air releases. The Web site allows you to search one database or several databases at a time about a specific location or facility. You can also create maps that display environmental information using the "Enviromapper" application located at <**www.epa.gov/enviro/html/mod/index.html**>. Enviromapper allows users to map different types of environmental information, including the location of drinking water supplies, toxic and air releases, hazardous waste sites, water discharge permits, and Superfund sites at the national, state, and county levels.

EPA's Waste Management—Facility Siting Application is a powerful new Web-based tool that provides assistance in locating waste management facilities. The tool allows the user to enter a ZIP code; city and state; or latitude and longitude to identify the location of fault lines, flood planes, wetlands, and karst terrain in the selected area. The user also can use the tool to display other EPA regulated facilities, monitoring sites, water bodies, and community demographics. The Facility Siting Application can be found at <**www.epa.gov/epaoswer/non-hw/industd/index.htm**>.

I. General Siting Considerations

Examining the topography of a site is the first step in siting a unit. Topographic information is available from the U.S. Geological Survey (USGS), the Natural Resources Conservation Service (NRCS)[1], the state's geological survey office or environmental regulatory agency, or local colleges and universities. Remote sensing data or maps from these organizations can help you determine whether your prospective site is located in any of the areas of concern discussed in this section. USGS maps can be downloaded or ordered from their Web site at <**mapping.usgs.gov**>. Also, the University of Missouri-Rolla maintains a current list of state geological survey offices on its library's Web site at <**www.umr.edu/~library/geol/geoloff.html**>.

A. Floodplains

A floodplain is a relatively flat, lowland area adjoining inland and coastal waters. The

[1] This agency of the U.S. Department of Agriculture was formerly known as the Soil Conservation Service (SCS).

Flood waters overflowed from the Mississippi River (center) into its floodplain (foreground) at Quincy, Illinois in the 1993 floods that exceeded 100-year levels in parts of the Midwest.

100-year floodplain—the area susceptible to inundation during a large magnitude flood with a 1 percent chance of recurring in any given year—is usually the floodplain of concern for waste management units. You should determine whether a candidate site is in a 100-year floodplain. Siting a waste management unit in a 100-year floodplain increases the likelihood of floods inundating the unit, increases the potential for damage to liner systems and support components (e.g., leachate collection and removal systems or other unit structures), and presents operational concerns. This, in turn, creates environmental and human health and safety concerns, as well as legal liabilities. It can also be very costly to build a unit to withstand a 100-year flood without washout of waste or damage to the unit, or to reconstruct a unit after such a flood. Further, locating your unit in a floodplain can exacerbate the damaging effects of a flood, both upstream and downstream, by reducing the temporary water storage capacity of the floodplain. As such, it is preferable to locate potential sites outside the 100-year floodplain.

How is it determined if a prospective site is in a 100-year floodplain?

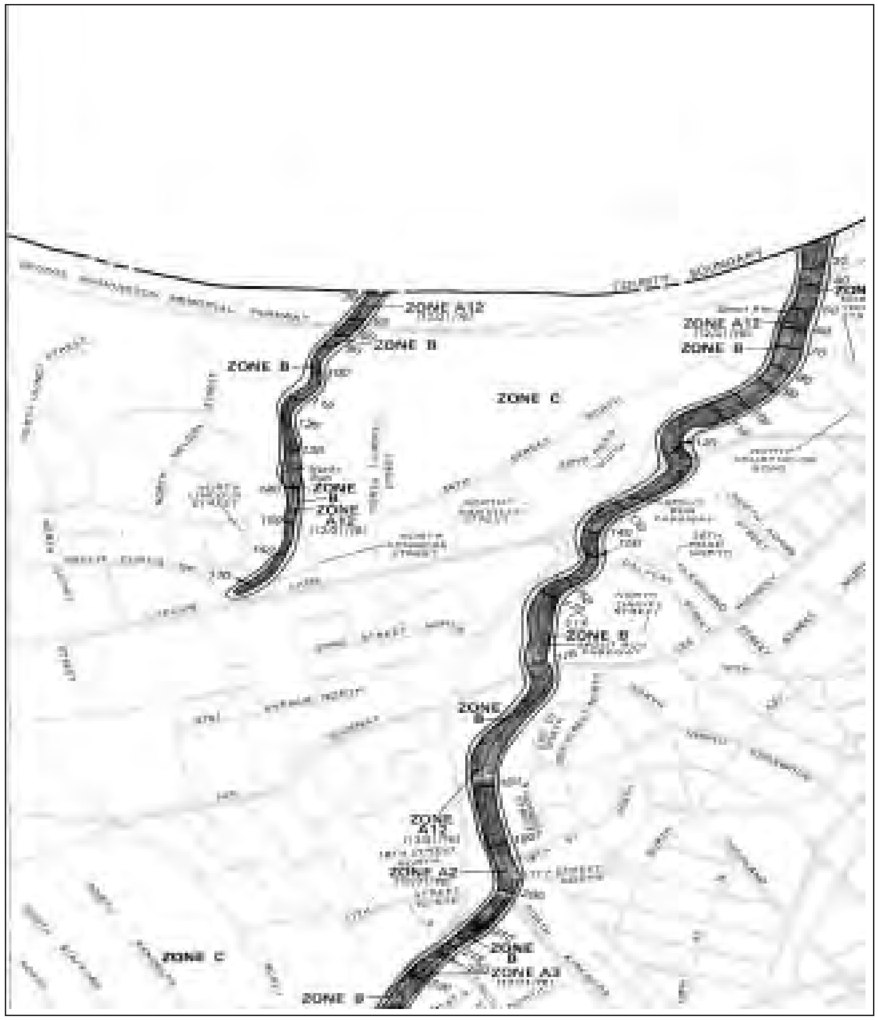
The first step in determining whether a prospective site is located in a 100-year floodplain is to consult with the Federal Emergency Management Agency (FEMA). FEMA has prepared flood hazard boundary maps for most regions. If a prospective site does not appear to be located in a floodplain, further exploration is not necessary. If uncertainty exists as to whether the prospective site might be in a floodplain, several sources of information are available to help make this determination. More detailed flood insurance rate maps (FIRMs) can be obtained from FEMA. FIRMs divide floodplain areas into three zones: A, B, and C. Class A zones are the most susceptible to flooding while class C zones are the least susceptible. FIRMs can be obtained from FEMA's Web site at <**msc.fema.gov/MSC/hardcopy.htm**>.

Additional information can be found on flood insurance rate maps in FEMA's publication *How to Read a Flood Insurance Rate Map* (visit: <**www.fema.gov/nfip/ readmap.htm**>). FEMA also publishes *The National Flood Insurance Program Community Status Book* which lists communities with flood insurance rate maps or floodway maps. Floodplain maps can also be obtained through the US Geological Survey (USGS); National Resources Conservation Service (NRCS); the Bureau of Land Management; the Tennessee Valley Authority; and state, local, and tribal agencies.[2]

Note that river channels shown in floodplain maps can change due to hydropower or flood control projects. As a result, some floodplain boundaries might be inaccurate. If you suspect this to be the case, consult recent aerial photographs to determine how river channels have been modified.

[2] Copies of flood maps from FEMA are available at Map Service Center, P.O. Box 1038, Jessup, MD 20794-1038, by phone 800 358-9616, or the Internet at <**www.fema.gov/nfip/readmap.htm**>.

If maps cannot be obtained, and a potential site is suspected to be located in a floodplain, you can conduct a field study to delineate the floodplain and determine the floodplain's properties. To perform a delineation, you can draw on meteorological records and physiographic information, such as existing and planned watershed land use, topography, soils and geographic mapping, and aerial photographic interpretation of land forms. Additionally, you can use the U.S. Water Resources Council's methods of determining flood potential based on stream gauge records, or you can estimate the peak discharge to approximate the probability of exceeding the 100-year flood. Contact the USGS, Office of Surface Water, for additional information concerning these methods.[3]



FEMA provides flood maps like this one for most floodplains
Source: FEMA, Q3 Flood Data Users Guide **<www.fema.gov/msc>**.

What can be done if a prospective site is in a floodplain?

If a new waste management unit or lateral expansion will be sited in a floodplain, design the unit to prevent the washout of waste, avoid significant alteration of flood flow, and maintain the temporary storage capacity of the floodplain. Engineering models can be used to estimate a floodplain's storage capacity and floodwater flow velocity. The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center has developed several computer models for simulating flood properties.[4] The models can predict how a waste management unit sited in a floodplain can affect its storage capacity and can also simulate flood control structures and sediment transport. If a computer model predicts that placement of the waste management unit in the floodplain raises the base flood level by more than 1 foot, the unit might alter the storage capacity of the floodplain. If designing a new unit, you should site it to minimize these effects. The impact of your unit's location on the speed and flow of flood waters determines the likelihood of waste washout. To quantify this, estimate the shear stress on the unit's support components caused by the impinging flood waters at the depth, velocity,

[3] Information on stream gaging and flood forecasting can be obtained from the USGS, Office of Surface Water, at 413 National Center, Reston, VA 22092, by phone 703 648-5977, or the Internet at **<water.usgs.gov>**.

[4] The HEC-1, HEC-2, HEC-5, and HEC-6 software packages are available free of charge through the USACE Web site at **<http://www.hec.usace.army.mil/software/software_distrib/>**.

Knowing the behavior of waters at their peak flood level is important for determining whether waste will wash out.

and duration associated with the peak (i.e., highest) flow period of the flood.

While these methods can help protect your unit from flood damage and washout, be aware that they can further contribute to a decrease in the water storage and flow capacity of the floodplain. This, in turn, can raise the level of flood waters not only in your area but in upstream and downstream locations, increasing the danger of flood damage and adding to the cost of flood control programs. Thus, serious consideration should be given to siting a waste management unit outside a 100-year floodplain.

B. Wetlands

Wetlands, which include swamps, marshes, and bogs, are vital and delicate ecosystems. They are among the most productive biological communities on earth and provide habitat for many plants and animals. The U.S. Fish and Wildlife Service estimates that up to 43 percent of all endangered or threatened species rely on wetlands for their survival.[5]

Riprap (rock cover) reduces stream channel erosion (left) and gabions (crushed rock encased in wire mesh) help stabilize erodible slopes (right).

Sources: U.S. Department of the Interior, Office of Surface Mining (left); The Construction Site—A Directory To The Construction Industry (right).

[5] From EPA's Wetlands Web site, Values and Functions of Wetlands factsheet, <**www.epa.gov/owow/wetlands/facts/fact2.html**>.

For regulatory purposes under the Clean Water Act, wetlands are defined as areas "that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions."

40 Code of Federal Regulations (CFR) 232.2(r)

Wetlands protect water quality by assimilating water pollutants, removing sediments containing heavy metals, and recharging groundwater supplies. Wetlands also prevent potentially extensive and costly floods by temporarily storing flood waters and reducing their velocity. These areas also offer numerous recreational opportunities.

Potential adverse impacts associated with locating your unit in a wetland include dewatering the wetland (i.e., causing removal or drainage of water), contaminating the wetland, and causing loss of wetland acreage. Damage could also be done to important wetland ecosystems by destroying their aesthetic qualities and diminishing wildlife breeding and feeding opportunities. Siting in a wetland increases the potential for damage to your unit, especially your liner system and structural components, as a result of ground settlement, action of the high water table, and flooding. Alternatives to siting a waste management unit in a wetland area should be given serious consideration based upon Section 404 requirements in the Clean Water Act (CWA) as discussed below.

If a waste management unit is to be sited in a wetland area, the unit will be subject to additional regulations. In particular, Section 404 of the Clean Water Act (CWA) authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into wetlands and other waters of the United States.[6] Activities in waters of the United States regulated under this permitting program include "placement of fill material for construction or maintenance of any liner, berm, or other infrastructure associated with solid waste landfills," as well as fills for development, water resource projects, infrastructure improvements, and conversion of wetlands to uplands for farming and forestry (40 CFR Section 232.2—definition of "discharge of fill material"). EPA regulations under Section 404 (33 United States Code Section 1344) stipulates that no discharge of dredged or fill material can be permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. Therefore, in

Different types of wetlands: spruce bog (left) and eco pond in the Florida Everglades (right).

[6] For the full text of the Clean Water Act, including Section 404, visit the U.S. House of Representatives Internet Law Library Web site at <**uscode.house.gov/download.htm**>, under Title 33, Chapter 26.

compliance with the guidelines established under Section 404, all permit applicants must:

- Take steps to avoid wetland impacts where practicable.
- Minimize impacts to wetlands where they are unavoidable.
- Compensate for any remaining, unavoidable impacts by restoring or creating wetlands.

The EPA and USACE jointly administer a review process to issue permits for regulated activities. For projects with potentially significant impacts, an individual permit is usually required. For most discharges with only minimal adverse effects, USACE may allow applicants to comply with existing general permits, which are issued on a nationwide, regional, or statewide basis for particular activity categories as a means to expedite the permitting process. In making permitting decisions, the agencies will consider other federal laws that might restrict placement of waste management units in wetlands. These include the Endangered Species Act; the Migratory Bird Conservation Act; the Coastal Zone Management Act; the Wild and Scenic Rivers Act; the Marine Protection, Research and Sanctuaries Act; and the National Historic Preservation Act.

How is it determined if a prospective site is in a wetland?

As a first step, determine if the prospective site meets the definition of a wetland. If the prospective site does not appear to be a wetland, then no further exploration is necessary. If it is uncertain whether the prospective site is a wetland, then several sources are available to help you make this determination and define the boundaries of the wetland. Although this can be a challenging process, it will help you avoid future liability since filling a wetland without the appropriate federal, state, or local permits would be a violation of many laws. It might be possible to learn the extent of wetlands without performing a new delineation, since many wetlands have previously been mapped. The first step, therefore, should be to determine whether wetlands information is available for your area.

At the federal level, four agencies are principally involved with wetlands identification and delineation: USACE, EPA, the U.S. Fish and Wildlife Service (FWS), and National Resource Conservation Service (NRCS). EPA also has a Wetlands Information Hotline (800 832-7828) and a wetlands Web site at <**www.epa.gov/owow/wetlands**> which provides information about EPA's wetlands program; facts about wetlands; the laws, regulations, and guidance affecting wetlands; and science, education, and information resources for wetlands. The local offices of NRCS (in agricultural areas) or regional USACE Engineer Divisions and Districts <**www.usace.army.mil/divdistmap.html**> might know whether wetlands in the vicinity of the potential site have already been delineated.

Additionally, FWS maintains the National Wetlands Inventory (NWI) Center,[7] from which you can obtain wetlands mapping for much of the United States. This mapping, however, is based on aerial photography, which is not reliable for specific field determinations. If you have recently purchased your site, you also might be able to find out from the previous property owner whether any delineation has been completed that might not be on file with these agencies. Even if existing delineation information for the site is found, it might still be prudent to contact a qualified wetlands consultant to verify the wetland boundaries, especially if the delineation is not a field determination or is more than a few years old.

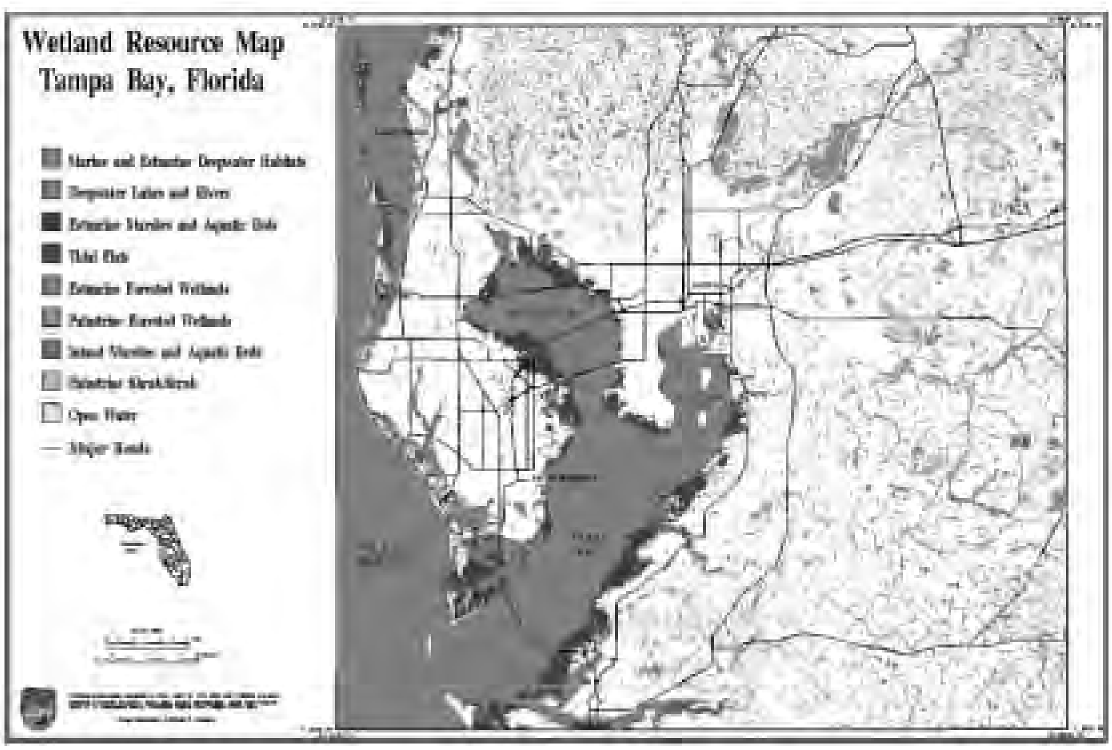
If the existence of a wetland is uncertain, you should obtain a wetlands delineation.

[7] To contact NWI, write to National Wetlands Inventory Center, 9720 Executive Center Drive, Suite 101, Monroe Building, St. Petersburg, FL 33702, call 727 570-5400, or fax 727 570-5420. For additional information online or to search for maps of your area, visit: <**www.nwi.fws.gov**>.

This procedure should be performed only by an individual with experience in performing a wetlands delineation[8] using standard delineation procedures or applicable state or local delineation standards. The delineation procedure, with which you should become familiar before hiring a delineator, involves collecting maps, aerial photographs, plant data, soil surveys, stream gauge data, land use data, and other information. Note that it is mandatory that wetlands delineation for CWA Section 404 permitting purposes be conducted in accordance with the 1987 *U.S. Army Corps of Engineers Wetlands Delineation Manual*[9] (USACE, 1991). The manual provides guidelines and methods for determining whether an area is a wetland for purposes of Section 404. A three-parameter approach for assessing the presence and location of hydrophytic vegetation (i.e., plants that are adapted for life in saturated soils), wetland hydrology, and hydric soils is discussed.

What can be done if a prospective site is in a wetland?

Before constructing a waste management unit in a wetland area, consider whether you can locate the unit elsewhere. If an alternative location can be identified, strongly consider pursuing such an option, as required by Section 404 of the CWA. Because wetlands are important ecosystems that should be protected, identification of practicable location alternatives is a necessary first step in the siting process. Even if no viable alternative loca-



NWI wetland resource maps like this one show the locations of various different types of wetlands and are available for many areas.

Source: NWI web site, sample GIS Think Tank maps page, **<wetlands.fws.gov/>**.

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[8] Currently, there is no federal certification program. In March 1995, USACE proposed standards for a Wetlands Delineator Certification Program (WDCP), but the standards have not been finalized. If the WDCP standards are finalized and implemented, you should use WDCP-certified wetland consultants.

[9] The 1987 manual can be ordered from the National Technical Information Service (NTIS) at 703 605-6000 or obtained online at <**www.wes.army.mil/el/wetlands/wlpubs.html**>.

tions are identified, it might be beneficial to keep a record of the alternatives investigated, noting why they were not acceptable. Such records might be useful during the interaction between facilities, states, and members of the community.

If no alternatives are available, you should consult with state and local regulatory agencies concerning wetland permits. Most states operate permitting programs under the CWA, and state authorities can guide you through the permitting process. To obtain a permit, the state might require that the unit facility manager assess wetland impacts and then:

- Prevent contamination from leachate and runoff.
- Minimize dewatering effects.
- Reduce the loss of wetland acreage.
- Protect the waste management unit against settling.

C. Active Fault Areas

Faults occur when stresses in a geologic material exceed its ability to withstand these forces. Areas surrounding faults are subject to earthquakes and ground failures, such as landslides or soil liquefaction. Fault movement can directly weaken or destroy structures, or seismic activity associated with faulting can cause damage to structures through vibrations. Structural damage to the waste management unit could result in the release of contaminants. In addition, fault movement might create avenues to groundwater supplies, increasing the risk of groundwater contamination.

Liquefaction is another common problem encountered in areas of seismic activity. The vibrating motions caused by an earthquake tend to rearrange the sand grains in soils. If the grains are saturated, the saturated granular material turns into a viscous fluid, a process referred to as liquefaction. This diminishes the bearing capacity of the soils and can lead to foundation and slope failures.

To avoid these hazards, do not build or expand a unit within 200 feet of an active fault. If it is not possible to site a unit more than 200 feet from an active fault, you should design the unit to withstand the potential ground movement associated with the fault area. A fault is considered active if there has been movement along it within the last 10,000 to 12,000 years.

How is it determined if a prospective site is in a fault area?

A series of USGS maps, Preliminary Young Fault Maps, Miscellaneous Field Investigation 916, identifies active faults.[10] These maps, however, might not be completely accurate due to recent shifts in fault lines. If a prospective site is well outside the 200 foot area of concern, no fault area considerations exist. If it is unclear how close a prospective site is to an active fault, further evaluation will be necessary. A geologic reconnaissance of the site and surrounding areas can be useful in verifying that active faults do not exist at the site.

If a prospective site is in an area known or suspected to be prone to faulting, you should conduct a fault characterization to determine if the site is near a fault. A characterization includes identifying linear features that suggest the presence of faults within a 3,000-foot radius of the site. Such features might be shown or described on maps, aerial photographs,[11] logs, reports, scientific literature, or insurance claim reports, or identified by a detailed field reconnaissance of the area.

If the characterization study reveals faults within 3,000 feet of the proposed unit or lat-

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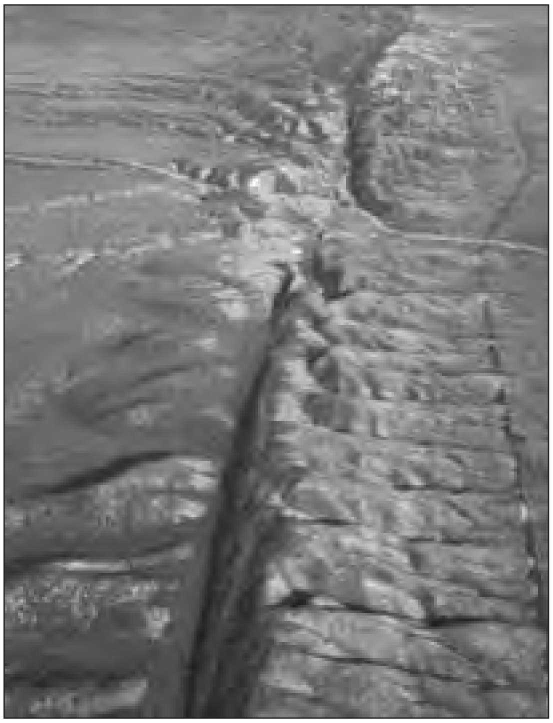
[10] Information about ordering these maps is available by calling 888 ASK-USGS or 703 648-6045.

[11] The National Aerial Photographic Program (NAPP) and the National High Altitude Program (NHAP), both administered by USGS, are sources of aerial photographs. To order from USGS, call 605 594-6151. For more information, see **<edc.usgs.gov/nappmap.html>**. Local aerial photography firms and surveyors are also good sources of information.



In this aerial view, the infamous San Andreas fault slices through the Carrizo Plain east of San Luis Obispo, California.

Source: USGS.

eral expansion, you should conduct further investigations to determine whether any of the faults are active within 200 feet of the unit. These investigations can involve drilling and trenching the subsurface to locate fault zones and evidence of faulting. Perpendicular trenching should be used on any fault within 200 feet of the proposed unit to examine the seismic epicenter for indications of recent movement.

What can be done if a prospective site is in a fault area?

If an active fault exists on the site where the unit is planned, consider placing the unit 200 feet back from the fault area. Even with such setbacks, only place a unit in a fault area if it is possible to ensure that no damage to the unit's structural integrity would result. A setback of less than 200 feet might be adequate if ground movement would not damage the unit.

If a lateral expansion or a new unit will be located in an area susceptible to seismic activity, there are two particularly important issues to consider: horizontal acceleration and movement affecting side slopes. Horizontal acceleration becomes a concern when a location analysis reveals that the site is in a zone with a risk of horizontal acceleration in the range of 0.1 g to 0.75 g (g = acceleration of gravity). In these zones, the unit design should incorporate measures to protect the unit from potential ground shifts. To address side slope concerns, you should conduct a seismic stability analysis to determine the most effective materials and gradients for protecting the unit's slopes from any seismic instabilities. Also, design the unit to withstand the impact of vertical accelerations.

If the unit is in an area susceptible to liquefaction, you should consider ground improvement measures. These measures include grouting, dewatering, heavy tamping, and excavation. See Table 1 for examples of techniques that are currently used.

Additional engineering options for fault areas include the use of flexible pipes for runoff and leachate collection, and redundant containment systems. In the event of foundation soil collapse or heavy shifting, flexible runoff and leachate collection pipes—along with a bedding of gravel or permeable material—can absorb some of the shifting-related stress to which the pipes are subjected. Also consider a secondary containment measure, such as an additional liner system. In earthquake-like conditions, a redundancy of this nature might be necessary to prevent contamination of the surrounding area if the primary liner system fails.

Table 1
Examples of Improvement Techniques for Liquefiable Soil Foundation Conditions

Method	Principle	Most Suitable Soil Conditions/Types	Applications
Blasting	Shock waves and vibrations cause limited liquefaction, displacement, remolding, and settlement to higher density.	Saturated, clean sands; partly saturated sands and silts after flooding.	Induce liquefaction in controlled and limited stages and increase relative density to potentially nonliquefiable range.
Vibrocompaction	Densification by vibration and compaction of backfill material of sand or gravel.	Cohesionless soils with less than 20 percent fines.	Induce liquefaction in controlled and limited stages and increase relative density to nonliquefiable condition. The dense column of backfill provides (a) vertical support, (b) drainage to relieve pore water pressure, and (c) shear resistance in horizontal and inclined directions. Used to stabilize slopes and strengthen potential failure surfaces.
Compaction piles	Densification by displacement of pile volume and by vibration during driving; increase in lateral effective earth pressure.	Loose sandy soils; partly saturated clayey soils; loess.	Useful in soils with fines. Increases relative density to nonliquefiable condition. Provides shear resistance in horizontal and inclined directions. Used to stabilize slopes and strengthen potential failure surfaces.
Displacement and compaction grout	Highly viscous grout acts as radial hydraulic jack when pumped in under high pressure.	All soils.	Increase in soil relative density and horizontal effective stress. Reduce liquefaction potential. Stabilize the ground against movement.
Mix-in-place piles and walls	Lime, cement, or asphalt introduced through rotating auger or special in-place mixer.	Sand, silts, and clays; all soft or loose inorganic soils.	Slope stabilization by providing shear resistance in horizontal and inclined directions, which strengthens potential failure surfaces or slip circles. A wall could be used to confine an area of liquefiable soil.
Heavy tamping (dynamic compaction)	Repeated application of high- intensity impacts at surface.	Cohesionless soils best; other types can also be improved.	Suitable for some soils with fines; usable above and below water. In cohesionless soils, induces liquefaction in controlled and limited stages and increases relative density to potentially nonliquefiable range.

Source: RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities. (EPA, 1995c).

D. Seismic Impact Zones

A seismic impact zone is an area having a 2 percent or greater probability that the maximum horizontal acceleration caused by an earthquake at the site will exceed 0.1 g in 50 years. This seismic activity can damage leachate collection and removal systems, leak detection systems, or other unit structures through excessive bending, shearing, tension, and compression. If a unit's structural components fail, leachate can contaminate surrounding areas. Therefore, for safety reasons, it is recommended that a unit not be located in a seismic impact zone. If a unit must be sited in a seismic impact zone, the unit should be designed to withstand earthquake-related hazards, such as landslides, slope failures, soil compaction, ground subsidence, and soil liquefaction.

Additionally, if you build a unit in a seismic impact zone, avoid rock and soil types that are especially vulnerable to earthquake shocks. These include very steep slopes of weak, fractured, and brittle rock or unsaturated loess,[12] which are vulnerable to transient shocks caused by tensional faulting. Avoid

[12] Loess is a wind-deposited, moisture-deficient silt that tends to compact when wet.

loess and saturated sand as well, because seismic shocks can liquefy them, causing sudden collapse of structures. Similar effects are possible in sensitive cohesive soils when natural moisture exceeds the soil's liquid limit. For a discussion of liquid limits, refer to the "Soil Properties" discussion in Chapter 7, Section B – Designing and Installing Liners. Earthquake-induced ground vibrations can also compact loose granular soils. This could result in large uniform or differential settlements at the ground surface.

How is it determined if a prospective site is in a seismic impact zone?

If a prospective site is in an area with no history of earthquakes, then seismic impact zone considerations might not exist. If it is unclear whether the area has a history of seismic activity, then further evaluation will be necessary. As a first step, consult the USGS field study map series MF-2120, *Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico*.[13] These maps provide state- and county-specific information about seismic impact zones. Additional information is available from the USGS National Earthquake Information Center (NEIC),[14] which maintains a database of known earthquake and fault zones. Further information concerning the USGS National Seismic Hazard Mapping Project can be accessed at <**geohazards.cr.usgs.gov/eq**>. USGS's Web site also allows you to find ground motion hazard parameters (including peak ground acceleration and spectra acceleration) for your site by entering a 5 digit ZIP code <**eqint.cr.usgs.gov/eq/html/zipcode.shtml**>, or a latitude-longitude coordinate pair <**eqint.cr.usgs.gov/eq/html/lookup.shtml**>. The USGS Web site explains how these values can be used to determine the probability of excedance for a particular level of ground motion at your site. This can help you determine if the structural integrity of the unit is susceptible to damage from ground motion.

For waste management unit siting purposes, use USGS' recently revised *Peak Acceleration (%g) with 2 % Probability of Exceedance in 50 Years* maps available at <**geohazards.cr.usgs.gov/eq/hazmapsdoc/junecover.html**>. It is important to note that ground motion values having a 2 percent probability of exceedance in 50 years are approximately the same as those having 10 percent probability of being exceeded in 250 years. According to USGS calculations, the annual exceedance probabilities of these two differ by about 4 percent (for a more complete discussion visit: <**geohazards.cr.usgs.gov/eq/faq/parm08.html**>).

If a site is or might be in a seismic impact zone, it is useful to analyze the effects of seismic activity on soils in and under the unit. Computer software programs are available that can evaluate soil liquefaction potential (defined in Section C of this chapter). LIQUFAC, a software program developed by the Naval Facilities Engineering Command in Washington, DC, can calculate safety factors for each soil layer in a given soil profile and the corresponding one dimensional settlements due to earthquake loading.

What can be done if a prospective site is in a seismic impact zone?

If a waste management unit cannot be sited outside a seismic impact zone, structural components of the unit—including liners, leachate collection and removal systems, and surface-water control systems—should be designed to resist the earthquake-related stresses expected in the local soil. You should consult professionals experienced in seismic analysis and

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[13] For information on ordering these maps, call 888 ASK-USGS, write to USGS Information Services, Box 25286, Denver, CO 80225, or fax 303 202-4693. Online information is available at <**ask.usgs.gov/products.html**>.

[14] To contact NEIC, call 303 273-8500, write to United States Geological Survey, National Earthquake Information Center, Box 25046, DFC, MS 967, Denver, CO 80225, fax 303 273-8450, or e-mail sedas@neic.cr.usgs.gov. For online information, visit: <**neic.usgs.gov**>.

design to ensure that your unit is designed appropriately. To determine the potential effects of seismic activity on a structure, the seismic design specialist should evaluate soil behavior with respect to earthquake intensity. This evaluation should account for soil strength, degree of compaction, sorting (organization of the soil particles), saturation, and peak acceleration of the potential earthquake.

After conducting an evaluation of soil behavior, choose appropriate earthquake protection measures. These might include shallower slopes, dike and runoff control designs using conservative safety factors, and contingency plans or backup systems for leachate collection if primary systems are disrupted. Unit components should be able to withstand the additional forces imposed by an earthquake within acceptable margins of safety.

Additionally, well-compacted, cohesionless embankments or reasonably flat slopes in insensitive clay (clay that maintains its compression strength when remolded) are less likely to fail under moderate seismic shocks (up to 0.15 g - 0.20 g). Embankments made of insensitive, cohesive soils founded on cohesive soils or rock can withstand even greater seismic shocks. For earthen embankments in seismic regions, consider designing the unit with internal drainage and core materials resistant to fracturing. Also, prior to or during unit construction in a seismic impact zone, you should evaluate excavation slope stability to determine the appropriate grade of slopes to minimize potential slip.

For landfills and waste piles, using shallower waste side slopes is recommended, as steep slopes are more vulnerable to slides and collapse during earthquakes. Use fill sequencing techniques that avoid concentrating waste in one area of the unit for an extended period of time. This prevents waste pile side slopes from becoming too steep and unstable and alleviates differential loading of the foundation components. Placing too much waste in one area of the unit can lead to catastrophic shifting during an earthquake or heavy seismic activity. Shifting of this nature can cause failure of crucial system components or of the unit in general.

In addition, seismic impact zones have design issues in common with fault areas, especially concerning soil liquefaction and earthquake-related stresses. To address liquefaction, consider employing the soil improvement techniques described in Table 1. Treating liquefiable soils in the vicinity of the unit will improve foundation stability and help prevent uneven settling or possible collapse of heavily saturated soils underneath or near the unit.

To protect against earthquake-related stresses, consider installing redundant liners and special leachate collection and removal system components, such as secondary liner systems, composite liners, and leak detection systems combined with a low permeability soil layer. These measures function as backups to the primary containment and collection systems and provide a greater margin of safety for units during possible seismic stresses. Examples of special leachate systems include high-strength, flexible materials for leachate containment systems; geomembrane liner systems underlying leachate containment systems; and perforated polyvinyl chloride or high-density polyethylene piping in a bed of gravel or other permeable material.

E. Unstable Areas

Siting in unstable areas should be avoided because these locations are susceptible to naturally occurring or human-induced events or forces capable of impairing the integrity of a waste management unit. Naturally occurring unstable areas include regions with poor soil foundations, regions susceptible to mass movement, or regions containing karst terrain, which can include hidden sinkholes. Unstable areas caused by human activity can include areas near cut or fill slopes, areas with excessive drawdown of ground water, and areas where significant quantities of oil or natural gas have been extracted. If it is necessary to site a waste management unit in an unstable area, technical and construction techniques should be considered to mitigate against potential damage.

The three primary types of failure that can occur in an unstable area are settlement, loss of bearing strength, and sinkhole collapse. Settlement can result from soil compression if your unit is, or will be located in, an unstable area over a thick, extensive clay layer. The unit's weight can force water from the compressible clay, compacting it and allowing the unit to settle. Settlement can increase as waste volume increases and can result in structural failure of the unit if it was not properly engineered. Settlement beneath a waste management unit should be assessed and compared to the elongation strength and flexibility properties of the liner and leachate collection pipe system. Even small amounts of settlement can seriously damage leachate collection piping and sumps. A unit should be engineered to minimize the impacts of settlement if it is, or will be in an unstable area.

Loss of bearing strength is a failure mode that occurs in soils that tend to expand and rapidly settle or liquefy. Soil contractions and expansions can increase the risk of leachate or waste release. Another example of loss of bearing strength occurs when excavation near the unit reduces the mass of soil at the toe of the slope, thereby reducing the overall strength (resisting force) of the foundation soil.

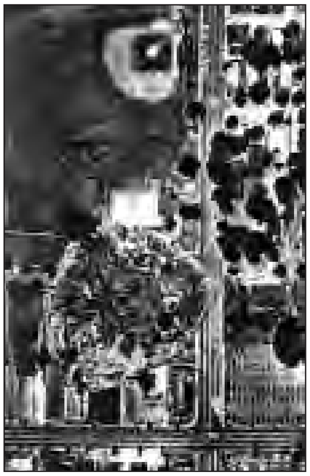
Catastrophic collapse in the form of sinkholes can occur in karst terrain. As water, especially acidic water, percolates through limestone, the soluble carbonate material dissolves, leaving cavities and caverns. Land overlying caverns can collapse suddenly, resulting in sinkholes that can be more than 100 feet deep and 300 feet wide.

How is it determined if a prospective site is in an unstable area?

If a stability assessment has not been performed on a potential site, you should have a qualified professional conduct one before designing a waste management unit on the prospective site. The qualified professional should assess natural conditions, such as soil geology and geomorphology, as well as human-induced surface and subsurface features or events that could cause differential ground settlement. Naturally unstable conditions can become more unpredictable and destructive if amplified by human-induced changes to the environment. If a unit is to be built at an assessed site that exhibits stability problems, tailor the design to account for any instability detected. A stability assessment typically includes the following steps:

Screen for expansive soils. Expansive soils can lose their ability to support a foundation when subjected to certain natural or human-induced events, such as heavy rain or explosions. Expansive soils usually are clay-rich and, because of their molecular structure, tend to swell and shrink by taking up and releasing water. Such soils include smectite (montmorillonite group) and vermiculite clays. In addition, soils rich in white alkali (sodium sulfate), anhydrite (calcium sulfate), or pyrite (iron sulfide) can also swell as water content increases. These soils are more common in the arid western states.

Check for soil subsidence. Soils subject to rapid subsidence include loesses, unconsolidated clays, and wetland soils. Unconsolidated clays can undergo considerable compaction when oil or water is removed. Similarly, wetland soils, which by their



Sinkholes, like this one that occurred just north of Orlando, Florida in 1981, are a risk of development in Karst terrain. Left: aerial view (note baseball diamond for scale); right: ground-level view. Photos courtesy of City of Winter Park, Florida public relations office.

nature are water-bearing, are also subject to subsidence when water is withdrawn.

Look for areas subject to mass movement or slippage. Such areas are often situated on slopes and tend to have rock or soil conditions conducive to downhill sliding. Examples of mass movements include avalanches, landslides, and rock slides. Some sites might require cutting or filling slopes during construction. Such activities can cause existing soil or rock to slip.

Search for karst terrain. Karst features are areas containing soluble bedrock, such as limestone or dolomite, that have been dissolved and eroded by water, leaving characteristic physiographic features including sinkholes, sinking streams, caves, large springs, and blind valleys. The principal concern with karst terrains is progressive or catastrophic subsurface failure due to the presence of sinkholes, solution cavities, and subterranean caverns. Karst features can also hamper detection and control of leachate, which can move rapidly through hidden conduits beneath the unit. Karst maps, such as *Engineering Aspects of Karst, Scale 1:7,500,000, Map No. 38077-AW-NA-07M-00,* produced by the USGS[15] and state specific geological maps can be reviewed to identify karst areas.

Scan for evidence of excessive groundwater drawdown or oil and gas extraction. Removing underground water can increase the effective overburden on the foundation soils underneath the unit. Excessive drawdown of water might cause settlement or bearing capacity failure on the foundation soils. Extraction of oil or natural gas can have similar effects.

Subsidence, slippage, and other kinds of slope failure can damage structures.

Investigate the geotechnical and geological characteristics of the site. It is important to establish soil strengths and other engineering properties. A geotechnical engineering con-

15 For information on ordering this map, call 888 ASK-USGS, write USGS Information Services, Box 25286, Denver, CO 80255, or fax 303 202-4693. Online information is available at <**www-atlas.usgs.gov/atlasmap.html**>.

sultant can accomplish this by performing standard penetration tests, field vane shear tests, and laboratory tests. This information will determine how large a unit you can safely place on the site. Other soil properties to examine include water content, shear strength, plasticity, and grain size distribution.

Examine the liquefaction potential. It is extremely important to ascertain the liquefaction potential of embankments, slopes, and foundation soils. Refer to Section C of this chapter for more information about liquefiable soils.

What can be done if a prospective site is in an unstable area?

It is advisable not to locate or expand your waste management unit in an unstable area. If your unit is or will be located in such an area, you should safeguard the structural integrity of the unit by incorporating appropriate measures into the design. The integrity of the unit might be jeopardized if this is not done.

For example, to safeguard the structural integrity of side slopes in an unstable area, reduce slope height, flatten slope angle, excavate a bench in the upper portion of the slope, or buttress slopes with compacted earth or rock fill. Alternatively, build retaining structures, such as retaining walls or slabs and piles. Other approaches include the use of geotextiles and geogrids to provide additional strength, wick and toe drains to relieve excess pore pressures, grouting, and vacuum and wellpoint pumping to lower ground- water levels. In addition, surface drainage can be controlled to decrease infiltration, thereby reducing the potential for mud and debris slides.

Additional engineering concerns arise in the case of waste management units in areas containing karst terrain. The principal concern with karst terrains is progressive or catastrophic subsurface failure due to the presence of sinkholes, solution cavities, and subterranean caverns. Extensive subsurface characterization studies should be completed before designing and building in these areas. Subsurface drilling, sinkhole monitoring, and geophysical testing are direct means that can be used to characterize a site. Geophysical techniques include electromagnetic conductivity, seismic refraction, ground-penetrating radar, and electrical resistivity (see the box below for more information). More than one technique should be used to confirm and correlate findings and anomalies, and a qualified geophysicist should interpret the results of these investigations.

Remote sensing techniques, such as aerial photograph interpretation, can also provide additional information on karst terrains. Surface mapping can help provide an understanding of structural patterns and relationships in karst terrains. An understanding of local carbonate geology and stratigraphy can help with the interpretation of both remote sensing and geophysical data.

You should incorporate adequate engineering controls into any waste management unit located in a karst terrain. In areas where karst development is minor, loose soils overlying the limestone can be excavated or heavily compacted to achieve the needed stability. Similarly, in areas where the karst voids are relatively small, the voids can be filled with slurry cement grout or other material.

Engineering solutions can compensate for the weak geologic structures by providing ground supports. For example, ground modifications, such as grouting or reinforced raft foundations, could compensate for a lack of ground strength in some karst areas. Raft constructions, which are floating foundations consisting of a concrete footing extending over a very large area, reduce and evenly distribute waste loads where soils have a low bearing capacity or where soil conditions are variable and erratic. Note, however, that raft foundations might not always prevent the

Geophysical Techniques

Electromagnetic Conductivity or Electromagnetic Induction (EMI). A transmitter coil generates an electromagnetic field which induces eddy currents in the earth located below the transmitter. These eddy currents create secondary electromagnetic fields which are measured by a receiver coil. The receiver coil produces an output voltage that can be related to subsurface conductivity variations. Analysis of these variations allows users to map subsurface features, stratigraphic profiles, and the existence of buried objects.

Seismic Refraction. An artificial seismic source (e.g., hammer, explosives) creates compression waves that are refracted as they travel along geologic boundaries. These refracted waves are detected by electromechanical transducers (geophones) which are attached to a seismograph that records the time of arrival of all waves (refracted and non-refracted). These travel times are compared and analyzed to identify the number of stratigraphic layers and the depth of each layer.

Ground-Penetrating Radar. A transmitting antenna dragged along the surface of the ground radiates short pulses of high-frequency radio waves into the ground. Subsurface structures reflect these waves which are recorded by a receiving antenna. The variations in reflected return signals are used to generate an image or map of the subsurface structure.

Electrical Resistivity. An electrical current is injected into the ground by a pair of surface electrodes (called the current electrodes). By measuring the resulting voltage (potential field) between a second pair of electrodes (called the potential electrodes), the resistivity of subsurface materials is measured. The measured resistivity is then compared to known values for different soil and rock types. Increasing the distance between the two pairs of electrodes increases the depth of measurement.

extreme collapse and settlement that can occur in karst areas. In addition, due to the unpredictable and catastrophic nature of ground failure in unstable areas, the construction of raft foundations and other ground modifications tends to be complex and can be costly, depending on the size of the area.

F. Airport Vicinities

The vicinity of an airport includes not only the facility itself, but also large reserved open areas beyond the ends of runways. If a unit is intended to be sited near an airport, there are particular issues that take on added importance in such areas. You should familiarize yourself with Federal Aviation Administration (FAA) regulations and guidelines. The primary concern associated with waste management units near airports is the hazard posed to aircraft by birds, which often feed at units managing putrescible waste. Planes can lose propulsion when birds are sucked into jet engines, and can sustain other damage in collisions with birds. Industrial waste management units that do not receive putrescible wastes should not have a problem with birds. Another area of concern for landfills and waste piles near airports is the height of the accumulated waste. If you own or operate such a unit, you should exercise caution when managing waste above ground level.

How is it determined if a prospective site will be located too close to an airport?

If the prospective site is not located near any airports, additional evaluation is not necessary. If there is uncertainty whether the prospective site is located near an airport, obtain local maps of the area using the various Internet resources previously discussed or from state and local regulatory agencies to identify any nearby public-use airports.

Topographic maps available from USGS are also suitable for determining airport locations. If necessary, FAA can provide information on the location of all public-use airports. In accordance with FAA guidance, if a new unit or an expansion of an existing unit will be within 5 miles of the end of a public-use airport runway, the affected airport and the regional FAA office should be notified to provide them an opportunity for review and comment.

What can be done if a prospective site is in an airport vicinity?

If a proposed waste management unit or a lateral expansion is to be located within 10,000 feet of an airport used by jet aircraft or within 5,000 feet of an airport used only by piston-type aircraft, design and operate your unit so it does not pose a bird hazard to aircraft. For above-ground units, design and operate your unit so it does not interfere with flight patterns. If it appears that height is a potential concern, consider entrenching the unit or choosing a site outside the airport's flight patterns. Most nonhazardous industrial waste management units do not usually manage wastes that are attractive food sources for birds, but if your unit handles waste that potentially attracts birds, take precautions to prevent birds from becoming an aircraft hazard. Discourage congregation of birds near your unit by preventing water from collecting on site; eliminating or covering wastes that might serve as a source of food; using visual deterrents, including realistic models of the expected scavenger birds' natural predators; employing sound deterrents, such as cannon sounds, distress calls of scavenger birds, or the sounds of the birds' natural predators; removing nesting and roosting areas (unless such removal is prohibited by the Endangered Species Act); or constructing physical barriers, such as a canopy of fine wires or nets strung around the disposal and storage areas when practical or technically feasible.

G. Wellhead Protection Areas

Wellhead protection involves protecting the ground-water resources that supply public drinking water systems. A wellhead protection area (WHPA) is the area most susceptible to contamination surrounding a wellhead. WHPAs are designated and often regulated to prevent public drinking water sources from becoming contaminated. The technical definition, delineation, and regulation of WHPAs vary from state to state. You should contact your state or local regulatory agency to determine what wellhead protection measures are in place near prospective sites. Section II of this chapter provides examples of how some states specify minimum allowable distances between waste management units and public water supplies, as well as drinking water wells. Locating a waste management unit in a WHPA can create a potential avenue for drinking water contamination through accidental release of leachate, contaminated runoff, or waste. In addition, some states might have additional restrictions for areas in designated "sole source aquifier" systems.

How is it determined if a prospective site is in a wellhead protection area?

A list of state wellhead protection program contacts is available on EPA's Web site at **<www.epa.gov/ogwdw/safewater/source/contacts.html>**. Also, USGS, NRCS, local water authorities, and universities can provide maps and further expertise that can help you to identify WHPAs. If there is uncertainty regarding the proximity of the prospective site to a WHPA, contact the appropriate state or local regulatory agency.

What can be done if a prospective site is in a wellhead protection area?

If a new waste management unit or lateral expansion will be located in a WHPA or suspected WHPA, consider design modifications to help prevent any ground-water contamination. For waste management units placed in these areas, work with state regulatory agencies to ensure that appropriate ground-water barriers are installed between the unit and the ground-water table. These barriers should be designed using materials of extremely low permeability, such as geomembrane liners or low permeability soil liners. The purpose of such barriers is to prevent any waste, or leachate that has percolated through the waste, from reaching the ground water and possibly affecting the public drinking water source.

In addition to ground-water barriers, the use of leachate collection, leak detection, and runoff control systems should also be considered. Leachate contamination is possibly the greatest threat to a public ground-water supply posed by a waste management unit. Incorporation of leachate collection, leak detection, and runoff control systems should further prevent any leachate from escaping into the ground water. Further discussion concerning liner systems, leachate collection and removal systems, and leak detection systems is included in Chapter 7, Section B–Designing and Installing Liners.

Control systems that separate storm-water run-on from any water that has contacted waste should also be considered. Proper control measures that redirect storm water to the supply source area should help alleviate this tendency. For additional information concerning storm water run-on and runoff control systems, refer to Chapter 6–Protecting Surface Water.

II. Buffer Zone Considerations

Many states require buffer zones between waste management units and other nearby land uses, such as schools. The size of a buffer zone often depends on the type of waste management unit and the land use of the surrounding areas. You should consult with state regulatory agencies and local advisory boards about buffer zone requirements before constructing a new unit or expanding an existing unit. A summary of state buffer zone requirements is included in the appendix at the end of this chapter.

Buffer zones provide you with time and space to mitigate situations where accidental releases might cause adverse human health or environmental impacts. The size of the buffer zone will be directly related to the intended benefit. These zones provide four primary benefits:

- Maintenance of quality of the surrounding ground water.
- Prevention of contaminant migration off site.
- Protection of drinking water supplies.
- Minimization of nuisance conditions perceived in surrounding areas.

Protection of ground water will likely be the primary concern for all involved parties. You should ensure that materials processed and disposed at your unit are isolated from ground-water resources. Placing your unit further from the water table and potential receptors, and increasing the number of physical barriers between your unit and the water table and potential receptors, provides for ground-water protection. It is therefore advised that, in addition to incorporating a liner system, where necessary, into a waste

Many nearby areas and land uses, such as schools, call for consideration of buffer zones.

management unit's design, you select a site where an adequate distance separates the bottom of a unit from the ground-water table. (See the appendix for a summary of these minimum separation distances.)[16] In the event of a release, this separation distance will allow for corrective action and natural attenuation to protect ground water.[17]

Additionally, in the event of an unplanned release, an adequate buffer zone will allow time for remediation activities to control contaminants before they reach sensitive areas. Buffer zones also provide additional protection for drinking water supplies. Drinking water supplies include ground water, individual and community wells, lakes, reservoirs, and municipal water treatment facilities.

Finally, buffer zones help maintain good relations with the surrounding community by protecting surrounding areas from any noise, particulate emissions, and odor associated with your unit. Buffer zones also help to prevent access by unauthorized people. For units located near property boundaries, houses, or historic areas, trees or earthen berms can provide a buffer to reduce noise and odors. Planting trees around a unit can also improve the aesthetics of a unit, obstruct any view of unsightly waste, and help protect property values in the surrounding community. When planting trees as a buffer, place them so that their roots will not damage the unit's liner or final cover.

A. Recommended Buffer Zones

You should check with state and local officials to determine what buffer zones might apply to your waste management unit. Areas for which buffer zones are recommended include property boundaries, drinking water wells, other sources of water, and adjacent houses or buildings.

Property boundaries. To minimize adverse effects on adjacent properties, consider incorporating a buffer zone or separation distance into unit design. You should consider planting trees or bushes to provide a natural buffer between your unit and adjacent properties.

Drinking water wells, surface-water bodies, and public water supplies. Locating a unit near or within the recharge area for sole source aquifers and major aquifers, coastal areas, surface-water bodies, or public water supplies, such as a community well or water treatment facility, also raises concerns. Releases from a waste management unit can pose serious threats to human health not only where water is used for drinking, but also where surface waters are used for recreation.

[16] A detailed discussion of technical considerations concerning the design and installation of liner systems, both in situ soil liners and synthetic liners, is included in Chapter 7, Section B – Designing and Installing Liners.

[17] Natural attenuation can be defined as chemical and biological processes that reduce contaminant concentrations.

Houses or buildings. Waste management units can present noise, odor, and dust problems for residents or businesses located on adjacent property, thereby diminishing property values. Additionally, proximity to property boundaries can invite increased trespassing, vandalism, and scavenging.

B. Additional Buffer Zones

There are several other areas for which to consider establishing buffer zones, including critical habitats, park lands, public roads, and historic or archaeological sites.

Critical habitats. These are geographical areas occupied by endangered or threatened species. These areas contain physical or biological features essential to the proliferation of the species. When designing a unit near a critical habitat, it is imperative that the critical habitat be conserved. A buffer zone can help prevent the destruction or adverse modification of a critical habitat and minimize harm to endangered or threatened species.[18]

Buffer zones can help protect endangered species and their habitats.

Park lands. A buffer between your unit and park boundaries helps maintain the aesthetics of the park land. Park lands provide recreational opportunities and a natural refuge for wildlife. Locating a unit too close to these areas can disrupt recreational qualities and natural wildlife patterns.

Public roads. A buffer zone will help reduce unauthorized access to the unit, reduce potential odor concerns, and improve aesthetics for travelers on the nearby road.

Historic or archaeological sites. A waste management unit located in close proximity to one of these sites can adversely impact the aesthetic quality of the site. These areas include historic settlements, battlegrounds, cemeteries, and Indian burial grounds. Also check whether a prospective site itself has historical or archaeological significance.

Historic sites call for careful consideration of buffer zones.

In summary, it is important to check with local authorities to ensure that placement of a new waste management unit or lateral expansion of an existing unit will not conflict with any local buffer zone criteria. You should also review any relevant state or tribal

[18] For the full text of the Endangered Species Act, visit the U.S. House of Representatives Internet Law Library Web site at <**uscode.house.gov/download.htm**>, under Title 16, Chapter 35.

regulations that specify buffer zones for your unit. For units located near any sensitive areas as described in this section, consider measures to minimize any possible health, environmental, and nuisance impacts.

III. Local Land Use and Zoning Considerations

In addition to location and buffer zone considerations, become familiar with any local land use and zoning requirements. Local governments often classify the land within their communities into areas, districts, or zones. These zones can represent different use categories, such as residential, commercial, industrial, or agricultural. You should consider the compatibility of a planned new unit or a planned lateral expansion with nearby existing and future land use, and contact local authorities early in the siting process. Local planning, zoning, or public works officials can discuss with you the development of a unit, compliance with local regulations, and available options. Local authorities might impose conditions for protecting adjacent properties from potential adverse impacts from the unit.

Addressing local land use and zoning issues during the siting process can prevent these issues from becoming prominent concerns later. Land use and zoning restrictions often address impacts on community and recreational areas, historical areas, and other critical areas. You should consider the proximity of a new unit or lateral expansion to such areas and evaluate any potential adverse effects it might have on these areas. For example, noise, dust, fumes, and odors from construction and operation of a unit could be considered a nuisance and legal action could be brought by local authorities or nearby property owners.

In situations where land use and zoning restrictions might cause difficulties in expanding or siting a unit, work closely with local authorities to learn about local land use and zoning restrictions and minimize potential problems. Misinterpreting or ignoring such restrictions can cause complications with intended development schedules or designs. In many cases, the use of vegetation, fences, or walls to screen your activities can reduce impacts on nearby properties. In addition, it might be possible to request amendments, rezonings, special exceptions, or variances to restrictions. These administrative mechanisms allow for flexibility in use and development of land. Learning about local requirements as early as possible in the process will maximize the time available to apply for variances or rezoning permits, or to incorporate screening into the plans for your unit.

IV. Environmental Justice Considerations

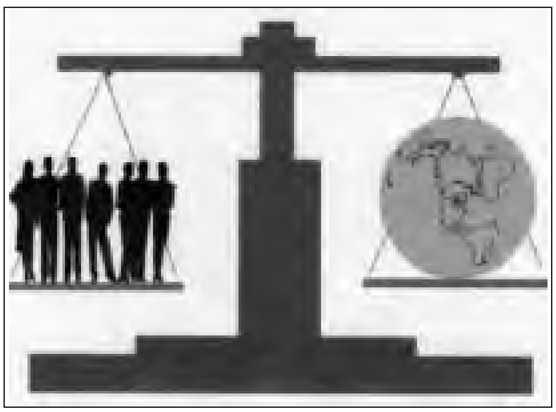
In the past several years, there has been growing recognition from communities and federal and state governments that some socioeconomic and racial groups might bear a disproportionate burden of adverse environmental effects from waste management activities. President Clinton issued Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, on February 11, 1994.[19] To be consistent with the definition of environmental justice in this executive order, you should identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of waste management pro-

[19] For the full text of Presidential Executive Order No. 12898 and additional information concerning environmental justice issues go to EPA's Web site at **<es.epa.gov/program/iniative/justice/justice.html>**.

grams, policies, and activities on minority and low-income populations.

One of the criticisms made by advocates of environmental justice is that local communities endure the potential health and safety risks associated with waste management units without enjoying any of the economic benefits. During unit siting or expansion, address environmental justice concerns in a manner that is most appropriate for the operations, the community, and the state or tribal government.

You should look for opportunities to minimize environmental impacts, improve the surrounding environment, and pursue opportunities to make the waste management



facility an asset to the community. When planning these opportunities, it is beneficial to maintain a relationship with all involved parties based on honesty and integrity, utilize cross-cultural formats and exchanges, and recognize industry, state, and local knowledge of the issues. It is also important to take advantage of all potential opportunities for developing partnerships.

Examples of activities that incorporate environmental justice issues include tailoring activities to specific needs; providing interpreters, if appropriate; providing multilingual materials; and promoting the formation of a community/state advisory panel.

Tailor the public involvement activities to the specific needs. Good public involvement programs are site-specific—they take into account the needs of the facility, neighborhood, and state. There is no such thing as a "one-size-fits-all" public involvement program. Listening to each other carefully will identify the specific environmental justice concerns and determine the involvement activities most appropriate to address those needs.

Provide interpreters for public meetings. Interpreters can be used to ensure the information is exchanged. Provide interpreters, as needed, for the hearing impaired and for any languages, other than English, spoken by a significant percentage of the audience.

Provide multilingual fact sheets and other information. Public notices and fact sheets should be distributed in as many languages as necessary to ensure that all interested parties receive necessary information. Fact sheets should be available for the visually impaired in the community on tape, in large print, or braille.

Promote the formation of a community/ state advisory panel to serve as the voice of the community. The Louisiana Department of Environmental Quality, for example, encourages the creation of environmental justice panels comprised of community members, industry, and state representatives. The panels meet monthly to discuss environmental justice issues and find solutions to any concerns identified by the group.

Considering the Site Activity List

General Siting Considerations

- ❑ Check to see if the proposed unit site is:
  - — In a 100-year floodplain.
  - — In or near a wetland area.
  - — Within 200 feet of an active fault.
  - — In a seismic impact zone.
  - — In an unstable area.
  - — Close to an airport.
  - — Within a wellhead protection area.
- ❑ If the proposed unit site is in any of these areas:
  - — Design the unit to account for the area's characteristics and minimize the unit's impacts on such areas.
  - — Consider siting the unit elsewhere.

Buffer Zone Considerations

(Note that many states require buffer zones between waste management units and other nearby land uses.)

- ❑ Check to see if the proposed unit site is near:
  - — The ground-water table.
  - — A property boundary.
  - — A drinking water well.
  - — A public water supply, such as a community well, reservoir, or water treatment facility.
  - — A surface-water body, such as a lake, stream, river, or pond.
  - — Houses or other buildings.
  - — Critical habitats for endangered or threatened species.
  - — Park lands.
  - — A public road.
  - — Historic or archaeological sites.
- ❑ If the proposed unit site is near any of these areas or land uses, determine how large a buffer zone, if any, is appropriate between the unit and the area or land use.

Considering the Site Activity List (cont.)

Local Land Use and Zoning Considerations

- ❑ Contact local planning, zoning, and public works agencies to discuss restrictions that apply to the unit.
- ❑ Comply with any applicable restrictions, or obtain the necessary variances or special exceptions.

Environmental Justice Considerations

- ❑ Determine whether minority or low-income populations would bear a disproportionate burden of any environmental effects of the unit's waste management activities.
- ❑ Work with the local community to devise strategies to minimize any potentially disproportionate burdens.

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Appendix: State Buffer Zone Considerations

The universe of industrial wastes and unit types is broad and diverse. States have established various approaches to address location considerations for the variety of wastes and units in their states. The tables below summarize the range of buffer zone restrictions and most common buffer zone values specified for each unit type by some states to address their local concerns. The numbers in the tables are not meant to advocate the adoption of a buffer zone of any particular distance; rather, they serve only as examples of restrictions states have individually developed.

- Surface impoundments. Restrictions with respect to buffer zones vary among states. In addition, states allow exemptions or variances to these buffer zone restrictions on a case-by-case basis. Table 1 presents the range of values and the most common value used by states for each buffer zone category.

Table 1
State Buffer Zone Restrictions for Surface Impoundments

Buffer Zone Category	Range of Values—minimum distance (number of states with this common value)		Most Common Value (number of states with this common value)	
Groundwater Table	1 to 15 feet	(4)	5 feet	(2)
Property Boundaries	100 to 200 feet	(4)	100 feet	(2)
Drinking Water Wells	1,200 to 1,320 feet	(2)	1,200 feet 1,320 feet	(1) (1)
Public Water Supply	500 to 1,320 feet	(4)	1,320 feet	(2)
Surface Water Body	100 to 1,320 feet	(4)	100 feet	(2)
Houses or Buildings	300 to 1,320 feet	(4)	1,320 feet	(2)
Roads	1,000 feet	(1)	1,000 feet	(1)

- Landfills. Table 2 presents the range of values and the most common state buffer zone restrictions for landfills.

Table 2
State Buffer Zone Restrictions for Landfills

Buffer Zone Category	Range of Values—minimum distance (number of states with this common value)		Most Common Value (number of states with this common value)	
Groundwater Table	1 to 15 feet	(12)	5 feet	(4)
Property Boundaries	20 to 600 feet	(14)	100 feet	(7)
Drinking Water Wells	500 to 1,320 feet	(9)	500 feet 600 feet 1,200 feet	(2) (2) (2)
Public Water Supply	400 to 5,280 feet	(13)	1,200 feet	(3)
Surface Water Body	100 to 2,000 feet	(20)	100 feet 1,000 feet	(5) (5)
Houses or Buildings	200 to 1,320 feet	(14)	500 feet	(7)
Roads	50 to 1,000 feet	(8)	1,000 feet	(5)
Park Land	1,000 to 5,280 feet	(7)	1,000 feet	(4)
Fault Areas	200 feet	(2)	200 feet	(2)

- Waste Piles. Table 3 presents the state buffer zone restrictions for waste piles. Of the four states with buffer zone restrictions, only two states specified minimum distances.

Table 3
State Buffer Zone Restrictions for Waste Piles

Buffer Zone Category	Range of Values-minimum distance (number of states with this common value)		Most Common Value (number of states with this common value)	
Groundwater Table	4 feet*	(1)	4 feet*	(1)
Property Boundaries	50 feet	(1)	50 feet	(1)
Surface Water Body	50 feet	(1)	50 feet	(1)
Houses or Buildings or Recreational Area	200 feet	(1)	200 feet	(1)
Historic Archeological Site or Critical Habitat	Minimum distance not specified	(1)	Minimum distance not specified	(1)

* If no liner or storage pad is used, then this state requires four feet between the waste and the seasonal high water table.

- Land Application.[20] Table 4 presents the range of values and the most common state buffer zone restrictions for land application.

Table 4
State Buffer Zone Restrictions for Land Application

Buffer Zone Category	Range of Values-minimum distance (number of states with this common value)		Most Common Value (number of states with this common value)	
Groundwater Table	4 to 5 feet	(3)	4 feet 5 feet	(1) (1)
Property Boundaries	50 to 200 feet	(4)	50 feet	(2)
Drinking Water Wells	200 to 500 feet	(2)	200 feet 500 feet	(1) (1)
Public Water Supply	300 to 5,280 feet	(3)	300 feet 1,000 feet 5,280 feet	(1) (1) (1)
Surface Water Body	100 to 1,000 feet	(5)	100 feet	(2)
Houses or Buildings	200 to 3,000 feet	(6)	300 feet 500 feet	(2) (2)
Park Land	2,640 feet	(1)	2,640 feet	(1)
Fault Areas	200 feet	(1)	200 feet	(1)
Max. Depth of Treatment	5 feet	(1)	5 feet	(1)
Pipelines	25 feet	(1)	25 feet	(1)
Critical Habitat	No minimum distance set	(2)	No minimum distance set	(2)
Soil Conditions	Not on frozen, ice or snow covered, or water saturated soils	(1)	Not on frozen, ice or snow covered, or water saturated soils	(1)

[20] In the review of state regulations performed to develop Table 5, it was not possible to distinguish between units used for treatment and units where wastes are added as a soil amendment. It is recommended that you consult applicable state agencies to determine which buffer zone restrictions are relevant to your land application unit.

Based on the review of state requirements, Table 5 presents the most common buffer zones restrictions across all four unit types.

Table 5
Common Buffer Zone Restrictions Across All Four Unit Types

Buffer Zone Category (total number of states for all unit types)		Most Common Values (number of states with this common value)	
Groundwater Table	(20)	4 feet 5 feet	(4) (4)
Property Boundaries	(23)	50 feet 100 feet	(8) (5)
Drinking Water Wells	(13)	500 feet	(3)
Public Water Supply	(20)	1,000 feet 1,200 feet 5,280 feet	(3) (3) (3)
Surface Water Body	(30)	100 feet 200 feet 1,000 feet	(5) (5) (7)
Houses or Buildings	(25)	500 feet	(9)

Part II
Protecting Air Quality

Chapter 5
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This chapter will help you address:

- *Airborne particulates and air emissions that can cause human health risks and damage the environment by adopting controls to minimize particulate emissions.*
- *Assessing risks associated with air emissions and implementing pollution prevention, treatment, or controls as needed to reduce risks for a facility's waste management units not addressed by requirements under the Clean Air Act.*
- *Using a Clean Air Act Title V permit, at facilities that must obtain one, as a vehicle for addressing air emissions from certain waste management units.*

Health effects from airborne pollutants can be minor and reversible (such as eye irritation), debilitating (such as asthma), or chronic and potentially fatal (such as cancer). Potential health impacts depend on many factors, including the quantity of air pollution to which people are exposed, the duration of exposures, and the toxicity associated with specific pollutants. An air risk assessment takes these factors into account to predict the risk or hazards posed at a particular site or facility.

> This chapter will help you address the following questions.
>
> - Is a particular facility subject to CAA requirements?
> - What is an air risk assessment?
> - Do waste management units pose risks from volatile air emissions?
> - What controls will reduce particulate and volatile emissions from a facility?

Air releases from waste management units include particulates or wind-blown dust and gaseous emissions from volatile compounds

It is recommended that every facility implement controls to address emissions of airborne particulates. Particulates have immediate and highly visible impacts on surrounding neighborhoods. They can affect human health and can carry constituents off site as well. Generally, controls are achieved through good operating practices.

For air releases from industrial waste management units, you need to know what regulatory requirements under the Clean Air Act (CAA) apply to your facility, and whether those requirements address waste management units. The followup question for facilities whose waste management units are not addressed by CAA requirements, is "are there risks from air releases that should be controlled?"

This Guide provides two tools to help you answer these questions. First, this chapter includes an overview of the major emission control requirements under the CAA and a decision guide to evaluate which of these might apply to a facility. The steps of the decision guide are summarized in Figure 1. Each facility subject to any of these requirements will most likely be required to obtain a CAA Title V operating permit. The decision guide will help you clarify some of the key facility information you need to identify applicable CAA requirements.

If your answers in the decision guide indicate that the facility is or might be subject to specific regulatory obligations, the next step is to consult with EPA, state, or local air quality program staff. Some CAA regulations are industry-specific and operation-specific within an industry, while others are pollutant specific or specific to a geographic area. EPA, state, or local air quality managers can help you precisely determine applicable requirements and whether waste management units are addressed by those requirements.

You might find that waste management units are not addressed or that a specific facility clearly does not fit into any regulatory category under the CAA. It is then prudent to look beyond immediate permit requirements to assess risks associated with volatile organic compounds (VOCs) released from the unit. A two-tiered approach to this assessment is recommended, depending on the complexity and amount of site specific data you have.

Limited Site-Specific Air Assessment: The CD-ROM version of the Guide contains the Industrial Waste Air Model (IWAIR). If a waste contains any of the 95 constituents included in the model, you can use this risk model to assess whether VOC emissions pose a risk that warrants additional emission controls or that could be addressed more effectively with pollution prevention or waste treatment before placement in the waste management unit. The IWAIR model allows users to supply inputs for an emission estimate and for a dispersion factor for the unit.

Comprehensive Risk Assessment: This assessment relies on a comprehensive analysis of waste and site-specific data and use of models designed to assess multi-pathway exposures to airborne contaminants. There are a number of modeling tools available for this analysis. You should consult closely with your air quality management agency as you proceed.

Airborne emissions are responsible for the loss of visibility between the left and right photographs of the Grand Canyon. Source: National Park Service, Air Resources Division.

I. Federal Airborne Emission Control Programs

Four major federal programs address airborne emissions that can degrade air quality. For more information about the CAA and EPA's implementation of it, visit the Technology Transfer Network, EPA's premier technical Web site for information transfer and sharing related to air pollution topics, at **<www.epa.gov/ttn>**.

If the facility is a major source or otherwise subject to Title V of the CAA, the owner must obtain a Title V operating permit. These permits are typically issued by the state air permitting authority. As part of the permitting process, you will be required to develop an emissions inventory for the facility. Some states have additional permitting requirements. Whether or not emissions from a waste management unit will be specifically addressed through the permit process depends on a number of factors, including the type of facility and state permitting resources and priorities. It is prudent, however, where there are no applicable air permit requirements to assess whether there might be risks associated with waste management units and to address these risks.

A. National Ambient Air Quality Standards

The CAA authorizes EPA to establish emission limits to achieve National Ambient Air Quality Standards (NAAQS).[1] EPA has designated NAAQS for the following criteria pollutants: ozone, sulfur dioxide, nitrogen dioxide, lead, particulate matter (PM), and carbon monoxide. The NAAQS establish individual pollutant concentration ceilings that should be rarely exceeded in a predetermined geographical area (National Ambient Air Quality District). NAAQS are not enforced directly by EPA. Instead, each state must submit a State Implementation Plan (SIP) describing how it will achieve or maintain NAAQS. Many SIPs call for airborne emission limits on industrial facilities.

If a waste emits VOCs, some of which are precursors to ozone, the waste management unit could be affected by EPA's NAAQS for ground-level ozone. Currently, states are implementing an ozone standard of 0.12 parts per million (ppm) as measured over a 1-hour period. In 1997, EPA promulgated a revised standard of 0.08 ppm with an 8-hour averaging time to protect public health and the environment over longer exposure periods[2] (see 62 FR 38856, July 18, 1997). EPA is currently developing regulations and guidance for implementing the 8-hour ozone standard. EPA expects to designate areas as attaining or not attaining the standard in 2004. At that time, areas not attaining the standard will need to develop plans to control emissions and to demonstrate how they will reach attainment. Consult with your state to determine whether efforts to comply with the ozone NAAQS involve VOC emission limits that apply to a specific facility. General questions about the 8-hour standard should be directed to EPA's Office of Air Quality Planning and Standards, Air Quality Strategies and Standards Division, Ozone Policy and Strategies Group, MD-15, Research Triangle Park, NC 27711, telephone 919 541-5244.

B. New Source Performance Standards

New Source Performance Standards (NSPSs) are issued for categories of sources that cause or contribute significant air pollu-

[1] 42 U.S.C. § 7409

[2] For a discussion of the history of the litigation over the revised ozone standard and EPA's plan for implementing it, including possible revisions to 40 CFR 50.9(b), see 67 FR 48896 (July 26, 2002).

tion that can reasonably be anticipated to endanger public health or welfare. For industry categories, NSPSs establish national technology-based emission limits for air pollutants, such as particulate matter (PM) or VOCs. States have primary responsibility for assuring that the NSPSs are followed. These standards are distinct from NAAQS because they establish direct national emission limits for specified sources, while NAAQS establish air quality targets that states meet using a variety of measures that include emission limits. Table 1 lists industries for which NSPSs have been established and locations of the NSPSs in the Code of Federal Regulations. You should check to see if any of the 74 New Source Performance Standards (NSPSs)[3] apply to the facility.[4] Any facility subject to a NSPS must obtain a Title V permit (see Section D below.).

C. National Emission Standards for Hazardous Air Pollutants

Section 112 of the CAA Amendments of 1990[5] requires EPA to establish national standards to reduce emissions from a set of certain pollutants called hazardous air pollutants (HAPs). Section 112(b) contains a list of 188 HAPs (see Table 2) to be regulated by National Emission Standards for Hazardous Air Pollutants (NESHAPs) referred to as Maximum Achievable Control Technology (MACT) standards, that are generally set on an industry-by-industry basis.

MACT standards typically apply to major sources in specified industries; however, in some instances, non-major sources also can be subject to MACT standards. A major source is defined as any stationary source or group of stationary sources that (1) is located within a contiguous area and under common control, and (2) emits or has the potential to emit at least 10 tons per year (tpy) of any single HAP or at least 25 tpy of any combination of HAPs. All fugitive emissions of HAPs, including emissions from waste management units, are to be taken into account in determining whether a stationary source is a major source. Each MACT standard might limit specific operations, processes, or wastes that are covered. Some MACT standards specifically cover waste management units, while others do not. If a facility is covered by a MACT standard, it must be permitted under Title V (see below).

EPA has identified approximately 170 industrial categories and subcategories that are or will be subject to MACT standards. Table 3 lists the categories for which standards have been finalized, proposed, or are expected. The CAA calls for EPA to promulgate the standards in four phases. EPA is currently in the fourth and final phase of developing proposed regulations.

CAA also requires EPA to assess the risk to public health remaining after the implementation of NESHAPs and MACT standards. EPA must determine if more stringent standards are necessary to protect public health with an ample margin of safety or to prevent an adverse environmental effect. As a first step in this process the CAA requires EPA to submit a Report to Congress on its methods for making the health risks from residual emissions determination. The final report, Residual Risk Report to Congress (U.S. EPA, 1997b), was signed on March 3, 1999 and is available from EPA's Web site at **<www.epa.gov/ttn/oarpg/t3/reports/risk_rep.pdf>**. If significant residual risk exists after application of a MACT, EPA must promulgate health-based standards for that source category to further reduce HAP emissions. EPA must set residual risk standards within 8 years after promulgation of each NESHAP.

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[3] 40 CFR Part 60.

[4] While NSPSs apply to new facilities, EPA also established emission guidelines for existing facilities.

[5] 42 U.S.C. § 7412.

Table 1. Industries for Which NSPSs Have Been Established

For electronic versions of the 40 CFR Part 60 subparts referenced below, visit <**www.access.gpo.gov/nara/cfr**>. Be sure to check the Federal Register for updates that have been published since publication of this Guide.

Facility	40 CFR Part 60 subpart
Ammonium Sulfate Manufacture	PP
Asphalt Processing & Asphalt Roofing Manufacture	UU
Auto/ld Truck Surface Coating Operations	MM
Basic Oxygen Process Furnaces after 6/11/73	N
Beverage Can Surface Coating Industry	WW
Bulk Gasoline Terminals	XX
Calciners and Dryers in Mineral Industry	UUU
Coal Preparation Plants	Y
Commercial & Industrial SW Incinerator Units	CCCC
Electric Utility Steam Generating Units after 9/18/78	DA
Equipment Leaks of VOC in Petroleum Refineries	GGG
Equipment Leaks of VOC in SOCMI	VV
Ferroalloy Production Facilities	Z
Flexible Vinyl & Urethane Coating & Printing	FFF
Fossil-fuel Fired Steam Generators after 8/17/71	D
Glass Manufacturing Plants	CC
Grain Elevators	DD
Graphic Arts: Publication Rotogravure Printing	QQ
Hot Mix Asphalt Facilities	I
Incinerators	E
Industrial Surface Coating, Plastic Parts	TTT
Industrial Surface Coating-Large Appliances	SS
Industrial-Commercial-Institutional Steam Generation Unit	DB
Kraft Pulp Mills	BB
Large Municipal Waste Combustors after 9/20/94	EB
Lead-Acid Battery Manufacturing Plants	KK
Lime Manufacturing	HH
Magnetic Tape Coating Facilities	SSS
Medical Waste Incinerators (MWI) after 6/20/96	EC
Metal Coil Surface Coating	TT
Metallic Mineral Processing Plants	LL
Municipal Solid Waste Landfills after 5/30/91	WWW
Municipal Waste Combustors (MWC)	EA
New Residential Wood Heaters	AAA
Nitric Acid Plants	G
Nonmetallic Mineral Processing Plants	OOO
Onshore Natural Gas Processing Plants, VOC Leaks	KKK
Onshore Natural Gas Processing: SO_2 Emissions	LLL
Petroleum Dry Cleaners, Rated Capacity 84 Lb	JJJ
Petroleum Refineries	J
Petroleum Refinery Wastewater Systems	QQQ
Phosphate Fertilizer-Wet Process Phosphoric Acid	T
Phosphate Fertilizer-Superphosphoric Acid	U
Phosphate Fertilizer-Diammonium Phosphate	V
Phosphate Fertilizer-Triple Superphosphate	W
Phosphate Fertilizers: GTSP Storage Facilities	X
Phosphate Rock Plants	NN
Polymer Manufacturing Industry	DDD
Polymeric Coating of Supporting Substrates Fac.	VVV
Portland Cement Plants	F
Pressure Sensitive Tape & Label Surface Coating	RR
Primary Aluminum Reduction Plants	S
Primary Copper Smelters	P
Primary Lead Smelters	R
Primary Zinc Smelters	Q
Rubber Tire Manufacturing Industry	BBB
Secondary Brass and Bronze Production Plants	M
Secondary Lead Smelters	L
Sewage Treatment Plants	O
Small Indust./Comm./Institut. Steam Generating Units	DC
Small Municipal Waste Combustion Units	AAAA
SOCMI - Air Oxidation Processes	III
SOCMI - Distillation Operations	NNN
SOCMI Reactors	RRR
SOCMI Wastewater	YYY
Stationary Gas Turbines	GG
Steel Plants: Elec. Arc Furnaces after 08/17/83	AAA
Steel Plants: Electric Arc Furnaces	AA
Storage Vessels for Petroleum Liquids (6/73–5/78)	K
Storage Vessels for Petroleum Liquids (5/78–6/84)	KA
Sulfuric Acid Plants	H
Surface Coating of Metal Furniture	EE
Synthetic Fiber Production Facilities	HHH
Volatile Storage Vessel (Incl. Petroleum) after 7/23/84	KB
Wool Fiberglass Insulation Manufacturing Plants	PPP

Table 2
HAPs Defined in Section 112 of the CAA Amendments of 1990

CAS#	CHEMICAL NAME
75-07-0	Acetaldehyde
60-35-5	Acetamide
75-05-8	Acetonitrile
98-86-2	Acetophenone
53-96-3	2-Acetylaminofluorene
107-02-8	Acrolein
79-06-1	Acrylamide
79-10-7	Acrylic acid
107-13-1	Acrylonitrile
107-05-1	Allyl chloride
92-67-1	4-Aminobiphenyl
62-53-3	Aniline
90-04-0	o-Anisidine
1332-21-4	Asbestos
71-43-2	Benzene (including benzene from gasoline)
92-87-5	Benzidine
98-07-7	Benzotrichloride
100-44-7	Benzyl chloride
92-52-4	Biphenyl
117-81-7	Bis(2-ethylhexyl) phthalate (DEHP)
542-88-1	Bis(chloromethyl)ether
75-25-2	Bromoform
106-99-0	1,3-Butadiene
156-62-7	Calcium cyanamide
133-06-2	Captan
63-25-2	Carbaryl
75-15-0	Carbon disulfide
56-23-5	Carbon tetrachloride
463-58-1	Carbonyl sulfide
120-80-9	Catechol
133-90-4	Chloramben
57-74-9	Chlordane
7782-50-5	Chlorine
79-11-8	Chloroacetic acid
532-27-4	2-Chloroacetophenone
108-90-7	Chlorobenzene
510-15-6	Chlorobenzilate
67-66-3	Chloroform
107-30-2	Chloromethyl methyl ether
126-99-8	Chloroprene
1319-77-3	Cresols/Cresylic acid (isomers and mixture)
95-48-7	o-Cresol
108-39-4	m-Cresol
106-44-5	p-Cresol
98-82-8	Cumene
94-75-7	2,4-D, salts and esters
72-55-9	DDE
334-88-3	Diazomethane
132-64-9	Dibenzofurans
96-12-8	1,2-Dibromo-3-chloropropane
84-74-2	Dibutylphthalate
106-46-7	1,4-Dichlorobenzene(p)
91-94-1	3,3-Dichlorobenzidene
111-44-4	Dichloroethyl ether (Bis(2-chloroethyl)ether)
542-75-6	1,3-Dichloropropene
62-73-7	Dichlorvos
111-42-2	Diethanolamine
121-69-7	N,N-Diethyl aniline (N,N-Dimethylaniline)
64-67-5	Diethyl sulfate
119-90-4	3,3-Dimethoxybenzidine
60-11-7	Dimethyl aminoazobenzene
119-93-7	3,3'-Dimethyl benzidine
79-44-7	Dimethyl carbamoyl chloride
68-12-2	Dimethyl formamide
57-14-7	1,1-Dimethyl hydrazine
131-11-3	Dimethyl phthalate
77-78-1	Dimethyl sulfate
534-52-1	4,6-Dinitro-o-cresol, and salts
51-28-5	2,4-Dinitrophenol
121-14-2	2,4-Dinitrotoluene
123-91-1	1,4-Dioxane (1,4-Diethyleneoxide)
122-66-7	1,2-Diphenylhydrazine
106-89-8	Epichlorohydrin (l-Chloro- 2,3-epoxypropane)
106-88-7	1,2-Epoxybutane
140-88-5	Ethyl acrylate
100-41-4	Ethyl benzene
51-79-6	Ethyl carbamate (Urethane)
75-00-3	Ethyl chloride (Chloroethane)
106-93-4	Ethylene dibromide (Dibromoethane)
107-06-2	Ethylene dichloride (1,2-Dichloroethane)
107-21-1	Ethylene glycol
151-56-4	Ethylene imine (Aziridine)
75-21-8	Ethylene oxide
96-45-7	Ethylene thiourea
75-34-3	Ethylidene dichloride (1,1-Dichloroethane)
50-00-0	Formaldehyde
76-44-8	Heptachlor
118-74-1	Hexachlorobenzene
87-68-3	Hexachlorobutadiene
77-47-4	Hexachlorocyclopenta-diene
67-72-1	Hexachloroethane
822-06-0	Hexamethylene-1,6-diisocyanate
680-31-9	Hexamethylphosphor-amide
110-54-3	Hexane
302-01-2	Hydrazine
7647-01-0	Hydrochloric acid
7664-39-3	Hydrogen fluoride (Hydrofluoric acid)
123-31-9	Hydroquinone
78-59-1	Isophorone
58-89-9	Lindane (all isomers)
108-31-6	Maleic anhydride
67-56-1	Methanol
72-43-5	Methoxychlor
74-83-9	Methyl bromide (Bromomethane)
74-87-3	Methyl chloride (Chloromethane)
71-55-6	Methyl chloroform (1,1,1-Trichloroethane)
78-93-3	Methyl ethyl ketone (2-Butanone)
60-34-4	Methyl hydrazine
74-88-4	Methyl iodide (Iodomethane)
108-10-1	Methyl isobutyl ketone (Hexone)
624-83-9	Methyl isocyanate
80-62-6	Methyl methacrylate
1634-04-4	Methyl tert butyl ether
101-14-4	4,4-Methylene bis(2-chloroaniline)
75-09-2	Methylene chloride (Dichloromethane)
101-68-8	Methylene diphenyl diisocyanate (MDI)
101779	4,4'-Methylenedianiline
91-20-3	Naphthalene
98-95-3	Nitrobenzene
92-93-3	4-Nitrobiphenyl
100-02-7	4-Nitrophenol
79-46-9	2-Nitropropane
684-93-5	N-Nitroso-N-methylurea
62-75-9	N-Nitrosodimethylamine
59-89-2	N-Nitrosomorpholine
56-38-2	Parathion
82-68-8	Pentachloronitrobenzene (Quintobenzene)
87-86-5	Pentachlorophenol
108-95-2	Phenol
106-50-3	p-Phenylenediamine
75-44-5	Phosgene
7803-51-2	Phosphine

Table 2

HAPs Defined in Section 112 of the CAA Amendments of 1990 (cont)

CAS#	CHEMICAL NAME
7723-14-0	Phosphorus
85-44-9	Phthalic anhydride
1336-36-3	Polychlorinated biphenyls (Aroclors)
1120-71-4	1,3-Propane sultone
57-57-8	beta-Propiolactone
123-38-6	Propionaldehyde
114-26-1	Propoxur (Baygon)
78-87-5	Propylene dichloride (1,2-Dichloropropane)
75-56-9	Propylene oxide
75-55-8	1,2-Propylenimine (2-Methyl aziridine)
91-22-5	Quinoline
106-51-4	Quinone (p-Benzoquinone)
100-42-5	Styrene
96-09-3	Styrene oxide
1746-01-6	2,3,7,8-Tetrachlorodi-benzo-p-dioxin
79-34-5	1,1,2,2-Tetrachloroethane
127-18-4	Tetrachloroethylene (Perchloroethylene)
7550-45-0	Titanium tetrachloride
108-88-3	Toluene
95-80-7	2,4-Toluene diamine
584-84-9	2,4-Toluene diisocyanate
95-53-4	o-Toluidine
8001-35-2	Toxaphene (chlorinated camphene)
120-82-1	1,2,4-Trichlorobenzene
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
95-95-4	2,4,5-Trichlorophenol
88-06-2	2,4,6-Trichlorophenol
121-44-8	Triethylamine
1582-09-8	Trifluralin
540-84-1	2,2,4-Trimethylpentane
108-05-4	Vinyl acetate
593-60-2	Vinyl bromide
75-01-4	Vinyl chloride
75-35-4	Vinylidene chloride (1,1-Dichloroethylene)
1330-20-7	Xylenes (mixed isomers)
95-47-6	o-Xylenes
108-38-3	m-Xylenes
106-42-3	p-Xylenes
[none]	Antimony Compounds
[none]	Arsenic Compounds (inorganic including arsine)
[none]	Beryllium Compounds
[none]	Cadmium Compounds
[none]	Chromium Compounds
[none]	Cobalt Compounds
[none]	Coke Oven Emissions
[none]	Cyanide Compounds[a]
[none]	Glycol ethers[b]
[none]	Lead Compounds
[none]	Manganese Compounds
[none]	Mercury Compounds
[none]	Fine mineral fibers[c]
[none]	Nickel Compounds
[none]	Polycylic Organic Matter[d]
[none]	Radionuclides (including radon)[e]
[none]	Selenium Compounds

NOTE: For all listings above which contain the word "compounds" and for glycol ethers, the following applies: Unless otherwise specified, these listings are defined as including any unique chemical substance that contains the named chemical (i.e., antimony, arsenic, etc.) as part of that chemical's infrastructure.

a X'CN where X = H' or any other group where a formal dissociation can occur. For example KCN or $Ca(CN)_2$.

b On January 12, 1999 (64 FR 1780), EPA proposed to modify the definition of glycol ethers to exclude surfactant alcohol ethoxylates and their derivatives (SAED). On August 2, 2000 (65 FR 47342), EPA published the final action. This action deletes each individual compound in a group called the surfactant alcohol ethoxylates and their derivatives (SAED) from the glycol ethers category in the list of hazardous air pollutants (HAP) established by section 112(b)(1) of the Clean Air Act (CAA). EPA also made conforming changes in the definition of glycol ethers with respect to the designation of hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).
"The following definition of the glycol ethers category of hazardous air pollutants applies instead of the definition set forth in 42 U.S.C. 7412(b)(1), footnote 2: Glycol ethers include mono- and di-ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-(OCH_2CH_2)n-OR'
Where:
n= 1, 2, or 3
R= alkyl C7 or less, or phenyl or alkyl substituted phenyl
R'= H, or alkyl C7 or less, or carboxylic acid ester, sulfate, phosphate, nitrate, or sulfonate.

c Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less. (Currently under review.)

d Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C. (Currently under review.)

e A type of atom which spontaneously undergoes radioactive decay.

Table 3

Source Categories With MACT Standards

Source Category	Federal Register Citation	Source Category	Federal Register Citation
Fuel Combustion		Marine Vessel Loading Operations	60 FR 48399(F) 9/19/95
Coal- and Oil-fired Electric Utility Steam Generating Units	65 FR 79825(N) 12/20/00	Organic Liquids Distribution (Non-Gasoline)	*
Combustion Turbines	*	**Surface Coating Processes**	
Engine Test Facilities	*	Aerospace Industries	60 FR 45956(F) 9/1/15
Industrial Boilers	*	Auto and Light Duty Truck	*
Institutional/Commercial Boilers	*	Flat Wood Paneling	64 FR 63025(N) 11/18/99
Process Heaters	*	Large Appliance	65 FR 81134(P) 12/22/00
Reciprocating Internal Combustion Engines	*	Magnetic Tapes	59 FR 64580(F) 12/15/94
Rocket Testing Facilities	*	Manufacture of Paints, Coatings, and Adhesives	*
Non-Ferrous Metals Processing		Metal Can	*
Primary Aluminum Production	62 FR 52383(F) 10/7/97	Metal Coil	65 FR 44616(P) 7/18/00
Primary Copper Smelting	63 FR 19582(P) 4/20/98	Metal Furniture	*
Primary Lead Smelting	64 FR 30194(F) 6/4/99	Miscellaneous Metal Parts and Products	*
Primary Magnesium Refining	*	Paper and Other Webs	65 FR 55332(P) 9/13/00
Secondary Aluminum Production	65 FR 15689(F) 3/23/00	Plastic Parts and Products	*
Secondary Lead Smelting	60 FR 32587(F) 6/23/95	Printing, Coating, and Dyeing of Fabrics	*
Ferrous Metals Processing		Printing/Publishing	61 FR 27132(F) 5/30/96
Coke Ovens: Charging, Top Side, and Door Leaks	58 FR 57898(F) 10/27/93	Shipbuilding and Ship Repair	60 FR 64330(F) 12/16/96
Coke Ovens: Pushing, Quenching and Battery Stacks	66 FR 35327(P) 7/3/01	Wood Building Products	*
Ferroalloys Production		Wood Furniture	60 FR 62930(F) 12/7/95
Silicomanganese and Ferromanganese	64 FR 27450(F) 5/20/00	**Waste Treatment and Disposal**	
Integrated Iron and Steel Manufacturing	66 FR 36835(P) 7/13/01	Hazardous Waste Incineration	64 FR 52828(F) 9/30/99
Iron Foundries	*	Municipal Solid Waste Landfills	65 FR 66672(P) 11/7/00
Steel Foundries	*	Off-Site Waste and Recovery Operations	61 FR 34140(F) 7/1/96
Steel Pickling–HCl Process Facilities and Hydrochloric Acid Regeneration Plants	64 FR 33202(F) 6/22/99	Publicly Owned Treatment Works	64 FR 57572(F) 10/26/99
Mineral Products Processing		Site Remediation	*
Asphalt Processing	*	**Agricultural Chemicals Production**	
Asphalt Roofing Manufacturing	*	Pesticide Active Ingredient Production	64 FR 33549(F) 6/23/99
Asphalt/Coal Tar Application–Metal Pipes	*	**Fibers Production Processes**	
Clay Products Manufacturing	*	Acrylic Fibers/Modacrylic Fibers	64 FR 34853(F) 6/30/99
Lime Manufacturing	*	Spandex Production	65 FR 76408(P) 12/6/00
Mineral Wool Production.	64 FR 29490(F) 6/1/99	**Food and Agriculture Processes**	
Portland Cement Manufacturing	64 FR 31897(F) 6/14/99	Manufacturing of Nutritional Yeast	66 FR 27876(F) 5/21/01
Refractories Manufacturing	*	Solvent Extraction for Vegetable Oil Production	66 FR 19006(F) 4/12/01
Taconite Iron Ore Processing	*	Vegetable Oil Production	66 FR 8220(N) 1/30/01
Wool Fiberglass Manufacturing	64 FR 31695(F) 6/14/99	**Pharmaceutical Production Processes**	
Petroleum and Natural Gas Production and Refining		Pharmaceuticals Production	66 FR 40121(F) 6/1/99
Oil and Natural Gas Production	64 FR 32610(F) 6/17/99	**Polymers and Resins Production**	
Natural Gas Transmission and Storage	64 FR 32610(F) 6/17/99	Acetal Resins Production	64 FR 34853(F) 6/30/99
Petroleum Refineries–Catalytic Cracking Units, Catalytic Reforming Units, and Sulfur Recovery Units	63 FR 48890(P) 9/11/98	Acrylonitrile-Butadiene-Styrene Production	61 FR 48208(F) 9/12/96
Petroleum Refineries–Other Sources Not Distinctly Listed	60 FR 43244(F) 8/18/95	Alkyd Resins Production	*
Liquids Distribution		Amino Resins Production	65 FR 3275(F) 1/20/00
Gasoline Distribution (Stage 1)	59 FR 64303(F) 12/14/94	Boat Manufacturing	66 FR 44218(F) 8/22/01
		Butyl Rubber Production	61 FR 46906(F) 9/5/96
		Cellulose Ethers Production	65 FR 52166(P) 8/28/00
		Epichlorohydrin Elastomers Production	61 FR 46906(F) 9/5/96

Table 3

Source Categories With MACT Standards (cont.)

Source Category	Federal Register Citation
Epoxy Resins Production	60 FR 12670(F) 3/8/95
Ethylene-Propylene Rubber Production	61 FR 46906(F) 9/5/96
Flexible Polyurethane Foam Production	63 FR 53980(F) 10/7/98
Hypalon (tm) Production	61 FR 46906(F) 9/5/96
Maleic Anhydride Copolymers Production	*
Methyl Methacrylate-Acrylonitrile Butadiene-Styrene Production	61 FR 48208(F) 9/12/96
Methyl Methacrylate-Butadiene-Styrene Terpolymers Production	61 FR 48208(F) 9/12/96
Neoprene Production	61 FR 46906(F) 9/5/96
Nitrile Butadiene Rubber Production	61 FR 46906(F) 9/5/96
Nitrile Resins Production	61 FR 48208(F) 9/12/96
Non-Nylon Polyamides Production	60 FR 12670(F) 3/8/95
Phenolic Resins Production	65 FR 3275(F) 1/20/00
Polybutadiene Rubber Production	61 FR 46906(F) 9/5/96
Polycarbonates Production	64 FR 34853(F) 6/30/99
Polyester Resins Production	*
Polyether Polyols Production	64 FR 29420(F) 6/1/99
Polyethylene Terephthalate Production	61 FR 48208(F) 9/12/96
Polymerized Vinylidene Chloride Production	*
Polymethyl Methacrylate Resins Production	*
Polystyrene Production	61 FR 48208(F) 9/12/96
Polysulfide Rubber Production	61 FR 46906(F) 9/5/96
Polyvinyl Acetate Emulsions Production	*
Polyvinyl Alcohol Production	*
Polyvinyl Butyral Production	*
Polyvinyl Chloride and Copolymers Production	65 FR 76958(P) 12/8/00
Reinforced Plastic Composites Production	66 FR 40324(P) 8/2/01
Styrene-Acrylonitrile Production	61 FR 48208(F) 9/12/96
Styrene-Butadiene Rubber and Latex Production	61 FR 46906(F) 9/5/96
Production of Inorganic Chemicals	
Ammonium Sulfate Production–Caprolactam By-Product Plants	*
Carbon Black Production	65 FR 76408(P) 12/6/00
Chlorine Production	*
Cyanide Chemicals Manufacturing	65 FR 76408(P) 12/6/00
Fumed Silica Production	64 FR 63025(N) 11/18/99
Hydrochloric Acid Production	*
Hydrogen Fluoride Production	64 FR 34853(F) 6/30/99
Phosphate Fertilizers Production	64 FR 31358(F) 6/10/99
Phosphoric Acid Manufacturing	64 FR 31358(F) 6/10/99
Production of Organic Chemicals	
Ethylene Processes	65 FR 76408(P) 12/6/00
Quaternary Ammonium Compounds Production	*
Synthetic Organic Chemical Manufacturing	59 FR 19402(F) 4/22/94
Miscellaneous Processes	
Benzyltrimethylammonium Chloride Production	*
Carbonyl Sulfide Production	*
Chelating Agents Production	*
Chlorinated Paraffins Production	*
Chromic Acid Anodizing	60 FR 04948(F) 1/25/95
Combustion Sources at Kraft, Soda, and Sulfite Pulp and Paper Mills	66 FR 3180(F) 1/12/01
Commercial Dry Cleaning (Perchloroethylene)–Transfer Machines	58 FR 49354(F) 9/22/93
Commercial Sterilization Facilities	59 FR 62585(F) 12/6/94
Decorative Chromium Electroplating	60 FR 04948(F) 1/25/95
Ethylidene Norbornene Production	*
Explosives Production	*
Flexible Polyurethane Foam Fabrication Operations	66 FR 41718(P) 8/8/01
Halogenated Solvent Cleaners	59 FR 61801(F) 12/2/94
Hard Chromium Electroplating	60 FR 04948(F) 1/25/95
Hydrazine Production	*
Industrial Cleaning (Perchloroethylene)–Dry-to-Dry machines	58 FR 49354(F) 9/22/93
Industrial Dry Cleaning (Perchloroethylene)–Transfer Machines	58 FR 49354(F) 9/22/93
Industrial Process Cooling Towers	59 FR 46339(F) 9/8/94
Leather Finishing Operations	67 FR 9155(F) 2/27/02
Miscellaneous Viscose Processes	65 FR 52166(F) 8/28/00
OBPA/1,3-Diisocyanate Production	*
Paint Stripping Operations	*
Photographic Chemicals Production	*
Phthalate Plasticizers Production	*
Plywood and Composite Wood Products	*
Pulp and Paper Production	65 FR 80755(F) 12/22/00
Rubber Chemicals Manufacturing	*
Rubber Tire Manufacturing	63 FR 62414(P) 10/18/00
Semiconductor Manufacturing	*
Symmetrical Tetrachloropyridine Production	*
Tetrahydrobenzaldehyde Manufacture	63 FR 26078(F) 5/21/98
Wet-Formed Fiberglass Mat Production	65 FR 34277(P) 5/26/00

This table contains final rules (F), proposed rules (P), and notices (N) promulgated as of February 2002. It does not identify corrections or clarifications to rules. An * denotes sources required by Section 112 of the CAA to have MACT standards by 11/15/00 for which proposed rules are being prepared but have not yet been published.

D. Title V Operating Permits

For many facilities, the new federal operating permit program established under Title V of the CAA will cover all sources of airborne emissions.[6] Generally, it requires a permit for any facility emitting or having the potential to emit more than 100 tpy of any air pollutants though lower thresholds apply in non-attainment areas.[7] Permits are also required for all sources subject to MACT or NSPS standards, the Title IV acid rain program, and new source review permits under Parts C and D of Title V. All airborne emission requirements that apply to an industrial facility, including emission limitations, operational requirements, monitoring requirements, and reporting requirements, will be incorporated in its operating permit. A Title V permit provides a vehicle for ensuring that existing air quality control requirements are appropriately applied to facility emission units.

Under the new program, operating permits that meet federal requirements will generally be issued by state agencies. In developing individual permits, states can determine whether to explicitly apply emission limitations and controls to waste management units. See Section F of this chapter (A Decision Guide to Applicable CAA Requirements), and consult with federal, state, and local air program staff to determine if your waste management unit is subject to airborne emission limits and controls under CAA regulations. Listings of EPA regional and state air pollution control agencies can be obtained from the States and Territorial Air Pollution Program Administrators (STAPPA) & Association of Local Air Pollution Control Officials (ALAPCO). STAPPA/ALAPCO's Web site is **<www.cleanairworld.org/scripts/us_temp.asp?id=307>**.

E. Federal Airborne Emission Regulations for Solid Waste Management Activities

While EPA has not established airborne emission regulations for industrial waste management units under RCRA, standards developed for hazardous waste management units and municipal solid waste landfills (MSWLFs) can serve as a guide in evaluating the need for controls at specific units.

1. Hazardous Waste Management Unit Airborne Emission Regulations

Under Section 3004(n) of RCRA, EPA established standards for the monitoring and control of airborne emissions from hazardous waste treatment, storage, and disposal facilities. Subparts AA, BB, and CC of 40 CFR Part 264 address VOC releases from process vents, equipment leaks, tanks, surface impoundments, and containers. Summaries of Subparts AA, BB, and CC are provided in the text box on the next page.

2. Municipal Solid Waste Landfill Airborne Emission Regulations

On March 12, 1996, EPA promulgated airborne emission regulations for large new and existing MSWLFs.[8] These regulations apply to all new MSWLFs constructed or modified on

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[6] Federal Operating Permit Regulations were promulgated as 40 CFR Part 71 on July 1, 1996 and amended on February 19, 1999 to cover permits in Indian Country and states without fully approved Title V programs.

[7] Under CAA Section 302(g), "air pollutant" is defined as any pollutant agent or combination of agents, including any physical, chemical, biological, or radioactive substance or matter which is emitted into or otherwise enters the ambient air.

[8] 61 FR 9905; March 12, 1996, codified at 40 CFR Subpart WWW and CC (amended 63 FR 32750, June 16, 1998).

or after May 30, 1991, and to existing landfills that have accepted waste on or after November 8, 1987. In addition to methane, MSWLFs potentially emit non-methane organic compounds (NMOCs) in the gases generated during waste decomposition, as well as in combustion of the gases in control devices, and from other sources, such as dust from vehicle traffic and emissions from leachate treatment facilities or maintenance shops. Under the regulations, any affected MSWLF that emits more than 50 Mg/yr (55 tpy) of NMOCs is required to install controls.

Best demonstrated technology requirements for both new and existing municipal landfills prescribe installation of a well-designed and well-operated gas collection system and a control device. The collection system should be designed to allow expansion for new cells that require controls. The control device (presumed to be a combustor) must demonstrate either an NMOC reduction of 98 percent by weight in the collected gas or an outlet NMOC concentration of no more than 20 parts per million by volume (ppmv).

3. Offsite Waste and Recovery Operations NESHAP

On July 1, 1996, EPA established standards for offsite waste and recovery operations

Summary of Airborne Emission Regulations for Hazardous Waste Management Units

Subpart AA regulates organic emissions from process vents associated with distillation, fractionation, thin film evaporation, solvent extraction, and air or stream stripping operations (40 CFR §§264.1030-1036). Subpart AA only applies to these types of units managing hazardous waste streams with organic concentration levels of at least 10 parts per million by weight (ppmw). Subpart AA regulations require facilities with covered process vents to either reduce total organic emissions from all affected process vents at the facility to below 3 lb/h and 3.1 tons/yr, or reduce emissions from all process vents by 95 percent through the use of a control device, such as a closed-vent system, vapor recovery unit, flare, or other combustion unit.

Subpart BB sets inspection and maintenance requirements for equipment, such as valves, pumps, compressors, pressure relief devices, sampling connection systems, open-ended valves or lines, flanges, or control devices that contain or contact hazardous wastes with organic concentrations of at least 10 percent by weight (40 CFR §§264.1050-1065). Subpart BB does not establish numeric criteria for reducing emissions, it simply establishes monitoring, leak detection, and repair requirements.

Subpart CC establishes controls on tanks, surface impoundments, and containers in which hazardous waste has been placed (40 CFR §§264.1080-1091). It applies only to units containing hazardous waste with an average organic concentration greater than 500 ppmw. Units managing hazardous waste that has been treated to reduce the concentrations of organics by 95 percent are exempt. Non-exempt surface impoundments must have either a rigid cover or, if wastes are not agitated or heated, a floating membrane cover. Closed vent systems are required to control the emissions from covered surface impoundments. These control systems must achieve the same 95 percent emission reductions described above under Subpart AA.

(OSWRO) that emit HAPs.[9] To be covered by OSWRO, a facility must emit or have the potential to emit at least 10 tpy of any single HAP or at least 25 tpy of any combination of HAPs. It must receive waste, used oil, or used solvents from off site that contain one or more HAPs.[10] In addition, the facility must operate one of the following: a hazardous waste treatment, storage, or disposal facility; RCRA-exempt hazardous wastewater treatment operation; nonhazardous wastewater treatment facility other than a publicly owned treatment facility; or a RCRA-exempt hazardous waste recycling or reprocessing operation, used solvent recovery operation, or used oil recovery operation.

OSWRO contains MACT standards to reduce HAP emissions from tanks, surface impoundments, containers, oil-water separators, individual drain systems, other material conveyance systems, process vents, and equipment leaks. For example, OSWRO establishes two levels of air emission controls for tanks depending on tank design capacity and the maximum organic HAP vapor pressure of the offsite material in the tank. For process vents, control devices must achieve a minimum of 95 percent organic HAP emission control. To control HAP emissions from equipment leaks, the facility must implement leak detection and repair work practices and equipment modifications for those equipment components containing or contacting offsite waste having a total organic HAP concentration greater than 10 percent by weight (see 40 CFR 63.683(d) cross ref. to 40 CFR 63.680 (c) (3)).

F. A Decision Guide to Applicable CAA Requirements

The following series of questions, summarized in Figure 1, is designed to help you identify CAA requirements that might apply to a facility. This will not give you definitive answers, but can provide a useful starting point for consultation with federal, state, or local permitting authorities to determine which requirements apply to a specific facility and whether such requirements address waste management units at the facility. If a facility is clearly not subject to CAA requirements, assessing potential risks from VOC emissions at a waste management unit using the IWAIR or a site-specific risk assessment is recommended.

The following steps provide a walk through of this evaluation process:

1. Determining Emissions From the Unit

a) Determining VOC's present in the waste (waste characterization). Then assume all the VOC's are emitted from the unit, or

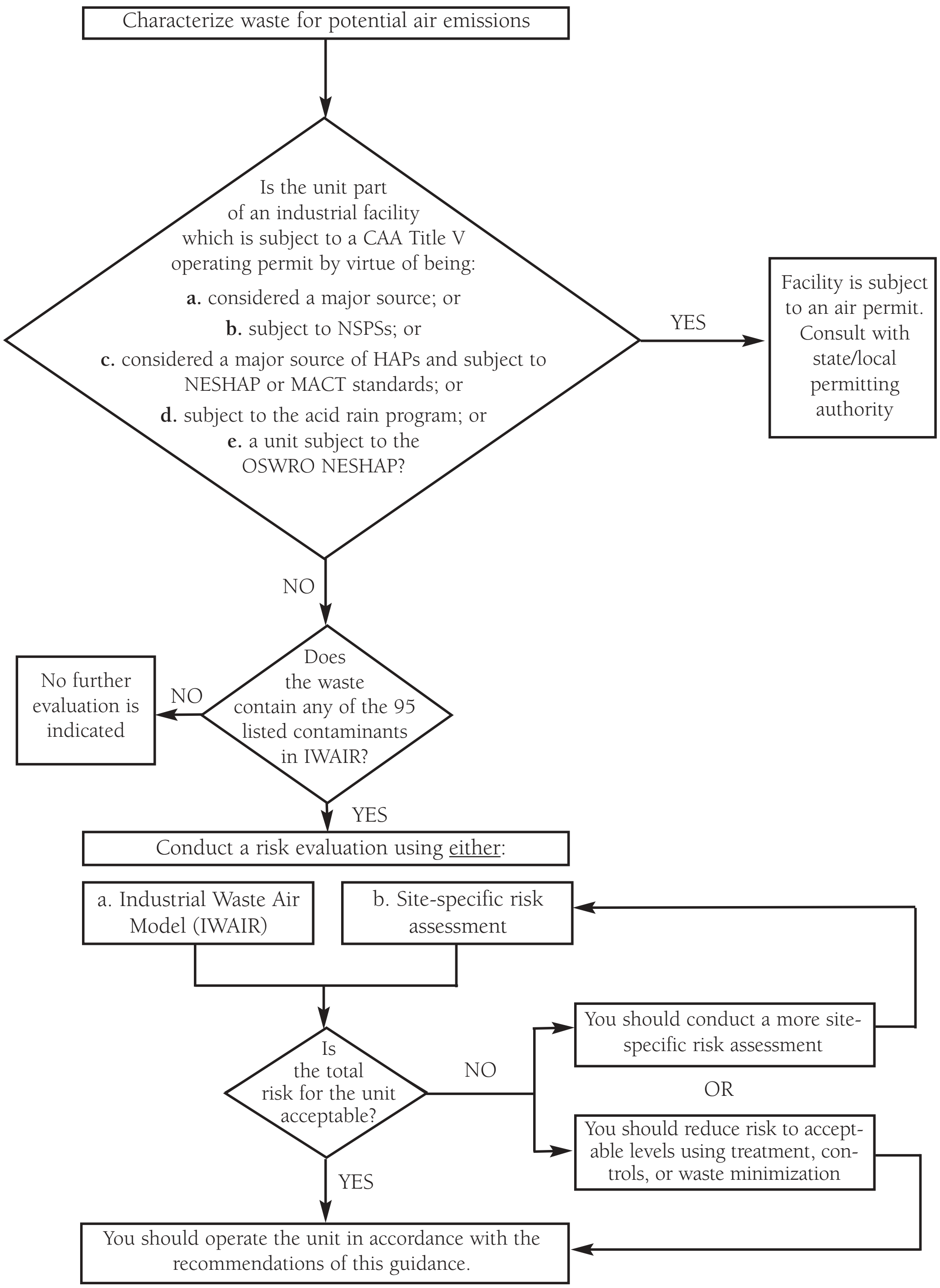
b) Estimating emissions using an emissions model. This also requires waste characterization. The CHEMDAT8 model is a logical model for these types of waste units. You can use the EPA version on the Internet or the one contained in the IWAIR modeling tool for the Guide, or

c) Measuring emissions from the unit. While this is the most resource intensive alternative, measured data will provide the most accurate information.

[9] 61 FR 34139; July 1, 1996, as amended, 64 FR 38970 (July 20, 1999) and 66 FR 1266 (January 8, 2001).

[10] OSWRO identified approximately 100 HAPs to be covered. This HAP list is a subset of the CAA Section 112 list.

Figure 1. Evaluating VOC Emission Risk



2. Is the Waste Management Unit Part of an Industrial Facility That Is Subject to a CAA Title V Operating Permit?

A facility is subject to a Title V operating permit if it is considered a major source of air pollutants, or is subject to a NSPS, NESHAP, or Title IV acid rain provision.[11] As part of the permitting process, the facility should develop an emissions inventory. Some states have additional permitting requirements. If a facility is subject to a Title V operating permit, all airborne emission requirements that apply to an industrial facility, including emission limitations as well as operational, monitoring, and reporting requirements, will be incorporated in its operating permit. You should consult with appropriate federal, state, and local air program staff to determine whether your waste management unit is subject to air emission limits and controls.[12]

If you answer yes to any of the questions in items a. through e. below, the facility is subject to a Title V operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

Whether or not emissions from waste management unit(s) will be specifically addressed through the permit process depends on a number of factors, including the type of facility and CAA requirements and state permitting resources and priorities. It is prudent, when there are no applicable air permit requirements, to assess whether there might be risks associated with waste management units and to address these potential risks.

If you answer no to all the questions below, continue to Step 3.

Stationary source is defined as any building, structure, facility, or installation that emits or may emit any regulated air pollutant or any hazardous air pollutant listed under Section 112 (b) of the Act.

An **air pollutant** is defined as any air pollution agent or combination of agents, including a physical, chemical, biological, radioactive substance or matter which is emitted into or otherwise enters the ambient air.

a. Is the facility considered a major source?

If the facility meets any of the following three definitions, it is considered a major source (under 40 CFR § 70.2) and subject to Title V operating permit requirements.

i. Any **stationary source** or group of stationary sources that emits or has the potential to emit at least 100 tpy of any **air pollutant**.

ii. Any stationary source or group of stationary sources that emits or has the potential to emit at least 10 tpy of any single HAP or at least 25 tpy of any combination of HAPs.

iii. A stationary source or group of stationary sources subject to the nonattainment area provisions of CAA Title I that emits, or has the potential to emit, above the threshold values for its nonattainment area category. The nonattainment area category and the source's emission levels for VOCs and NO_x, particulate matter (PM-10), and carbon monoxide (CO) determine whether the stationary source meets the definition of a "major source." For nonattainment areas, stationary sources are considered "major

[11] EPA can designate additional source categories subject to Title V operating permit requirements.

[12] Implementation of air emission controls can generate new residual waste. Ensure that these wastes are managed appropriately, in compliance with state requirements and consistent with the Guide.

sources" if they emit or have the potential to emit at least the levels found in Table 4 below.

If yes, the facility is subject to a Title V operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine whether the facility is subject to a Title V operating permit.

b. Is the facility subject to NSPSs?

Any stationary source subject to a standard of performance under 40 CFR Part 60 is subject to NSPS. (A list of NSPSs can be found in Table 1 above.)

If yes, the facility is subject to a Title V operating permit. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine if the facility is subject to a Title V operating permit.

c. Is the facility a major source of HAPs as defined by Section 112 of CAA and subject to a NESHAP or MACT standard?

Under Title V of CAA, an operating permit is required for all facilities subject to a MACT standard. NESHAPs or MACT standards are national standards to reduce HAP emissions. Each MACT standard specifies particular operations, processes, and/or wastes that are covered. EPA has identified approximately 170 source categories and subcategories that are or will be subject to MACT standards. (Table 3 above lists the source categories for which EPA is required to promulgate MACT standards.) MACT standards have been or will be promulgated for all major source categories of HAPs and for certain area sources.

If yes, the facility should be permitted under CAA Title V. Consult with the appropriate federal, state, and/or local permitting authority.

If no, continue to determine if the facility must obtain a Title V operating permit.

d. Is the facility subject to the acid rain program under Title IV of CAA?

If a facility, such as a fossil-fuel fired power plant, is subject to emission reduction requirements or limitations under the acid rain program, it must obtain a Title V operating permit (40 CFR § 72.6). The acid rain program focuses on the reduction of annual sulfur dioxide and nitrogen oxides emissions.

Table 4.
Major Source Determination in Nonattainment Areas

Nonattainment Area Category[13]	**VOCs or NO_x**	**PM-10**	**CO**
Marginal or Moderate	100 tpy	100 tpy	100 tpy
Serious	50 tpy	70 tpy	50 tpy
Severe	25 tpy	—	—
Extreme	10 tpy	—	—

[13] The nonattainment categories are based upon the severity of the area's pollution problems. The four categories for VOCs and NO_x range from Moderate to Extreme. Moderate areas are the closest to meeting the attainment standard, and require the least amount of action. Nonattainment areas with more serious air quality problems must implement various control measures. The worse the air quality, the more controls areas will have to implement. PM-10 and CO have only two categories, Moderate and Serious.

A **major source** under Title III is defined as any stationary source or group of stationary sources that emits or has the potential to emit at least 10 tpy of any single hazardous air pollutant (HAP) or at least 25 tpy of any combination of HAPs.

An **area source** is any stationary source which is not a major source but which might be subject to controls. Area sources represent a collection of facilities and emission points for a specific geographic area. Most area sources are small, but the collective volume of large numbers of facilities can be a concern in densely developed areas, such as urban neighborhoods and industrial areas. Examples of areas sources subject to MACT standards include chromic acid anodizing, commercial sterilization facilities, decorative chromium electroplating, hard chromium electroplating, secondary lead smelting, and halogenated solvent cleaners.

HAPs are any of the 188 pollutants listed in Section 112(b) of CAA. (Table 2 above identifies the 188 HAPs.)

If yes, the facility must obtain a Title V permit. Consult with the appropriate federal, state, and/or local permitting authority.

When you consult with the appropriate permitting authority, it is important to clarify whether waste management units at the facility are addressed by the requirements. If waste management units will not be addressed through the permit process, you should evaluate VOC emission risks.

If no, continue to determine if the facility must obtain a Title V operating permit.

e. Is the waste management unit subject to the OSWRO NESHAP? This is just an example of the types of questions you will need to answer to determine whether a NESHAP or MACT standard covers your facility.

To be covered by the OSWRO standards, your facility must meet all these conditions:

i. Be identified as a major source of HAP emissions.

ii. Receive waste, used oil, or used solvents (subject to certain exclusions, 40 CFR 63.680 (b) (2)) from off site that contain one or more HAPs.[14]

iii. Operate one of the following six types of waste management or recovery operations (see 40 CFR 63.680 (a) (2)):

- Hazardous waste treatment, storage, or disposal facility.
- RCRA-exempt hazardous wastewater treatment operation.
- Nonhazardous wastewater treatment facility other than a publicly owned treatment facility.
- RCRA-exempt hazardous waste recycling or reprocessing operation.
- Used solvent recovery operations.
- Used oil recovery operations.

If yes, the unit should be covered by the OSWRO standards and Title V permitting. Consult with the appropriate federal, state, and/or local permitting authority.

If no, it is highly recommended that you conduct an air risk evaluation as set out in step 3.

[14] OSWRO identified approximately 100 HAPs to be covered. This HAP list is a subset of the CAA Section 112 list.

3. *Conducting a Risk Evaluation Using One of the Following Options:*

a. Using IWAIR included with the Guide if your unit contains any of the 95 contaminants that are covered in the model.

b. Initiating a site-specific risk assessment for individual units. Total all target constituents from all applicable units and consider emissions from other sources at the facility as well.

II. Assessing Risk

Air acts as a medium for the transport of airborne contamination and, therefore, constitutes an exposure pathway of potential concern. Models that can predict the fate and transport of chemical emissions in the atmosphere can provide an important tool for evaluating and protecting air quality. The Industrial Waste Air Model (IWAIR) included in the Guide was developed to assist facility managers, regulatory agency staff, and the public in evaluating inhalation risks from waste management unit emissions. Although IWAIR is simple to use, it is still essential to understand the basic concepts of atmospheric modeling to be able to interpret the results and understand the nature of any uncertainties. The purpose of this section is to provide general information on the atmosphere, chemical transport in the atmosphere, and the risks associated with inhalation of chemicals so you can understand important factors to consider when performing a risk assessment for the air pathway.

From a risk perspective, because humans are continuously exposed to air, the presence of chemicals in air is important to consider in any type of assessment. If chemicals build up to high concentrations in a localized area, human health can be compromised. The concentration of chemicals in a localized area and the resulting air pollution that can occur in the atmosphere is dependent upon the quantity and the rate of the emissions from a source and the ability of the atmosphere to disperse the chemicals. Both meteorological and geographic conditions in a local area will influence the emission rate and subsequent dispersion of a chemical. For example, the meteorologic stability of the atmosphere, a factor dependent on air temperature, influences whether the emission stream will rise and mix with a larger volume of air (resulting in the dilution of pollutants) or if the emissions stream will remain close to the ground. Figure 2 is a conceptual diagram of a waste site illustrating potential paths of human exposure through air.

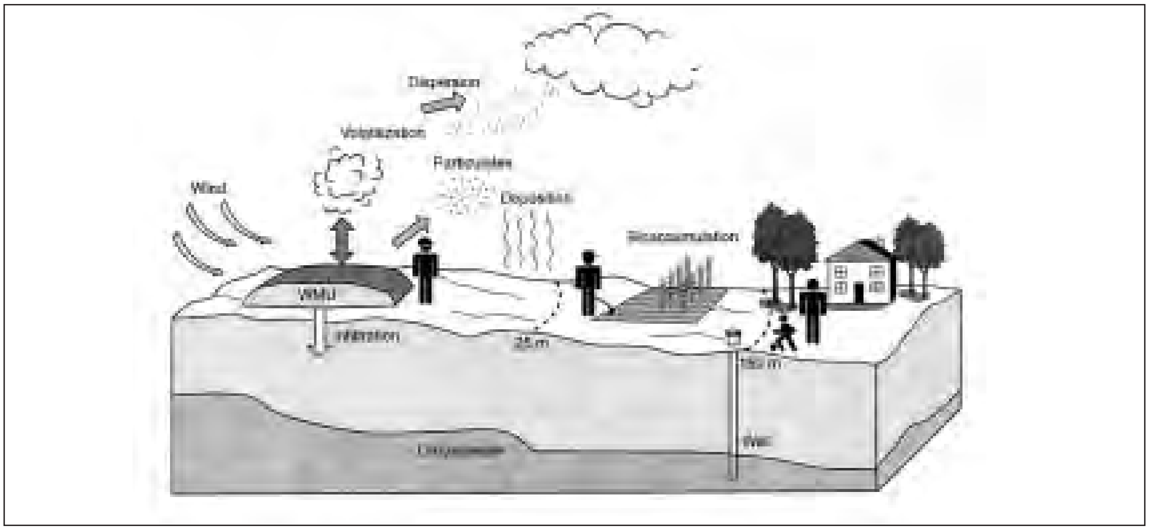
A. Assessing Risks Associated with Inhalation of Ambient Air

In any type of risk assessment, there are basic steps that are necessary for gathering and evaluating data. An overview of some of these steps is presented in this section to assist you in understanding conceptually the information discussed in the IWAIR section (Section B). The components of a risk assessment that are discussed in this section are: identification of chemicals of concern, source characterization, exposure assessment, and risk characterization. Each of these steps is described below as it applies specifically to risk resulting from the inhalation of organic chemicals emitted from waste management units to the ambient air.

Identification of Chemicals of Concern

A preliminary step in any risk assessment is the identification of chemicals of concern. These are the chemicals present that are anticipated to have potential health effects as

Figure 2. Conceptual Site Diagram



a result of their concentrations or toxicity factors. An assessment is performed for a given source, to evaluate chemical concentrations and toxicity of different chemicals. Based on these factors along with potential mechanisms of transport and exposure pathways, the decision is made to include or exclude chemicals in the risk assessment.

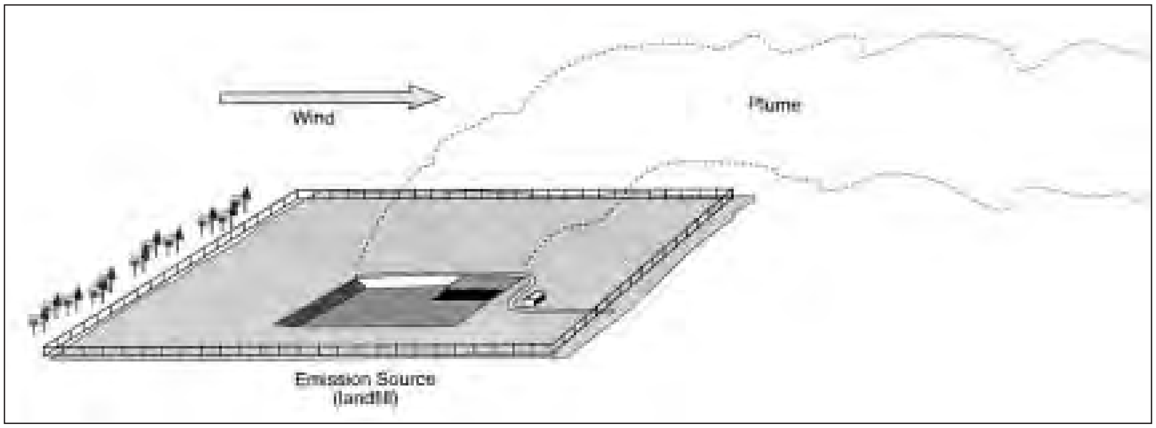
Source Characterization

In this step, the critical aspects of the source (e.g., type of WMU, size, chemical concentrations, location) are necessary to obtain. When modeling an area source, such as those included in the Guide, the amount of a given chemical that volatilizes and disperses from a source is critically dependent on the total surface area exposed. The source characterization should include information on the surface area and elevation of the unit. The volatilization is also dependent on other specific attributes related to the waste management practices. Waste management practices of importance include application frequency in land application units and the degree of aeration that occurs in a surface impoundment. Knowledge of the overall content of the waste being deposited in the WMU is also needed to estimate chemical volatilization. Depending on its chemical characteristics, a chemical can bind with the other constituents in a waste, decreasing its emissions to the ambient air. Source characterization involves defining each of these key parameters for the WMU being modeled. The accuracy of projections concerning volatilization of chemicals from WMUs into ambient air is improved if more site-specific information is used in characterizing the source.

Exposure Assessment

The goal of an exposure assessment is to estimate the amount of a chemical that is available and is taken in by an individual, typically referred to as a receptor. An exposure assessment is performed in two steps: 1) the first step uses fate and transport modeling to determine the chemical concentration in air at a specified receptor location and, 2) the second step estimates the amount of the chemical the receptor will intake by identifying life-style activity patterns. The first step, the fate and transport modeling, uses a combination of an emission and dispersion model to estimate the amount of chemical that individuals residing or working within the vicini-

Figure 3. Emissions from a WMU



ty of the source are exposed to through inhalation of ambient air. When a chemical volatilizes from a WMU into the ambient air, it is subjected to a number of forces that result in its diffusion and transport away from the point of release.

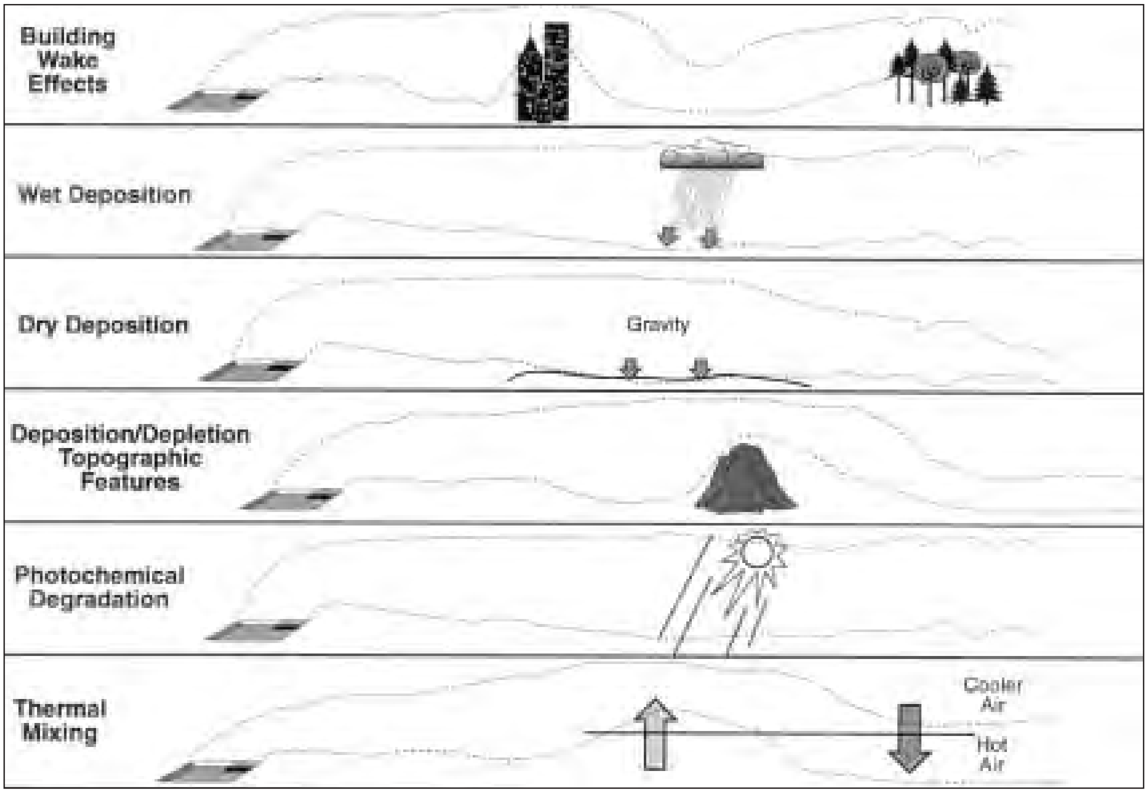
In modeling the movement of the volatile chemical away from the WMU, it is often assumed that the chemical behaves as a plume (i.e., the chemical is continuously emitted into the environment) whose movement is modeled to produce estimated air concentrations at points of interest. This process is illustrated in Figure 3.

The pattern of diffusion and movement of chemicals that volatilize from WMUs depends on a number of interrelated factors. The ultimate concentration and fate of emissions to the air are most significantly impacted by three meteorologic conditions: atmospheric stability, wind speed, and wind direction. These meteorologic factors interact to determine the ultimate concentration of a pollutant in a localized area.

- **Atmospheric stability:** The stability of the atmosphere is influenced by the vertical temperature structure of the air above the emission source. In a stable environment, there is little or no movement of air parcels, and, consequently, little or no movement and mixing of contaminants. In such a stable air environment, chemicals become "trapped" and unable to move. Conversely, in an unstable environment there is significant mixing and therefore greater dispersion and dilution of the plume.[15]
- **Prevailing wind patterns and their interaction with land features:** The nature of the wind patterns immediately surrounding the WMU can significantly impact the local air concentrations of airborne chemicals. Prevailing wind patterns combine with topographic features such as hills and buildings to affect the movement of the plume. Upon release, the initial direction that emissions will travel is the direction of the wind. The strength of the wind will determine how dilute the concentration of the pollutant will be in that direction. For example, if a strong wind is present at the time the pollutants are released, it is likely the pollutants will rapidly leave the source and become dispersed quickly into a large volume of air.

[15] An example of an unstable air environment is one in which the sun shining on the earth's surface has resulted in warmer air at the earth's surface. This warmer air will tend to rise, displacing any cooler air that is on top of it. As these air parcels essentially switch places, significant mixing occurs.

Figure 4. Forces That Affect Contaminant Plumes.



In addition to these factors affecting the diffusion and transport of a plume away from its point of release, the concentration of specific chemicals in a plume can also be affected by depletion. As volatile chemicals are transported away from the WMU, they can be removed from the ambient air through a number of depletion mechanisms including wet deposition (the removal of chemicals due to precipitation) and dry deposition (the removal of chemicals due to the forces of gravity and impacts of the plume on features such as vegetation). Chemicals can also be transformed chemically as they come in contact with the sun's rays (i.e., photochemical degradation). Figure 4 illustrates the forces acting to transport and deplete the contaminant plume.

Because the chemicals being considered in IWAIR are volatiles and semi-volatiles and the distances of transport being considered are relatively short, the removal mechanisms shown in the figure are likely to have a relatively minor effect on plume concentration (both wet and dry deposition have significantly greater effects on airborne particulates).

Once the constituent's ambient outdoor concentration is determined, the receptor's extent of contact with the pollutant must be characterized. This step involves determining the location and activity patterns relevant to the receptor being considered. In IWAIR, the receptors are defined as residents and workers located at fixed distances from the WMU, and the only route of exposure considered for these receptors is the inhalation of volatiles. Typical activity patterns and body physiology of workers and residents are used to determine the intake of the constituent. Intake estimates quantify the extent to which the individual is exposed to the contaminant and are a function of the breathing rate, exposure concentration, exposure duration, exposure frequency, exposure averaging time (for carcinogens), and body weight. Estimated exposures are presented in terms of the mass of the chemical per kilogram of receptor body weight per day.

Risk Characterization

The concentrations that an individual takes into his or her body that were determined during the exposure assessment phase are combined with toxicity values to generate risk estimates. Toxicity values used in IWAIR include inhalation-specific cancer slope factors (CSFs) for carcinogenic effects and reference concentrations (RfCs) for noncancer effects. These are explained in the General Risk Section in Chapter 1—Understanding Risk and Building Partnerships. Using these toxicity values, risk estimates are generated for carcinogenic effects and noncancer effects. Risk estimates for carcinogens are summed by IWAIR.

B. IWAIR Model

IWAIR is an interactive computer program with three main components: an emissions model; a dispersion model to estimate fate and transport of constituents through the atmosphere and determine ambient air concentrations at specified receptor locations; and a risk model to calculate either the risk to exposed individuals or the waste constituent concentrations that can be protectively managed in the unit. To operate, the program requires only a limited amount of site-specific information, including facility location, WMU characteristics, waste characteristics, and receptor information. A brief description of each component follows. The *IWAIR Technical Background Document* (U.S. EPA, 2002a)contains a more detailed explanation of each.

1. Emissions Model

The emissions model uses waste characterization, WMU, and facility information to estimate emissions for 95 constituents that are identified in Table 5. The emission model selected for incorporation into IWAIR is EPA's CHEMDAT8 model. The entire CHEMDAT8 model is run as the emission component of the IWAIR model. CHEMDAT8 has undergone extensive review by both EPA and industry representatives and is publicly available from EPA's Web page, **<www.epa.gov/ttnchie1/software/water/water8.html>**.

To facilitate emission modeling with CHEMDAT8, IWAIR prompts the user to provide the required waste- and unit-specific data. Once these data are entered, the model calculates and displays chemical-specific emission rates. If users decide not to develop or use the CHEMDAT8 rates, they can enter their own site-specific emission rates (g/m^2-s).

2. Dispersion Model

IWAIR's second modeling component estimates dispersion of volatilized contaminants and determines air concentrations at specified receptor locations, using default dispersion factors developed with EPA's Industrial Source Complex, Short-Term Model, version 3 (ISCST3). ISCST3 was run to calculate dispersion for a standardized unit emission rate (1 µg/m2 - s) to obtain a unitized air concentration (UAC), also called a dispersion factor, which is measured in μ/m^3 per $\mu g/m^2$-s. The total air concentration estimates are then developed by multiplying the constituent-specific emission rates derived from CHEMDAT8 (or from another source) with a site-specific dispersion factor. Running ISCST3 to develop a new dispersion factor for each location/WMU is very time consuming and requires extensive meteorological data and technical expertise. Therefore IWAIR incorporates default dispersion factors

Table 5. Constituents Included in IWAIR

Chemical Abstracts (CAS) Number	Compound Name	Chemical Abstracts (CAS) Number	Compound Name
75-07-0	Acetaldehyde	77-47-4	Hexachlorocyclopentadine
67-64-1	Acetone	67-72-1	Hexachloroethane
75-05-8	Acetonitrile	78-59-1	Isophorone
107-02-8	Acrolein	7439-97-6	Mercury
79-06-1	Acrylamide	67-56-1	Methanol
79-10-7	Acrylic acid	110-49-6	Methoxyethanol acetate, 2-
107-13-1	Acrylonitrile	109-86-4	Methoxyethanol, 2-
107-05-1	Allyl chloide	74-83-9	Methyl bromide
62-53-3	Aniline	74-87-3	Methyl chloride
71-43-2	Benzene	78-93-3	Methyl ethyl ketone
92-87-5	Benzidine	108-10-1	Methyl isobutyl ketone
50-32-8	Benzo(a)pyrene	80-62-6	Methyl methacrylate
75-27-4	Bromodichloromethane	1634-04-4	Methyl tert-butyl ether
106-99-0	Butadine, 1,3-	56-49-5	Methylcholanthrene, 3-
75-15-0	Carbon disulfide	75-09-2	Methylene chloride
56-23-5	Carbon tetrachloride	68-12-2	N-N-Dimethyl formamide
108-90-7	Chlorobenzene	91-20-3	Naphthalene
124-48-1	Chlorodibromomethane	110-54-3	n-Hexane
67-66-3	Chloroform	98-95-3	Nitrobenzene
95-57-8	Chloropphenol, 2-	79-46-9	Nitropropane, 2-
126-99-8	Chloroprene	55-18-5	NiNitrosodiethylamine
1006-10-15	cis-1,3-Dichloropropylene	924-16-3	N-Nitrosodi-n-butylamine
1319-77-3	Cresols (total)	930-55-2	N-Nitrosoyrrolidine
98-82-8	Cumene	95-50-1	o-Dichlorobenzene
108-93-0	Cyclohexanol	95-53-4	o-Toluidine
96-12-8	Dibromo-3-chloropropane, 1,2-	106-46-7	p-Dichlorobenzene
75-71-8	Dichlorodifluoromethane	108-95-2	Phenol
107-06-2	Dichloroethane, 1,2-	85-44-9	Phthalic anhydride
75-35-4	Dichloroethylene, 1,1-	75-56-9	Propylene oxide
78-87-5	Dichloropropane, 1,2-	110-86-1	Pyridine
57-97-6	Dimethylbenz[a]anthracene , 7,12-	100-42-5	Stryene
95-65-8	Dimethylphenol, 3,4-	1746-01-6	TCDD-2,3,7,8-
121-14-2	Dinitrotoluene, 2,4-	630-20-6	Tetrachloroethane, 1,1,1,2-
123-91-1	Dioxane, 1,4-	79-34-5	Tetrachloroethane, 1,1,2,2-
122-66-7	Diphenylhydrazine, 1,2-	127-18-4	Tetrachloroethylene
106-89-8	Epichlorohydrin	108-88-3	Toluene
106-88-7	Epoxybutane, 1,2-	10061-02-6	trans-1,3-Dichloropropylene
11-11-59	Ethoxyethanol acetate, 2-	75-25-2	Tribromomethane
110-80-5	Ethoxyethanol, 2-	76-13-1	Freon 113 (Trichloro-1,2,2- 1,1,2- trifluoroethane)
100-41-4	Ethylbenzene	120-82-1	Trichlorobenzene, 1,2,4-
106-93-4	Ethylene dibromide	71-55-6	Trichloroethane, 1,1,1-
107-21-1	Ethylene glycol	79-00-5	Trichloroethane, 1,1,2-
75-21-8	Ethylene oxide	79-01-6	Trichloroethylene
50-00-0	Formaldehyde	75-69-4	Trichlorofluoromethane
98-01-1	Furfural	121-44-8	Triethylamine
87-68-3	Hexachloro-1,3-butadiene	108-05-4	Vinyl acetate
118-74-1	Hexchlorobenzene	75-01-4	Vinyl chloride
		1330-20-7	Xylenes

developed by ISCST3 for many separate scenarios designed to cover a broad range of unit characteristics, including:

- 60 meteorological stations, chosen to represent the 9 general climate regions of the continental U.S.
- 4 unit types.
- 17 surface area sizes for landfills, land application units and surface impoundments, and 11 surface area sizes and 7 heights for waste piles.
- 6 receptor distances from the unit (25, 50, 75, 150, 500, 1000 meters).
- 16 directions in relation to the edge of the unit.

The default dispersion factors were derived by modeling many scenarios with various combinations of parameters, then choosing as the default the maximum dispersion factor for each waste management unit/surface area/meteorological station/receptor distance combination.

Based on the size and location of a unit, as specified by a user, IWAIR selects an appropriate dispersion factor from the default dispersion factors in the model. If the user specifies a unit surface area that falls between two of the sizes already modeled, a linear interpolation method will estimate dispersion in relation to the two closest unit sizes.

Alternatively, a user can enter a site-specific dispersion factor developed by conducting independent modeling with ISCST3 or with a different model and proceed to the next step, the risk calculation.

3. Risk Model

The third component to the model combines the constituent's air concentration with receptor exposure factors and toxicity benchmarks to calculate either the risk from concentrations managed in the unit or the waste concentration (Cw) in the unit that should not be exceeded to protect human health. In calculating either estimate, the model applies default values for exposure factors, including inhalation rate, body weight, exposure duration, and exposure frequency. These default values are based on data presented in the *Exposure Factors Handbook* (U.S. EPA, 1995a) and represent average exposure conditions. IWAIR maintains standard health benchmarks (CSFs for carcinogens and RfCs for noncarcinogens) for 95 constituents. These health benchmarks are from the Integrated Risk Information System (IRIS) and the Health Effects Assessment Summary Tables (HEAST). IWAIR uses these data to perform either a forward calculation to obtain risk estimates or a backward calculation to obtain protective waste concentration estimates.

4. Estimation Process

Figure 5 provides an overview of the stepwise approach the user follows to calculate risk or protective waste concentration estimates with IWAIR. The seven steps of the estimation process are shown down the right side of the figure, and the user specified inputs are listed to the left of each step. As the user provides input data, the program proceeds to the next step. Each step of the estimation process is discussed below.

a. **Select Calculation Method.** The user selects one of two calculation methods. Use the forward calculation to arrive at chemical-specific and cumulative risk estimates if the user knows the concentrations of constituents in the waste. Use the backward calculation method to estimate protective waste concentrations not to be exceeded in new units. The screen where this step is performed is shown in Figure 6.

Figure 5. IWAIR Approach for Developing Risk or Protective Waste Concentrations: This figure shows the steps in the tool to assist the user in developing risk or protective waste concentration estimates.

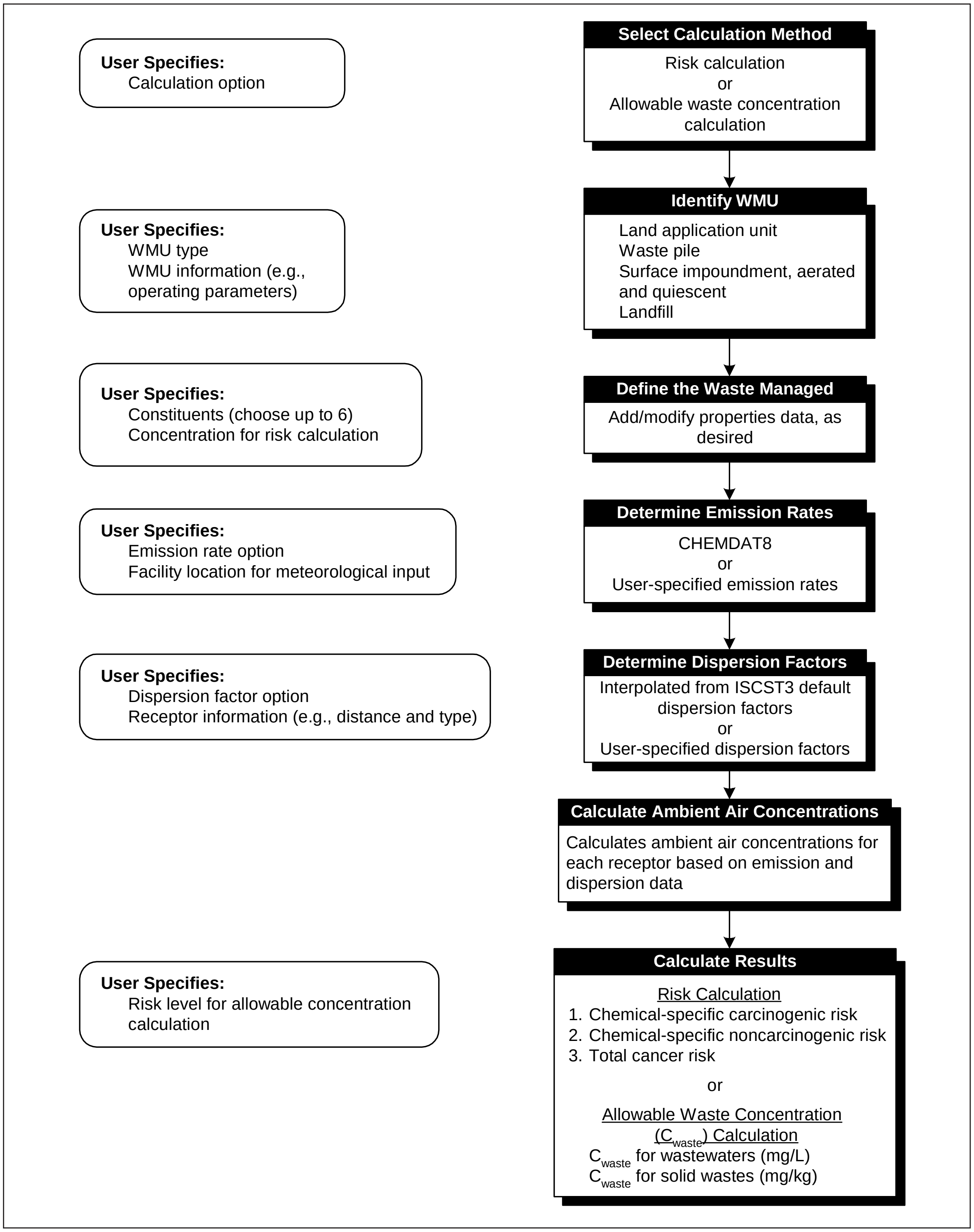


Figure 6. Screen 1, Method, Met Station, WMU.

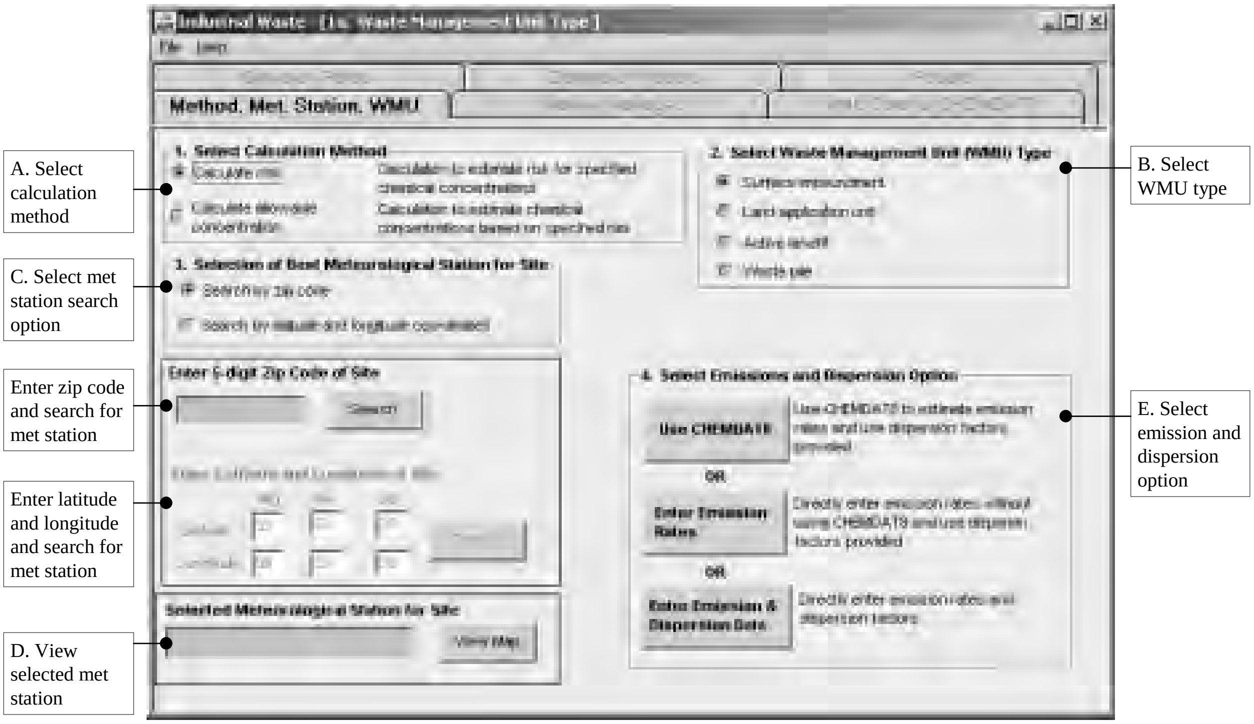
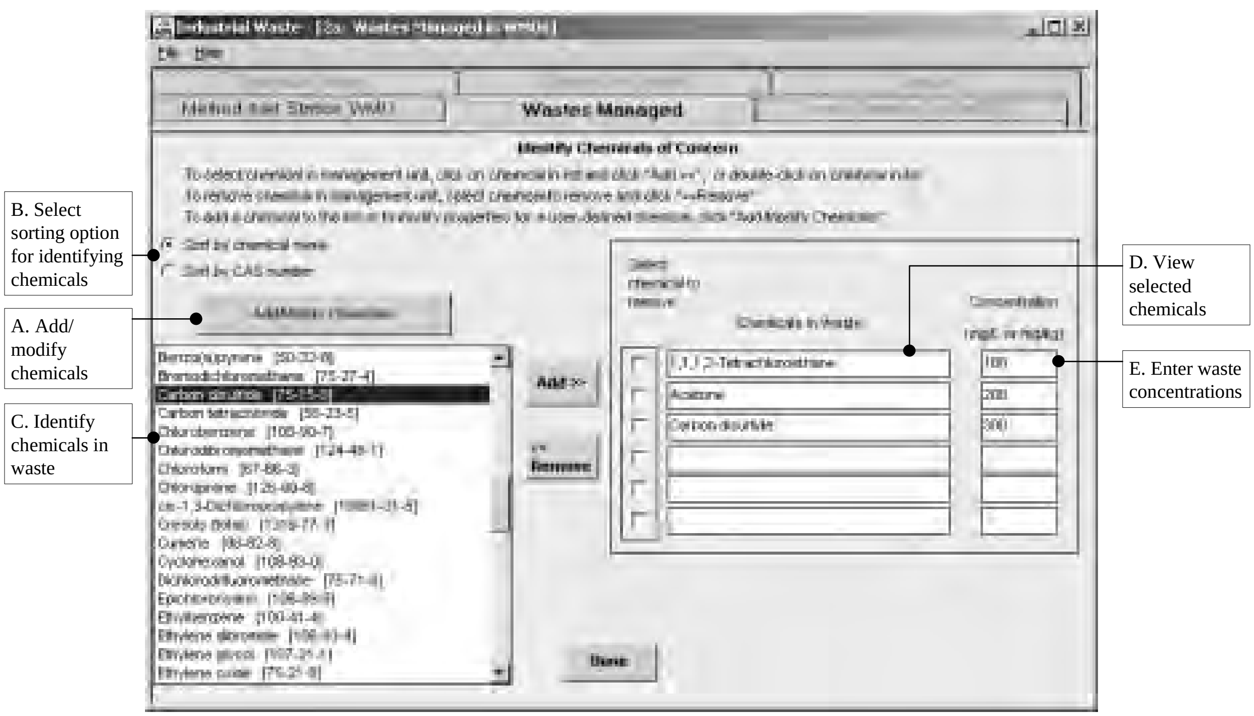


Figure 7. Screen 2, Wastes Managed.



b. **Identify Waste Management Unit.** Four WMU types can be modeled: surface impoundments (SIs), land application units (LAUs), active landfills (LFs), and wastepiles (WPs). For each WMU, you will be asked to specify some design and operating parameters such as surface area, depth for surface impoundments and landfills, height for wastepiles, and tilling depth for LAUs. The amount of unit specific data needed as input will vary depending on whether the user elects to develop CHEMDAT8 emission rates. IWAIR provides default values for several of the operating parameters that the user can choose, if appropriate.

c. **Define Waste Managed.** Specify constituents and concentrations in the waste if you choose a forward calculation to arrive at chemical specific risk estimates. If you choose a backward calculation to estimate protective waste concentrations, then specify constituents of concern. The screen where this step is performed is shown in Figure 7.

d. **Determine Emission Rates.** You can elect to develop CHEMDAT8 emission rates or provide your own site-specific emission rates for use in calculations. IWAIR will also ask for facility location information to link the facility's location to one of the 60 IWAIR meteorological stations. Data from the meteorological stations provide wind speed and temperature information needed to develop emission estimates. In some circumstances the user might already have emissions information from monitoring or a previous modeling exercise. As an alternative to using the CHEMDAT8 rates, a user can provide their own site-specific emission rates developed with a different model or based on emission measurements.

e. **Determine Dispersion.** The user can provide site-specific unitized dispersion factors ($\mu g/m^3$ per $\mu g/m^2$-s) or have the model develop dispersion factors based on user-specified WMU information and the IWAIR default dispersion data. Because a number of assumptions were made in developing the IWAIR default dispersion data you can elect to provide site-specific dispersion factors which can be developed by conducting independent modeling with ISCST3 or with a different model. Whether you use IWAIR or provide dispersion factors from another source, specify distance to the receptor from the edge of the WMU and the receptor type (i.e., resident or worker). These data are used to define points of exposure.

f. **Calculate Ambient Air Concentration.** For each receptor, the model combines emission rates and dispersion data to estimate ambient air concentrations for all waste constituents of concern.

g. **Calculate Results.** The model calculates results by combining estimated ambient air concentrations at a specified exposure point with receptor exposure factors and toxicity benchmarks. Presentation of results depends on whether you chose a forward or backward calculation:

Forward calculation: Results are estimates of cancer and non-cancer risks from inhalation exposure to volatilized constituents in the waste. If risks are too high, options are: 1) implement unit controls to reduce volatile air emissions, 2) implement pollution prevention or treatment to reduce volatile organic compound (VOC) concentrations before the waste enters the unit, or 3) conduct a full site-specific risk assessment to more precisely characterize risks from the unit.

Backward calculation: Results are estimates of constituent concentrations in waste that can be protectively managed in the unit so as not to exceed a defined risk level (e.g., 1 x 10^{-6} or hazard quotient of 1) for specified receptors. A target risk level for your site can be calculated based on a number of site-specific factors including, proximity to potential receptors, waste characteristics, and waste management practices. This information should be used to determine preferred characteristics for wastes entering the unit. There are several options if it appears that planned waste concentrations might be too high: 1) implement pollution prevention or treatment to reduce VOC concentrations in the waste, 2) modify waste management practices to better control VOCs (for example, use closed tanks rather than surface impoundments), or 3) conduct a full site-specific risk assessment to more precisely characterize risks from the unit.

5. *Capabilities and Limitations of the Model*

In many cases, IWAIR will provide a reasonable alternative to conducting a full-scale site-specific risk analysis to determine if a WMU poses unacceptable risk to human health. Because the model can accommodate only a limited amount of site-specific information, however, it is important to understand its capabilities and recognize situations when it might not be appropriate to use.

Capabilities

- The model provides a reasonable representation of VOC inhalation risks associated with waste management units.
- The model is easy-to-use and requires a minimal amount of data and expertise.
- The model is flexible and provides features to meet a variety of user needs.
- A user can enter emission and/or dispersion factors derived from another model (perhaps to avoid some of the limitations below) and still use IWAIR to conduct a risk evaluation.
- The model can run a forward calculation from the unit or a backward calculation from the receptor point.
- A user can modify health benchmarks (HBNs) and target risk level, when appropriate and in consultation with other stakeholders.

Limitations

- **Release Mechanisms and Exposure Routes.** The model considers exposures from breathing ambient air. It does not address potential risks attributable to particulate releases nor does it address risks associated with indirect routes of exposure (i.e, non-inhalation routes of exposure). Additionally, in the absence of user-specified emission rates, volatile emission estimates are developed with CHEMDAT8 based on unit- and waste-specific data. The CHEMDAT8 model was developed to address only volatile emissions from waste management units. Competing mechanisms that can generate additional exposures to the constituents in the waste such as runoff, erosion, and particulate emissions are not accounted for in the model.

- **Waste Management Practices.** The user specifies a number of unit-specific parameters that significantly impact the inhalation pathway (e.g., size, type, and location of WMU, which is important in identifying meteorological conditions). However, the model cannot accommodate information concerning control technologies such as covers that might influence the degree of volatilization (e.g., whether a wastepile is covered immediately after application of new waste). In this case, it might be advisable to generate site-specific emission rates and enter those into IWAIR.
- **Terrain and Meteorological Conditions.** If a facility is located in an area of intermediate or complex terrain or with unusual meteorological conditions, it might be advisable to either 1) generate site-specific air dispersion modeling results for the site and enter those results into the program, or 2) use a site-specific risk modeling approach different from IWAIR. The model will inform the user which of the 60 meteorological stations is used for a facility. If the local meteorological conditions are very different from the site chosen by the model, it would be more accurate to choose a different model.

  The terrain type surrounding a facility can impact air dispersion modeling results and ultimately risk estimates. In performing air dispersion modeling to develop the IWAIR default dispersion factors, the model ISCST3 assumes the area around the WMU is of simple or flat terrain. The *Guideline on Air Quality Models* (U.S. EPA, 1993) can assist users in determining whether a facility is in an area of simple, intermediate, or complex terrain.
- **Receptor Type and Location.** IWAIR has predetermined adult worker and resident receptors, six receptor locations, and predetermined exposure factors. The program cannot be used to characterize risk for other possible exposure scenarios. For example, the model can not evaluate receptors that are closer to the unit than 25 meters or those that are further from the unit than 1,000 meters. If the population of concern for your facility is located beyond the limits used in IWAIR, consider using a model that is more appropriate for the risks posed from your facility.

C. Site-specific Risk Analysis

IWAIR is not the only model that can be applicable to a site. In some cases, a site-specific risk assessment might be more advantageous. A site-specific approach can be tailored to accommodate the individual needs of a particular WMU. Such an approach would rely on site-specific data and on the application of existing fate and transport models. Table 6 summarizes available emissions and/or dispersion models that can be applied in a site-specific analysis. Practical considerations include the source of the model(s), the ease in obtaining the model(s), and the nature of the model(s) (i.e., is it proprietary), and the availability of site-specific data required for use of the model. Finally, the model selection process should determine whether or not the model has been verified against analytical solutions, other models, and/or field data. Proper models can be selected based on the physical and chemical

Table 6

Source Characterization Models

Model Name	Summary
AP-42	The EPA's Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (AP-42), is a compilation of emission factors for a wide variety of air emission sources, including fugitive dust sources (Section 13.2). Emission factors are included for paved roads, unpaved roads, heavy construction operations, aggregate handling and storage piles, industrial wind erosion (this is the 1988 Cowherd model), and abrasive blasting. These are simple emission factors or equations that relate emissions to inputs (e.g., silt loading or content, moisture content, mean vehicle weight, area, activity level, and wind speed). Guidance is provided for most inputs, but the more site-specific the input data used, the more accurate the results. The entire AP-42 documentation is available at **<www.epa.gov/ttn/chief/efinformation.html>**.
CHEMDAT8	The CHEMDAT8 model allows the user to conduct source and chemical specific emissions modeling. CHEMDAT8 is a Lotus 1-2-3 spreadsheet that includes analytical models to estimate volatile organic compound emissions from treatment, storage, and disposal facility processes under user-specified input parameters. CHEMDAT8 calculates the fractions of waste constituents of interest that are distributed among pathways (partition fractions) applicable to the facility under analysis. Emissions modeling using CHEMDAT8 is conducted using data entered by the user for unit-specific parameters. The user can choose to override the default data and enter their estimates for these unit-specific parameters. Thus, modeling emissions using CHEMDAT8 can be done with a limited amount of site-specific information. Available at **<www.epa.gov/ttnchie1/software/water/water8.html>**, hotline at 919 541-5610 for more information.
Cowherd	The Cowherd model, Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites, allows the user to calculate particulate emission rates for wind erosion using data on wind speed and various parameters that describe the surface being eroded. The latest (1988) version of this model is event-based (i.e., erosion is modeled as occurring in response to specific events in which the wind speed exceeds levels needed to cause wind erosion). An older (1985) version of the model is not event-based (i.e., erosion is modeled as a long-term average, without regard to specific wind speed patterns over time). The older version is less complicated and requires fewer inputs, but produces more conservative results (i.e., higher emissions). The documentation on both models provides guidance on developing all inputs. Both require data on wind speed (fastest mile for the 1988 version and annual average for the 1985 version), anemometer height, roughness height, and threshold friction velocity. The 1985 version also requires input on vegetative cover. The 1988 version requires data on number of disturbances per year and, if the source is not a flat surface, pile shape and orientation to the fastest mile. The 1985 version of the model is presented in Rapid Assessment of Exposures to Particulate Emissions from Surface Contamination Sites (U.S. EPA, 1985). Office of Health and Environmental Assessment, Washington DC. The 1988 version of the model is available as part of AP-42, Section 13.2.5 (see above).

Table 6
Source Characterization Models

Model Name	Summary
ISCLT3	The Industrial Source Complex Model-Long Term, ISCLT3, is a steady state Gaussian plume dispersion model that can be used to model dispersion of continuous emissions from point or area sources over transport distances of less than 50km. It can estimate air concentration for vapors and particles, and dry deposition rates for particles (but not vapors), and can produce these outputs averaged over seasonal, annual, or longer time frames. ISCLT3 inputs include readily available meteorological data known as STAR (STability ARray) summaries (these are joint frequency distributions of wind speed class by wind direction sector and stability class, and are available from the National Climate Data Center in Asheville, North Carolina), and information on source characteristics (such as height, area, emission rate), receptor locations, and a variety of modeling options (such as rural or urban). Limitations of ISCLT3 include inability to model wet deposition, deposition of vapors, complex terrain, or shorter averaging times than seasonal, all of which can be modeled by ISCST3. In addition, the area source algorithm used in ISCLT3 is less accurate than the one used in ISCST3. The runtime for area sources, however, is significantly shorter for ISCLT3 than for ISCST3. ISCLT3 is available at **<www.epa.gov/scram001/tt22.htm>**.
ISCST3	A steady-state Gaussian plume dispersion model that can estimate concentration, dry deposition rates (particles only), and wet deposition rates. Is applicable for continuous emissions, industrial source complexes, rural or urban areas, simple or complex terrain, transport distances of less than 50 km, and averaging times from hourly to annual. Available at **<www.epa.gov/scram001/tt22.htm>**.
Landfill Air Emissions Estimation Model (LAEEM)	Used to estimate emission rates for methane, carbon dioxide, nonmethane volatile organic compounds, and other hazardous air pollutants from municipal solid waste landfills. The mathematical model is based on a first order decay equation that can be run using site-specific data supplied by the user for the parameters needed to estimate emissions or, if data are not available, using default value sets included in the model. Developed by the Clean Air Technology Center (CATC). Can be used to estimate emission rates for methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from landfills. Can also be used by landfill owners and operators to determine if a landfill is subject to the control requirements of the federal New Source Performance Standard (NSPS) for new municipal solid waste (MSW) landfills (40 CFR 60 Subpart WWW) or the emission guidelines for existing MSW landfills (40 CFR 60 Subpart CC). Developed for municipal solid waste landfills; might not be appropriate for all industrial waste management units. Available at **<www.epa.gov/ttn/chief/software/index.html>**.

Table 6

Source Characterization Models

Model Name	Summary
Wastewater Treatment Compound Property Processor and Air Emissions Estimator Program (WATER9)	WATER9 is a Windows based computer program and consists of analytical expressions for estimating air emissions of individual waste constituents in wastewater collection, storage, treatment, and disposal facilities; a database listing many of the organic compounds; and procedures for obtaining reports of constituent fates, including air emissions and treatment effectiveness. WATER9 is a significant upgrade of features previously obtained in the computer programs WATER8, Chem9, and Chemdat8. WATER9 contains a set of model units that can be used together in a project to provide a model for an entire facility. WATER9 is able to evaluate a full facility that contains multiple wastewater inlet streams, multiple collection systems, and complex treatment configurations. It also provides separate emission estimates for each individual compound that is identified as a constituent of the wastes. WATER9 has the ability to use site-specific compound property information, and the ability to estimate missing compound property values. Estimates of the total air emissions from the wastes are obtained by summing the estimates for the individual compounds. The EPA document *Air Emissions Models for Waste and Wastewater* (U.S. EPA, 1994a) includes the equations used in the WATER9 model. Available at **<www.epa.gov/ttnchie1/software/water/water9/index.html>**. Contact the Air Emissions Model Hotline at 919 541-5610 for support or more information.
Toxic Modeling System Short Term (TOXST)	An interactive PC-based system to analyze intermittent emissions from toxic sources. Estimates the dispersion of toxic air pollutants from point, area, and volume sources at a complex industrial site. This system uses a Monte Carlo simulation to allow the estimation of ambient concentration impacts for single and multiple pollutants from continuous and intermittent sources. In addition, the model estimates the average annual frequency with which user-specified concentration thresholds are expected to be exceeded at receptor sites around the modeled facility. TOXST requires the use of ISCT3 model input files for physical source parameters. Available at **<www.epa.gov/rgytgrnj/programs/artd/toxics/arpp/etools.htm>**.
Toxic Screening Model (TSCREEN)	TSCREEN, a Model for Screening Toxic Air Pollutant Concentrations, should be used in conjunction with the "Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants." The air toxics dispersion screening models imbedded in TSCREEN that are used for the various scenarios are SCREEN2, RVD, PUFF, and the Britter-McQuaid model. Using TSCREEN, a particular release scenario is selected via input parameters, and TSCREEN model to simulate that scenario. The model to be used and the worst case meteorological conditions are automatically selected based on criteria given in the workbook. TSCREEN has a front-end control program to the models that also provides, by use of interactive menus and data entry screen, the same steps as the workbook.

attributes of the site in question. As with all modeling, however, you should consult with your state prior to investing significant resources in a site-specific analysis. The state might have preferred models or might be able to help plan the analysis.

III. Emission Control Techniques

A. Controlling Particulate Matter

Particulate matter (PM) consists of airborne solid and liquid particles. PM is easily inhaled and can cause various health problems. PM also impacts the environment by decreasing visibility and harming plants as well as transporting constituents off site. Constituents can sorb to particulate matter and, therefore, wind blown dust is a potential pathway for constituents to leave the site. It is recommended that facilities adopt controls to address emissions of airborne particulates.

Solid PM that becomes airborne directly or indirectly as a result of human activity, is referred to as fugitive dust[16] and it can be generated from a number of different sources. The most common sources of fugitive dust at waste management units include vehicular traffic on unpaved roads and land-based units, wind erosion from land-based units, and waste handling procedures. Developing a fugitive dust control plan is an efficient way to tackle these problems. The plan should include a description of all operations conducted at the unit, a map, a list of all fugitive dust sources at the unit, and a description of the control measures that will be used to minimize fugitive dust emissions. OSHA has established standards for occupational exposure to dust (see 29 CFR § 1910.1000). You should check to see if your state also has regulations or guidance concerning dust or fugitive emission control.

PM emissions at waste management units vary with the physical and chemical characteristics of waste streams; the volume of waste handled; the size of the unit, its location, and associated climate; and waste transportation and placement practices. The subsections below discuss the main PM-generating operations and identify emission control techniques. The waste management units of main concern for PM emissions include landfills, waste piles, land application units, and closed surface impoundments.

1. Vehicular Operations

Waste and cover material are often transported to units using trucks. If the waste has the potential for PM to escape to the atmosphere during transport, you should cover the waste with tarps or place wastes in containers such as double bags or drums.[17]

A unit can also use vehicles to construct lifts in landfills, apply liquids to land application units, or dredge surface impoundments. Consider using "dedicated" equipment—vehicles that operate only within the unit and are not routinely removed from the unit to perform other activities. This practice reduces the likelihood that equipment movement will spread contaminated PM outside the unit. To control PM emissions when equipment must be removed from the landfill unit, such as for maintenance, a wash station can remove any contaminated material from the equipment before it leaves the unit. You should ensure that this is done in a curbed wash area where wash water is captured and properly handled.

To minimize PM emissions from all vehicles, it is recommended that you construct temporary roadways with gravel or other

[16] Fugitive emissions are defined as emissions not caught by a capture system and therefore exclude PM emitted from exhaust stacks with control devices.

[17] Containerizing wastes provides highly effective control of PM emissions, but, due to the large volume of many industrial waste streams, containerizing waste might not always be feasible.

coarse aggregate material to reduce silt content and thus, dust generation. In addition, consider regularly cleaning paved roads and other travel surfaces of dust, mud, and contaminated material.

In land application units, the entire application surface is often covered with a soil-waste mix. The most critical preventive control measure, therefore, involves minimizing contact between the application surface and waste delivery vehicles. If possible, allow only dedicated application vehicles on the surface, restricting delivery vehicles to a staging or loading area where they deposit waste into application vehicles or holding tanks. If delivery vehicles must enter the application area, ensure that mud and waste are not tracked out and deposited on roadways, where they can dry and then be dispersed by wind or passing vehicles.

2. *Waste Placement and Handling*

PM emissions from waste placement and handling activities are less likely if exposed material has a high moisture content. Therefore, consider wetting the waste prior to loadout. Increasing the moisture content, however, might not be suitable for all waste streams and can result in an unacceptable increase in leachate production. To reduce the need for water or suppressants, cover or confine freshly exposed material. In addition, consider increasing the moisture content of the cover material.

It can also be useful to apply water to unit surfaces after waste placement. Water is generally applied using a truck with a gravity or pressure feed. Watering might or might not be advisable depending on application intensity and frequency, the potential for tracking of contaminated material off site, and climactic conditions. PM control efficiency generally

increases with application intensity and frequency but also depends on activity levels, climate, and initial surface conditions. Infrequent or low-intensity water application typically will not provide effective control, while too frequent or high-intensity application can increase leachate volume, which can strain leachate collection systems and threaten ground water and surface water. Addition of excess water to bulk waste material or to unit surfaces also can reduce the structural integrity of the landfill lifts, increase tracking of contaminated mud off site, and increase odor. These undesirable possibilities can have long-term implications for the proper management of a unit. Before instituting a watering program, therefore, ensure that addition of water does not produce undesirable impacts on ground- and surface-water quality. You should consult with your state agency with respect to these problems.

Chemical dust suppressants are an alternative to water application. The suppressants are detergent-like surfactants that increase the total number of droplets and allow particles to more easily penetrate the droplets, increasing the total surface area and contact potential. Adding a surfactant to a relatively small quantity of water and mixing vigorously produces small-bubble, high-energy foam in the 100 to 200 μm size range. The foam occupies very little liquid volume, and when applied to the surface of the bulk material, wets the fines

Table 7. Example List of Chemical Suppressants*

Type	Product	Manufacturer
Bitumens	AMS 2200, 2300®	Arco Mine Sciences
	Coherex®	Witco Chemical
	Docal 1002®	Douglas Oil Company
	Peneprime®	Utah Emulsions
	Petro Tac P®	Syntech Products Corporation
	Resinex®	Neyra Industries, Inc.
	Retain®	Dubois Chemical Company
Salts	Calcium chloride	Allied Chemical Corporation
	Dowflake, Liquid Dow®	Dow Chemical
	DP-10®	Wen-Don Corporation
	Dust Ban 8806®	Nalco Chemical Company
	Dustgard®	G.S.L. Minerals and Chemical Corporation
	Sodium silicate	The PQ Corporation
Adhesives	Acrylic DLR-MS®	Rohm and Haas Company
	Bio Cat 300-1®	Applied Natural Systems, Inc.
	CPB-12®	Wen-Don Corporation
	Curasol AK®	American Hoechst Corporation
	DCL-40A, 1801, 1803®	Calgon Corporation
	DC-859, 875®	Betz Laboratories, Inc.
	Dust Ban®	Nalco Chemical Company
	Flambinder®	Flambeau Paper Company
	Lignosite®	Georgia Pacific Corporation
	Norlig A, 12®	Reed Lignin, Inc.
	Orzan Series®	Crown Zellerbach Corporation
	Soil Gard®	Walsh Chemical

* Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

Source: U.S. EPA, 1989.

more effectively than water. When applied to a unit, suppressants cement loose material into a more impervious surface or form a surface which attracts and retains moisture. Examples of chemical dust suppressants are provided in Table 7. The degree of control achieved is a function of the application intensity and frequency and the dilution ratio. Chemical dust suppressants tend to require less frequent application than water, reducing the potential for leachate generation. Their efficiency varies, depending on the same factors as water application, as well as spray nozzle parameters, but generally falls between 60 and 90 percent reduction in fugitive dust emissions. Suppressant costs, however, can be high.

At land application units, if wastes contain considerable moisture, PM can be suppressed through application of more waste rather than water or chemical suppressants. This method, however, is only viable if it would not cause an exceedence of a design waste application rate or exceed the capacity of soil and plants to assimilate waste.

At surface impoundments, the liquid nature of the waste means PM is not a major concern while the unit is operational. Inactive or closed surface impoundments, however, can emit PM during scraping or bulldozing operations to remove residual materials. The uppermost layer of the low permeability soils, such as compacted clay, which can be used to line a surface impoundment, contains the highest contaminant concentrations. Particulate emissions from this uppermost layer, therefore, are the chief contributor to contaminant emissions. When removing residuals from active units, you should ensure that equipment scrapes only the residuals, avoiding the liner below.

3. Wind Erosion

Wind erosion occurs when a dry surface is exposed to the atmosphere. The effect is most pronounced with bare surfaces of small particles, such as silty soil; heavier or better anchored material, such as stones or clumps of vegetation, has limited erosion potential and requires higher wind speeds before erosion can begin.

Compacted clay and in-situ soil liners tend to form crusts as their surfaces dry. Crusted surfaces usually have little or no erosion potential. Examine the crust thickness and strength during site inspections. If the crust does not crumble easily the erosion potential might be minimal.

Wind fences or barriers are effective means by which to control fugitive dust emissions from open dust sources. The wind fence or barrier reduces wind velocity and turbulence in an area whose length is many times the height of the fence. This allows settling of large particles and reduces emissions from the exposed surface. It can also shelter materials handling operations to reduce entrainment during load-in and loadout. Wind fences or barriers can be portable and either man-made structures or vegetative barriers, such as trees. A number of studies have attempted to determine the effectiveness of wind fences or barriers for the control of windblown dust under field conditions. Several of these studies have shown a decrease in wind velocity, however, the degree of emissions reduction varies significantly from study to study depending on test conditions.

Other wind erosion control measures include passive enclosures such as three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material, and open-ended buildings. Such enclosures are most easily used with small, temporary waste piles. At land application units that use spray application, further wind erosion control can be achieved simply by not spraying waste on windy days.

Windblown PM emissions from a waste pile depend on how frequently the pile is disturbed, the moisture content of the waste, the proportion of aggregate fines, and the height of the pile. When small-particle wastes are loaded onto a waste pile, the potential for dust emissions is at a maximum, as small particles are easily disaggregated and picked up by wind. This tends to occur when material is either added to or removed from the pile or when the pile is otherwise reshaped. On the other hand, when the waste remains undisturbed for long periods and is weathered, its potential for dust emissions can be greatly reduced. This occurs when moisture from precipitation and condensation causes aggregation and cementation of fine particles to the surface of larger particles, and when vegetation grows on the pile, shielding the surface and strengthening it with roots.

Finally, limiting the height of the pile can reduce PM emissions, as wind velocities generally increase with distance from the ground.

B. VOC Emission Control Techniques

If air modeling indicates that VOC emissions are a concern, you should consider pollution prevention and treatment options to reduce risk. There are several control techniques you can use. Some are applied before the waste is placed in the unit, reducing emissions; others contain emissions that occur after waste placement; still others process the captured emissions.

1. Choosing a Site to Minimize Airborne Emission Problems

Careful site choice can reduce VOC emissions. Locations that are sheltered from wind by trees or other natural features are preferable. Knowing the direction of prevailing winds and determining whether the unit would be upwind from existing and expected future residences, businesses, or other population centers can result in better siting of units. After a unit is sited, observe wind direction during waste placement, and plan or move work areas accordingly to reduce airborne emission impacts on neighbors.

2. Pretreatment of Waste

Pretreating waste can remove organic compounds and possibly eliminate the need for further air emission controls. Organic removal or pretreatment is feasible for a variety of wastes. These processes, which include steam or air stripping, thin-film evaporation, solvent extraction, and distillation, can sometimes remove essentially all of the highly volatile compounds from your waste. Removal of the volatiles near the point of generation can obviate the need for controls on your subsequent process units and can facilitate recycling the recovered organics back to the process.

The control efficiency of organic removal depends on many factors, such as emissions from the removal system, and the uncontrolled emissions from management units before the removal device was installed. Generally, overall organic removal efficiencies of 98 to over 99 percent can be achieved.

3. Enclosure of Units

You might be able to control VOC emissions from your landfill or waste pile by installing a flexible membrane cover, enclosing the unit in a rigid structure, or using an air-supported structure. Fans maintain positive pressure to inflate an air-supported structure. Some of the air-supported covers that have been used consist of PVC-coated polyester with a polyvinyl fluoride film backing. The efficiency of air-supported structures depends primarily on how well the structure prevents leaks and how quickly any leaks that do occur are detected. For effective control, the air vented from the structure should be sent to a control device, such as a carbon adsorber. Worker safety issues related to access to the interior of any flexible membrane cover or other pollutant concentration system should also be considered.

Wind fences or barriers can also aid in reducing organic emissions by reducing air mixing on the leeward side of the screen. In addition, wind fences reduce soil moisture loss due to wind, which can in turn result in decreased VOC emissions.

Floating membrane covers provide control on various types of surface impoundments, including water reservoirs in the western United States. For successful control of organic compounds, the membrane must provide a seal at the edge of the impoundment and rainwater must be removed. If gas is generated under the cover, vents and a control device might also be needed. Emission control depends primarily on the type of membrane, its thickness, and the nature of the organic compounds in the waste. Again, we recommend that you consult with your state or local air quality agency to identify the most appropriate emission control for your impoundment.

4. *Treatment of Captured VOCs*

In some cases, waste will still emit some VOCs despite waste reduction or pretreatment efforts. Enclosing the unit serves to prevent the immediate escape of these VOCs to the atmosphere. To avoid eventually releasing VOCs through an enclosure's ventilation system, a treatment system is necessary. Some of the better-known treatment methods are discussed below; others also are be available.

a. *Adsorption*

Adsorption is the adherence of particles of one substance, in this case VOCs, to the surface of another substance, in this case a filtration or treatment matrix. The matrix can be replaced or flushed when its surface becomes saturated with the collected VOCs.

Carbon Adsorption. In carbon adsorption, organics are selectively collected on the surface of a porous solid. Activated carbon is a common adsorbent because of its high internal surface area: 1 gram of carbon can have a surface area equal to that of a football field and can typically adsorb up to half its weight in organics. For adsorption to be effective, replace, regenerate, or recharge the carbon when treatment efficiency begins to decline. In addition, any emissions from the disposal or regeneration of the carbon should be controlled. Control efficiencies of 97 to 99 percent have been demonstrated for carbon adsorbers in many applications.

Biofiltration. While covering odorous materials with soil is a longstanding odor control practice, the commercial use of biofiltration is a relatively recent development. Biofilters reproduce and improve upon the soil cover concept used in landfills. In a biofilter, gas emissions containing biodegradable VOCs pass through a bed packed with damp, porous organic particles. The biologically active filter bed then adsorbs the VOCs. Microorganisms attached to the wetted filter material aerobically degrade the adsorbed chemical compounds. Biofiltration can be a highly effective and low-cost alternative to other, more conventional, air pollution control technologies such as thermal oxidation, catalytic incineration, condensation, carbon adsorption, and absorption. Successful commercial biofilter applications include treatment of gas emissions from composting operations, rendering plants, food and tobacco processing, chemical manufacturing, foundries, and other industrial facilities.[18]

b. *Condensation*

Condensers work by cooling the vented vapors to their dew point and removing the organics as liquids. The efficiency of a condenser is determined by the vapor phase concentration of the specific organics and the condenser temperature. Two common types of condensers are contact condensers and surface condensers.

c. *Absorption*

In absorption, the organics in the vent gas dissolve in a liquid. The contact between the absorbing liquid and the vent gas is accomplished in spray towers, scrubbers, or packed or plate columns. Some common solvents that might be useful for volatile organics

[18] Mycock, J.C., J.D. McKenna, and L. Theodore. 1995. Handbook of Air Pollution Control Engineering and Technology.

include water, mineral oils, or other nonvolatile petroleum oils. Absorption efficiencies of 60 to 96 percent have been reported for organics. The material removed from the absorber can present a disposal or separation problem. For example, organics must be removed from the water or nonvolatile oil without losing them as emissions during the solvent recovery or treatment process.

d. Vapor Combustion

Vapor combustion is another control technique for vented vapors. The destruction of organics can be accomplished in flares; thermal oxidizers, such as incinerators, boilers, or process heaters; and in catalytic oxidizers. Flares are an open combustion process in which oxygen is supplied by the air surrounding the flame. Flares are either operated at ground level or elevated. Properly operated flares can achieve destruction efficiencies of at least 98 percent. Thermal vapor incinerators can also achieve destruction efficiencies of at least 98 percent with adequately high temperature, good mixing, sufficient oxygen, and an adequate residence time. Catalytic incinerators provide oxidation at temperatures lower than those required by thermal incinerators. Design considerations are important because the catalyst can be adversely affected by high temperatures, high concentrations of organics, fouling from particulate matter or polymers, and deactivation by halogens or certain metals.

5. Special Considerations for Land Application Units

Since spraying wastes increases contact between waste and air and promotes VOC emissions, if the waste contains volatile organics you might want to choose another application method, such as subsurface injection. During subsurface injection, waste is supplied to the injection unit directly from a remote holding tank and injected approximately 6 inches into the soil; hence, the waste is not exposed to the atmosphere. In addition, you should consider pretreating the waste to remove the organics before placing it in the land application unit.

Protecting Air Activity List

We recommend that you consider the following issues when evaluating and controlling air emissions from industrial waste management units:

- ❑ Understand air pollution laws and regulations, and determine whether and how they apply to a unit.
- ❑ Evaluate waste management units to identify possible sources of volatile organic emissions.
- ❑ Work with your state agency to evaluate and implement appropriate emission control techniques, as necessary.

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Part III
Protecting Surface Water

Chapter 6
Protecting Surface Water

Contents

Contents (cont.)

Protecting Surface Water

This chapter will help you:

- *Protect surface waters by limiting the discharge of pollutants into the waters of the United States.*
- *Guard against inappropriate discharges of pollutants associated with process wastewaters and storm water to ensure the safety of the nation's surface waters.*
- *Reduce storm-water discharges by complying with applicable regulations, implementing available storm-water controls, and identifying best management practices (BMPs) to control storm water.*

Over 70 percent of the Earth's surface is water. Of all the Earth's water, 97 percent is found in the oceans and seas, while 3 percent is fresh water. This fresh water is found in glaciers, lakes, ground water, wetlands, and rivers. Because water is such a valuable commodity, the protection of our surface waters should be everyone's goal. Pollutants[1] associated with waste management units and storm-water discharges must be controlled.

This chapter summarizes how EPA and states determine the quality of surface waters and subsequently describes the existing surface-water protection programs for ensuring the health and integrity of waterbodies. The fate and transport of pollutants in the surface-water environment is also discussed. Finally, various methods that are used to control pollutant discharges to surface waters are described.

This chapter will help you address the following questions:

- What surface-water protection programs are applicable to my waste management unit?
- What are the objectives of run-on and runoff control systems?
- What should be considered in designing surface-water protection systems?
- What BMPs should be implemented to protect surface waters from pollutants associated with waste management units?
- What are some of the engineering and physical mechanisms available to control storm water?

I. Determining the Quality and Health of Surface Waters

The protection of aquatic resources is governed by the Clean Water Act (CWA). The objective of the CWA is to "restore and maintain the chemical, physical, and biological

[1] To be consistent with the terminology used in the Clean Water Act, the term pollutant is used in this chapter in place of the term constituent. In this chapter, pollutant means an effluent or condition introduced to surface waters that results in degradation. Water pollutants include human and animal wastes, nutrients, soil and sediments, toxics, sewage, garbage, chemical wastes, and heat.

> ### What is water quality?
> Water quality reflects the composition of water as affected by natural causes and human activities, expressed in terms of measurable quantities and related to intended water use. Water quality is determined by comparing physical, chemical, biological, microbiological, and radiological quantities and parameters to a set of standards and criteria. Water quality is perceived differently by different people. For example, a public health official might be concerned with the bacterial and viral safety of water used for drinking and bathing, while fishermen might be concerned that the quality of water be sufficient to provide the best habitat for fish. For each intended use and water quality benefit, different parameters can be used to express water quality.

integrity of the nation's waters" (Section 101(a)). Section 304(a) of the CWA authorizes EPA to publish recommended water quality criteria that provide guidance for states to use in adopting water quality standards under Section 303(c). Section 303 of the CWA also establishes the Total Maximum Daily Load (TMDL) Program which requires EPA and the states to identify waters not meeting water quality standards and to establish TMDLs for those waters.

A. Water Quality Criteria

Under authority of Section 304 of the CWA, EPA publishes water quality "criteria" that reflect available scientific information on the maximum acceptable concentration levels of specific chemicals in water that will protect aquatic life, human health, and drinking water. EPA has also established nutrient criteria (e.g., phosphorus and nitrogen) and biological criteria (i.e., biointegrity values). These criteria are used by the states for developing enforceable water quality standards and identifying problem areas.

Water quality criteria are developed from toxicity studies conducted on different organisms and from studies of the effects of toxic compounds on humans. Federal water quality criteria specify the maximum exposure concentrations that will provide protection of aquatic life and human health. Generally, however, the water quality criteria describe the quality of water that will support a particular use of the water body. For the protection of aquatic life a two-value criterion has been established to account for acute and chronic toxicity of pollutants. The human health criterion specifies the risk incurred with exposure to the toxic compounds at a specified concentration. The human health criterion is associated with the increased risk of contracting a debilitating disease, such as cancer.

B. Water Quality Standards

Water quality standards are laws or regulations that states (and authorized tribes) adopt to enhance and maintain the quality of water and protect public health. States have the primary responsibility for developing and implementing these standards. Water quality standards consist of three elements: 1) the "designated beneficial use" or "uses" of a waterbody or segment of a waterbody, 2) the water quality "criteria" necessary to protect the uses of that particular waterbody, and 3) an antidegradation policy. "Designated use" is a term that is specified in water quality standards for a body of water or a segment of a body of water (e.g., a particular branch of a river). Typical uses include public water supply, propagation of fish and wildlife, and recreational, agricultural, industrial, and navigational purposes. Each state develops its own use classification system based on the generic

U.S. EPA Selected Water Quality Criteria in Micrograms per Liter

	Aquatic Life Freshwater		Marine		Human Health 10^{-6} Risk	
Chemical	**Acute**	**Chronic**	**Acute**	**Chronic**	**Water and Fish Ingestion**	**Fish Ingestion Only**
Benzene	5300	—	5100	700	0.66	40
Cadmium	—	—	43	9.3	10	—
DDT	1.1	0.001	0.13	0.001	0.000024	0.000024
PCBs	2	0.014	10	0.03	0.000079	0.000079

uses cited in the CWA. The states may differentiate and subcategorize the types of uses that are to be protected, such as cold-water or warm-water fisheries, or specific species that are to be protected (e.g., trout, salmon, bass). States may also designate special uses to protect sensitive or valuable aquatic life or habitat. In addition, the water quality criteria adopted into a state water quality standard may or may not be the same number published by EPA under section 304. States have the discretion to adjust the EPA's criteria to reflect local environmental conditions and human exposure patterns.

The CWA requires that the states review their standards at least once every three years and submit the results to EPA for review. EPA is required to either approve or disapprove the standards, depending on whether they meet the requirements of the CWA. When EPA disapproves a standard, and the state does not revise the standard to meet EPA's objection, the CWA requires the Agency to propose substitute federal standards.

C. Total Maximum Daily Load (TMDL) Program

Lasting solutions to water quality problems and pollution control can be best achieved by looking at the fate of all pollutants in a watershed. The CWA requires EPA to administer the total maximum daily load (TMDL) program, under which the states establish the allowable pollutant loadings for impaired waterbodies (i.e., waterbodies not meeting state water quality standards) based on their "waste assimilative capacity." EPA must approve or disapprove TMDLs established by the states. If EPA disapproves a state TMDL, EPA must establish a federal TMDL.

A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. The calculation must include a margin of safety to ensure that the waterbody can be used for the purposes the state has designated. The calculation must also account for seasonal variation in water quality.

The quantity of pollutants that can be discharged into a surface-water body without use impairment (also taking into account natural inputs such as erosion) is known as the "assimilative capacity." The assimilative capacity is the range of concentrations of a substance or a mixture of substances that will not impair attainment of water quality standards. Typically, the assimilative capacity of surface-water bodies might be higher for biodegradable organic matter, but it can be very low for some toxic chemicals that accumulative in the tissues of aquatic organisms and become injurious to animals and people using them as food.

What is a watershed?

Watersheds are areas of land that drain to surface-waterbodies. A watershed generally includes lakes, rivers, estuaries, wetlands, streams, and the surrounding landscape. Ground-water recharge areas are also considered part of a watershed. Because watersheds are defined by natural hydrology, they represent the most logical basis for managing surface-water resources. Managing the watershed as a whole allows state and local authorities to gain a more complete understanding of overall conditions in an area and the cumulative stressors which affect the surface-water body. Information on EPA's strategy to protect and restore water quality and aquatic ecosystems at the watershed level can be found at **<www.epa.gov/owow/watershed/index2.html>**

II. Surface-Water Protection Programs Applicable to Waste Management Units

To ensure that a state's water quality standards and TMDLs are being met, discharges of pollutants are regulated through the National Pollutant Discharge Elimination System (NPDES) Permit Program and the National Pretreatment Program. These permitting programs are implemented and enforced at the state or local level.

A. National Pollutant Discharge Elimination System (NPDES) Permit Program

The CWA requires most "point sources" (i.e., entities that discharge pollutants of any kind into waters of the United States) to have a permit establishing pollution limits, and specifying monitoring and reporting requirements. This permitting process is known as the National Pollutant Discharge Elimination System (NPDES). Permits are issued for three types of wastes that are collected in sewers and treated at municipal wastewater treatment plants or that discharge directly into receiving waters: process wastewater, nonprocess wastewater, and storm water. Most discharges of municipal and industrial storm water require NPDES permits, but some other storm water discharges do not require permits. To protect public health and aquatic life and assure that every facility treats wastewater, NPDES permits include the following terms and conditions.

- Site-specific effluent (or discharge) limitations.
- Standard and site-specific compliance monitoring and reporting requirements.
- Monitoring, reporting, and compliance schedules that must be met.

There are various methods used to monitor NPDES permit conditions. The permit will require the facility to sample its discharges and notify EPA and the state regulatory agency of these results. In addition, the permit will require the facility to notify EPA and the state regulatory agency when the facility determines it is not in compliance with the requirements of a permit. EPA and state regulatory agencies also send inspectors to facilities in order to determine if they are in compliance with the conditions imposed under their permits.

NPDES permits typically establish specific "effluent limitations" relating to the type of discharge. For process wastewaters, the permit incorporates the more stringent of technology-based limitations (either at 40 CFR Parts 405 through 471 or developed on a case-by-case basis according to the permit writer's best professional judgement) or water quality-based effluent limits (WQBELs). Some waste management units, such as surface impoundments, might have an NPDES permit to discharge wastewaters directly to surface waters. Other units might need an NPDES permit for storm-water discharges.

NPDES permits are issued by EPA or states with NPDES permitting authority. If you are located in a state with NPDES authority, you should contact the state directly to determine the requirements for your discharges. EPA's Office of Wastewater Management's Web page contains a complete, updated list of the states with approved NPDES permit programs, as well as a fact sheet and frequently asked questions about the NPDES permit program at <**cfpub.epa.gov/npdes**>. If a state does not have NPDES permitting authority, you should follow any state requirements for discharges and contact EPA to determine the applicable federal requirements for discharges.

When is an NPDES permit needed?

To answer questions about whether or not a facility needs to seek NPDES permit coverage, or to determine whether a particular program is administered by EPA or a state agency, contact your state or EPA regional storm-water office. Currently, 44 states and the U.S. Virgin Islands have federally-approved state NPDES permit programs. The following 6 states do not have final EPA approval: Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico.

(As of March 2001)

1. *Storm-Water Discharges*

EPA has defined 11 categories of "storm-water discharges associated with industrial activity" that require a permit to discharge to navigable waters (40 CFR Part 122.26 (b)(14)). These 11 categories are: 1) facilities subject to storm-water effluent limitations guidelines, new source performance standards (NSPS), or toxic pollutant effluent standards under 40 CFR Part 129 (specifies manufacturers of 6 specific pesticides), 2) "heavy" manufacturing facilities, 3) mining and oil and gas operations with "contaminated" storm-water discharges, 4) hazardous waste treatment, storage, or disposal facilities, 5) landfills, land application sites, and open dumps, 6) recycling facilities, 7) steam electric generating facilities, 8) transportation facilities, 9) sewage treatment plants, 10) construction operations disturbing five or more acres, and 11) other industrial facilities where materials are exposed to storm water. Nonhazardous waste landfills, waste piles, and land application units are included in category 5. Under a new Section 122.26(b)(15), storm water discharges from construction operations disturbing between one and five acres will be required to obtain a NPDES permit effective in March 2003. There will be, however, some waivers from permit requirements available.

To provide flexibility for the regulated community in acquiring NPDES storm-water discharge permits, EPA has two NPDES permit application options: individual permits and general permits.[2] Applications for indi-

[2] Initially, a group application option was available for facilities with similar activities to jointly submit a single application for permit coverage. A multi-sector general permit was then issued based upon information provided in the group applications. The group application option was only used during the initial stages of the program and is no longer available.

> ### What types of pollutants are regulated by NPDES?
>
> Conventional pollutants are contained in the sanitary wastes of households, businesses, and industries. These pollutants include human wastes, ground-up food from sink disposals, and laundry and bath waters. Conventional pollutants include fecal coliform, oil and grease, total suspended solids (TSS), biochemical oxygen demand (BOD), and pH.
>
> Toxic pollutants are particularly harmful to animal or plant life. They are primarily grouped into organics (including pesticides, solvents, polychlorinated biphenyls (PCBs), and dioxins) and metals (including lead, silver, mercury, copper, chromium, zinc, nickel, and cadmium).
>
> Nonconventional pollutants are any additional substances that are not considered conventional or toxic that may require regulation. These include nutrients such as nitrogen and phosphorus.

vidual permits require the submission of a site drainage map, a narrative description of the site that identifies potential pollutant sources, and quantitative testing data for specific parameters. General permits usually involve the submission of a Notice of Intent (NOI) that includes only general information, which is neither industry-specific or pollutant-specific and typically do not require the collection of monitoring data. NPDES general storm-water permits typically require the development and implementation of storm-water pollution prevention plans and BMPs to limit pollutants in storm-water discharges.

The EPA has also issued the Multi-Sector General Permit (60 FR 50803; September 29, 1995) which covers 29 different industry sectors. The Agency reviewed, on a sector-by-sector basis, information concerning industrial activities, BMPs, materials stored outdoors, and end-of-pipe storm-water sampling data. Based on this review, EPA identified pollutants of concern in each industry sector, the sources of these pollutants, and the BMPs used to control them. The Multi-Sector General Permit requires the submission of an NOI, as well as development and implementation of a site-specific pollution prevention plan, as the basic storm-water control strategy for each industry sector.

2. Discharges to Surface Waters

Most surface impoundments that are addressed by the Guide are part of a facility's wastewater treatment process that results in an NPDES-permitted discharge to surface waters. The NPDES permit only sets pollution limits for the final discharge of treated wastewater. Generally, the NPDES permit would not establish any regulatory requirements regarding the design or operation of the surface impoundments that are part of the treatment process except that, once designed and constructed, a provision requires use of those treatment processes except in limited circumstances. Individual state environmental agencies, under their own statutory authorities, can impose requirements on surface impoundment design and operation.

B. National Pretreatment Program

1. Description of the National Pretreatment Program

For industrial facilities that discharge wastewaters to publicly owned treatment works (POTW) through domestic sewer lines, pretreatment of the wastewater may be required (40 CFR Part 403). Under the

National Pretreatment Program, EPA, states, and local regulatory agencies establish discharge limits to reduce the level of pollutants discharged by industry into municipal sewer systems. These limits control the pollutant levels reaching a POTW, improve the quality of the effluent and sludges produced by the POTW, and increase the opportunity for beneficial use of the end products (e.g., effluents, sludges, etc). Further information about industrial pretreatment and the National Pretreatment Program is available on the Office of Wastewater Management's Web page at <**cfpub.epa.gov/npdes/home.cfm?program_id=3**>.

POTWs are designed to treat domestic wastes and biodegradable commercial and industrial wastes. The CWA and EPA define the pollutants from these sources as "conventional pollutants" which includes those specific pollutants that are expected to be present in domestic discharges to POTWs. Commercial and industrial facilities can, however, discharge toxic pollutants that a treatment plant is neither designed nor able to remove. Such discharges, from both industrial and commercial sources, can cause serious problems at POTWs. The undesirable outcome of these discharges can be prevented by using treatment techniques or management practices to reduce or eliminate the discharge of these pollutants.

The act of treating wastewater prior to discharge to a POTW is commonly referred to as "pretreatment." The National Pretreatment Program provides the statutory and regulatory basis to require non-domestic dischargers to comply with pretreatment standards to ensure that the goals of the CWA are attained. The objectives of the National Pretreatment Program are to:

- Prevent the introduction of pollutants into POTWs which will interfere with the operation of a POTW, including interference with the disposal of municipal sludge.
- Prevent the introduction of pollutants into POTWs which will pass through the treatment works or otherwise be incompatible with such works.
- Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

To help accomplish these objectives, the National Pretreatment Program is charged with controlling 126 priority pollutants from industries that discharge into sewer systems as described in the CWA, Section 307(a), and listed in 40 CFR Part 423 Appendix A. These priority pollutants fall into two categories, metals and toxic organics.

- The metals include lead, mercury, chromium, and cadmium. Such toxic metals cannot be destroyed or broken down through treatment or environmental degradation. They can cause various human health problems such as lead poisoning and cancer.
- The toxic organics include solvents, pesticides, dioxins, and polychlorinated biphenyls (PCBs). These can be cancer-causing and lead to other serious ailments, such as kidney and liver damage, anemia, and heart failure.

The objectives of the National Pretreatment Program are achieved by applying and enforcing three types of discharge standards: 1) prohibited discharge standards (provide for overall protection of POTWs), 2) categorical standards applicable to specific point source categories (provide for general protection of POTWs), and 3) local limits (address the water quality and other concerns at specific POTWs).

Prohibited Discharge Standards. All industrials users (IUs), whether or not subject to any other federal, state, or local pretreatment requirements, are subject to the general and specific prohibitions identified in 40 CFR Part 403.5 (a) and (b), respectively. General prohibitions forbid the discharge of any pollutant to a POTW that can pass through or cause interference. Specific prohibitions forbid the discharge of pollutants that pose fire or explosion hazards; corrosives; solid or viscous pollutants in amounts that will obstruct system flows; quantities of pollutants that will interfere with POTW operations; heat that inhibits biological activity; specific oils; pollutants that can cause the release of toxic gases; and pollutants that are hauled to the POTW (except as authorized by the POTW).

Categorical Standards. Categorical pretreatment standards are national, uniform, technology-based standards that apply to discharges to POTWs from specific industrial categories (e.g., battery manufacturing, coil coating, grain mills, metal finishing, petroleum refining, rubber manufacturing) and limit the discharge of specific pollutants. These standards are described in 40 CFR Parts 405 through 471.

Categorical pretreatment standards can be concentration-based or mass-based. Concentration- based standards are expressed as milligrams of pollutant allowed per liter of wastewater discharged (mg/l) and are issued where production rates for the particular industrial category do not necessarily correlate with pollutant discharges. Mass-based standards are generally expressed as a mass per unit of production (e.g., milligrams of pollutant per kilogram of product produced) and are issued where production rates do correlate with pollutant discharges. Thus, limiting the amount of water discharge (i.e., water conservation) is important to reducing the pollutant load to the POTW. For a few categories where reducing a facility's flow volume does not provide a significant difference in the pollutant load discharged, EPA has established both mass- and concentration-based standards. Generally, both a daily maximum limitation and a long-term average limitation (e.g., average daily values in a calendar month) are established for each regulated pollutant.

Local Limits. Federal regulations located at 40 CFR Parts 403.8 (f) (4) and 122.21 (j) (4) require authorities to evaluate the need for local limits and, if necessary, implement and enforce specific limits protective of that POTW. Local limits might be developed for pollutants such as metals, cyanide, BOD, TSS, oil & grease, and organics that can interfere with or pass through the treatment works, cause sludge contamination, or cause worker health and safety problems if discharged at excess levels.

All POTWs designed to accommodate flows of more than 5 million gallons per day and smaller POTWs with significant industrial discharges are required to establish pretreatment programs. The EPA Regions and states with approved pretreatment programs serve as approval authorities for the National Pretreatment Program. In that capacity, they review and approve requests for POTW pretreatment program approval or modification, oversee POTW program implementation, review requested modifications to categorical pretreatment standards, provide technical guidance to POTWs and IUs, and initiate enforcement actions against noncompliant POTWs and IUs.

2. Treatment of Waste at POTW Plants

A waste treatment works' basic function is to speed up the natural processes by which water is purified and returned to receiving lakes and streams. There are two basic stages in the treatment of wastes, primary and secondary. In the primary stage, solids are allowed to settle and are removed from wastewater. The secondary stage uses biological processes to further purify wastewater. Sometimes, these stages are combined into one operation. POTWs can also perform other "advanced treatment" operations to remove ammonia, phosphorus, pathogens and other pollutants in order to meet effluent discharge requirements.

Primary treatment. As sewage enters a plant for treatment, it flows through a screen, which removes large floating objects such as rags and sticks that can clog pipes or damage equipment. After sewage has been screened, it passes into a grit chamber, where cinders, sand, and small stones settle to the bottom. At this point, the sewage still contains organic and inorganic matter along with other suspended solids. These solids are minute particles that can be removed from sewage by treatment in a sedimentation tank. When the speed of the flow of sewage through one of these tanks is reduced, the suspended solids will gradually sink to the bottom, where they form a mass of solids called raw primary sludge. Sludge is usually removed from tanks by pumping, after which it can be further treated for use as fertilizer, or disposed of through incineration if necessary. To complete primary treatment, effluent from the sedimentation tank is usually disinfected with chlorine before being discharged into receiving waters. Sometimes chlorine is fed into the water to kill pathogenic bacteria and to reduce unpleasant odors.

Secondary treatment. The secondary stage of treatment removes about 85 percent of the organic matter in sewage by making use of the bacteria in it. The two principal techniques used in secondary treatment are trickling filters and the activated sludge process.

Trickling filters. A trickling filter is a bed of stones from three to six feet deep through which the sewage passes. More recently, interlocking pieces of corrugated plastic or other synthetic media have also been used in trickling beds. Bacteria gather and multiply on these stones until they can consume most of the organic matter in the sewage. The cleaner water trickles out through pipes for further treatment. From a trickling filter, the sewage flows to another sedimentation tank to remove excess bacteria. Disinfection of the effluent with chlorine is generally used to complete the secondary stage. Ultraviolet light or ozone are also sometimes used in situations where residual chlorine would be harmful to fish and other aquatic life.

Activated sludge. The activated sludge treatment process speeds up the work of the bacteria by bringing air and sludge, heavily laden with bacteria, into close contact with sewage. After the sewage leaves the settling tank in the primary stage, it is pumped into an aeration tank, where it is mixed with air and sludge loaded with bacteria and allowed to remain for several hours. During this time, the bacteria break down the organic matter into harmless by-products. The sludge, now activated with additional millions of bacteria and other tiny organisms, can be used again by returning it to the aeration tank for mixing with new sewage and ample amounts of air. From the aeration tank, the sewage flows to another sedimentation tank to remove excess bacteria. The final step is generally the addition of chlorine to the effluent.

Advanced treatment. New pollution problems have created additional treatment needs on wastewater treatment systems. Some pollutants can be more difficult to remove from water. Increased demands on the water supply only aggravate the problem. These challenges are being met through better and more complete methods of removing pollutants at treatment plants, or through prevention of pollution at the source (refer to

Chapter 3 – Integrating Pollution Prevention for more information). Advanced waste treatment techniques in use or under development range from biological treatment capable of removing nitrogen and phosphorus to physical-chemical separation techniques such as filtration, carbon adsorption, distillation, and reverse osmosis. These wastewater treatment processes, alone or in combination, can achieve almost any degree of pollution control desired. As waste effluents are purified to higher degrees by such treatment, the effluent water can be used for industrial, agricultural, or recreational purposes, or even as drinking water supplies.

III. Understanding Fate and Transport of Pollutants

A. How Do Pollutants Move From Waste Management Units To Surface Water?

1. *Overland Flow*

The primary means by which pollutants are transported to surface-water bodies is via overland flow or "runoff." Runoff to surface water is the amount of precipitation after all "losses" have been subtracted. Losses include infiltration into soils, interception by vegetation, depression storage and ponding, and evapotranspiration (i.e., evaporation from the soil and transpiration by plants).

There is a correlation between the pollutant loadings to surface water and the amount of precipitation (rainfall, snow, etc.) that falls on the watershed in which a waste management unit is located. In addition, the characteristics of the soil at a facility also influence pollutant loading to surface water. If, for example, the overland flow is diminished due to high soil infiltration, so is the transport of particulate pollutants to surface water. Also, if wastes are land applied and surface overland flow is generated by a rainfall event, a significant portion of pollutants can be moved over land into adjacent surface water.

A diagram representing rainfall transformation into runoff and other components of the hydrologic cycle is shown in Chapter 7: Section A–Assessing Risk. The first stage of runoff formation is condensation of atmospheric moisture into rain droplets or snowflakes. During this process, water comes in contact with atmospheric pollutants. The pollution content of rainwater can therefore reach high levels. In addition, rain water dis-

What is "runoff?"

Runoff is water or leachate that drains or flows over the land from any part of a waste management unit.

What is "run-on?"

Run-on is water from outside a waste management unit that flows into the unit. Run-on includes storm water from rainfall or the melting of snow or ice that falls directly on the unit, as well as the water that drains from adjoining areas.

solves atmospheric carbon dioxide and sulfur and nitrogen oxides, and acts as a weak acid after it hits the ground, reacting with soil and limestone formations. Overland flow begins after rain particles reach the earth's surface (note that during winter months runoff formation can be delayed by snowpack formation and subsequent melting). Rain hitting an exposed waste management unit will liberate and pick up particulates and pollutants from the unit and can also dissolve other chemicals it comes in contact with. Precipitation that flows into a waste management unit, called "run-on," can also free-up and subsequently transport pollutants out of the unit. Runoff carries the pollutants from the waste management unit as it flows downgradient following the natural contours of the watershed to nearby lakes, rivers, or wetland areas.

2. Ground Water to Surface Water

Ground water and surface water are fundamentally interconnected. In fact, it is often difficult to separate the two because they "feed" each other. As a result, pollutants can move from one media to another. Shallow water table aquifers interact closely with streams, sometimes discharging water into a stream or lake and sometimes receiving water from the stream or lake. Many rivers, lakes, and wetlands rely heavily on ground-water discharge as a source of water. During times of low precipitation, some bodies of water would not contain any water at all if it were not for ground-water discharge.

An unconfined aquifer that feeds a stream is said to provide the stream's "baseflow." Gravity is the dominant driving force in ground-water movement in unconfined aquifers. As such, under natural conditions, ground water moves "downhill" until it reaches the land surface at a spring or through a seep in the side or bottom of a river bed, lake, wetland, or other surface-water body. Ground water can also leave the aquifer via the pumping of a well. The process of ground water outflowing into a surface-water body or leaving the aquifer through pumping is called discharge.

Discharge from confined aquifers occurs in much the same way except that pressure, rather than gravity, is the driving force in moving ground water to the surface. When the intersection between the aquifer and the land's surface is natural, the pathway is called a spring. If discharge occurs through a well, that well is a "flowing artesian well."

3. Air to Surface Water

Pollutants released into the air are carried by wind patterns away from their place of origin. Depending on weather conditions and the chemical and physical properties of the pollutants, pollutants can be carried significant distances from their source and can undergo physical and chemical changes as they travel. Some of these chemical changes include the formation of new pollutants such as ozone, which is formed from nitrogen oxides (NO_x) and hydrocarbons.

Atmospheric deposition occurs when pollutants in the air fall on the land or surface waters. When pollutants are deposited in snow, fog, or rain, the process is called wet deposition, while the deposition of pollutants as dry particles or gases is called dry deposition. Pollutants can be deposited into water bodies either directly from the air onto the surface of the water, or through indirect deposition, where the pollutants settle on the land and are then carried into a water body by runoff.

Any pollutant that is emitted into the air can become a surface-water problem due to deposition. Some of the common pollutants that can be transported to surface-water bodies via air include different forms of nitrogen, mercury, copper, polychlorinated biphenols (PCBs), polycyclic aromatic hydrocarbons (PAHs), chlordane, dieldrin, lead, lindane, polycyclic organic matter (POM), dioxins, and furans.

B. What Happens When Pollutants Enter Surface Water?

All pollutants entering surface water via runoff, ground-water infiltration, or air transport have an effect on the aquatic ecosystem. Additive and synergistic effects are also factors because many different pollutants can enter a surface-water body from diverse sources and activities. As such, solutions to water quality problems are best achieved by looking at all activities and inputs to surface water in a watershed.

Surface-water ecosystems (i.e., rivers, lakes, wetlands, estuaries) are considered to be in a dynamic equilibrium with their inputs and surroundings. These ecosystems can be divided into two components, the biotic (living) and abiotic (nonliving). Pollutants are continually moving between the two. For example, pollutants can move from the abiotic environment (i.e., the water column) into aquatic organisms, such as fish. The intake of the pollutant can occur as water moves across the gills or directly through the skin. Toxic pollutants can accumulate in fish (known as bioaccumulation), as the fish uptakes more of the pollutant than it can metabolize or excrete. Pollutants can eventually concentrate in an organism to a level where death results. At that point, the pollutants will be released back into the abiotic environment as the organism decays.

The Dissolved Oxygen Problem

The dissolved oxygen balance is an important water quality consideration for streams and estuaries. Dissolved oxygen is the most important parameter for protecting fish and other aquatic organisms. Runoff with a high concentration of biodegradable organics (organic matter) can have a serious effect on the amount of dissolved oxygen in the water. Low dissolved oxygen levels can be very detrimental to fish. The content of organic matter in waste discharges is commonly expressed as the biochemical oxygen demand (BOD) load. Organic matter can come from a variety of sources, including waste management units. When runoff containing organic matter is introduced into receiving waters, decomposers immediately begin to breakdown the organic matter using dissolved oxygen to do so. Further, if there are numerous inputs of organic matter into a single water body, for example a stream, the effects will be additive (i.e., more and more dissolved oxygen will be removed from the stream as organic matter is added along the stream reach and decomposes). This is also an example of how an input that might not be considered a pollutant (i.e., organic matter) can lead to harmful effects due to the naturally occurring process within a surface-water body.

Pollutants can also move within the abiotic environment, as for example, between water and its bottom sediments. Pollutants that are attached to soil particles being carried downstream will be deposited on the bottom of the streambed as the particles fall out of the water column. In this manner, pollutants can accumulate in areas of low flow. Thus, it is obvious that the hydrodynamical, biological, and chemical processes in aquatic systems cannot be separated and must be addressed simultaneously when considering pollutant loads and impacts to surface water. Table 1 presents some additional information on the biological and chemical processes that occur in water bodies.

C. Pollutants Of Concern

As you assess the different types of best management practices (BMPs) that can be used at waste management units to protect surface waters (discussed in Section IV of this chapter), you should also identify the pollutants in the unit that pose the greatest threats to surface water. Factors to consider include the solubility of the constituents in the waste management unit, how easily these potential pollutants can be mobilized, degradation rates, vapor pressures, and biochemical decay coefficients of the pollutants and any other factors that could encourage their release into the environment.

While all pollutants can become toxic at high enough levels, there are a number of compounds that are toxic at relatively low levels. These pollutants have been designated by the EPA as priority pollutants. The list of priority pollutants is included in Table 2. The list of priority pollutants is continuously under review by EPA and is periodically updated. The majority of pollutants on the list are classified as organic chemicals. Others are heavy metals which are being mobilized into the environment by human activities at rates greatly exceeding those of natural geological processes. Several of the priority pollutants are also considered carcinogenic (i.e., they can increase the risk of cancer to the human population or to aquatic organisms, such as fish). Priority pollutants of particular concern for surface-water bodies include:

- Metals, such as cadmium, copper, chromium, lead, mercury, nickel, and zinc, that arise from industrial operations, mining, transportation, and agricultural use.
- Organic compounds, such as pesticides, PCBs, solvents, petroleum hydrocarbons, organometallic compounds, phenols, formaldehyde, and biochemical methylation of metals in aquatic sediments.
- Dissolved gases, such as chlorine and ammonium.
- Anions, such as cyanides, fluorides, sulfides, and sulphates.
- Acids and alkalis.

IV. Protecting Surface Waters

A. Controls to Address Surface-Water Contamination from Overland Flow

Protecting surface water entails preventing storm-water contamination during both the construction of a waste management unit and the operational life of the unit. During construction the primary concern is sediment eroding from exposed soil surfaces. Temporary sediment and erosion control measures, such as silt fences around construction perimeters, straw bales around storm-water inlets, and seeding or straw covering of exposed slopes, are typically used to limit and manage erosion. States or local

Table 1. Biological and Chemical Processes Occurring in Surface-Water Bodies

After pollutants are transported to lakes, rivers, and other water bodies, they can be subject to a variety of biological and chemical processes that affect how they will interact and impact the aquatic ecosystem. These processes determine how pollutants are mobilized, degraded, or released into the biotic and abiotic environments.

Metabolism of a toxicant consists of a series of chemical transformations that take place within an organism. A wide range of enzymes act on toxicants, that can increase water solubility, and facilitate elimination from the organism. In some cases, however, metabolites can be more toxic than their parent compound. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Bioaccumulation is the uptake and sequestration of pollutants by organisms from their ambient environment. Typically, the concentration of the substance in the organism exceeds the concentration in the environment since the organism will store the substance and not excrete it. Phillips. 1993. In: Calow (ed), *Handbook of Ecotoxicology,* Volume One. Blackwell Scientific Publications.

Biomagnification is the concentration of certain substances up a food chain. It is a very important mechanism in concentrating pesticides and heavy metals in organisms such as fish. Certain substances such as pesticides and heavy metals move up the food chain, work their way into a river or lake and are eaten by large birds, other animals, or humans. The substances become concentrated in tissues or internal organs as they move up the chain. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Biological degradation is the decomposition of a substance into more elementary compounds by action of microorganisms such as bacteria. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Hydrolysis is a chemical process of decomposition in which the elements of water react with another substance to yield one or more new substances. This transformation process changes the chemical structure of the substance. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Precipitation is a chemical or physical change whereby a pollutant moves from a dissolved form in a solution to a solid or insoluble form and subsequently drops out of the solution. Precipitation reduces the mobility of constituents, such as metals and is not generally reversible. Boulding. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

Oxidation/Reduction (Redox) process is a complex of biochemical reactions in sediment that influences the valence state of elements (and their ions) found in sediments. Under anaerobic conditions the overall process shifts to a reducing condition. The chemical properties for elements can change substantially with changes in the oxidation state. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Photochemical process is the chemical changes brought about by the radiant energy of the sun acting upon various polluting substances. Sullivan. 1993. *Environmental Regulatory Glossary,* 6th Ed. Government Institutes.

Table 2. Priority Pollutants[3]

001	Acenaphthene	043	Methylene chloride	085	Vinyl chloride
002	Acrolein	044	Methyl chloride	086	Aldrin
003	Acrylonitrile	045	Methyl bromide	087	Dieldrin
004	Benzene	046	Bromoform	088	Chlordane
005	Benzidine	047	Dichlorobromomethane	089	4,4-DDT
006	Carbon tetrachloride	048	Chlorodibromomethane	090	4,4-DDE
007	Chlorobenzene	049	Hexachlorobutadiene	091	4,4-DDD
008	1,2,4-trichlorobenzene	050	Hexachlorocyclopentadiene	092	Alpha-endosulfan
009	Hexachlorobenzene	051	Isophorone	093	Beta-endosulfan
010	1,2-dichloroethane	052	Naphthalene	094	Endosulfan sulfate
011	1,1,1-trichloreothane	053	Nitrobenzene	095	Endrin
012	Hexachloroethane	054	2-nitrophenol	096	Endrin aldehyde
013	1,1-dichloroethane	055	4-nitrophenol	097	Heptachlor
014	1,1,2-trichloroethane	056	2,4-dinitrophenol	098	Heptachlor epoxide
015	1,1,2,2-tetrachloroethane	057	4,6-dinitro-o-cresol	099	Alpha-BHC
016	Chloroethane	058	N-nitrosodimethylamine	100	Beta-BHC
017	Bis(2-chloroethyl) ether	059	N-nitrosodiphenylamine	101	Gamma-BHC
018	2-chloroethyl vinyl ethers	060	N-nitrosodi-n-propylamine	102	Delta-BHC
019	2-chloronaphthalene	061	Pentachlorophenol	103	PCB–1242
020	2,4,6-trichlorophenol	062	Phenol	104	PCB–1254
021	Parachlorometa cresol	063	Bis(2-ethylhexyl) phthalate	105	PCB–1221
022	Chloroform	064	Butyl benzyl phthalate	106	PCB–1232
023	2-chlorophenol	065	Di-N-Butyl Phthalate	107	PCB–1248
024	1,2-dichlorobenzene	066	Di-n-octyl phthalate	108	PCB–1260
025	1,3-dichlorobenzene	067	Diethyl Phthalate	109	PCB–1016
026	1,4-dichlorobenzene	068	Dimethyl phthalate	110	Toxaphene
027	3,3-dichlorobenzidine	069	Benzo(a) anthracene	111	Antimony
028	1,1-dichloroethylene	070	Benzo(a)pyrene	112	Arsenic
029	1,2-trans-dichloroethylene	071	Benzo(b) fluoranthene	113	Asbestos
030	2,4-dichlorophenol	072	Benzo(b) fluoranthene	114	Beryllium
031	1,2-dichloropropane	073	Chrysene	115	Cadmium
032	1,2-dichloropropylene	074	Acenaphthylene	116	Chromium
033	2,4-dimethylphenol	075	Anthracene	117	Copper
034	2,4-dinitrotoluene	076	Benzo(ghi) perylene	118	Cyanide, Total
035	2,6-dinitrotoluene	077	Fluorene	119	Lead
036	1,2-diphenylhydrazine	078	Phenanthrene	120	Mercury
037	Ethylbenzene	079	Dibenzo(,h) anthracene	121	Nickel
038	Fluoranthene	080	Indeno (1,2,3-cd) pyrene	122	Selenium
039	4-chlorophenyl phenyl ether	081	Pyrene	123	Silver
040	4-bromophenyl phenyl ether	082	Tetrachloroethylene	124	Thallium
041	Bis(2-chloroisopropyl) ether	083	Toluene	125	Zinc
042	Bis(2-chloroethoxy) methane	084	Trichloroethylene	126	2,3,7,8-TCDD

[3] The list of pollutants is current as of the Federal Register dated April 2, 2001.

municipalities often require the use of sediment and erosion controls at any construction site disturbing greater than a certain number of acres, and can have additional requirements in especially sensitive watersheds. You should consult with the state and local regulatory agencies to determine the sediment and erosion control requirements for construction.

Once a waste management unit has been constructed, permanent run-on and runoff controls are necessary to protect surface water. Run-on controls are designed to prevent storm water from entering the active areas of units. If run-on is not prevented from entering active areas, it can seep into the waste and increase the amount of leachate that must be managed. It can also deposit pollutants from nearby sites, such as pesticides from adjoining farms, further burdening treatment systems. Excessive run-on can also damage earthen containment systems, such as dikes and berms. Run-on that contacts the waste can carry pollutants into receiving waters through overland runoff or into ground water through infiltration. You can divert run-on to the waste management unit by taking advantage of natural contours in the land or by constructing ditches or berms designed to intercept and drain storm water away from the unit. Run-on diversion systems should be designed to handle the peak discharge of a design storm event (e.g., a 24-hour, 25-year storm[4]). Also note that surface impoundments should be designed with sufficient freeboard and adequate capacity to accommodate not only waste, but also precipitation and run-on.

Runoff controls can channel, divert, and convey storm water to treatment facilities or, if appropriate, to other intended discharge points. Runoff from landfills, land treatment units, or waste piles should be managed as a potentially contaminated material. The runoff from active areas of a landfill or waste pile should be managed as leachate. You should design a leachate collection and removal system to handle the potentially contaminated runoff, in addition to the leachate that might be generated by the unit. You should segregate noncontact runoff to reduce the volume that will need to be treated as leachate. The Multi-Sector General Permit does not authorize discharges of leachate which includes storm water that comes in contact with waste. The discharge of leachate would be regulated under either an individually drafted NPDES permit with site- specific discharge limitations, or an alternative NPDES general permit if one is available. Note that for land application sites, runoff from the site can also adversely affect nearby surface water if pollutants are picked up and carried overland.

BMPs are measures used to reduce or eliminate pollutant releases to surface waters via overland flow. They fall into three categories, baseline, activity-specific, and site-specific, and can take the form of a process, activity, or physical structure. The use of

Why are "run-on" controls necessary?

Run-on controls are designed to prevent: 1) contamination of storm water, 2) erosion that can damage the physical structure of units, 3) surface discharge of waste constituents, 4) creation of leachate, and 5) already contaminated surface water from entering the unit.

What is the purpose of a "runoff" control system?

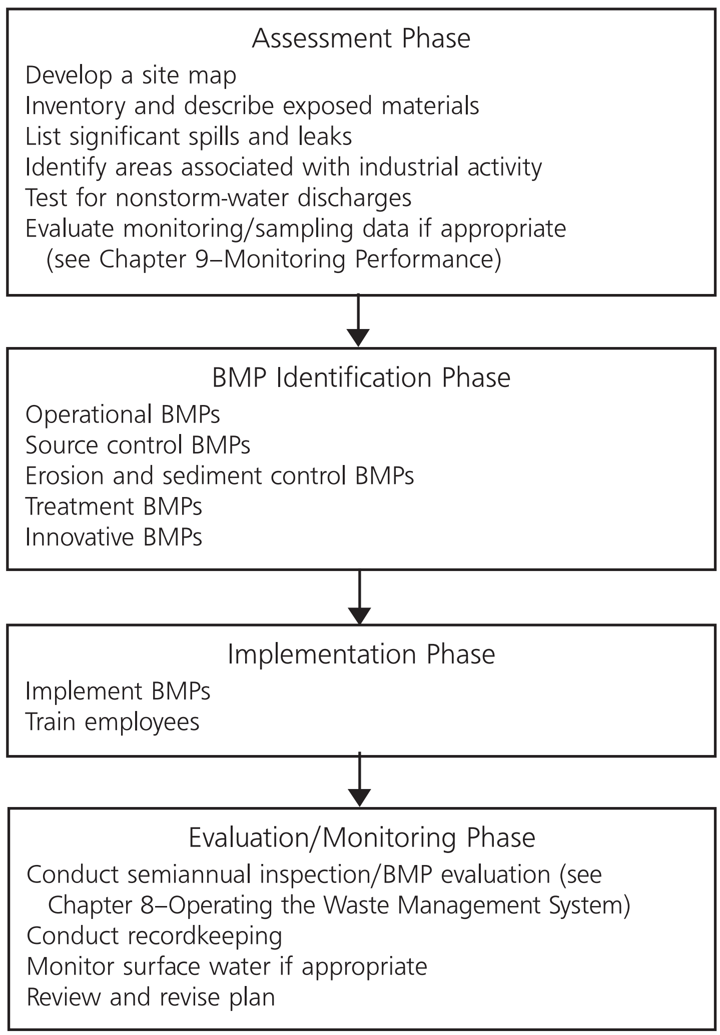
Runoff control systems are designed to collect and control at a minimum the water flow resulting from a storm event of a specified duration, such as a 24-hour, 25-year storm event.

[4] This discharge is the amount of water resulting from a 24-hour rainfall event of a magnitude with a 4 percent statistical likelihood of occurring in any given year (i.e, once every 25 years). Such an event might not occur in a given 25-year period, or might occur more than once during a single year.

BMPs to protect surface water should be considered in both the design and operation of a waste management unit. Before identifying and implementing BMPs, you should assess the potential sources of storm-water contamination including possible erosion and sediment discharges caused by storm events. A thorough assessment of a waste management unit involves several steps including creating a map of the waste management unit area; considering the design of the unit; identifying areas where spills, leaks, or discharges could or do occur; inventorying the types of wastes contained in the unit; and reviewing current operating practices (refer to Chapter 8–Operating the Waste Management System for more information). Figure 1 illustrates the process of identifying and selecting the most appropriate BMPs.

Designing a storm-water management system to protect surface water involves knowledge of local precipitation patterns, surrounding topographic features, and geologic conditions. You should consider sampling runoff to ascertain the quantity and concentration of pollutants being discharged. (Refer to the Chapter 9–Monitoring Performance for more information). Collecting and evaluating this type of information can help you to select the most appropriate BMPs to prevent or control pollutant discharges. The same considerations (e.g., types of wastes to be contained in the unit, precipitation patterns, local topography and geology) should be made while designing and constructing a new waste management unit to ensure that the proper baseline, activity-specific, and site-specific BMPs are implemented and installed from the start of operations. After assessing the potential and existing sources of storm-water contamination, the next step is to select appropriate BMPs to address these contamination sources.

Figure 1. BMP Identification and Selection Flow Chart
Recommended Steps



Adapted from U.S. EPA, 1992e.

1. Baseline BMPs

These practices are, for the most part, inexpensive and relatively simple. They focus on preventing circumstances that could lead to surface-water contamination before it can occur. Many industrial facilities already have these measures in place for product loss prevention, accident and fire prevention, worker health and safety, or compliance with other regulations (refer to Chapter 8–Operating the Waste Management System for more information). Baseline BMPs include the measures summarized below.

Good housekeeping. A clean and orderly work environment is an effective first step toward preventing contamination of run-on and runoff. You should conduct an inventory of all materials and store them so as to prevent leaks and spills and, if appropriate, maintain them in areas protected from precipitation and other elements.

Preventive maintenance. A maintenance program should be in place and should include inspection, upkeep, and repair of the waste management unit and any measures specifically designed to protect surface water.

Visual inspections. Inspections of surface-water protection measures and waste management unit areas should be conducted to uncover potential problems and identify necessary changes. Areas deserving close attention include previous spill locations; material storage, handling, and transfer areas; and waste storage, treatment, and disposal areas. Any problems such as leaks or spills that could lead to surface-water contamination should be corrected as soon as practical.

Spill prevention and response. General operating practices for safety and spill prevention should be established to reduce accidental releases that could contaminate run-on and runoff. Spill response plans should be developed to prevent any accidental releases from reaching surface water.

Mitigation practices. These practices contain, clean-up, or recover spilled, leaked, or loose material before it can reach surface water and cause contamination. Other BMPs should be considered and implemented to avoid releases, but procedures for mitigation should be devised so that unit personnel can react quickly and effectively to any releases that do occur. Mitigation practices include sweeping or shoveling loose waste into appropriate areas of the unit; vacuuming or pumping spilled materials into appropriate treatment or handling systems; cleaning up liquid waste or leachate using sorbents such as sawdust; and applying gelling agents to prevent spilled liquid from flowing towards surface water.

Training employees to operate, inspect, and maintain surface-water protection measures is itself considered a BMP, as is keeping records of installation, inspection, maintenance, and performance of surface-water protection measures. For more information on employee training and record keeping, refer to Chapter 8–Operating the Waste Management System.

2. Activity-Specific BMPs

After assessment and implementation of baseline BMPs, you should also consider planning for activity-specific BMPs. Like baseline BMPs, they are often procedural rather than structural or physical measures, and they are often inexpensive and easy to implement. In the BMP manual for industrial facilities, *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices* (U.S. EPA, 1992f), EPA developed activity-specific BMPs for nine industrial activities, including waste management. The BMPs that are relevant to waste management are summarized below.

Preventing waste leaks and dust emissions due to vehicular travel. To prevent leaks, you should ensure that trucks moving waste into and around a waste management unit have baffles (if they carry liquid waste) or sealed gates, spill guards, or tarpaulin covers (if the waste is solid or semisolid). To minimize tracking dust off site where it can be picked up by storm water, wash trucks in a curbed truck wash area where wash water is captured and properly handled. For more information on these topics, consult Chapter 8–Operating the Waste Management System . You should be aware that washwater from vehicle and equipment cleaning is considered to be "process wastewater," and is not eligible for discharge under the Multi-Sector General Permit program for industrial storm-water discharges. Such discharges would require coverage under either a site-specific individual NPDES permit or an NPDES general storm-water permit.

For land application, choosing appropriate slopes. You should minimize runoff by designing a waste management unit site with slopes less than six percent. Moderate slopes help reduce storm-water runoff velocity which encourages infiltration and reduces erosion and sedimentation. Note that storm-water discharges from land application units are regulated under the Multi-Sector General Permit program.

3. Site-Specific BMPs

In addition to baseline and activity-specific BMPs, you should also consider site-specific BMPs, which are more advanced measures tailored to specific pollutant sources at a particular waste management unit and usually consist of the installation of structural or physical measures. These site-specific BMPs can be grouped into five areas: flow diversion, exposure minimization, erosion and sedimentation prevention, infiltration, and other prevention practices. For many of the surface-water protection measures described in this section, it is important to design for an appropriate storm event (i.e., structures that control run-on and runoff should be designed for the discharge of a 24-hour, 25-year storm event).

When selecting and designing surface-water protection measures or systems, you should consult state, regional, and local watershed management organizations. Some of these organizations maintain management plans devised at the overall watershed level that address storm-water control. Thus, these agencies might be able to offer guidance in developing surface-water protection systems for optimal coordination with other discharges in the watershed. Again, after site-specific BMPs have been installed, you should evaluate the effectiveness of the selected BMPs on a regular basis to ensure that they are functioning properly .

BMP Maintenance

BMPs must be maintained on a regular basis to ensure adequate surface-water protection. Maintenance is important because storms can damage surface-water protection measures such as storage basin embankments or spillways. Runoff can also cause sediments to settle in storage basins or ditches and can carry floatables (i.e., tree branches, lumber, leaves, litter) to the basin. Facilities might need to repair storm-water controls and periodically remove sediment and floatables.

a. Flow Diversion

Flow diversion can be used to protect surface water in two ways. First, it can channel storm water away from waste management units to minimize contact of storm water with waste. Second, it can carry polluted or potentially polluted materials to treatment facilities. Flow diversion mechanisms include storm-water conveyances and diversion dikes.

What are some advantages of conveyances?

Conveyances direct storm-water flows around industrial areas, waste management units, or other waste containment areas to prevent temporary flooding; require little maintenance; and provide long-term control of storm-water flows.

What are some disadvantages of conveyances?

Conveyances require routing through stabilized structures to minimize erosion. They also can increase flow rates, might be impractical if there are space limitations, and might not be economical.

Storm-Water Conveyances (Channels, Gutters, Drains, and Sewers)

Storm-water conveyances, such as channels, gutters, drains, and sewers, can prevent storm-water run-on from entering a waste management unit or runoff from leaving a unit untreated. Some conveyances collect storm water and route it around waste management units or other waste containment areas to prevent contact with the waste, which might otherwise contaminate storm water with pollutants. Other conveyances collect water that potentially came into contact with the waste management unit and carry it to a treatment plant (or possibly back to the unit for reapplication in the case of land application units, some surface impoundments, and leachate-recirculating landfills). Conveyances should not mix the stream of storm water diverted around the unit with that of water that might have contacted waste. Remember, storm water that contacts waste is considered leachate and can only be discharged in accordance with an NPDES permit other than the Multi-Sector General Permit.

Storm-water conveyances can be constructed of or lined with materials such as concrete, clay tile, asphalt, plastic, metal, riprap, compacted soil, and vegetation. The material used will vary depending on the use of the conveyance and the expected intensity of storm-water flow. Storm-water conveyances should be designed with a capacity to accept the estimated storm-water flow associated with the selected design storm event. Section V of this chapter discusses methods for determining storm water flow.

Diversion Dikes

Diversion dikes, often made with compacted soil, direct run-on away from a waste management unit. Dikes are built uphill from a unit and usually work with storm-water conveyances to divert storm water from the unit. To minimize the potential for erosion, diversion dikes are often constructed to redirect runoff at a shallow slope to minimize its velocity. A similar means of flow diversion is grading the area around the waste management unit to keep storm water away from the area, instead of or in addition to using diversion dikes to redirect water that would otherwise flow into these areas. In planning for the installation of dikes, you should consider the slope of the drainage area, the height of the dike, the size of the flow it will need to divert, and the type of conveyance that will be used with the dike.

b. Exposure Minimization

Like flow diversion, exposure minimization practices, such as curbing, diking, and covering can reduce contact of storm water with waste. They often are small structures immediately covering or surrounding a higher risk area, while flow diversion practices operate on the scale of an entire waste management unit.

Curbing and Diking

These are raised borders enclosing areas where liquid spills can occur. Such areas could include waste transfer points in land application, truck washes, and leachate management areas at landfills and waste piles. The raised dikes or curbs prevent spilled liquids from flowing to surface waters, enabling prompt cleanup of only a small area.

Covering

Erecting a roof, tarpaulin, or other permanent or temporary covering (see Figure 2) over the active area of a landfill or waste transfer location can keep precipitation from falling directly on waste materials and prevent run-on from occurring. If temporary coverings are used, you should ensure that sufficient weight is attached to prevent wind from moving the cover, and to repair or replace the cover material if holes or leaks develop.

c. Erosion and Sedimentation Prevention

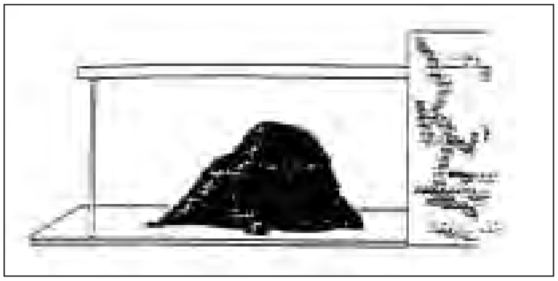
Erosion and sedimentation practices serve to limit erosion (the weathering of soil or rock particles from the ground by wind, water, or human activity) and to prevent particles that are eroded from reaching surface waters as sediment. Erosion and sedimentation can threaten aquatic life, increase treatment costs for downstream water treatment plants, and impede recreational and navigational uses of waterways. Erosion and sedimentation are of particular concern at waste management units because the sediment can be contaminated with waste constituents and because erosion can undercut or otherwise weaken waste containment structures. Practices such as vegetation, interceptor dikes, pipe slope drains, silt fences, storm drain inlet protection, collection and sedimentation basins, check dams, terraces and benches, and outlet protection can help limit erosion and sedimentation.

> *What are some advantages of diversion dikes?*
>
> Diversion dikes limit storm-water flows over industrial site areas; can be economical, temporary structures when built from soil onsite; and can be converted from temporary to permanent at any time.
>
> *What are some disadvantages of diversion dikes?*
>
> Diversion dikes are not suitable for large drainage areas unless there is a gentle slope and might require maintenance after heavy rains.

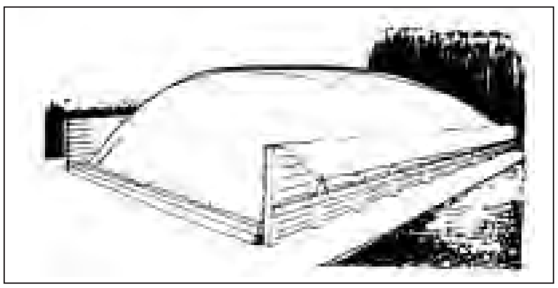
Vegetation

Erosion and sedimentation can be reduced by ensuring that areas where storm water is likely to flow are vegetated. Vegetation slows erosion and sedimentation by shielding soil surfaces from rainfall, improving the soil's water storage capacity, holding soil in place, slowing runoff, and filtering out sediment. One method of providing vegetation is to preserve natural growth. This is achieved by

Figure 2. Coverings



Roof, overhang, or other permanent structure



Tarp or other covering

From U.S. EPA, 1992e.

managing the construction of the waste management unit to minimize disturbance of surrounding grass and plants. If it is not possible to leave all areas surrounding a unit undisturbed, preserve strips of existing vegetation as buffer zones in strategically chosen areas of the site where erosion and sediment control is most needed, such as on steep slopes uphill of the unit and along stream banks downhill from the unit. If it is not possible to leave sufficient buffer zones of existing vegetation, you should create buffer zones by planting such areas with new vegetation.

Temporary or permanent seeding of erodible areas is another means of controlling erosion and sedimentation using vegetation. Permanent seeding, often of grass, is appropriate for establishing long-term ground cover after construction and other land-disturbing activities are complete. Temporary seeding can help prevent erosion and sedimentation in areas that are exposed but will not be disturbed again for a considerable time. These areas include soil stockpiles, temporary roadbanks, and dikes. Local regulations might require temporary seeding of areas that would otherwise remain exposed beyond a certain period of time. You should consult local officials to determine whether such requirements apply. Seeding might not be feasible for quickly establishing cover in arid climates or during nongrowing seasons in other climates. Sod, although more expensive, can be more tolerant of these conditions than seed and establish a denser grass cover more quickly. Compost used in combination with seeding can also be used effectively to establish vegetation on slopes.

Physical and chemical stabilization, and various methods of providing cover are also often considered in conjunction with vegetative measures or when vegetative measures cannot be used. Physical stabilization is appropriate where stream flow might be increased due to construction or other activities associated with the waste management unit and where vegetative measures are not practical. Stream-bank stabilization might involve the reinforcement of stream banks with stones, concrete or asphalt, logs, or gabions (i.e., structures formed from crushed rock encased in wire mesh). Methods of providing cover such as mulching, compost, matting, and netting can be used to cover surfaces that are steep, arid, or otherwise unsuitable for planting. These methods also can work in conjunction with planting to stabilize and protect seeds. (Mattings are sheets of mulch that are more stable than loose mulch chips. Netting is a mesh of jute, wood fiber, plastic, paper, or cotton that can hold mulch on the ground or stabilize soils. These measures are sometimes used with seeding to provide insulation, protect against birds, and hold seeds and soil in place.) Chemical stabilization (also known as chemical mulch, soil binder, or soil palliative) can hold the soil in place and protect against erosion by spraying vinyl, asphalt, or rubber onto soil surfaces. Erosion and sediment control is immediate upon spraying and does not depend on climate or season. Stabilizer should be applied according to manufacturer's instructions to ensure that water quality is not affected. Coating large areas with thick layers of stabilizer, however, can create an impervious surface and speed runoff to downgradient areas and should be avoided.

Interceptor Dikes and Swales

Dikes (ridges of compacted soil) and swales (excavated depressions in which storm water flows) work together to prevent entry of run-on into erodible areas. A dike is built across a slope upgradient of an area to be protected, such as a waste management unit, with a swale just above the dike. Water flows down the slope, accumulates in the swale, and is blocked from exiting it by the dike. The swale is graded to direct water slowly downhill across the slope to a stabilized outlet structure. Since flows are concentrated in the swale, it is important to vegetate the swale to prevent erosion of its channel and to grade it so that predicted flows will not damage the vegetation.

Pipe Slope Drains

Pipe slope drains are flexible pipes or hoses used to traverse a slope that is already damaged or at high risk of erosion. They are often used in conjunction with some means of blocking water flow on the slope, such as a dike. Water collects against the dike and is then channeled to one point along the dike where it enters the pipe, which conveys it downhill to a stabilized (usually riprap-lined) outlet area at the bottom of the slope. You should ensure that pipes are of adequate size to accommodate the design storm event and are kept clear of clogs.

Silt Fences, Straw Bales, and Brush Barriers

Silt fences and straw bales (see Figures 3 and 4) are temporary measures designed to capture sediment that has already eroded and reduce the velocity of storm water. Silt fences and straw bales should not be considered permanent measures unless fences are maintained on a routine basis and straw bales are replaced regularly. They could be used, for example, during construction of a waste management unit or on a final cover before permanent grass growth is established.

Silt fences consist of geotextile fabric supported by wooden posts. These fences slow the flow of storm water and retain sediment as the water filters through the fabric. If properly installed, straw bales perform a similar function. Straw bales should be placed end to end (with no gaps in between) in a shallow, excavated trench and staked into place. Silt fences and straw bales limit sediment from entering receiving waters if properly maintained. Both measures require frequent inspection and maintenance, including checking for channels eroded beneath the fence or bales, removing

What are some advantages of silt fences, straw bales, and brush barriers?

They prevent eroded materials from reaching surface waters and prevent downstream damage from sediment deposits at minimal cost.

What are some disadvantages of silt fences, straw bales, and brush barriers?

These measures are not appropriate for streams or large swales and pose a risk of washouts if improperly installed.

accumulated sediment, and replacing damaged or deteriorated sections.

Brush barriers work like silt fences and straw bales but are constructed of readily available materials. They consist of brush and other vegetative debris piled in a row and are often covered with filter fabric to hold them in place and increase sediment interception. Brush barriers are inexpensive due to their reuse of material that is likely available from clearing the site. New vegetation often grows in the organic material of a brush barrier, helping anchor the barrier with roots. Depending on the material used, it might be possible to leave a former brush barrier in place and allow it to biodegrade, rather than remove it.

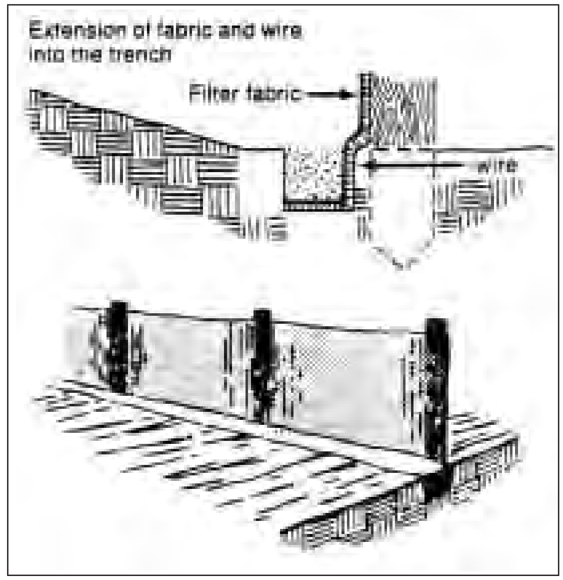
Storm Drain Inlet Protection

Filtering measures placed around inlets or drains to trap sediment are known as inlet protection (see Figure 5). These measures prevent sediment from entering inlets or drains and possibly making their way to the receiving waters into which the storm drainage system discharges. Keeping sediment out of storm-water drainage systems also serves to prevent clogging, loss of capacity, and other problems associated with siltation of drainage structures. Inlet protection methods include sod, excavated areas for settlement of sediment, straw bales or filter fences, and gravel or stone with wire mesh. These measures are appropriate for inlets draining small areas where soil will be disturbed. Some state or local jurisdictions require installation of these measures before disturbance of more than a certain acreage of land begins. Regular maintenance to remove accumulated sediment is important for proper operation.

Collection and Sedimentation Basins

A collection or sedimentation basin (see Figure 6) is an area that retains runoff long enough to allow most of the sediment to settle out and accumulate on the bottom of the basin. Since many pollutants are attached to suspended solids, they will also settle out in the basin with the sediment. The quantity of sediment removed will depend on basin volume, inlet and outlet configuration, basin depth and shape, and retention time. Regular maintenance and dredging to remove accu-

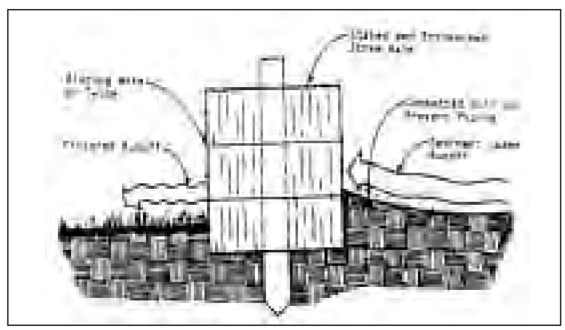
Figure 3. Silt Fence



Bottom: Perspective of silt fence. Top: Cross-section detail of base of silt fence.

From U.S. EPA, 1992e.

Figure 4. Straw Bale



From U.S. EPA, 1992e.

mulated sediment and to minimize growth of aquatic plants that can reduce effectiveness is critical to the operation of basins. All dredged materials, whether they are disposed or reused, should be managed appropriately.

Basins can also present a safety hazard. Fences or other measures to prevent unwanted public access to the basins and their associated inlet and outlet structures are prudent safety precautions. In designing collection or sedimentation basins (a form of surface impoundment), consider storm- water flow, sediment and pollutant loadings, and the characteristics of expected pollutants. In the case of certain pollutants, it might be appropriate to line the basins to protect the ground water below. Lining a basin with concrete also facilitates maintenance by allowing dredging vehicles to drive into a drained basin and remove accumulated sediment. Poor implementation of baseline and activity-specific BMPs can result in high sediment and pollutant loads, leading to unusually frequent dredging of settled materials. For this reason, when operating sedimentation basins, it is important that baseline and activity-specific BMPs are being implemented properly. We recommend that construction of these basins be supervised by a qualified engineer familiar with state and local storm-water requirements.

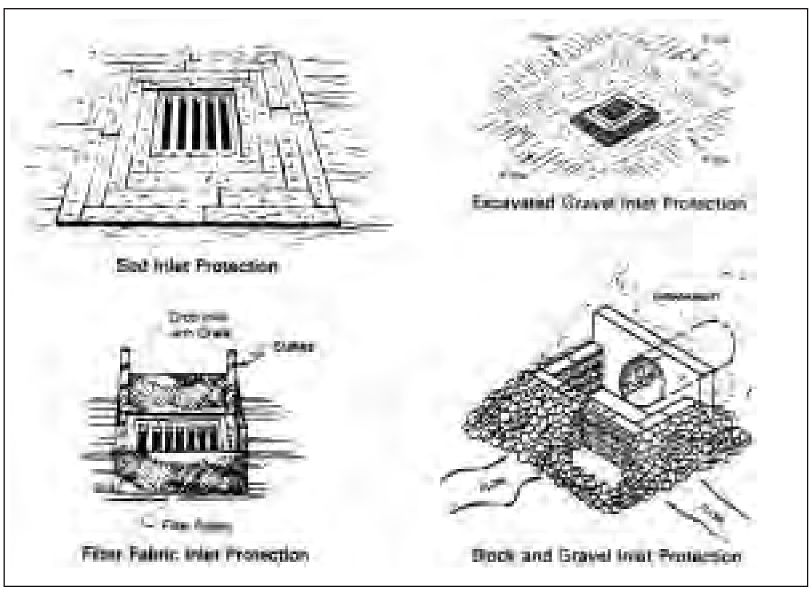
What are some advantages of sedimentation basins?

They protect downstream areas against clogging or damage and contain smaller sediment particles than sediment traps can due to their longer retention time.

What are some disadvantages?

Sedimentation basins are generally not suitable for large areas, require regular maintenance and cleaning, and will not remove very fine silts and clays unless used with other measures.

Figure 5. Storm Drain Inlet Protection



From U.S. EPA, 1992e.

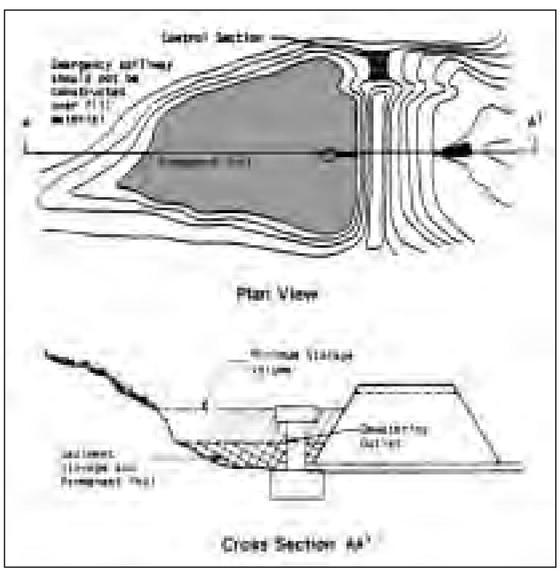
Check Dams

Small rock or log dams erected across a ditch, swale, or channel can reduce the speed of water flow in the conveyance. This reduces erosion and also allows sediment to settle out along the channel. Check dams are especially useful in steep, fast-flowing swales where vegetation cannot be established. For best results, it is recommended that you place check dams along the swale so that the crest of each check dam is at the same elevation as the toe (lowest point) of the previous (upstream) check dam. Check dams work best in conveyances draining small areas and should be installed only in man-made conveyances. Placement of check dams in streams is not recommended and might require a permit.

Terraces and Benches

Terraces and benches are earthen embankments with flat tops or ridge-and-channels. Terraces and benches hold moisture and minimize sediment loading in runoff. They can be used on land with no vegetation or where it is anticipated that erosion will be a problem. Terraces and benches reduce erosion damage by capturing storm-water runoff and directing it to an area where the runoff will not cause erosion or damage. For best results, this area should be a grassy waterway, vegetated area, or tiled outlet. Terraces and benches might not be appropriate for use on sandy or rocky slopes.

Figure 6.
Collection and Sedimentation Basin



From U.S. EPA, 1992e.

Outlet Protection

Stone, riprap, pavement, or other stabilized surfaces placed at a storm-water conveyance outlet are known as outlet protection (see Figure 7). Outlet protection reduces the speed of concentrated storm-water flows exiting the outlet, lessening erosion and scouring of channels downstream. It also removes sediment by acting as a filter medium. It is recommended that you consider installing outlet protection wherever predicted outflow velocities might cause erosion.

d. Infiltration

Infiltration measures such as vegetated filter strips, grassed swales, and infiltration trenches encourage quick infiltration of storm water into the ground rather than allowing it to remain as overland flow. Infiltration not only reduces runoff velocity, but can also provide some treatment of runoff, preserve natural stream flow, and recharge ground water. Infiltration measures can be inappropriate on unstable slopes or in cases where runoff might be contaminated,

What are some advantages of terraces and benches?

Terraces and benches reduce runoff speed and increase the distance of overland runoff flow. In addition, they hold moisture better than do smooth slopes and minimize sediment loading in runoff.

What are some disadvantages of terraces and benches?

Terraces and benches can significantly increase cut and fill costs and cause sloughing if excess water infiltrates the soil. They are not practical for sandy, steep, or shallow soils.

or where wells, foundations, or septic fields are nearby.

Vegetated Filter Strips and Grassed Swales

Vegetated filter strips are gently sloped areas of natural or planted vegetation. They allow water to pass over them in sheetflow (runoff that flows in a thin, even layer), infiltrate the soil, and drop sediment. Vegetated filter strips are appropriate where soils are well draining and the ground-water table is deep below the surface. They will not work effectively on slopes of 15 percent or more due to high runoff velocity. Strips should be at least 20 feet wide and 50 to 75 feet long in general, and longer on steeper slopes. If possible, it is best to leave existing natural vegetation in place as filter strips, rather than planting new vegetation, which will not function to capture eroded particles until it becomes established.

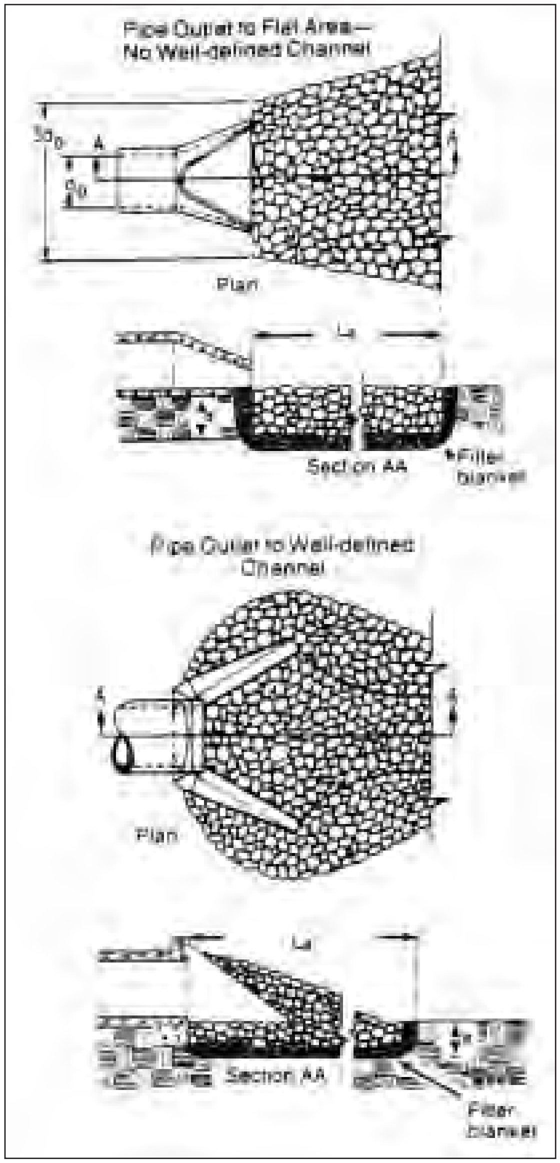
Grassed swales function similarly to non-vegetated swales (discussed earlier in this chapter) except that grass planted along the swale bottom and sides will slow water flow and filter out sediment. Permeable soil in which the swale is cut encourages reduction of water volume through infiltration. Check dams (discussed earlier in this chapter) are sometimes provided in grassed swales to further slow runoff velocity, increasing the rate of infiltration.

To optimize swale performance, it is best to use a soil which is permeable but not excessively so; very sandy soils will not hold vegetation well and will not form a stable channel structure. It is also recommended that you grade the swale to a very gentle slope to maximize infiltration.

Infiltration Trenches

An infiltration trench (see Figure 8) is a long, narrow excavation ranging from 3 to 12 feet deep. It is filled with stone to allow for temporary storage of storm water in the open spaces between the stones. The water eventually infiltrates the surrounding soil or is collected by perforated pipes in the bottom of the trench and conveyed to an outflow point. Such trenches can remove fine sediments and

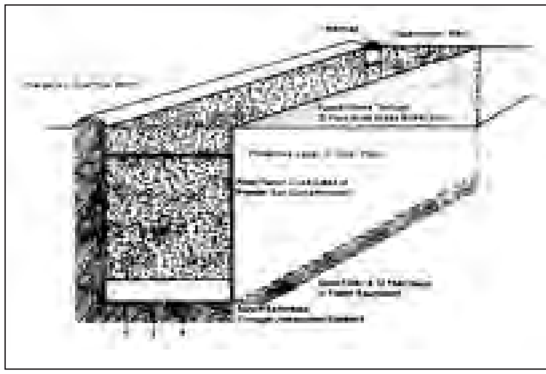
Figure 7. Outlet Protection



From U.S. EPA, 1992e.

soluble pollutants. They should not be built in relatively impervious soils, such as clay, that would prevent water from draining from the bottom of the trench; less than 3 feet above the water table; in soil that is subject to deep frost penetration; or at the foot of slopes steeper than 5 percent. Infiltration trenches should not be used to handle contaminated runoff. Runoff can be pretreated using a grass buffer/filter strip or treated in the trench with filter fabric.

Figure 8. Infiltration Trench



From U.S. EPA, 1992e.

e. *Other Practices*

Additional practices exist that can help prevent contamination of surface water such as preventive monitoring, dust control, vehicle washing, and discharge to wetlands. Many of these practices are simple and inexpensive to implement while others, such as monitoring, can require more resources.

Preventive Monitoring

Preventive monitoring includes automatic and control systems, monitoring of operations by waste management unit personnel, and testing of equipment. These processes can help to ensure that equipment functions as designed and is in good repair so that spills and leaks, which could contaminate adjacent surface waters, are minimized and do not go undetected when they do occur. Some automatic monitoring equipment, such as pressure gauges coupled with pressure relief devices, can correct problems without human intervention, preventing leaks or spills that could contaminate surface water if allowed to occur. Other monitoring equipment can provide early warning of problems so that personnel can intervene before leaks or spills occur. Systems that could contaminate surface water if they failed and that could benefit from automatic monitoring or early warning devices include leachate pumping and treatment systems, liquid waste distribution and storage systems at land application units, and contaminated runoff conveyances.

Dust Control

In addition to being an airborne pollutant, dust can settle in areas where it can be picked up by runoff or can be transported by air and deposited directly into surface waters. Dust particles can carry pollutants and can also result in sedimentation of waterbodies. Several methods of dust control are available to prevent this. These include irrigation, chemical treatments, minimization of exposed soil areas, wind breaks, tillage, and sweeping. For further information on dust control, consult Chapter 8–Operating the Waste Management System.

Vehicle Washing

Materials that accumulate on tires and other vehicle surfaces and then disperse across a facility are an important source of surface-water contamination. Vehicle washing removes materials such as dust and waste. Washing stations can be located near waste transfer areas or near the waste management site exit. Pressurized water spray is usually sufficient to remove dust. Waste water from vehicle washing operations should be contained and handled appropriately. Discharge of such waste water requires an NPDES permit other than the Multi-Sector General Permit.

Discharges to Wetlands

Discharge to constructed wetlands is a method less frequently used and can involve complicated designs. The discharge of storm water into natural wetlands, or the modification of wetlands to improve their treatment capacity, can damage a wetland ecosystem and, therefore, is subject to federal, state, and local regulations.

Constructed wetlands provide an alternative to natural wetlands. A specially designed pond or basin, which is lined in some cases, is stocked with wetland plants that can control sedimentation and manage pollutants through biological uptake, microbial action, and other mechanisms. Together, these processes often result in better pollutant removal than would be expected from sedimentation alone. When designing constructed wetlands, you should consider 1) that maintenance might include dredging, similar to that required for sedimentation basins, 2) provisions for a dry-weather flow to maintain the wetlands, 3) measures to limit mosquito breeding, 4) structures to prevent escape of floating wetland plants (such as water hyacinths) into downstream areas where they are undesirable, and 5) a program of harvesting and replacing plants.

> *What are some advantages of constructed wetlands?*
>
> Provide aesthetic as well as water quality benefits and areas for wildlife habitat.
>
> *What are some disadvantages of constructed wetlands?*
>
> Discharges to wetlands might be subject to multiple federal, state, and local regulations. In addition, constructed wetlands might not be feasible if land is not available and might not be effective as a storm-water control measure until time has been allowed for substantial plant growth.

B. Controls to Address Surface-water Contamination from Ground Water to Surface Water

Generally, the use of liners and groundwater monitoring systems will reduce potential contamination from ground water to surface water. For more information on protecting ground water, refer to Chapter 7: Sections A–Assessing Risk, Section B–Designing and Installing Liners, and Section C–Designing a Land Application Program.

C. Controls to Address Surface-water Contamination from Air to Surface Water

Emission control techniques for volatile organic compounds (VOC) and particulates can assist in reducing potential contamination of surface water from air. Refer to Chapter 5–Protecting Air Quality, for more information on air emission control techniques.

V. Methods of Calculating Run-on and Runoff Rates

The design and operation of surface-water protection systems will be driven by anticipated storm-water flow. Run-on and runoff flow rates for the chosen design storm event should be calculated in order to: 1) choose the proper type of storm-water controls to install, and 2) properly design the controls and size the chosen control measures to minimize impacts to surface water. Controls based on too small a design storm event, or sized without calculating flows will not function properly and can result in releases of contaminated storm water. Similarly, systems can also be designed for too large a flow, resulting in unnecessary control and excessive costs.

The usual approach for sizing surface-water protection systems relies on the use of standardized "design storms." A design storm is, in theory, representative of many recorded storms and reflects the intensity, volume, and duration of a storm predicted to occur once in a given number of years. In general, surface-water protection structures should be designed to handle the discharge from a 24-hour, 25-year storm event (i.e., a rainfall event of 24 hours duration and of such a magnitude that it has a 4 percent statistical likelihood of occurring in any given year). Figure 9 presents a typical intensity-duration-frequency curve for rainfall events.

The Hydrometeorological Design Studies Center (HDSC) at the National Weather Service has prepared *Technical Paper 40, Rainfall Frequency Atlas of the United States for Durations From 30 Minutes to 24 Hours and Return Periods From 1 to 100 Years* (published

Rational Method for Calculating Storm-Water Runoff Flow

$Q = cia$

where,

Q = peak flow rate (runoff), expressed in cubic feet per second (cfs)*

c = runoff coefficient, unitless. The coefficient c is not directly calculable, so average values based on experience are used. Values of c range from 0 (all infiltration, no runoff) to 1 (all runoff, no infiltration). For example, flat lawns with sandy soil have a c value of 0.05 to 0.10, while concrete streets have a c value of 0.80 to 0.95.

i = average rainfall intensity, expressed in inches per hour, for the time of concentration, tc, which is a calculable flow time from the most distant point in the drainage area to the point at which Q is being calculated. Once tc is calculated and a design storm event frequency is selected, i can be obtained from rainfall intensity-duration-frequency graphs (see Figure 9).

a = drainage area, expressed in acres. The drainage area is the expanse in which all runoff flows to the point at which Q is being calculated.

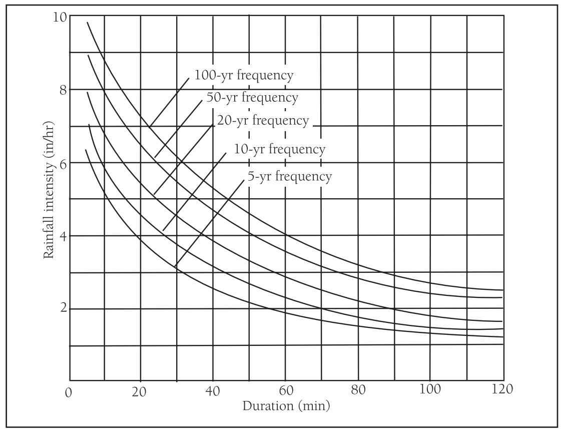
* Examining the units of i and a would indicate that Q should be in units of ac-in/hr. However, since 1 ac-in/hr = 1.008 cfs, the units are interchangeable with a negligible loss of accuracy. Units of cfs are usually desired for subsequent calculations.

in 1961). This document contains rainfall intensity information for the entire United States. Another HDSC document, *NOAA Atlas 2, Precipitation Frequency Atlas of the Western United States* (published in 1973) comes in 11 volumes, one for each of the 11 westernmost of the contiguous 48 states. Precipitation frequency maps for the eleven western most states are available on the Western Regional Climate Center's Web page at **<www.wrcc. sage.dri.edu/ pcpnfreq.html>**. HDSC is currently assembling more recent data for some areas. Your state or local regulatory agency might be able to provide data for your area.

Several methods are available to help you calculate storm-water flows. The Rational Method can be used for calculating runoff for areas of less than 200 acres. Another useful tool for estimating storm-water flows is the Natural Resource Conservation Service's TR-55 software.[5] TR-55 estimates runoff volume from accumulated rainfall and then applies the runoff volume to a simplified hydrograph for peak discharge total runoff estimations.

Computer models are also available to aid in the design of storm-water control systems. For example, EPA's Storm Water Management Model (SWMM) is a comprehensive model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and finally to receiving water bodies. Using SWMM, it might be possible to perform both single-event and continuous simulation on

Figure 9. Typical Intensity-Duration-Frequency Curves



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catchments having storm sewers and natural drainage, for prediction of flows, stages, and pollutant concentrations.

Some models, including SWMM, were developed for purposes of urban storm-water control system design, so it is important to ensure that their methodology is applicable to the design of industrial waste management units. As with all computer models, these should be used as part of the array of design tools, rather than as a substitute for careful consideration of the unit's design by qualified professionals.

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[5] TR-55, Urban Hydrology for Small Watersheds Technical Release 55, presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. This software is suited for use in small and especially urbanizing watersheds. TR-55 can be downloaded from the National Resource Conservation Service at **<www.wcc.nrcs.usda.gov/water/quality/common/tr55/tr55.html>**.

Storm Water Management Model (SWMM). Simulates the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and receiving waters.

BASINS: A Powerful Tool for Managing Watersheds. A multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art environmental assessment and modeling tools into one package.

Source Loading and Management Model (SLAMM). Explores relationships between sources of urban runoff pollutants and runoff quality. It includes a wide variety of source area and outfall control practices. SLAMM is strongly based on actual field observations, with minimal reliance on theoretical processes that have not been adequately documented or confirmed in the field. SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control.

Simulation for Water Resources in Rural Basins (SWRRB). Simulates hydrologic, sedimentation, and nutrient and pesticide transport in large, complex rural watersheds. It can predict the effect of management decisions on water, sediment, and pesticide yield with seasonable accuracy for ungauged rural basins throughout the United States.

Pollutant Routing Model (P-ROUTE). Estimates aqueous pollutant concentrations on a stream reach by stream reach flow basis, using 7Q10 or mean flow.

Enhanced Stream Water Quality Model (QUAL2E). Simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration and their effects on the dissolved oxygen balance. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources.

Protecting Surface Water Activity List

You should conduct the following activities when designing or operating surface-water protection measures or systems in conjunction with waste management units.

- ❑ Comply with applicable National Pollutant Discharge Elimination System (NPDES), state, and local permitting requirements.
- ❑ Assess operating practices, identify potential pollutant sources, determine what constituents in the unit pose the greatest threats to surface water, and calculate storm-water runoff flows to determine the need for and type of storm-water controls.
- ❑ Choose a design storm event (e.g., a 24-hour, 25-year event) and obtain precipitation intensity data for that event to determine the most appropriate storm-water control devices.
- ❑ Select and implement baseline and activity-specific BMPs, such as good housekeeping practices and spill prevention and response plans as appropriate for your waste management unit.
- ❑ Select and establish site-specific BMPs, such as diversion dikes, collection and sedimentation basins, and infiltration trenches as appropriate for your waste management unit.
- ❑ Develop a plan for inspecting and maintaining the chosen storm-water controls; if possible, include these measures as part of the operating plan for the waste management unit.

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Part IV
Protecting Ground-Water Quality

Chapter 7: Section A
Assessing Risk

Contents

Contents

Assessing Risk

This chapter will help you:

- *Protect ground water by assessing risks associated with new waste management units and tailoring management controls accordingly.*
- *Understand the three-tiered evaluation discussed in this chapter that can be used to determine whether a liner system is necessary, and if so, which liner system is recommended, or whether land application is appropriate.*
- *Follow guidance on liner design and land application practices.*

Ground water is the water found in the soil and rock that make up the Earth's surface. Although it comprises only about 0.69 percent of the Earth's water resources, ground water is of great importance. It represents about 25 percent of fresh water resources, and when the largely inaccessible fresh water in ice caps and glaciers is discounted, ground water is the Earth's largest fresh water resource—easily surpassing lakes and rivers, as shown in Table 1. Statistics about the use of ground water as a drinking water source underscore the importance of this resource. Ground water is a source of drinking water for more than half of the people in the United States.[1] In rural areas, 97 percent of households rely on ground water as their primary source of drinking water.

Table 1.
Earth's Water Resources

Resource	Percent of Total	Percent of Nonoceanic
Oceans	97.25	—
Ice caps and glaciers	2.05	74.65
Ground water and soil moisture	0.685	24.94
Lakes and rivers	0.0101	0.37
Atmosphere	0.001	0.036
Biosphere	0.00004	0.0015

Adapted from Berner, E.K. and R. Berner. 1987. *The Global Water Cycle: Geochemistry and Environment*

In addition to its importance as a domestic water supply, ground water is heavily used by industry and agriculture. It provides approximately 37 percent of the irrigation water and 18 percent of the total water used by industry.[2] Ground water also has other important environmental functions, such as providing recharge to lakes, rivers, wetlands, and estuaries.

Water beneath the ground surface occurs in an upper unsaturated (vadose) zone and a deeper saturated zone. The unsaturated zone is the area above the water table where the soil pores are not filled with water, although some water might be present. The subsurface area below the water table where the pores and cracks are filled with water is called the saturated zone. This chapter focuses on

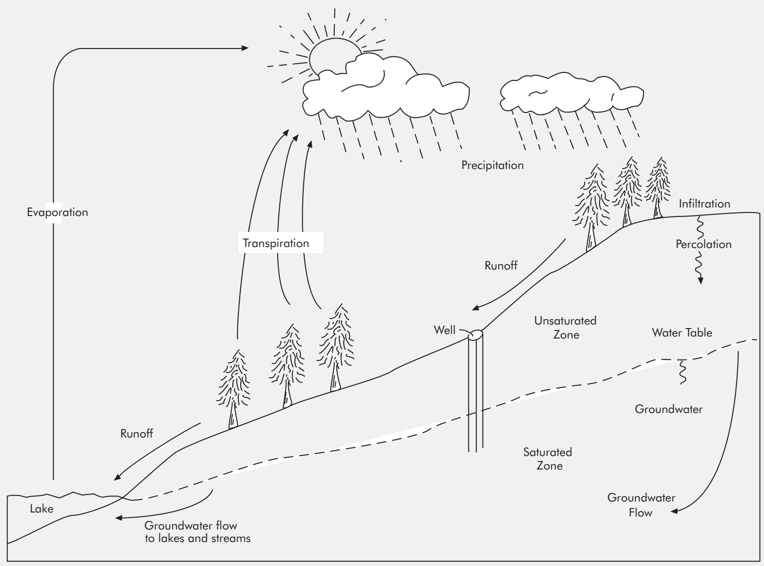
[1] Surface water, in the form of lakes and rivers, is the other major drinking water source. Speidel, D., L. Ruedisili, and A. Agnew. 1988. *Perspectives on Water: Uses and Abuses*.

[2] Excludes cooling water for steam-electric power plants. U.S. Geological Survey. 1998. *Estimated Use of Water in the United States in 1995.*

ground water in the saturated zone, where most ground-water withdrawals are made.

Because ground water is a major source of water for drinking, irrigation, and process water, many different parties are concerned about ground-water contamination, including the public; industry; and federal, state, and local governments. Many potential threats to the quality of ground water exist, such as the leaching of fertilizers and pesticides, contamination from faulty or overloaded septic fields, and releases from industrial facilities, including waste management units.

If a source of ground water becomes contaminated, remedial action and monitoring can be costly. Remediation can require years of effort, or in some circumstances, might be technically infeasible. For these reasons, preventing ground-water contamination is important, or at least minimizing impacts to ground water by implementing controls tailored to the risks associated with the waste.



Ground Water in the Hydrologic Cycle

The hydrologic cycle involves the continuous movement of water between the atmosphere, surface water, and the ground. Ground water must be understood in relation to both surface water and atmospheric moisture. Most additions (recharge) to ground water come from the atmosphere in the form of precipitation, but surface water in streams, rivers, and lakes will move into the ground-water system wherever the hydraulic head of the water surface is higher than the water table. Most water entering the ground as precipitation returns to the atmosphere by evapotranspiration. Most water that reaches the saturated zone eventually returns to the surface by flowing to points of discharge, such as rivers, lakes, or springs. Soil, geology, and climate will determine the amounts and rates of flow among the atmospheric, surface, and ground-water systems.

This chapter addresses how ground-water resources can be protected through the use of a systematic approach of assessing potential risk to ground water from a proposed waste management unit (WMU). It discusses assessing risk and the three-tiered ground-water risk assessment approach implemented in the Industrial Waste Management Evaluation Model (IWEM), which was developed as part of this Guide. Additionally, the chapter discusses the use of this tool and how to apply its results and recommendations. It is highly recommended that you also consult with your state regulatory agency, as appropriate. More specific information on the issues described in this chapter is available in the companion documents to the IWEM software: *User's Guide for the Industrial Waste Management Evaluation Model* (U.S. EPA, 2002b), and *Industrial Waste Management Evaluation Model (IWEM) Technical Background Document* (U.S. EPA, 2002a).

I. Assessing Risk

A. General Overview of the Risk Assessment Process

Our ground-water resources are essential for biotic life on the planet. They also act as a medium for the transport of contaminants and, therefore, constitute an exposure pathway of concern. Leachate from WMUs can be a source of ground-water contamination. Residents who live close to a WMU and who use wells for water supply can be directly exposed to waste constituents by drinking or bathing in contaminated ground water. Residents also can be exposed by inhaling volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) that are released indoors while using ground water for showering or via soil gas migration from subsurface plumes.

The purpose of this section is to provide general information on the risk assessment process and a specific description of how each of the areas of risk assessment is applied in performing ground-water risk analyses. Greater detail on each of the steps in the process as they relate to assessing ground-water risk is provided in later sections of this chapter.

In any risk assessment, there are basic steps that are necessary for gathering and evaluating data. This Guide uses a four-part process to estimate the likelihood of chemicals coming into contact with people now or in the future, and the likelihood that such contact will harm these people. This process shows how great (or small) the risks might be. It also points to who is at risk, what is causing the risk, and how certain one can be about the risks. A general overview of these steps is presented below to help explain how the process is used in performing the assessments associated with IWEM. The components of a risk assessment that are discussed in this section are: problem formulation, exposure assessment, toxicity assessment, and risk characterization. Each of these steps is described as it specifically applies to risk resulting from the release of chemical constituents from WMUs to ground water.

1. Problem Formulation

The first step in the risk assessment process is problem formulation. The purpose of this step is to clearly define the risk question to be answered and identify the objectives, scope, and boundaries of the assessment. This phase can be viewed as developing the overall risk assessment study design for a specific problem. Activities that might occur during this phase include:

- Articulating a clear understanding of the purpose and intended use of the risk assessment.
- Identifying the constituents of concern.
- Identifying potential release scenarios.
- Identifying potential exposure pathways.
- Collecting and reviewing available data.
- Identifying data gaps.
- Recommending data collection efforts.
- Developing a conceptual model of what is occurring at the site.

Although this step can be formal or informal, it is critical to the development of a successful assessment that fully addresses the problem at hand. In addition, the development of a conceptual model helps direct the next phases of the assessment and provides a clear understanding of the scope and design of the assessment.

2. *Exposure Assessment*

The goals of an exposure assessment are to: 1) characterize the source, 2) characterize the physical setting of the area that contains the WMU, 3) identify potential exposure pathways, 4) understand the fate and transport of constituents of concern, and 5) calculate constituent doses.

Source characterization involves defining certain key parameters for the WMU. The accuracy of predicting risks improves as more site-specific information is used in the characterization. In general, critical aspects of the source (e.g., type of WMU, size, location, potential for leachate generation, and expected constituent concentrations in leachate) should be obtained. Knowledge of the overall composition of the waste deposited in the WMU and of any treatment processes occurring in the WMU is important to determine the overall characteristics of the leachate that will be generated.

The second step in evaluating exposure is to characterize the site with respect to its physical characteristics, as well as those of the human populations near the site. Important site characteristics include climate, meteorology, geologic setting, and hydrogeology. Consultation with appropriate technical experts (e.g., hydrogeologists, modelers) might be needed to characterize the site. Characterizing the populations near the site with respect to proximity to the site, activity patterns, and the presence of sensitive subgroups might also be appropriate. This group of data will be useful in determining the potential for exposure to and intake of constituents.

The next step in this process includes identifying exposure pathways through ground water and estimating exposure concentrations at the well[3]. In modeling the movement of the constituents away from the WMU, the Guide generally assumes that the constituents behave as a plume (see Figure 1), and the plume's movement is modeled to produce estimated concentrations of constituents at points of interest. As shown in Figure 1, the unsaturated zone receives leachate from the WMU. In general, the flow in the unsaturated zone tends to be gravity-driven, although other factors (e.g., soil porosity, capillarity, moisture potential) can also influence downward flow.

Transport through the unsaturated zone delivers constituents to the saturated zone, or aquifer. Once the contaminant arrives at the water table, it will be transported downgradient toward wells by the predominant flow field in the saturated zone. The flow field is governed by a number of hydrogeologic and climate-driven factors, including regional hydraulic gradient, hydraulic conductivity of the saturated zone, saturated zone thickness, local recharge rate (which might already be accounted for in the regional hydraulic gradient), and infiltration rate through the WMU.

The next step in the process is to estimate the exposure concentrations at a well. Many processes can occur in the unsaturated zone and in the saturated zone that can influence the concentrations of constituents in leachate in a downgradient well. These processes include dilution and attenuation, partitioning to solid, hydrolysis, and degradation. Typically, these factors should be considered when estimating the expected constituent concentrations at a receptor.

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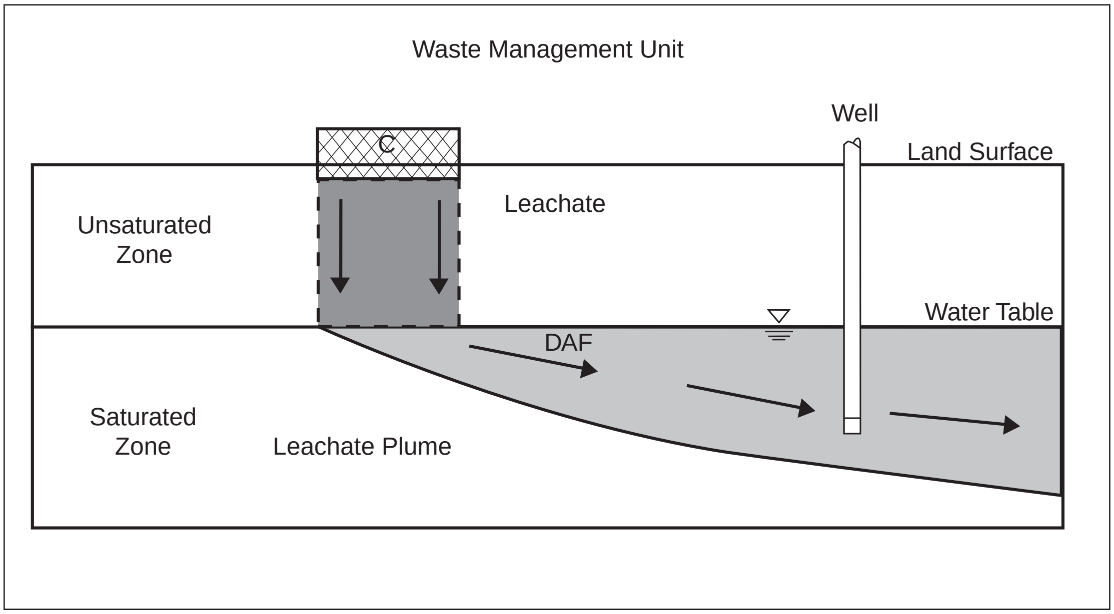
[3] In this discussion and in IWEM, the term "well" is used to represent an actual or hypothetical ground-water monitoring well or drinking water well, located downgradient from a WMU.

Figure 1: Representation of Contaminant Plume Movement



The final step in this process is estimating the dose. The dose is determined based on the concentration of a constituent in a medium and the intake rate of that medium for the receptor. For example, the dose is dependent on the concentration of a constituent in a well and the ingestion rate of ground water from that well by the receptor. The intake rate is dependent on many behavior patterns, including ingestion rate, exposure duration, and exposure frequency. In addition, a risk assessor should consider the various routes of exposure (e.g., ingestion, inhalation) to determine a dose.

After all of this information has been collected, the exposure pathways at the site can be characterized by identifying the potentially exposed populations, exposure media, exposure points, and relevant exposure routes and then calculating potential doses.

3. Toxicity Assessment

The purpose of a toxicity assessment is to weigh available evidence regarding the potential for constituents to cause adverse effects in exposed individuals. It is also meant to provide, where possible, an estimate of the relationship between the extent of exposure to a constituent and the increased likelihood and/or severity of adverse effects. The intent is to establish a dose-response relationship between a constituent concentration and the incidence of an adverse effect. It is usually a five-step process that includes: 1) gathering toxicity information for the substances being evaluated, 2) identifying the exposure periods for which toxicity values are necessary, 3) determining the toxicity values for noncarcinogenic effects, 4) determining the toxicity values for carcinogenic effects, and 5) summarizing the toxicity information. The derivation and interpretation of toxicity values requires toxicological expertise and should not be undertaken by those without training and experience. It is recommended that you contact your state regulatory agency for more specific guidance.

4. Risk Characterization

This step involves summarizing and integrating the toxicity and exposure assessments and developing qualitative and quantitative expressions of risk. To characterize noncarcinogenic effects, comparisons are made between projected intakes of substances and toxicity values to predict the likelihood that exposure would result in a non-cancer health problem, such as neurological effects. To characterize potential carcinogenic effects, the probability that an individual will develop cancer over a lifetime of exposure is estimated from projected intake and chemical-specific dose-response information. The dose of a particular contaminant to which an individual was exposed—determined during the exposure assessment phase—is combined with the toxicity value to generate a risk estimate. Major assumptions, scientific judgements, and, to the extent possible, estimates of the uncertainties embodied in the assessment are also presented. Risk characterization is a key step in the ultimate decision-making process.

B. Ground-Water Risk

The previous section provided an overview of risk assessment; this section provides more detailed information on conducting a risk assessment specific to ground water. In particular, this section characterizes the phases of a risk assessment—problem formulation, exposure assessment, toxicity assessment, and risk characterization—in the context of a ground-water risk assessment.

1. Problem Formulation

The intent of the problem formulation phase is to define the risk question to be answered. For ground-water risk assessments, the question often relates to whether releases of constituents to the ground water are protective of human health, surface water, or ground-water resources. This section discusses characterizing the waste and developing a conceptual model of a site.

a. Waste Characterization

A critical component in a ground-water risk assessment is the characterization of the leachate released from a WMU. Leachate is the liquid formed when rain or other water comes into contact with waste. The characteristics of the leachate are a function of the composition of the waste and other factors (e.g., volume of infiltration, exposure to differing redox conditions, management of the WMU). Waste characterization includes both identification of the potential constituents in the leachate and understanding the physical and chemical properties of the waste.

Identification of the potential constituents in leachate requires a thorough understanding of the waste that will be placed in a WMU. Potential constituents include those used in typical facility processes, as well as degradation products from these constituents. For ground-water risk analyses, it is important to not only identify the potential constituents of concern in the leachate, but also the likely concentration of these constituents in leachate. To assist in the identification of constituents present in leachate, EPA has developed several leachate tests including the Toxicity Characteristic Leaching Procedure (TCLP), the Synthetic Precipitation Leaching Procedure (SPLP), and the Multiple Extraction Procedure (MEP). These and other tests that can be used to characterize leachate are discussed more fully in Chapter 2—Characterizing Waste and are described in EPA's SW-846 *Test Methods for Evaluating Solid Wastes* (U.S. EPA, 1996 and as updated).

In addition to identifying the constituents present, waste characterization includes understanding the physical, biological, and chemical properties of the waste. The physical and chemical properties of the waste stream affect the likelihood and rate that constituents will move through the WMU. For example, the waste properties influence the partitioning of constituents among the aqueous, vapor, and solid phases. Temperature, pH, pressure, chemical composition,[4] and the presence of microorganisms within WMUs may have significant effects on the concentration of constituents available for release in the leachate. Another waste characteristic that can influence leachate production is the presence of organic wastes as free liquids, also called non-aqueous phase liquids (NAPLs). The presence of NAPLs may affect the mobility of constituents based on saturation and viscosity. Finally, characteristics such as acidity and alkalinity can influence leachate generation by affecting the permeability of underlying soil or clay.

b. Development of a Conceptual Model

The development of a conceptual model is important for defining what is needed for the exposure assessment and the toxicity assessment. The conceptual model identifies the major routes of exposure to be evaluated and presents the current understanding of the toxicity of the constituents of concern.

For the ground-water pathway, the conceptual model identifies those pathways on which the risk assessor should focus. Potential pathways of interest include ground water used as drinking water, ground water used for other domestic purposes that might release volatile organics, ground-water releases to surface water, vapor intrusion from ground-water gases to indoor air, and ground water used as irrigation water. The conceptual model should address the likelihood of various ground-water pathways under present or future circumstances, provide insight to the likelihood of contact with receptors through the various pathways, and identify areas requiring further information.

The conceptual model should also address the toxicity of the constituents of concern. Information about constituent toxicity can be collected from publicly available resources such as the Integrated Risk Information System (IRIS) **<www.epa.gov/iris>** or from detailed, chemical-specific literature searches. The conceptual model should attempt to identify the toxicity data that are most relevant to likely routes of ground-water exposure and identify areas requiring additional research. The conceptual model should provide a draft plan of action for the next phases of the risk assessment.

2. Exposure Assessment

Exposure assessment is generally comprised of two components: characterization of the exposure setting and identification of the exposure pathways. Characterization of the exposure setting includes describing the source characteristics and the site characteristics. Identification of the exposure pathway involves understanding the process by which a constituent is released from a source, travels to a receptor, and is taken up by the receptor. This section discusses the concepts of characterizing the source, characterizing the site setting, understanding the general dynamics of contaminant fate and transport (or movement of harmful chemicals to a receptor), identifying exposure pathways, and calculating the dose to (or uptake by) a receptor.

a. Source Characterization

The characteristics of a source greatly influence the release of leachate to ground water. Some factors to consider include the type of WMU, the size of the unit, and the design and management of the unit. The type of WMU is important because each unit has distinct characteristics that affect release. Landfills, for example, tend to be permanent in nature, which provides a long time period for leachate generation. Waste piles, on the other hand, are temporary in design and

[4] Generally, the model considers a high ratio of solids to leachate, and therefore, the user should consider this before applying a 20 to 1 solids to leachate ratio.

allow the user to remove the source of contaminated leachate at a future date. Surface impoundments, which are generally managed with standing water, provide a constant source of liquid for leachate generation and potentially result in greater volumes of leachate.

The size of the unit is important because units with larger areas have the potential to generate greater volumes of contaminated leachate than units with smaller areas. Also, units such as landfills that are designed with a greater depth below the ground's surface can result in decreased travel time from the bottom of the unit to the water table, resulting in less sorption of constituents. In some cases, a unit might be hydraulically connected with the water table resulting in no attenuation in the unsaturated zone.

The design of the unit is important because it might include an engineered liner system that can reduce the amount of infiltration through the WMU, or a cover that can reduce the amount of water entering the WMU. Typical designs might include compacted clay liners or geosynthetic liners. For surface impoundments, sludge layers from compacted sediments might also help reduce the amount of leachate released. The compacted sediments can have a lower hydraulic conductivity than the natural soils resulting in slower movement of leachate from the bottom of the unit. Covers also affect the rate of leachate generation by limiting the amount of liquid that reaches the waste, thereby limiting the amount of liquid available to form leachate. Co-disposal of different wastes can result in increased or decreased rates of leachate generation. Generally, WMUs with appropriate design specifications can result in reduced leachate generation.

b. Site Characterization

Site characterization addresses the physical characteristics of the site as well as the populations at or near the site. Important physical characteristics include the climate, geology, hydrology, and hydrogeology. These physical characteristics help define the likelihood that water might enter the unit and the likelihood that leachate might travel from the bottom of the unit to the ground water. For example, areas of high rainfall are more likely to generate leachate than arid regions. The geology of the site also can affect the rate of infiltration through the unsaturated zone. For example, areas with fractured bedrock can allow leachate through more quickly than a packed clay material with a low hydraulic conductivity. Hydrology should also be considered because ground water typically discharges to surface water. The presence of surface waters can restrict flow to wells or might require analysis of the impact of contaminated ground water on receptors present in the surface water. Finally, factors related to the hydrogeology, such as the depth to the water table, also influence the rate at which leachate reaches the water table.

The characterization of the site also includes identifying and characterizing populations at or near the site. When characterizing populations, it is important to identify the relative location of the populations to the site. For example, it is important to determine whether receptors are downgradient from the unit and the likely distance from the unit to wells. It is also important to determine typical activity patterns, such as whether ground water is used for drinking water or agricultural purposes. The presence of potential receptors is critical for determining a complete exposure pathway. People might not live there now, but they might live there in 50 years, based on future use assumptions. State or local agencies have relevant information to help you identify areas that are designated as potential sources of underground drinking water.

c. *Understanding Fate and Transport*

In general, the flow in the unsaturated zone tends to be gravity-driven. As shown in Figure 1, the unsaturated zone receives leachate infiltration from the WMU. Therefore, the vertical flow component accounts for most of the fluid flux between the base of the WMU and the water table. Water-borne constituents are carried vertically downward toward the water table by the advection process. Mixing and spreading occur as a result of hydrodynamic dispersion and diffusion. Transport processes in the saturated zone include advection, hydrodynamic dispersion, and sorption. Advection is the process by which constituents are transported by the motion of the flowing ground water. Hydrodynamic dispersion is the tendency for some constituents to spread out from the path that they would be expected to flow. Sorption is the process by which leachate molecules adhere to the surface of individual clay, soil, or sediment particles. Attenuation of some chemicals in the unsaturated zone is attributable to various biochemical or physicochemical processes, such as degradation and sorption.

The type of geological material below the unit affects the rate of movement because of differences in hydraulic and transport properties. One of the key parameters controlling contaminant migration rates is hydraulic conductivity. The larger the hydraulic conductivity, the greater the potential migration rate due to lower hydraulic resistance of the formation. Hydraulic conductivity values of some hydrogeologic environments, such as bedded sedimentary rock aquifers, might not be as large as those of other hydrogeologic environments, such as sand and gravel or fractured limestone. As a general principle, more rapid movement of waste constituents can be expected through coarse-textured materials, such as sand and gravel, than through fine-textured materials, such as silt and clay. Other key flow and transport parameters include dispersivity (which determines how far a plume will spread horizontally and vertically as it moves away from the source) and porosity (which determines the amount of pore space in the geologic materials in the unsaturated and saturated zone used for flow and transport and can affect transport velocity).

As waste constituents migrate through the unsaturated and saturated zones, they can undergo a number of biochemical and physicochemical processes that can lead to a reduction in concentration of potential ground-water contaminants. These processes are collectively referred to as attenuation processes. Attenuation processes can remove or degrade waste constituents through filtration, sorption, precipitation, hydrolysis, biological degradation, bio-uptake, and redox reactions. Some of these processes (e.g., hydrolysis, biological degradation) can actually result in the formation of different chemicals and greater toxicity. Attenuation processes are dependent upon several factors, including ground-water pH, ground-water temperature, and the presence of other compounds in the subsurface environment. Table 2 provides additional information on attenuation processes.

d. *Exposure Pathways*

A complete exposure pathway usually consists of four elements: 1) a source and mechanism of chemical release, 2) a retention or transport medium (in this case, ground water), 3) a point of potential human contact with the contaminated medium (often referred to as the exposure point), and 4) an exposure route (e.g., ingestion). Residents who live near

Table 2:
Examples of Attenuation Processes

Biological degradation: Decomposition of a substance into more elementary compounds by action of microorganisms such as bacteria. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Bio-uptake: The uptake and (at least temporary) storage of a chemical by an exposed organism. The chemical can be retained in its original form and/or modified by enzymatic and non-enzymatic reactions in the body. Typically, the concentrations of the substance in the organism exceed the concentrations in the environment since the organism will store the substance and not excrete it. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Filtration: Physical process whereby solid particles and large dissolved molecules suspended in a fluid are entrapped or removed by the pore spaces of the soil and aquifer media. Boulding, R. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

Hydrolysis: A chemical process of decomposition in which the elements of water react with another substance to yield one or more entirely new substances. This transformation process changes the chemical structure of the substance. Sullivan. 1993. *Environmental Regulatory Glossary*, 6th Ed. Government Institutes.

Oxidation/Reduction (Redox) reactions: Involve a transfer of electrons and, therefore, a change in the oxidation state of elements. The chemical properties for elements can change substantially with changes in the oxidation state. U.S. EPA. 1991. *Site Characterization for Subsurface Remediation.*

Precipitation: Chemical or physical change whereby a contaminant moves from a dissolved form in a solution to a solid or insoluble form. It reduces the mobility of constituents, such as metals. Unlike sorption, precipitation is not generally reversible. Boulding, R. 1995. *Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.*

Sorption: The ability of a chemical to partition between the liquid and solid phase by determining its affinity for adhering to other solids in the system such as soils or sediments. The amount of chemical that "sorbs" to solids is dependent upon the characteristics of the chemical, the characteristics of the surrounding soils and sediments, and the quantity of the chemical. Sorption generally is reversible. Sorption often includes both adsorption and ion exchange.

a site might use ground water for their water supply, and thus, the exposure point would be a well. Exposure routes typical of residential use of contaminated ground water include direct ingestion through drinking water, dermal contact while bathing, and inhalation of VOCs during showering or from other household water uses (e.g., dishwashers).

Another potential pathway of concern is exposure to ground-water constituents from the intrusion of vapors of VOCs and SVOCs through the basements and concrete slabs beneath houses. This pathway is characterized by the vapors seeping into households through the cracks and holes in basements and concrete slabs. In some cases, concentrations of constituents can reach levels that present chronic health hazards. Factors that can contribute to the potential for vapor intrusion include the types of constituents present in the ground water, the presence of pavement or frozen surface soils (which result in higher subsurface pressure gradients and greater transport), and the presence of subsurface gases such as methane that affect the rate of transport of other constituents. Because of the complexity of this pathway and the evolving science regarding this pathway, IWEM focuses on the risks and pathways associated with residential exposures to contaminated ground water. If exposure through this route is likely, the user might consider Tier 3 modeling to assess this pathway. EPA is planning to issue a reference document regarding the vapor intrusion pathway in the near future.

e. Dose Calculation

The final element of the exposure assessment is the dose calculation. The dose to a receptor is a function of the concentration at the exposure point (i.e, the well) and the intake rate by the receptor. The concentration at the exposure point is based on the release from the source and the fate and transport of the constituent. The intake rate is dependent on the exposure route, the frequency of exposure, and the duration of exposure.

EPA produced the *Exposure Factors Handbook* (U.S. EPA, 1997a) as a reference for providing a consistent set of exposure factors to calculate the dose. This reference is available from EPA's National Center for Environmental Assessment Web site **<www.epa.gov/ncea>**. The purpose of the handbook is to summarize data on human behaviors and physical characteristics (e.g., body weight) that affect exposure to environmental contaminants and recommend values to use for these factors. The result of a dose calculation is expressed as a contaminant concentration per unit body weight per unit time that can then be used as the output of the exposure assessment for the risk characterization phase of the analysis.

3. Toxicity Assessment

A toxicity assessment weighs available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals, and where possible, provides an estimate of the increased likelihood and severity of adverse effects as a result of exposure to a contaminant. IWEM uses two different toxicity measures—maximum contaminant levels (MCLs) and health-based numbers (HBNs). Each of these measures is based on toxicity values reflecting a cancer or noncancer effect. Toxicity data are based on human epidemiologic data, animal data, or other supporting studies (e.g., laboratory studies). In general, data can be used to characterize the potential adverse effect of a constituent as either carcinogenic or non-carcinogenic. For the carcinogenic effect, EPA generally assumes there is a non-threshold effect and estimates a risk per unit dose. For the noncarcinogenic effect, EPA generally assumes there is a threshold below which no adverse effects occur. The toxicity values used in IWEM include:

- Oral cancer slope factors (CSFo) for oral exposure to carcinogenic contaminants.
- Reference doses (RfD) for oral exposure to contaminants that cause noncancer health effects.
- Inhalation cancer slope factors (CSFi) derived from Unit Risk Factors (URFs) for inhalation exposure to carcinogenic contaminants.
- Reference concentrations (RfC) for inhalation exposure to contaminants that cause noncancer health effects.

EPA defines the cancer slope factor (CSF) as, "an upper bound, approximating a 95 percent confidence limit, on the increased cancer risk from a lifetime exposure to an agent [contaminant]." Because the CSF is an upper bound estimate of increased risk, EPA is reasonably confident that the "true risk" will not exceed the risk estimate derived using the CSF and that the "true risk" is likely to be less than predicted. CSFs are expressed in units of proportion (of a population) affected per milligram/kilogram-day (mg/kg-day). For noncancer health effects, the RfD and the RfC are used as health benchmarks for ingestion and inhalation exposures, respectively. RfDs and RfCs are estimates of daily oral exposure or of continuous inhalation exposure, respectively, that are likely to be without an appreciable risk of adverse effects in the general population, including sensitive individuals, over a lifetime. The methodology used to develop RfDs and RfCs is expected to have an uncertainty spanning an order of magnitude.

a. Maximum Contaminant Levels (MCLs)

MCLs are maximum permissible contaminant concentrations allowed in public drinking water and are established under the Safe Drinking Water Act. For each constituent to be regulated, EPA first sets a Maximum Contaminant Level Goal (MCLG) as a level that protects against health risks. The MCL for each contaminant is then set as close to its MCLG as possible. In developing MCLs, EPA considers not only the health effects of the constituents, but also additional factors, such as the cost of treatment, available analytical and treatment technologies. Table 3 lists the 57 constituents that have MCLs that are incorporated in IWEM.

b. Health-based Numbers (HBNs).

The parameters that describe a chemical's toxicity and a receptor's exposure to the chemical are considered in calculation of the HBN(s) of that chemical. HBNs are the maximum contaminant concentrations in ground water that are not expected to cause adverse noncancer health effects in the general population (including sensitive subgroups) or that will not result in an additional incidence of cancer in more than approximately one in one million individuals exposed to the contaminant. Lower concentrations of the contaminant are not likely to cause adverse health effects. Exceptions might occur, however, in individuals exposed to multiple contaminants that produce the same health effect. Similarly, a higher incidence of cancer among sensitive subgroups, highly exposed subpopulations, or populations exposed to more than one cancer-causing contaminant might be expected. As noted previously, the exposure factors used to calculate HBNs are described in the *Exposure Factors Handbook* (U.S. EPA, 1997a).

4. Risk Characterization

Risk characterization is the integration of the exposure assessment and the toxicity assessment to generate qualitative and quantitative expressions of risk. For carcinogens, the target risk level used in IWEM to calculate the HBNs is 1×10^{-6}. A risk of 1×10^{-6} describes an increased chance of one in a million of a person developing cancer over a lifetime, due to chronic exposure to a specific chemical. The target hazard quotient used to calculate the HBNs for noncarcinogens is 1. A hazard quotient of 1 indicates that the estimated dose is equal to the RfD (the level below which no adverse effect is expected). An HQ of 1, therefore, is frequently EPA's threshold of concern for noncancer effects. These targets are used to calculate unique HBNs for each constituent of concern and each exposure route of concern (i.e., ingestion or inhalation).

Usually, doses less than the RfD (HQ = 1) are not likely to be associated with adverse health effects and, therefore, are less likely to be of regulatory concern. As the frequency or magnitude of the exposures exceeding the RfD increase (HQ > 1), the probability of adverse effects in a human population increases. However, it should not be categorically concluded that all doses below the RfD

Table 3.
List of Constituents in IWEM with Maximum Contaminant Levels (MCLs)

(States can have more stringent standards than federal MCLs.)

Organics with an MCL	mg/l		mg/l
Benzene	0.005	HCH (Lindane) gamma-	0.0002
Benzo[a]pyrene	0.0002	Heptachlor	0.0004
Bis(2-ethylhexyl)phthalate	0.006	Heptachlor epoxide	0.0002
Bromodichloromethane*	0.10	Hexachlorobenzene	0.001
Butyl-4,6-dinitrophenol,2-sec-(Dinoseb)	0.007	Hexachlorocyclopentadiene	0.05
Carbon tetrachloride	0.005	Methoxychlor	0.04
Chlordane	0.002	Methylene chloride (Dichloromethane)	0.005
Chlorobenzene	0.1	Pentachlorophenol	0.001
Chlorodibromomethane*	0.10	Polychlorinated biphenyls (PCBs)	0.0005
Chloroform*	0.10	Styrene	0.1
Dibromo-3-chloropropane 1,2-(DBCP)	0.0002	TCD Dioxin 2,3,7,8-	0.00000003
Dichlorobenzene 1,2-	0.6	Tetrachloroethylene	0.005
Dichlorobenzene 1,4-	0.075	Toluene	1
Dichloroethane 1,2-	0.005	Toxaphene (chlorinated camphenes)	0.003
Dichloroethylene cis-1,2-	0.07	Tribromomethane (Bromoform)*	0.10
Dichloroethylene trans-1,2-	0.1	Trichlorobenzene 1,2,4-	0.07
Dichloroethylene 1,1-(Vinylidene chloride)	0.007	Trichloroethane 1,1,1-	0.2
Dichlorophenoxyacetic acid 2,4- (2,4-D)	0.07	Trichloroethane 1,1,2-	0.005
Dichloropropane 1,2-	0.005	Trichloroethylene (1,1,2- Trichloroethylene)	0.005
Endrin	0.002	2,4,5-TP (Silvex)	0.05
Ethylbenzene	0.7	Vinyl chloride	0.002
Ethylene dibromide (1,2- Dibromoethane)	0.00005	Xylenes	10
Inorganics with an MCL			
Antimony	0.006	Copper***	1.3
Arsenic**	0.05	Fluoride	4.0
Barium	2.0	Lead***	0.015
Beryllium	0.004	Mercury (inorganic)	0.002
Cadmium	0.005	Selenium	0.05
Chromium (total used for Cr III and Cr VI)	0.1	Thallium	0.002

For list of current MCLs, visit: **<www.epa.gov/safewater/mcl.html>**

* Listed as Total Trihalomethanes (TTHMs), constituents do not have individually listed MCLs

** Arsenic standard will be lowered to 0.01 mg/L by 2006.

*** Value is drinking water "action level" as specified by 40 CFR 141.32(e) (13) and (14).

are "acceptable" (or will be risk-free) and that all doses in excess of the RfD are "unacceptable" (or will result in adverse effects). For IWEM, the output from the risk characterization helps determine with 90 percent probability (i.e., with a confidence that for 90 percent of the realizations) whether or not a design system is protective (i.e., has a cancer risk of < 1 x 10^{-6}, non-cancer hazard quotient of < 1.0). IWEM does not address the cumulative risk due to simultaneous exposure to multiple constituents. The results of the risk assessment might encourage the user to conduct a more site-specific analysis, or consider opportunities for waste minimization or pollution prevention.

II. The IWEM Ground-Water Risk Evaluation

This section takes the principles of risk assessment described in Part I and applies them to evaluating industrial waste management unit liner designs. This is accomplished using IWEM and a three-tiered ground-water modeling approach to make recommendations regarding the liner design systems that should be considered for a potential unit, if a liner design system is considered necessary. The tiered approach was chosen to provide facility managers, the public, and state regulators flexibility in assessing the appropriateness of particular WMU designs as the user moves from a national assessment to an assessment using site-specific parameters.

The three tiers allow for three possible approaches. The first approach is a quick screening tool, a set of lookup tables, which provides conservative national criteria. While this approach, labeled Tier 1, does not take into account site- (or even state-) specific conditions, it does provide a rapid and easy screening. If the use of Tier 1 provides an agreeable assessment, the conservative nature of the model can be relied upon, and the additional resources required for further analysis can be avoided. Of course, where there is concern with the results from Tier 1, a more precise assessment of risk at the planned unit location should be conducted. The second approach is to try and accommodate many of the most important site-specific factors in a simplified form, useable by industry, state, and environmental representatives. This model, labeled Tier 2, is available as part of this Guide, and is a major new step in moving EPA guidance away from national, "one size fits all" approaches. Third, a site-specific risk analysis can be conducted. This approach should provide the most precise assessment of the risks posed by the planned unit. Such an analysis, labeled Tier 3, should be conducted by experts in ground-water modeling, and can require significant resources. This Guide identifies the benefits and sources for selecting site-specific models, but does not provide such models as part of this Guide. In many cases, corporations will go directly to conducting the more exacting Tier 3 analysis, which EPA believes is acceptable under the Guide. There is, however, still a need for the Tier 2 tool. State and environmental representatives might have limited resources to conduct or examine a Tier 3 assessment; Tier 2 can provide a point of comparison with the results of the Tier 3 analysis, narrow the technical discussion to those factors which are different in the models, and form a basis for a more informed dialogue on the reasonableness of the differences.

IWEM is designed to address Tier 1 and Tier 2 evaluations. Both tiers of the tool consider all portions of the risk assessment process (i.e., problem formulation, exposure assessment, toxicity assessment, and risk characterization) to generate results that vary from a national-level screening evaluation to a site-specific assessment. The Tier 3 evaluation is a complex, site-specific hydrogeologic investigation that would be performed with other models such as those listed at the end of this chapter. Those models could be used to evaluate hydrogeological complexities that are not addressed by IWEM. Brief outlines of the three tiers follow.

A Tier 1 evaluation involves comparing the expected leachate concentrations of wastes being assessed against a set of pre-calculated maximum recommended leachate concentrations (or Leachate Concentration Threshold Values—LCTVs). The Tier 1 LCTVs are nationwide, ground-water fate and transport modeling results from EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). EPACMTP simulates the fate and transport of leachate infiltrating from the bottom of a WMU and predicts concentrations of those contaminants in a well. In making these predictions, the model quantitatively accounts for many complex processes that dilute and attenuate the concentrations of waste constituents as they move through the subsurface to the well. The results that are generated show whether a liner system is considered necessary, and if so which liner systems will be protective for the constituents of concern. Tier 1 results are designed to be protective with 90 percent certainty at a $1x10^{-6}$ risk level for carcinogens or a noncancer hazard quotient of < 1.0.

The Tier 2 evaluation incorporates a limited number of site-specific parameters to help provide recommendations about which liner system (if any is considered necessary) is protective for constituents of concern in settings that are more reflective of your site. IWEM is designed to facilitate site-specific simulations without requiring the user to have any previous ground-water modeling experience. As with any ground-water risk evaluation, however, the user is advised to discuss the results of the Tier 2 evaluation with the appropriate state regulatory agency before selecting a liner design for a new WMU.

If the Tier 1 and Tier 2 modeling do not adequately simulate conditions at a proposed site because the hydrogeology of the site is complex, or because the user believes Tier 2 does not adequately address a particular site-specific parameter, the user is advised to consider a more in-depth, site-specific risk assessment. This Tier 3 assessment involves a more detailed, site-specific ground-water fate and transport analysis. The user should consult with state officials and appropriate trade associations to solicit recommendations for approaches for the analysis.

The remainder of this section discusses in greater detail how to use IWEM to perform a Tier 1 or Tier 2 evaluation. In addition, this section presents information concerning the use of Tier 3 models.

A. The Industrial Waste Management Evaluation Model (IWEM)

The IWEM is the ground-water modeling component of the *Guide for Industrial Waste Management*, used for recommending appropriate liner system designs, where they are considered necessary, for the management of RCRA Subtitle D industrial waste. IWEM compares the expected leachate concentration (entered by the user) for each waste constituent with a protective level calculated by a ground-water fate and transport model to determine whether a liner system is needed. When IWEM determines a liner system is necessary, it then evaluates two standard liner types (i.e., single clay-liner and composite liner). This section discusses components of the tool and important concepts whose understanding is necessary for its effective use. The user can refer to the *User's Guide for the*

Industrial Waste Management Evaluation Model (U.S. EPA, 2002b) for information necessary to perform Tier 1 and Tier 2 analyses, and the *Industrial Waste Management Evaluation Model Technical Background Document* (U.S. EPA, 2002a), for more information on the use and development of IWEM.

1. Leachate Concentrations

The first step in determining a protective waste management unit design is to identify the expected constituents in the waste and expected leachate concentrations from the waste. In order to assess ground-water risks using either the Tier 1 or Tier 2 evaluations provided in IWEM, the expected leachate concentration for each individual constituent of interest must be entered into the model. See Chapter 2—Characterizing Wastes, for a detailed discussion of the various approaches available to use in evaluating expected leachate concentrations.

2. Models Associated with IWEM

One of the highlights of IWEM is its ability to simulate the fate and transport of waste constituents at a WMU with a small number of site-specific inputs. To accomplish this task, IWEM incorporates the outputs of three other models, specifically EPACMTP, MINTEQA2, and HELP. This section discusses these three models.

a. EPACMTP

EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) is the backbone of IWEM. EPACMTP is designed to simulate subsurface fate and transport of contaminants leaching from the bottom of a WMU and predict concentrations of those contaminants in a downgradient well. In making these predictions, the model accounts for many complex processes that occur as waste constituents and their transformation products move to and through ground water. As leachate carrying waste constituents migrates through the unsaturated zone to the water table, attenuation processes, such as adsorption and degradation, reduce constituent concentrations. Ground-water transport in the saturated zone further reduces leachate concentrations through dilution and attenuation. The concentration of constituents arriving at a well, therefore, is lower than that in the leachate released from a WMU.

In the unsaturated zone, the model simulates one-dimensional vertical migration with steady infiltration of constituents from the WMU. In the saturated zone, EPACMTP simulates three-dimensional plume-movement (i.e., horizontal as well as transverse and vertical spreading of a contaminant plume). The model considers not only the subsurface fate and transport of constituents, but also the formation and the fate and transport of transformation (daughter and granddaughter) products. The model also can simulate the fate and transport of metals, taking into account geochemical influences on the mobility of metals.

b. MINTEQA2

In the subsurface, metal contaminants can undergo reactions with other substances in the ground water and with the solid aquifer or soil matrix material. Reactions in which the metal is bound to the solid matrix are referred to as sorption reactions, and the metal bound to the solid is said to be sorbed. During contaminant transport, sorption to the solid matrix results in retardation (slower movement) of the contaminant front. Transport models such as EPACMTP incorporate a retardation factor to account for sorption processes.

The actual geochemical processes that control the sorption of metals can be quite complex, and are influenced by factors such as pH, the type and concentration of the metal in the leachate plume, the presence and concentrations of other constituents in the leachate plume, and other factors. The EPACMTP model is not capable of simulating all these processes in detail. Another model, MINTEQA2[5], is used to determine a sorption coefficient for each of the metals species. For IWEM, distributions of variables (e.g., leachable organic matter, pH) were used to generate a distribution of isotherms for each metal species. EPACMTP, in turn, samples from these calculated sorption coefficients and uses the selected isotherm as a modeling input to account for the effects of nationwide or aquifer-specific ground-water and leachate geochemistry on the sorption and mobility of metals constituents.

c. HELP

The Hydrologic Evaluation of Landfill Performance (HELP) model is a quasi-two-dimensional hydrologic model for computing water balances of landfills, cover systems, and other solid waste management facilities. The primary purpose of the model is to assist in the comparison of design alternatives. HELP uses weather, soil, and design data to compute a water balance for landfill systems accounting for the effects of surface storage; snowmelt; runoff; infiltration; evapotranspiration; vegetative growth; soil moisture storage; lateral subsurface drainage; leachate recirculation; unsaturated vertical drainage; and leakage through soil, geomembrane, or composite liners. The HELP model can simulate landfill systems consisting of various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners. For further information on the HELP model, visit: **<wes.army.mil/el/elmodels/helpinfo.html>**.

For the application of HELP to IWEM, an existing database of infiltration and recharge rates was used for 97 climate stations in the lower 48 contiguous states. Five climate stations (located in Alaska, Hawaii, and Puerto Rico) were added to ensure coverage throughout all of the United States. These climatic data were then used along with data on the soil type and WMU design characteristics, to calculate a water balance for each applicable liner design as a function of the amount of precipitation that reaches the surface of the unit, minus the amount of runoff and evapotranspiration. The HELP model then computed the net amount of water that infiltrates through the surface of the unit (accounting for recharge), the waste, and the unit's bottom layer (for unsaturated soil and clay liner scenarios only), based on the initial moisture content and the hydraulic conductivity of each layer.

Although data were collected for all 102 sites, these data were only used for the unlined landfills, waste piles, and land application units. For the clay liner scenarios (landfills and waste piles only), EPA grouped sites and ran the HELP model only for a subset of the facilities that were representative of the ranges of precipitation, evaporation, and soil type. The grouping is discussed further in the *IWEM Technical Background Document* (U.S. EPA, 2002a).

In addition to climate factors and the particular unit design, the infiltration rates calculated by HELP are affected by the landfill cover design, the permeability of the waste material in waste piles, and the soil type of the land application unit. For every climate station and WMU design, multiple HELP infiltration rates are calculated. In Tier 1, for a selected WMU type and design, the EPACMTP Monte Carlo modeling process was used to randomly select from among the HELP-derived infiltration and recharge data.

[5] MINTEQA2 is a geochemical equilibrium speciation model for computing equilibria among the dissolved, absorbed, solid, and gas phases in dilute aqueous solution.

This process captured both the nationwide variation in climate conditions and variations in soil type. In Tier 2, the WMU location is a required user input, and the climate factors used in HELP are fixed. However, in Tier 2, the Monte Carlo process is still used to account for local variability in the soil type, landfill cover design, and permeability of waste placed in waste piles.

3. *Important Concepts for Use of IWEM*

Several important concepts are critical to understanding how IWEM functions. These concepts include 90th percentile exposure concentration, dilution and attenuations factors (DAFs), reference ground-water concentrations (RGCs), leachate concentration threshold values (LCTVs), and units designs.

a. *90th Percentile Exposure Concentration*

The 90th percentile exposure concentration was chosen to represent the estimated constituent concentration at a well for a given leachate concentration. The 90th percentile exposure concentration was selected because this concentration is protective for 90 percent of the model simulations conducted for a Tier 1 or Tier 2 analysis. In Tier 1, the 90th percentile concentration is used to calculate a DAF, which is then used to generate a leachate concentration threshold value (LCTV). In Tier 2, the 90th percentile concentration is directly compared with a reference ground-water concentration to determine whether a liner system is necessary, and if so whether the particular liner design is protective for a site.

The 90th percentile exposure concentration is determined by running EPACMTP in a Monte Carlo mode for 10,000 realizations. For each realization, EPACMTP calculates a maximum average concentration at a well, depending on the exposure duration of the reference ground-water concentration (RGC) of interest. For example, IWEM assumes a 30-year exposure duration for carcinogens, and therefore, the maximum average concentration is the highest 30-year average across the modeling horizon. After calculating the maximum average concentrations across the 10,000 realizations, the concentrations are arrayed from lowest to highest and the 90th percentile of this distribution is selected as the constituent concentration for IWEM.

Once the 90th percentile exposure concentration is determined, it is used in one of two ways. For both the Tier 1 analysis and the Tier 2 analysis, the 90th percentile exposure concentration is compared with the expected waste leachate concentration to generate a DAF. This calculation is discussed further in the following section. For Tier 2, the 90th percentile exposure concentration is the concentration of interest for the analysis. The 90th percentile exposure concentration can be directly compared with the reference ground-water concentration to assist in waste management decision-making.

b. *Dilution and Attenuation Factors*

DAFs represent the expected reduction in waste constituent concentration resulting from fate and transport in the subsurface. A DAF is defined as the ratio of the constituent concentration in the waste leachate to the concentration at the well, or:

$$DAF = \frac{C_L}{C_W}$$

where: DAF is the dilution and attenuation factor;

C_L is the leachate concentration (mg/L); and

C_W is the ground-water well concentration (mg/L).

The magnitude of a DAF reflects the combined effect of all dilution and attenuation processes that occur in the unsaturated and saturated zones. The lowest possible value of a DAF is one. A DAF of 1 means that there is no dilution or attenuation at all; the concentration at a well is the same as that in the waste leachate. High DAF values, on the other hand, correspond to a high degree of dilution and attenuation. This means that the expected concentration at the well will be much lower than the concentration in the leachate. For any specific site, the DAF depends on the interaction of waste constituent characteristics (e.g., whether or not the constituent degrades or sorbs), site-specific factors (e.g., depth to ground water, hydrogeology), and physical and chemical processes in the subsurface environment. In addition, the DAF calculation does not take into account when the exposure occurs, as long as it is within a 10,000-year time-frame following the initial release of leachate. Thus, if two constituents have different mobility, the first might reach the well in 10 years, while the second constituent might not reach the well for several hundred years. EPACMTP, however, can calculate the same or very similar DAF values for both constituents.

For the Tier 1 analysis in IWEM, DAFs are based on the 90th percentile exposure concentration. EPACMTP was implemented by randomly selecting one of the settings from the WMU database and assigning a unit leachate concentration to each site until 10,000 runs had been conducted for a WMU. The resulting 10,000 maximum well concentrations based on the averaging period associated with the exposure duration of interest (i.e., 1-year, 7-years, 30-years) were then arrayed from lowest to highest. The 90th percentile concentration of this distribution is then used as the concentration in the ground-water well (Cw) for calculating the DAF. The DAF is similarly calculated for the Tier 2, but because the site-specific leachate concentration is used in the EPACMTP model runs, the 90th percentile exposure concentration can be compared directly to the RGC.

c. *Reference Ground-Water Concentration (RGC)*

As used in this Guide and by IWEM, a reference ground-water concentration (RGC) is defined as a constituent concentration threshold in a well that is protective of human health. RGCs have been developed based on maximum contaminant levels (MCLs) and health-based-numbers (HBN). Each constituent can have up to five RGCs: 1) based on an MCL, 2) based on carcinogenic effects from ingestion, 3) based on carcinogenic effects from inhalation while showering, 4) based on non-carcinogenic effects from ingestion, and 5) based on non-carcinogenic effects from inhalation while showering.

The IWEM's database includes 226 constituents with at least one RGC. Of the 226 constituents, 57 have MCLs (see Table 3), 212 have ground-water ingestion HBNs, 139 have inhalation HBNs, and 57 have both an MCL and HBN. The HBNs were developed using standard EPA exposure assumptions for residential receptors. For carcinogens, IWEM used a target risk level equal to the probability that there might be one increased cancer case per one million exposed people (commonly referred to as a $1x10^{-6}$ cancer risk). The target hazard quotient used to calculate the HBNs for noncarcinogens was 1 (unitless). A hazard quotient of 1 indicates that the estimated dose is equal to the oral reference dose (RfD) or inhalation reference concentration (RfC). These targets were used to calculate unique HBNs for each constituent of concern and each exposure route of concern (ingestion or inhalation). For further information on the derivation of the IWEM RGCs, see the *Industrial Waste Management Evaluation Model Technical Background*

Document (U.S. EPA, 2002a). Users also can add new constituents and RGCs can vary depending on the protective goal. For example, states can impose more stringent drinking water standards than federal MCLs.[6] To keep the software developed for this Guide up-to-date, and to accommodate concerns at levels different from the current RGCs, the RGC values in the IWEM software tool can be modified by the user of the software.

d. Leachate Concentration Threshold Values (LCTVs)

The purpose of the Tier 1 analysis in IWEM is to determine whether a liner system is needed, and if so, to recommend liner system designs or determine the appropriateness of land application with minimal site-specific data. These recommendations are based on LCTVs that were calculated to be protective for each waste constituent in a unit. These LCTVs are the maximum leachate concentrations for which water in a well is not likely to exceed the corresponding RGC. The LCTV for each constituent accounts for dilution and attenuation in the unsaturated and saturated zones prior to reaching a well. An LCTV has been generated for a no liner/in situ soils scenario and for two standard liner types (i.e., single clay liner and composite liner) and each RGC developed for a constituent.

The LCTV for a specific constituent is the product of the RGC and the DAF:

$$LCTV = DAF * MCL$$

or $$LCTV = DAF * HBN$$

Where: LCTV is the leachate concentration threshold value

DAF is the dilution and attenuation factor

MCL is the maximum concentration level

HBN is the health-based number

The evaluation of whether a liner system is needed and subsequent liner system design recommendations is determined by comparing the expected waste constituent leachate concentrations to the corresponding calculated LCTVs. LCTVs are calculated for all unit types (i.e., landfills, waste piles, surface impoundments, land application units) by type of design (i.e., no liner/in situ soils, single liner, or composite liner).[7] The Tier 1 evaluation is generally the most protective and calculates LCTVs using data collected on WMUs throughout the United States.[8] LCTVs used in Tier 1 are designed to be protective to a level of $1x10^{-6}$ for carcinogens or a noncancer hazard quotient of < 1.0 with a 90 percent certainty considering the range of variability associated with the waste sites across the United States. LCTVs from the Tier 1 analysis are generally applicable to sites across the country; users can determine whether a specific liner design for a WMU is protective by comparing expected leachate concentrations for constituents in their waste with the LCTVs for each liner design.

The Tier 2 analysis differs from the Tier 1 analysis in that IWEM calculates a site-specific DAF in Tier 2. This allows the model to calculate a site-specific 90th percentile exposure concentration that can be compared with an RGC to determine if a liner system is needed and to recommend the appropriate liner system if necessary. The additional calculation of an LCTV is not necessary. IWEM continues to perform the calculation, however, to help users determine whether waste minimization might be appropriate to meet a specific design. For example, a facility might

[6] For example, a state can make secondary MCLs mandatory, which are not federally enforceable standards, or a state might use different exposure assumptions, which can result in a different HBN. In addition, states can choose to use a different risk target than is used in this Guidance.

[7] LCTVs are influenced by liner designs because of different infiltration rates.

[8] For additional information on the nationwide data used in the modeling, see the *IWEM Technical Background Document* (U.S. EPA, 2002a).

find it more cost effective to reduce the concentration of constituents in its waste and design a clay-lined landfill than to dispose of the current waste in a composite landfill. The LCTV calculated for the Tier 2 analysis is based on the expected leachate concentration for a specific site and site-specific data for several sensitive parameters. Because the Tier 2 analysis includes site-specific considerations, LCTVs from this analysis are not applicable to other sites.

e. *Determination of Liner Designs*

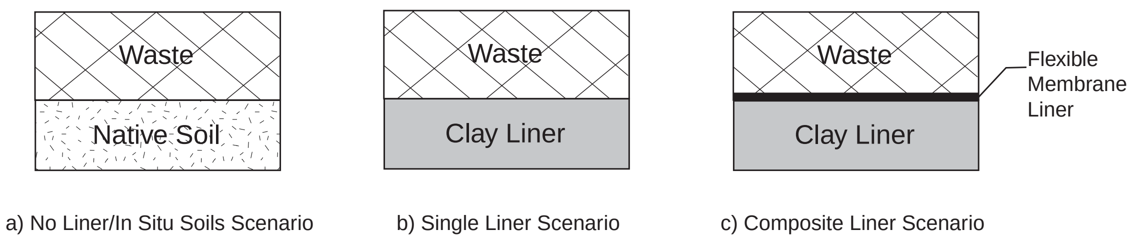
The primary method of controlling the release of waste constituents to the subsurface is to install a low permeability liner at the base of a WMU. A liner generally consists of a layer of clay or other material with a low hydraulic conductivity that is used to prevent or mitigate the flow of liquids from a WMU. The type of liner that is appropriate for a specific WMU, however, is highly dependent upon a number of location-specific characteristics, such as climate and hydrogeology. These characteristics are critical in determining the amount of liquid that migrates into the subsurface from a WMU and in predicting the release of contaminants to ground water.

The IWEM software is intended to assist the user in determining if a new industrial waste management unit can rely on a no liner/in situ soils design, or whether one of the two recommended liners designs, single clay liner or composite liner, should be used. The no liner/in situ soils design (Figure 2a) represents a WMU that relies upon location-specific conditions, such as low permeability native soils beneath the unit or low annual precipitation rates to mitigate the release of contaminants to groundwater. The single clay liner (Figure 2b) design represents a 3-foot thick clay liner with a low hydraulic conductivity (1×10^{-7} cm/sec) beneath a WMU. A composite liner design (Figure 2c) consists of a flexible membrane liner in contact with a clay liner. In Tier 2, users also can evaluate other liner designs by providing a site-specific infiltration rate based on the liner design. For land applications units, only the no liner/in situ soils scenario is evaluated because liners are not typically used at this type of facility.

To determine an appropriate design in Tier 1, IWEM compares expected leachate concentrations for all of the constituents in the leachate to constituent-specific LCTVs and then reports the minimum design system that is protective for all constituents. If the expected leachate concentrations of all waste constituents are lower than their respective no liner/in situ soils LCTVs, the proposed WMU does not need a liner to contain the waste. On the other hand, if the Tier 1 screening evaluation indicates a liner is recommended, a user can verify this recommendation with a follow-up Tier 2 (or possibly Tier 3) analysis for at least those constituents whose expected leachate concentrations exceed the Tier 1 LCTV values.

If the user proceeds to a Tier 2 analysis, IWEM will evaluate the three standard designs or it can evaluate a user-supplied liner design. The user can supply a liner design by providing a site-specific infiltration rate that reflects the expected infiltration rate through the user's liner system. In the Tier 2 analysis, IWEM conducts a location-adjusted Monte Carlo analysis based on user inputs to generate a 90th percentile exposure concentration for the site. The 90th percentile exposure concentration is then compared with the RGC to determine whether a liner is considered necessary, and where appropriate, recommend the design that is protective for each constituent expected in the leachate. If the Tier 2 analysis indicates that the no liner/in situ soils scenario or the user-defined liner is not protective, the user can proceed to a full site-specific Tier 3 analysis.

Figure 2. Three Liner Scenarios Considered in the Tiered Modeling Approach for Industrial Waste Guidelines



B. Tier 1 Evaluations

In a Tier 1 evaluation, IWEM compares the expected leachate concentration for each constituent with the LCTVs calculated for these constituents and determines a minimum recommended design that is protective for all waste constituents. The required inputs are: the type of WMU the user wishes to evaluate, the constituents of concern, and the expected leachate concentrations of constituents of concern. The results for each constituent have been compiled for each unit type and design and are available in the *IWEM Technical Background Document* (U.S. EPA, 2002a) and in the model on the CD-ROM version of this Guide.

The tabulated results for Tier 1 of IWEM have been generated by running the EPACMTP for a wide range of conditions that reflect the varying site conditions that can be expected to occur at waste sites across the United States. The process, which was used to simulate varying site conditions, is known as a Monte Carlo analysis. A Monte Carlo analysis determines the statistical probability or certainty that the release of leachate might result in a ground-water concentration exceeding regulatory or risk-based standards.

For the Tier 1 analysis, 10,000 realizations of EPACMTP were run for each constituent, WMU, and design combination to generate distributions of maximum average exposure concentrations for each constituent by WMU and design. These distributions reflect the variability among industrial waste management units across the United States. The 90th percentile concentration from this distribution was then used to calculate a DAF for each constituent by WMU and design. Each of these DAFs was then combined with constituent-specific RGCs to generate the LCTVs presented

About Monte Carlo Analysis

Monte Carlo analysis is a computer-based method of analysis developed in the 1940s that uses statistical sampling techniques in obtaining a probabilistic approximation to the solution of a mathematical equation or model. The name refers to the city on the French Riviera, which is known for its gambling and other games of chance. Monte Carlo analysis is increasingly used in risk assessments because it allows the risk manager to make decisions based on a statistical level of protection that reflects the variability and/or uncertainty in risk parameters or processes, rather than making decisions based on a single point estimate of risk. For further information on Monte Carlo analysis in risk assessment, see EPA's *Guiding Principles for Monte Carlo Analysis.* (U.S. EPA, 1997b).

in the IWEM software and in the tables included in the technical background document.

The advantages of a Tier 1 screening evaluation are that it is fast, and it does not require site-specific information. The disadvantage of the Tier 1 screening evaluation is that the analysis does not use site-specific information and might result in a design recommendation that is more stringent than is needed for a particular site. For instance, site-specific conditions, such as low precipitation and a deep unsaturated zone, might warrant a less stringent design. Before implementing a Tier 1 recommendation, it is recommended that you also perform a Tier 2 assessment for at least those waste constituents for which Tier 1 indicates that a no liner design is not protective. The following sections provide additional information on how to use the Tier 1 lookup tables.

1. How Are the Tier 1 Lookup Tables Used?

The Tier 1 tables provide an easy-to-use tool to assist waste management decision-making. Important benefits of the Tier 1 approach are that it requires minimum data from the user and provides immediate guidance on protective design scenarios. There are only three data requirements for the Tier 1 analysis: WMU type, constituents expected in the waste leachate, and the expected leachate concentration for each constituent in the waste. The Tier 1 tables are able to provide immediate guidance because EPACMTP simulations for each constituent, WMU, and design combinations were run previously for a national-scale assessment to generate appropriate LCTVs for each combination. Because the simulations represent a national-scale assessment, the LCTVs in the Tier 1 tables represent levels in leachate that are protective at most sites.

As noted previously in this chapter, one of the first steps in a ground-water risk assessment is to characterize the waste going into a unit. Characterization of the waste includes identifying the constituents expected in the leachate and estimating leachate concentrations for each of these constituents. Identification of constituents expected in leachate can be based on process knowledge or chemical analysis of the waste. Leachate concentrations can be estimated using process knowledge or an analytical leaching test appropriate to the circumstances, such as the Toxicity Characteristic Leaching Procedure (TCLP). For more information on identifying waste constituents, estimating waste constituent leachate concentrations, and selecting appropriate leaching tests, refer to Chapter 2 — Characterizing Waste.

The following example illustrates the Tier 1 process for evaluating a proposed design for an industrial landfill. The example assumes the expected leachate concentration for toluene is 1.6 mg/L and styrene is 1.0

Information Needed to Use Tier 1 Lookup Tables

Waste management unit types:	Landfill, surface impoundment, waste pile, or land application unit.
Constituents expected in the leachate:	Constituent names and/or CAS numbers.
Leachate concentrations:	Expected leachate concentration of each constituent or concentration in surface impoundments or waste to be applied.

mg/L. Both toluene and styrene have three LCTVs: one based on an MCL, one based on non-cancer ingestion, and one based on non-cancer inhalation. Tables 4 and 5 provide detailed summary information for the no liner/in situ soils scenario for MCL-based LCTVs and the HBN-based LCTVs, respectively, that is similar to the information that can be found in the actual look-up tables.

For the Tier 1 MCL-based analysis presented in Table 4, the results provide the following information: constituent CAS number, constituent name, constituent-specific MCL, user-provided leachate concentration, constituent-specific DAF, the constituent-specific LCTV, and whether the specified design is protective at the target risk level. To provide a recommendation as to whether a specific design is protective or not, IWEM compares the LCTV with the leachate concentration to determine whether the design is protective. In the example presented in Table 4, the no liner/in situ soils scenario is not protective for styrene because the leachate concentration provided by the user (1.0 mg/L) is greater than the Tier 1 LCTV (0.22 mg/L). For toluene, the no liner/in situ soils scenario is protective because the leachate concentration (1.6 mg/L) is less than the Tier 1 LCTV (2.2 mg/L).

For the health-based number (HBN)-based results presented in Table 5, the detailed results present similar information to that presented for the MCL-based results. The differences are that the HBN-results present the constituent-specific HBN rather than the MCL and include an additional column that identifies the pathway and effect that support the development of the LCTV. For the controlling pathway and effect column, IWEM would indicate whether the most protective pathway is ingestion of drinking water (indicated by ingestion) or inhalation during showering (indicated by inhalation) and whether the adverse effect is a cancer or non-cancer effect. In this example, both styrene and toluene have two HBN-based LCTVS: one for ingestion non-cancer and one for inhalation non-cancer. Only the results for the controlling HBN exposure pathway and effect are shown. In Table 5, only the results for the inhalation-during-showering pathway for non-cancer effects are shown because this is the most protective pathway (that is, the LCTV for the inhalation-during-showing pathway is lower than the LCTV for ingestion of drinking water) for both of these constituents. As shown in Table 5, comparison of the leachate concentration of styrene (1.0 mg/L) and toluene (1.6 mg/L) to their respective LCTVs (8.0 mg/L and 2.9 mg/L) indicates that the no liner/in situ soils design is protective for the Tier 1 HBN-based LCTVs.

Based on the results for the no liner/in situ soils scenario, the user could proceed to the comparison of the expected leachate concentration for styrene with the MCL-based LCTV for a single clay liner to determine whether the single clay liner design is protective. The

Table 4:
Example of Tier 1 Summary Table for MCL-based LCTVs for Landfills - No Liner/In situ Soils

CAS #	Constituent	MCL (mg/L)	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Protective?
100-42-5	Styrene	0.1	1.0	2.2	0.22	No
108-88-3	Toluene	1.0	1.6	2.2	2.2	Yes

Table 5:
Example of Tier 1 Summary Table for HBN-based LCTVs for Landfills - No Liner/In situ Soils

CAS #	Constituent	HBN (mg/L)	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Protective?	Controlling Pathway & Effect
100-42-5	Styrene	3.6	1.0	2.2	8.0	Yes	Inhalation Non-cancer
108-88-3	Toluene	1.3	1.6	2.2	2.9	Yes	Inhalation Non-cancer

user also can proceed to a Tier 2 or Tier 3 analysis to determine whether a more site-specific approach might indicate that the no liner/in situ soils design is protective for the site. Table 6 presents the Tier 1 results for the single clay liner. As shown, the single clay liner would not be protective for the MCL-based analysis because the expected leachate concentration for styrene (1.0 mg/L) exceeds the LCTV for styrene (0.61 mg/L). Based on these results, the user could continue on to evaluate whether a composite liner is protective for styrene.

Table 7 presents the results of the Tier 1 MCL-based analysis for a composite liner.[9] A comparison of the leachate concentration for styrene (1.0 mg/L) to the MCL-based LCTV (1000 mg/L) indicates that the composite liner is the recommended liner based on a Tier 1 analysis that will be protective for both styrene and toluene.

2. *What Do the Results Mean and How Do I Interpret Them?*

For the Tier 1 analysis, IWEM evaluates the no liner/in situ soils, single clay liner, and

Table 6:
Example of Tier 1 Summary Table for MCL-based LCTVs for Landfills - Single Clay Liner

CAS #	Constituent	MCL (mg/L)	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Protective?
100-42-5	Styrene	0.1	1.0	6.1	0.61	No
108-88-3	Toluene	1.0	1.6	6.1	6.1	Yes

Table 7:
Example of Tier 1 Summary Table for MCL-based LCTVs for Landfills - Composite Liner

CAS #	Constituent	MCL (mg/L)	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Protective?
100-42-5	Styrene	0.1	1.0	$5.4x10^4$	1000	Yes
108-88-3	Toluene	1.0	1.6	$2.9x10^4$	1000	Yes

[9] Table 7 also indicates the effect of the 1000 mg/L cap on the results. The LCTV results from multiplying the RGC with the DAF. In this example, the MCL for styrene (0.1 mg/L) multiplied by the unitless DAF (5.4×10^4) would result in an LCTV of 5,400 mg/L, but because LCTVs are capped, the LCTV for styrene in a composite liner is capped at 1,000 mg/L. See Chapter 6 of the *Industrial Waste Management Evaluation Model Technical Background Document* (U.S. EPA, 2002a) for further information.

composite liner design scenarios, in that order. Generally, if the expected leachate concentrations for all constituents are lower than the no liner LCTVs, the proposed unit does not need a liner to contain this waste. If any expected constituent concentration is higher than the no liner/in situ soils LCTV, a single compacted clay liner or composite liner would be recommended for containment of the waste using the Tier 1 analysis. If any expected concentration is higher than the single clay liner LCTV, the recommendation is at least a composite liner. If any expected concentration is higher than the composite liner LCTV, pollution prevention, treatment, or additional controls should be considered, or a Tier 2 or Tier 3 analysis can be conducted to consider site-specific factors before making a final judgment. For waste streams with multiple constituents, the most protective design that is recommended for any one constituent is the overall recommendation. In the example illustrated in Tables 4, 5, 6, and 7, the recommended design is a composite liner because the expected leachate concentration for styrene exceeds the no liner/in situ soils and clay liner LCTVs in the MCL-based analysis, but is lower than the composite liner LCTV. For the HBN-based analysis, a no liner/in situ soils design would provide adequate protection for the site because, as shown in Table 5, the leachate concentrations for styrene and toluene are lower than their respective HBN-based LCTVs.

The interpretation for land application is similar to the interpretation for landfills. However, only the no liner/in situ soils scenario is evaluated for land application because these types of units generally do not use liner systems. Thus, if all the waste leachate concentrations are below the no liner/in situ soils MCL-based and HBN-based LCTVs in the Tier 1 lookup tables, land-applying waste might be appropriate for the site. If the waste has one or more constituents whose concentrations exceed a land application threshold, the recommendation is that land application might not be appropriate. The model does not consider the other design scenarios.

After conducting the Tier 1 evaluation, users should consider the following steps:

- **Perform additional evaluations.** The Tier 1 evaluation provides a conservative screening assessment whose values are calculated to be protective over a range of conditions and situations. Although a user could elect to install a liner based on the Tier 1 results, it is appropriate that a user consider Tier 2 or Tier 3 evaluations to confirm these recommendations.
- **Consider pollution prevention, recycling, or treatment.** If you do not want to conduct a Tier 2 or Tier 3 analysis, and the waste has one or more “problem” constituents that call for a more stringent and costly design system (or which make land application inappropriate), you could consider pollution prevention, recycling, and treatment options for those constituents. Options that previously might have appeared economically infeasible, might be worthwhile if they can reduce the problem constituent concentration to a level that results in a different design recommendation or would make land application appropriate. Then, after implementing these measures, repeat the Tier 1 evaluation. Based on the results presented in Table 6, pollution prevention, recycling, or treatment measures could be used to reduce the expected leachate concentration for styrene below 0.61 mg/L so that a single liner is recommended for the unit. Consult Chapter 3—Integrating

Pollution Prevention, for ideas and tools.

- **Implement recommendations.** You can design the unit based on the design recommendations of the Tier 1 lookup tables without performing further analysis or considering pollution prevention or recycling activities. In the case of land application, a land application system might be developed (after evaluating other factors) if the lookup tables found no liner necessary for all constituents. In either case, it is recommended that you consult the appropriate agency to ensure compliance with state regulations.

Figure 3 illustrates the basic steps using the Tier 1 lookup tables to determine an appropriate design for a proposed waste management unit or whether land application is appropriate.

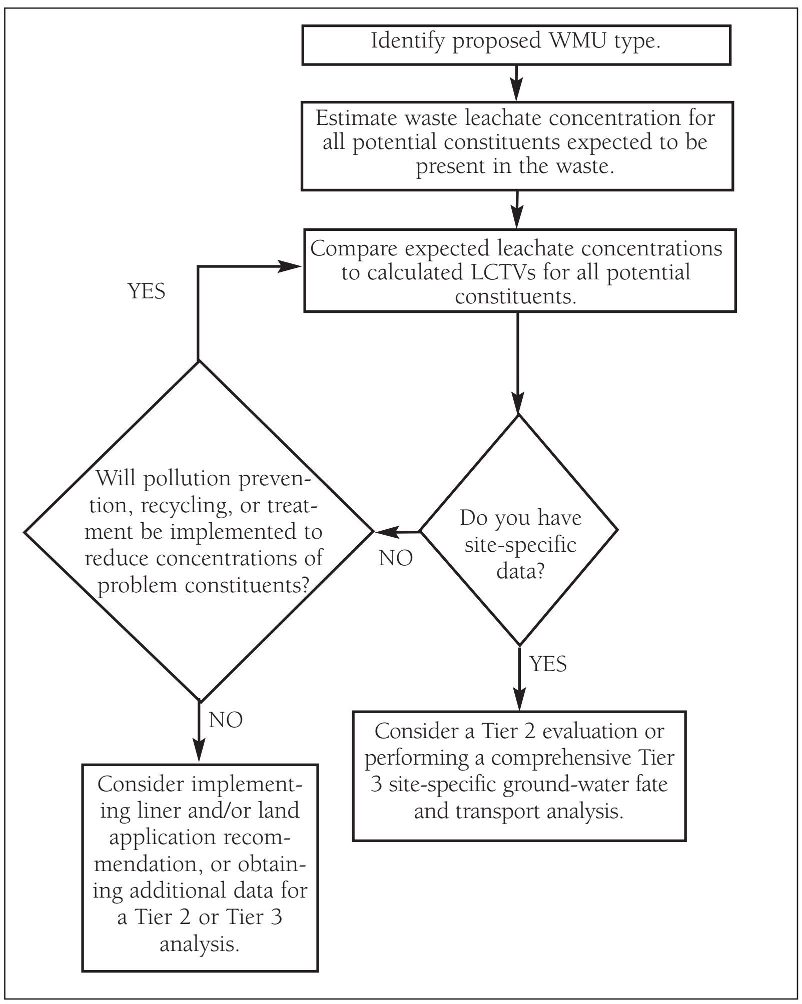
C. Tier 2 Evaluations

The Tier 2 evaluation is designed to provide a more accurate evaluation than Tier 1 by allowing the user to provide site-specific data. In many cases, a Tier 2 evaluation might suggest a less stringent and less costly design than a Tier 1 evaluation would recommend. This section describes the inputs for the analysis and the process for determining a protective recommendation.

1. *How is a Tier 2 Analysis Performed?*

Under Tier 2, the user can provide site-specific information to refine the design recommendations. The Tier 2 analysis leads the user through a series of data entry screens and then runs EPACMTP to generate a design recommendation based on the site-specific information provided by the user. The user can provide data related to the WMU, the subsurface environment, infiltration rates, physicochemical properties, and toxicity. The user can evaluate the three designs discussed above or provide data reflecting a site-specific

Figure 3. Using Tier 1 Lookup Tables



liner design. As a result, a Tier 2 analysis provides a protective design recommendation intended only for use at the user's site, and is not intended to be applied to other sites. This section discusses the inputs that a user can provide and the results from the analysis.

a. *Tier 2 Inputs*

In addition to the inputs required for the Tier 1 analysis, a Tier 2 analysis allows users to provide additional inputs that account for attributes that are specific to the user's site. The Tier 2 inputs that are common to the Tier 1 evaluation are:

- WMU type—waste pile, surface impoundment, or land application unit.
- Chemical constituents of concern present in the WMU.
- Leachate concentration (in mg/L) of each constituent.

If the user has already performed a Tier 1 analysis and continues to a Tier 2 analysis, the Tier 1 inputs are carried forward to the Tier 2 analysis. In the Tier 2 analysis, however, the user can change these data without changing the Tier 1 data.

In addition to the Tier 1 inputs, the user also provides values for additional parameters including WMU area, WMU depth for landfills, ponding depth for surface impoundments, and the climate center in the IWEM database that is nearest to the site. These parameters can have a significant influence on the LCTVs generated by the model and also are relatively easy to determine. The user also has the option to provide values for several more parameters. Table 8 presents the list of "required" and "optional" parameters.

Because site-specific data for all of the EPACMTP parameters might not be available, the model contains default values for the "optional" parameters that are used unless the user provides site-specific data. The default values are derived from a number of sources, including a survey of industrial waste management units, a hydrogeologic database, water-balance modeling, and values reported in the scientific literature. The selection of default values is explained in the *IWEM Technical Background Document* (U.S. EPA, 2002a). If site-specific data are available, they should be used to derive the most appropriate design scenario for a particular site.[10]

In addition to the above parameters, users can also enter certain constituent specific properties, as follows:

- **Organic carbon distribution coefficient (K_{OC}).** A function of the nature of a sorbent (the soil and its organic carbon content) and the properties of a chemical (the leachate constituent). It is equal to the ratio of the solid and dissolved phase concentrations, measured in milliliters per gram (mL/g). The higher the value of the distribution coefficient, the higher the adsorbed-phase concentration, meaning the constituent would be less mobile. For metals, IWEM provides an option to enter a site-specific soil-water partition coefficient (K_d), which overrides the MINTEQA2 default sorption isotherms.
- **Degradation coefficient.** The rate at which constituents degrade or decay within an aquifer due to biochemical processes, such as hydrolysis or biodegradation (measured in units of 1/year). The default decay rate in IWEM represents degradation from chemical hydrolysis only, since biodegradation rates are strongly influenced by site-specific factors. In Tier 2, a user can enter an overall

[10] A Tier 2 evaluation is not always less conservative than a Tier 1. For example, if a site has a very large area, a very shallow water table, and/or the aquifer thickness is well below the national average, then the Tier 2 evaluation results can be more stringent than the Tier 1 analysis results.

Table 8.
Input Parameters for Tier 2

Parameter	Description	Use in Model	Units	Applicable WMU	Required or Optional
WMU area	Area covered by the WMU	To determine the area for infiltration of leachate	Square meters (m^2)	All	Required
WMU location	Geographic location of WMU in terms of the nearest of 102 climate stations	To determine local climatic conditions that affect infiltration and aquifer recharge	Unitless	All	Required
Total waste management unit depth	Depth of the unit for landfills (average thickness of waste in the landfill, not counting the thickness of a liner below the waste or the thickness of a final cover on top of the waste) and surface impoundments (depth of the free-standing liquid in the impoundment, not counting the thickness of any accumulated sediment layer at the base of the impoundment)	For landfills, used to determine the landfill depletion rate. For surface impoundments, used as the hydraulic head to derive leakage	Meters (m)	LF SI	Required for landfills and surface impoundments
Depth of waste management unit below ground surface	Depth of the base of the unit below the ground surface	Used together with depth of the water table to determine distance leachate has to travel through unsaturated zone to reach ground water	Meters (m)	LF SI WP	Optional
Surface Impoundment sediment layer thickness	Thickness of sediment at the base of surface impoundment (discounting thickness of engineered liner, if present)	Limits infiltration from unit.	Meters (m)	SI	Optional
WMU operational life	Period of time WMU is in operation.	IWEM assumes leachate generation occurs over the same period of time.	Years	WP SI LAU	Optional
WMU infiltration rate	Rate at which leachate flows from the bottom of a WMU (including any liner) into unsaturated zone	Affected by area's rainfall intensity and design performance. Users either input infiltration rates directly or allow IWEM to estimate values based on the unit's geographic location,[11] liner design, cover design and WMU type.	Meters per year (m/yr)	All	Optional
Soil type	Predominant soil type in the vicinity of the WMU	Uses site-specific soil data to model leachate migration through unsaturated zone and determine regional recharge rate	sandy loam silt loam silty clay loam	All	Optional
Distance to a well	The distance from a WMU to a downgradient well.	To determine the horizontal distance over which dilution and attenuation occur.	Meters (m)	All	Optional
Hydrogeological setting	Information on the hydrogeological setting of the WMU	Determines certain aquifer characteristics (depth to water table, saturated zone thickness, saturated zone hydraulic conductivity, ground-water hydraulic gradient) when complete information not available	Varies	All	Optional

[11] For surface impoundments IWEM can use either the unit's geographic location or impoundment characteristics (such as ponding depth, and thickness of sediment layer) to estimate the infiltration rates.

Table 8.
Input Parameters for Tier 2 (con't)

Parameter	Description	Use in Model	Units	Applicable WMU	Required or Optional
Depth to the water table	The depth of the zone between the land surface and the water table	Used to predict travel time.	Meters (m)	All	Optional
Saturated zone thickness	Thickness of the saturated zone of the aquifer	Delineates the depth over which leachates can mix with ground waters.	Meters (m)	All	Optional
Saturated zone hydraulic conductivity	Hydraulic conductivity of the saturated zone, or the permeability of the saturated zone in the horizontal direction.	With hydraulic gradient, used to calculate ground-water flow rates.	Meters per year (m/yr)	All	Optional
Ground-water hydraulic gradient	Regional horizontal ground-water gradient	With hydraulic conductivity, used to calculate the ground-water flow rate.	Meters per meter (m/m)	All	Optional
Distance to nearest surface water body	The distance from the unit to the nearest water body	Affects the calculation of ground-water mounding at a site	Meters (m)	SI	Optional

degradation rate which overrides the IWEM default. A user can choose to include degradation due to hydrolysis and biodegradation in the overall degradation rate.

b. Tier 2 Results

After providing site-specific inputs, the user generates design recommendations for each constituent by launching EPACMTP from within IWEM. EPACMTP will then simulate the site and determine the 90th percentile exposure concentration for each design scenario. IWEM determines the minimum recommended design at a 90th percentile exposure concentration by performing 10,000 Monte Carlo simulations of EPACMTP for each waste constituent and design. Upon completion of the modeling analyses, IWEM will display the minimum design recommendation and the calculated, location-specific LCTVs based on the 90th percentile exposure concentration.

The overall result of a Tier 2 analysis is a design recommendation similar to the Tier 1 analysis. However, the basis for the recommendation differs slightly. To illustrate the similarities and differences between the results from the two tiers, the remainder of this section continues the example Tier 1 evaluation through a Tier 2 evaluation. In the Tier 1 example, the disposal of toluene and styrene in a proposed landfill is evaluated. The expected leachate concentration for toluene is 1.6 mg/L and the expected leachate concentration for styrene is 1.0 mg/L. In Tier 2, after inputting the site-specific data summarized in Table 9 and using default data for the remaining parameters, the user can then launch the EPACMTP model simulations.

After completing the EPACMTP model simulations, IWEM produces the results on screen. Table 10 presents the detailed results of a Tier 2 analysis for the no liner/in situ soils scenario. The data presented in this table are similar to the data presented in the Tier 1 results, but the Tier 2 analysis expands

Table 9.
A Sample Set of Site-Specific Data for Input to Tier 2

Parameters	Site-Specific Data
Infiltration rate*	Local climate: Madison, WI Soil type: fine-grained soil
Waste management unit area	15,000 m^2
Waste management unit depth	2 m
Depth to the water table	10 m
Aquifer thickness	25 m
Toxicity standards	Compare to all
Distance to a well	150 m

* The Tier 2 model uses an infiltration rate for the liner scenarios based on local climate and soil data.

the information provided to the user. It includes additional information regarding the toxicity standard, the reference ground-water concentration (RGC), and the 90th percentile exposure concentration. The toxicity standard is included because the user can select specific standards, provide a user-defined standard, or compare to all standards. In this example, all standards were selected; the user can identify the result for each standard from a single table. The LCTV continues to represent the maximum leachate

Table 10:
Example of Tier 2 Detailed Summary Table - No Liner/In situ Soils

CAS #	Constituent	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Toxicity Standard	Ref. Ground-water Conc. (mg/L)	90th Percentile Exposure Concentration (mg/L)	Protective?
100-42-5	Styrene	1.0	8.3	0.83	MCL	0.1	0.1201	No
100-42-5	Styrene	1.0	8.3	29.88	HBN - Ingestion Non-Cancer	3.6	0.1201	Yes
100-42-5	Styrene	1.0	8.3	40.67	HBN - Inhalation Non-cancer	4.9	0.1201	Yes
108-88-3	Toluene	1.6	8.3	8.3	MCL	1	0.1922	Yes
108-88-3	Toluene	1.6	8.4	10.92	HBN - Ingestion Non-cancer	1.3	0.1894	Yes
108-88-3	Toluene	1.6	8.4	41.16	HBN - Inhalation Non-cancer	4.9	0.1894	Yes

concentration for a design scenario that is still protective for a reference ground-water concentration, but the LCTV is not the basis for the design recommendation.

The RGC and 90th percentile exposure concentration are provided because they are the point of comparison for the Tier 2 analysis. (The LCTV, however, continues to provide information about a threshold that might be useful for pollution prevention or waste minimization efforts.) As shown in Table 10, the no liner/in situ soils scenario is protective for toluene because all of the 90th percentile exposure concentrations are less than the three RGCs for toluene, while the no liner/in situ soils scenario is not protective for styrene for the MCL comparison. For that standard, the 90th percentile exposure concentration (0.1201 mg/L) exceeds the RGC (0.1 mg/L). In this case, IWEM would launch EPACMTP to evaluate a clay liner to determine whether that liner design would be protective.

Table 11 provides the single clay liner results for a Tier 2 analysis. As shown in the table, the single clay liner is protective because the 90th percentile exposure concentration (0.0723 mg/L) is less than the reference ground-water concentration (0.1 mg/L). In addition, under the "Protective?" column, IWEM refers the user to the appropriate liner result if a less stringent design is recommended. In Table 11, the user is referred to the no liner/in situ soils results for the HBN-based ingestion and inhalation results because, as shown in Table 10, the no liner/in situ soils scenario is protective. If a Tier 2 analysis determines that a single clay liner is protective for all constituents, then IWEM would not continue to an evaluation of a composite liner. For this example of styrene and toluene disposed of in a landfill, the recommended minimum design is a single clay liner, because the 90th percentile exposure concentration (0.0723) is less than the MCL-based RGC (0.1).

2. *What Do the Results Mean and How Do I Interpret Them?*

The Tier 2 analysis provides LCTVs and recommendations for a minimum protective design. In the Tier 1 analysis, that recommendation is based on a comparison of expected leachate concentrations to LCTVs to determine whether a design scenario is protective. In the

Table 11:
Example of Tier 2 Detailed Summary Table - Single Clay Liner

CAS #	Constituent	Leachate Concentration (mg/L)	DAF	LCTV (mg/L)	Toxicity Standard	Ref. Ground-water Conc. (mg/L)	90th Percentile Exposure Concentration (mg/L)	Protective?
100-42-5	Styrene	1.0	14	1.4	MCL	0.1	0.0723	Yes
100-42-5	Styrene	1.0	14	50.4	HBN - Ingestion Non-Cancer	3.6	0.0722	See No liner Results
100-42-5	Styrene	1.0	14	68.6	HBN - Inhalation Non-cancer	4.9	0.0722	See No liner Results

Tier 2 analysis, LCTVs can be used to help waste managers determine whether waste minimization techniques might lower leachate concentrations and enable them to use less costly unit designs, but IWEM does not need to calculate an LCTV to make a design recommendation. If the 90th percentile ground-water concentration does not exceed the specified RGC, then the evaluated design scenario is protective for that constituent. If the 90th percentile ground-water concentrations for all constituents under the no liner/in situ soils scenario are below their respective RGCs , then IWEM will recommend that no liner/in situ soils is needed to protect the ground water. If the 90th percentile ground-water concentration of any constituent exceeds its RGC, then a single clay liner is recommended (or, in the case of land application units, land application is not recommended). Similarly, if the 90th percentile ground-water concentration of any constituent under the single clay liner scenario exceeds its RGC, then a composite liner is recommended. As previously noted, however, you may decide to conduct a Tier 3 site-specific analysis to determine which design scenario is most appropriate. See the ensuing section on Tier 3 analyses for further information. For waste streams with multiple constituents, the most protective liner design that is recommended for any one constituent is the overall recommendation. As in the Tier 1 evaluation, pollution prevention, recycling, and treatment practices could be considered when the protective standard of a composite liner is exceeded if you decide not to undertake a Tier 3 assessment to reflect site-specific conditions.

If the Tier 2 analysis found land application to be appropriate for the constituents of concern, then a new land application system may be considered (after evaluating other factors). Alternatively, if the waste has one or more "problem" constituents that make land application inappropriate, the user might consider pollution prevention, recycling, and treatment options for those constituents. If, after conducting the Tier 2 evaluation, the user is not satisfied with the resulting recommendations, or if site-specific conditions seem likely to suggest a different conclusion regarding the appropriateness of land application of a waste, then the user can conduct a more in-depth, site-specific, ground-water risk analysis (Tier 3).

In addition to the Tier 2 evaluation, other fate and transport models have been developed that incorporate location-specific considerations, such as the American Petroleum Institute's (API's) *Graphical Approach for Determining Site-Specific Dilution-Attenuation Factors.*[12] API developed its approach to calculate facility-specific DAFs quickly using graphs rather than computer models. Graphs visually indicate the sensitivity to various parameters. This approach can be used for impacted soils located above or within an aquifer. This approach accounts for attenuation with distance and time due to advective/dispersive processes. API's approach has a preliminary level of analysis that uses a small data set containing only measures of the constituent plume's geometry. The user can read other necessary factors off graphs provided as part of the approach. This approach also has a second level of analysis in which the user can expand the data set to include site-specific measures, such as duration of constituent leaching, biodegradation of constituents, or site-specific dispersivity values. At either level of analysis, the calculation results in a DAF. This approach is not appropriate for all situations; for example, it should not be used to estimate constituent concentrations in active ground-water supply wells or to model very complex hydrogeologic settings, such as fractured rock. It is recommended that you consult with the appropriate state agency to discuss the applicability of the API approach or any other location-adjusted model prior to use.

[12] A copy of API's user manual, *The Technical Background Document and User Manual (API Publication 4659)*, can be obtained from the American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005, 202 682-8375.

D. Strengths and Limitations

Listed below are some of IWEM's strengths and limitations that the user should be aware of:

1. *Strengths*

- The tool is relatively easy to use and requires a minimal amount of data and modeling expertise.
- The tool can perform rapid Tier 1 screening evaluations. Tier 2 evaluations allow for many site-specific adjustments.
- The tool is designed to be flexible with respect to the availability of site-specific data for a Tier 2 evaluation. The user needs to provide only a small number of inputs, but if more data are available, the tool can accommodate their input.
- Users can enter their own infiltration rates to evaluate additional design scenarios and still use IWEM to conduct a risk evaluation.
- The user can modify RGC values, when appropriate, and in consultation with other stakeholders.
- The user can modify properties of the 226 constituents (e.g., adding biodegradation), and can add additional constituents for evaluation.
- The tool provides recommendations for protective design systems. It can also be used to evaluate whether waste leachate reduction measures would be appropriate.

2. *Limitations*

- IWEM considers only exposures from contact with contaminated ground water via ingestion of drinking water and inhalation while showering. IWEM does not consider vapor intrusion into buildings. It also does not address potential risks through environmental pathways other than ground water, such as volatile emissions from a WMU, surface runoff and erosion, and indirect exposures through the food chain pathway. Other chapters in this Guide, however, address ways to assess or control potential risks via such other pathways.
- The use of a waste concentration to leachate concentration ratio of 10,000 in IWEM Tier 2 may overestimate the amount of contaminant mass in the WMU, allowing the modeling results to approach non-depleting source steady-state values for WMUs without engineered liners. This may result in an underestimation of the Tier 2 LCTVs.
- IWEM considers only human health risks. Exposure and risk to ecological receptors are not included.
- The conceptual flow model used in EPACMTP in conjunction with IWEM Tier 2 data input constraints might produce ground-water velocities that might be greater than can be assumed based on the site-specific hydraulic conductivity and hydraulic gradient values. The maximum values that the velocities can reach are limited by a model constraint that appropriately prevents the modeled water level from rising above the ground surface. Despite this constraint, modeled velocities might be greater than expected velocities based on site-specific hydraulic conductivity and hydraulic gradient.

- The risk evaluation in IWEM is based on the ground-water concentration of individual waste constituents. IWEM does not address the cumulative risk due to simultaneous exposure to multiple constituents (although it does use a carcinogenic risk level at the conservative end of EPA's risk range).
- IWEM is not designed for sites with complex hydrogeology, such as fractured (karst) aquifers.
- The tool is inappropriate for sites where non-aqueous phase liquid (NAPL) contaminants are present.
- IWEM does not account for all possible fate and transport processes. For example, colloid transport might be important at some sites but is not considered in IWEM. While the user can enter a constituent-specific degradation rate constant to account for biodegradation, IWEM simulates biodegradation in a relatively simple way by assuming the rate is the same in both the unsaturated and the saturated zones.

E. Tier 3: A Comprehensive Site-Specific Evaluation

If the Tier 1 and Tier 2 evaluations do not adequately simulate conditions at a proposed site, or if you decide that sufficient data are available to skip a Tier 1 or Tier 2 analysis, a site-specific risk assessment could be considered.[13] In situations involving a complex hydrogeologic setting or other site-specific factors that are not accounted for in IWEM, a detailed site-specific ground-water fate and transport analysis might be appropriate for determining risk to ground water and evaluating alternative designs or application rates. It is recommended that you consult with the appropriate state agency and use a qualified professional experienced in ground-water modeling. State officials and appropriate trade associations might be able to suggest a good consultant to perform the analysis.

Why is it important to use a qualified professional?

- Fate and transport modeling can be very complex; appropriate training and experience are required to correctly use and interpret models.
- Incorrect fate and transport modeling can result in a liner system that is not sufficiently protective or an inappropriate land application rate.
- To avoid incorrect analyses, check to see if the professional has sufficient training and experience at analyzing ground-water flow and contaminant fate and transport.

1. How is a Tier 3 Evaluation Performed?

A Tier 3 evaluation will generally involve a more detailed site-specific analysis than Tier 2. Sites for which a Tier 3 evaluation might be performed typically involve complex and heterogeneous hydrogeology. Selection and application of appropriate ground-water models require a thorough understanding of the waste and the physical, chemical, and hydrogeologic characteristics of the site.

A Tier 3 evaluation should involve the following steps:

- Developing a conceptual hydrogeological model of the site.
- Selecting a flow and transport simulation model.
- Applying the model to the site.

[13] For example, if ground-water flow is subject to seasonal variations, use of the Tier 2 evaluation tool might not be appropriate because the model is based on steady-state flow conditions.

As with all modeling, you should consult with the state before investing significant resources in a site-specific analysis. The state might have a list of preferred models and might be able to help plan the fate and transport analysis.

a. *Developing a Conceptual Hydrogeological Model*

The first step in the site-specific Tier 3 evaluation is to develop a conceptual hydrogeological model of the site. The conceptual model should describe the key features and characteristics to be captured in the fate and transport modeling. A complete conceptual hydrogeological model is important to ensure that the fate and transport model can simulate the important features of the site. The conceptual hydrogeological model should address questions such as:

- Does a confined aquifer, an unconfined aquifer, or both need to be simulated?
- Does the ground water flow through porous media, fractures, or a combination of both?
- Is there single, or are there multiple, hydrogeologic layers to be simulated?
- Is the hydrogeology constant or variable in layer thickness?
- Are there other hydraulic sources or sinks (e.g., extraction or injection wells, lakes, streams, ponds)?
- What is the location of natural no-flow boundaries and/or constant head boundaries?
- How significant is temporal (seasonal) variation in ground-water flow conditions? Does it require a transient flow model?
- What other contaminant sources are present?
- What fate processes are likely to be significant (e.g. sorption and biodegradation)?
- Are plume concentrations high enough to make density effects significant?

b. *Selecting a Fate and Transport Simulation Model*

Numerous computer models exist to simulate ground-water fate and transport. Relatively simple models are often based on analytical solutions of the mathematical equations governing ground-water flow and solute transport equations. However, such models generally cannot simulate the complexities of real world sites, and for a rigorous Tier 3 evaluation, numerical models based on finite-difference or finite-element techniques are recommended. The primary criteria for selecting a particular model should be that it is consistent with the characteristics of the site, as described in the conceptual site hydrogeological model, and that it is able to simulate the significant processes that control contaminant fate and transport.

In addition to evaluating whether a model will adequately address site characteristics, the following questions should be answered to ensure that the model will provide accurate, verifiable results:

- What is the source of the model? How easy is it to obtain and is the model well documented?
- Are documentation and user's manuals available for the model? If yes, are they clearly written and do they provide sufficient technical background on the mathematical formulation and solution techniques?

What are some useful resources for selecting a ground-water fate and transport model?

The following resources can help select appropriate modeling software:

- *Ground Water Modeling Compendium*, Second Edition (U.S. EPA, 1994c)
- *Assessment Framework for Ground-Water Modeling Applications* (U.S. EPA, 1994b)
- *Technical Guide to Ground-water Model Selection at Sites Contaminated with Radioactive Substances* (U.S. EPA, 1994a)
- *EPA's Center for Subsurface Modeling Support* (CSMoS—RSKERL; Ada, Oklahoma)
- Anderson, Mary P. and William W. Woessner. *Applied Groundwater Modeling: Simulation of Flow and Advective Transport* (Academic Press, 1992)
- EPA regional offices

- Has the model been verified against analytical solutions and other models? If yes, are the test cases available so that a professional consultant can test the model on his/her computer system?
- Has the model been validated using field data?

Table 12 provides a brief description of a number of commonly used ground-water fate and transport models.

c. *Applying the Model to the Site*

For proper application of a ground-water flow and transport model, expertise in hydrogeology and the principles of flow and transport, as well as experience in using models and interpreting model results are essential. The American Society for Testing and Materials (ASTM) has developed guidance that might be useful for conducting modeling. A listing of guidance material can be found in Table 13.

The first step in applying the model to a site is to calibrate it. Model calibration is the process of matching model predictions to observed data by adjusting the values of input parameters. In the case of ground-water modeling, the calibration is usually done by matching predicted and observed hydraulic head values. Calibration is important even for well-characterized sites, because the values of measured or estimated model parameters are always subject to uncertainty. Calibrating the flow model is usually achieved by adjusting the value(s) of hydraulic conductivity and recharge rates. In addition, if plume monitoring data or tracer test data are available, transport parameters such as dispersivity, and sorption and degradation parameters can also be calibrated. A properly calibrated model is a powerful tool for predicting contaminant fate and transport. Conversely, if no calibration is performed due to lack of suitable site data, any Tier 3 model predictions will remain subject to considerable uncertainty.

At a minimum, a site-specific analysis should provide estimated leachate concentrations at specified downgradient points for a proposed design. For landfills, surface impoundments and waste piles, you should compare these concentrations to appropriate MCLs, health-based standards, or state standards. For land application units, if a waste leachate concentration is below the values specified by the state, land application might be appropriate. Conversely, if a leachate concentration is above state-specified values, land application might not be protective of the ground water.

Table 12.
Example Site-Specific Ground-Water Fate and Transport Models

Model Name	Description
MODFLOW	MODFLOW is a 3-D, ground-water flow model for steady state and transient simulation of saturated flow problems in confined and unconfined aquifers. It calculates flow rates and water balances. The model includes flow towards wells, through riverbeds, and into drains. MODFLOW is the industry standard for ground-water modeling that was developed and still maintained by the United States Geological Survey (USGS). MODFLOW-2000 is the current version. MODFLOW is a public domain model; numerous pre- and post-processing software packages are available commercially. MODFLOW can simulate ground-water flow only. In order to simulate contaminant transport, MODFLOW must be used in conjunction with a compatible solute transport model (MT3DMS, see below). MODFLOW and other USGS models can be obtained from the USGS Web site at **<water.usgs.gov/nrp/gwsoftware/modflow.html>**.
MT3DMS	Modular 3-D Transport model (MT3D) is commonly used in contaminant transport modeling and remediation assessment studies. Originally developed for EPA, the current version is known as MT3DMS. MT3DMS has a comprehensive set of options and capabilities for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in ground-water flow systems under general hydrogeologic conditions. MT3DMS retains the same modular structure of the original MT3D code, similar to that implemented in MODFLOW. The modular structure of the transport model makes it possible to simulate advection, dispersion/diffusion, source/sink mixing, and chemical reactions separately without reserving computer memory space for unused options. New packages involving other transport processes and reactions can be added to the model readily without having to modify the existing code. NOTE: The original version of this model known as MT3D, released in 1991, was based on a mathematical formulation which could result in mass-balance errors. This version should be avoided. MT3DMS is maintained at the University of Alabama, and can be obtained at: **<hydro.geo.ua.edu/mt3d>**. MT3DMS is also included, along with MODFLOW, in several commercial ground-water modeling software packages.
BIOPLUME-III	BIOPLUME-III is a 2-D, finite difference model for simulating the natural attenuation of organic contaminants in ground water due to the processes of advection, dispersion, sorption, and biodegradation. Biotransformation processes are potentially important in the restoration of aquifers contaminated with organic pollutants. As a result, these processes require valuation in remedial action planning studies associated with hydrocarbon contaminants. The model is based on the USGS solute transport code MOC. It solves the solute transport equation six times to determine the fate and transport of the hydrocarbons, the electron acceptors (O_2, NO^{3-}, Fe^{3+}, SO_4^{2-}, and CO_2), and the reaction byproducts (Fe^{2+}). A number of aerobic and anaerobic electron acceptors (e.g., oxygen, nitrate, sulfate, iron (III), and carbon dioxide) have been considered in this model to simulate the biodegradation of organic contaminants. Three different kinetic expressions can be used to simulate the aerobic and anaerobic biodegradation reactions. BIOPLUME-III and other EPA supported ground-water modeling software can be obtained via the EPA Center for Subsurface Modeling Support at the RS Kerr Environmental Research Lab in Ada, Oklahoma: **<www.epa.gov/ada/csmos/models.html>**.

A well-executed site-specific analysis can be a useful instrument to anticipate and avoid potential risks. A poorly executed site-specific analysis, however, could over- or under-emphasize risks, possibly leading to adverse human health and environmental effects, or costly cleanup liability, or it could overemphasize risks, possibly leading to the unnecessary expenditure of limited resources. If possible, the model and the results of the final analyses, including input and output parameters and key assumptions, should be shared with stakeholders. Chapter 1—Understanding Risk and Building Partnerships provides a more detailed description of activities to keep the public informed and involved.

Table 13. ASTM Ground-Water Modeling Standards

The American Society for Testing and Materials (ASTM), Section D-18.21.10 concerns subsurface fluid-flow (ground-water) modeling. The ASTM ground-water modeling section is one of several task groups funded under a cooperative agreement between USGS and EPA to develop consensus standards for the environmental industry and keep the modeling community informed as to the progress being made in development of modeling standards.

The standards being developed by D-18.21.10 are "guides" in ASTM terminology, which means that the content is analogous to that of EPA guidance documents. The ASTM modeling guides are intended to document the state-of-the-science related to various topics in subsurface modeling.

The following standards have been developed by D-18.21.10 and passed by ASTM. They can be purchased from ASTM by calling 610 832-9585. To order or browse for publications, visit ASTM's Web site **<www.astm.org>** .

D-5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem

D-5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information

D-5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling

D-5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling

D-5611 Guide for Conducting a Sensitivity Analysis for a Ground-Water Flow Model Application

D-5718 Guide for Documenting a Ground-Water Flow Model Application

D-5719 Guide to Simulation of Subsurface Air Flow Using Ground-Water Flow Modeling Codes

D-5880 Guide for Subsurface Flow and Transport Modeling

D-5981 Guide for Calibrating a Ground-Water Flow Model Application

A compilation of most of the current modeling and aquifer testing standards also can be purchased. The title of the publication is *ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling*, publication number 03-418096-38.

For more information by e-mail, contact **service@astm.org**.

Assessing Risk Activity List

- ❑ Review the risk characterization tools recommended by this chapter.
- ❑ Characterize the waste in accordance with the recommendations of Chapter 2 — Characterizing Waste.
- ❑ Obtain expected leachate concentrations for all relevant waste constituents.
- ❑ If a Tier 1 evaluation is conducted, understand and use the Tier 1 Evaluation to obtain recommendations for the design of your waste management unit (as noted previously, you can skip the Tier 1 analysis and proceed directly to a Tier 2 or Tier 3 analysis).
- ❑ If a design system or other measures are recommended in a Tier 1 analysis, perform a Tier 2 analysis if you believe the recommendations are overly protective. Also, if data are available, you can conduct a Tier 2 or Tier 3 analysis without conducting a Tier 1 evaluation.
- ❑ If your site characteristics or your waste management needs are particularly complex, or do not adequately simulate conditions reflected in a Tier 1 or Tier 2 analysis, consult with your state and a qualified professional and consider a more detailed, site-specific Tier 3 analysis.

Resources

ASTM. 1996. ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling, Publication Number 03-418096-38.

ASTM. 1993. D-5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.

ASTM. 1993. D-5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-specific Information.

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ASTM. 1994. D-5719 Guide to Simulation of Subsurface Air Flow Using Ground-Water Flow Modeling Codes.

ASTM. 1995. D-5880 Guide for Subsurface Flow and Transport Modeling.

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Bagchi, A. 1994. Design, Construction, and Monitoring of Landfills.

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Boulding, R. 1995. Soil, Vadose Zone, and Ground-Water Contamination: Assessment, Prevention, and Remediation.

Lee, C. 1992. Environmental Engineering Dictionary, 2d. Ed.

Sharma, H., and S. Lewis. 1994. Waste Containment Systems, Waste Stabilization, and Landfills.

Speidel, D., L. Ruedisili, and A. Agnew. 1988. Perspectives on Water: Uses and Abuses.

Resources (cont.)

U.S. EPA. 2002a. Industrial Waste Management Evaluation Model (IWEM) Technical Background Document. EPA530-R-02-012.

U.S. EPA. 2002b. The User's Guide for the Industrial Waste Management Evaluation Model. EPA530-R- 02-013.

U.S. EPA. 2002c. EPACMTP Data/Parameters Background Document.

U.S. EPA. 2002d. EPACMTP Technical Background Document.

U.S. EPA. 1997a. Exposure Factors Handbook. EPA600-P-95-002F.

U.S. EPA. 1997b. Guiding Principles for Monte Carlo Analyses. EPA630-R-97-001.

U.S. EPA. 1994a. A Technical Guide to Ground-Water Model Selection at Sites Contaminated with Radioactive Substance. EPA 4-2-R-94-012.

U.S. EPA. 1994b. Assessment Framework for Ground-Water Modeling Applications. EPA500-B-94-003.

U.S. EPA. 1994c. Ground-Water Modeling Compendium, Second Edition. EPA500-B-94-003.

U.S. EPA. 1991. Seminar Publication: Site Characterization for Subsurface Remediation. EPA625-4-91-026.

U.S. EPA. 1989. Exposure Assessment Methods Handbook.

U.S. EPA. 1988. Selection Criteria For Mathematical Models Used In Exposure Assessments: Ground-water Models. EPA600-8-88-075.

U.S. EPA. 1988. Superfund Exposure Assessment Manual.

Part IV
Protecting Ground Water

Chapter 7: Section B
Designing and Installing Liners

Technical Considerations for New Surface Impoundments, Landfills, and Waste Piles

Contents

Designing and Installing Liners—Technical Considerations for New Surface Impoundments, Landfills, and Waste Piles

This chapter will help you:

- *Employ liner systems where needed to protect ground water from contamination.*
- *Select from clay liners, synthetic liners, composite liners, leachate collection systems, and leak detection systems as appropriate.*
- *Consider technical issues carefully to ensure that the liner system will function as designed.*

Once risk has been characterized and the most appropriate design system is chosen, the next step is unit design. The Industrial Waste Management Evaluation Model (IWEM), discussed in Chapter 7, Section A—Assessing Risk can be used to determine appropriate design system recommendations. A critical part of this design for new landfills, waste piles, and surface impoundments is the liner system. The liner system recommendations in the Guide do not apply to land application units, since such operations generally do not include a liner system as part of their design. (For design of land application units, refer to Chapter 7, Section C—Designing a Land Application Program.) You should work with your state agency to ensure consideration of any applicable design system requirements, recommendations, or standard practices the state might have. In this chapter, sections I though IV discuss four design options—no liner/in-situ soils, single liner, composite liner, and double liner. Section V covers leachate collection and leak detection systems, and section VI discusses construction quality assurance and quality control.

I. In-Situ Soil Liners

For the purpose of the Guide, in-situ soil refers to simple, excavated areas or impoundments, without any additional engineering controls. The ability of natural soils to hinder transport and reduce the concentration of constituent levels through dilution and attenuation can provide sufficient protection when the initial constituent levels in the waste stream are very low, when the wastes are inert, or when the hydrogeologic setting affords sufficient protection.

What are the recommendations for in-situ soils?

The soil below and adjacent to a waste management unit should be suitable for construction. It should provide a firm foundation for the waste. Due to the low risk associated with wastes being managed in these units, a liner might not be necessary; however, it is still helpful to review the recommended location considerations and operating practices for the unit.

What technical issues should be considered with the use of in-situ soils?

In units using in-situ natural soils, construction and design of an engineered liner will not be necessary; however, there are still technical concerns to consider. These include the following:

- The stability of foundation soils.
- The compatibility of the waste with native soils.
- The location where the unit will be sited.
- The potential to recompact existing soils.

Potential instability can occur in the foundation soil, if its load-bearing capacity and resistance to movement or consolidation are insufficient to support the waste. The groundwater table or a weak soil layer also can influence the stability of the unit. You should take measures, such as designing maximum slopes, to avoid slope failure during construction and operation of the waste management unit. Most soil slopes are stable at a 3:1 horizontal to vertical inclination. There are common sense operating practices to ensure that any wastes to be managed on in-situ soils will not inappropriately interact with the soils. When using in-situ soils, refer to Chapter 4—Considering the Site. Selecting an appropriate location will be of increased importance, since the added barrier of an engineered liner will not be present. Because in-situ soil can have non-homogeneous material, root holes, and cracks, its performance can be improved by scarifying and compacting the top portion of the in-situ natural soils.

II. Single Liners

If the risk evaluation recommended the use of a single liner, the next step is to determine the type of single liner system most appropriate for the site. The discussion below addresses three types of single liner systems: compacted clay liners, geomembrane liners, and geosynthetic clay liners. Determining which material, or combination of materials, is important for protecting human health and the environment.[1]

A. Compacted Clay Liners

A compacted clay liner can serve as a single liner or as part of a composite or double liner system. Compacted clay liners are composed of natural mineral materials (natural soils), bentonite-soil blends, and other materials placed and compacted in layers called lifts. If natural soils at the site contain a significant quantity of clay, then liner materials can be excavated from onsite locations known as borrow pits. Alternatively, if onsite soils do not contain sufficient clay, clay materials can be hauled from offsite sources, often referred to as commercial pits.

Compacted clay liners can be designed to work effectively as hydraulic barriers. To ensure that compacted clay liners are well constructed and perform as they are designed, it is important to implement effective quality control methods emphasizing soil investigations and construction practices. Three objectives of quality assurance and quality control for compacted soil liners are to ensure that 1) selected liner materials are suitable, 2) liner materials are properly placed and compacted, and 3) the completed liner is properly protected before, during, and after construction. Quality assurance and quality control are discussed in greater detail in section VI.

[1] Many industry and trade periodicals, such as Waste Age, MSW Management, Solid Waste Technologies, and World Wastes, have articles on liner types and their corresponding costs, as well as advertisements and lists of vendors.

What are the thickness and hydraulic conductivity recommendations for compacted clay liners?

Compacted clay liners should be at least 2 feet thick and have a maximum hydraulic conductivity of 1 x 10^{-7} cm/sec (4 x 10^{-8} in/sec). Hydraulic conductivity refers to the degree of ease with which a fluid can flow through a material. A low hydraulic conductivity will help minimize leachate migration out of a unit. Designing a compacted clay liner with a thickness ranging from 2 to 5 feet will help ensure that the liner meets desired hydraulic conductivity standards and will also minimize leachate migration as a result of any cracks or imperfections present in the liner. Thicker compacted clay liners provide additional time to minimize leachate migration prior to the clay becoming saturated.

What issues should be considered in the design of a compacted clay liner?

The first step in designing a compacted clay liner is selecting the clay material. The quality and properties of the material will influence the performance of the liner. The most common type of compacted soil is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Such soils are usually classified as CL, CH, or SC in the Unified Soil Classification System (USCS). Some of the factors to consider in choosing a soil include soil properties, interaction with wastes, and test results for potentially available materials.

Soil Properties

Minimizing hydraulic conductivity is the primary goal in constructing a soil liner. Factors to consider are water content, plasticity characteristics, percent fines, and percent gravel, as these properties affect the soil's ability to achieve a specified hydraulic conductivity.

Hydraulic conductivity. It is important to select compacted clay liner materials so that remolding and compacting of the materials will produce a low hydraulic conductivity. Factors influencing the hydraulic conductivity at a particular site include: the degree of compaction, compaction method, type of clay material used, soil moisture content, and density of the soil during liner construction. The hydraulic conductivity of a soil also depends on the viscosity and density of the fluid flowing through it. Consider measuring hydraulic conductivity using methods such as American Society of Testing and Materials (ASTM) D-5084.[2]

Water content. Water content refers to the amount of liquid, or free water, contained in a given amount of material. Measuring water content can help determine whether a clay material needs preprocessing, such as moisture adjustment or soil amendments, to yield a specified density or hydraulic conductivity. Compaction curves can be used to depict moisture and density relationships, using either ASTM D-698 or ASTM D-1557, the standard or modified Proctor test methods, depending on the compaction equipment used and the degree of firmness in the foundation materials.[3] The critical relationship between clay soil moisture content and density is explained thoroughly in Chapter 2 of EPA's 1993 technical guidance document *Quality*

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[2] ASTM D-5084, Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

[3] ASTM D-698, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)).
ASTM D-1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)).

Assurance and Quality Control for Waste Containment Facilities (U.S. EPA, 1993c).

Plasticity characteristics. Plasticity characteristics describe a material's ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced.

Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soil-water mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior. When soils with high plastic limits are too dry during placement, they tend to form clods, or hardened clumps, that are difficult to break down during compaction. As a result, preferential pathways can form around these clumps allowing leachate to flow through the material at a higher rate. Soil plasticity indices typically range from 10 percent to 30 percent. Soils with a plasticity index greater than 30 percent are cohesive, sticky, and difficult to work with in the field. Common testing methods for plasticity characteristics include the methods specified in ASTM D-4318, also known as Atterberg limits tests.[4]

Percent fines and percent gravel. Typical soil liner materials contain at least 30 percent fines and can contain up to 50 percent gravel, by weight. Common testing methods for percent fines and percent gravel are specified in ASTM D-422, also referred to as grain size distribution tests.[5] Fines refer to silt and clay-sized particles. Soils with less than 30 percent fines can be worked to obtain hydraulic conductivities below 1×10^{-7} cm/sec (4×10^{-8} in./sec), but use of these soils requires more careful construction practices.

Gravel is defined as particles unable to pass through the openings of a Number 4 sieve, which has an opening size equal to 4.76 mm (0.2 in.). Although gravel itself has a high hydraulic conductivity, relatively large amounts of gravel, up to 50 percent by weight, can be uniformly mixed with clay materials without significantly increasing the hydraulic conductivity of the material. Clay materials fill voids created between gravel particles, thereby creating a gravel-clay mixture with a low hydraulic conductivity. As long as the percent gravel in a compacted clay mixture remains below 50 percent, creating a uniform mixture of clay and gravel, where clay can fill in gaps, is more critical than the actual gravel content of the mixture.

You should pay close attention to the percent gravel in cases where a compacted clay liner functions as a bottom layer to a geosynthetic, as gravel can cause puncturing in geosynthetic materials. Controlling the maximum particle size and angularity of the gravel should help prevent puncturing, as well as prevent gravel from creating preferential flow paths. Similar to gravel, soil particles or rock fragments also can create preferential flow paths. To help prevent the development of preferential pathways and an increased hydraulic conductivity, it is best to use soil liner materials where the soil particles and rock fragments are typically small (e.g., 3/4 inch in diameter).

Interactions With Waste

Waste placed in a unit can interact with compacted clay liner materials, thereby influencing soil properties such as hydraulic con-

[4] ASTM D-4318, Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

[5] ASTM D-422, Standard Test Method for Particle-Size Analysis of Soils.

ductivity and permeability. Two ways that waste materials can influence the hydraulic conductivity of the liner materials are through dissolution of soil minerals and changes in clay structure. Soil minerals can be dissolved, or reduced to liquid form, as a result of interaction with acids and bases. For example, aluminum and iron in the soil can be dissolved by acids, and silica can be dissolved by bases. While some plugging of soil pores by dissolved minerals can lower hydraulic conductivity in the short term, the creation of piping and channels over time can lead to an increased hydraulic conductivity in the long term. The interaction of waste and clay materials can also cause the creation of positive ions, or cations. The presence of cations such as sodium, potassium, calcium, and magnesium can change the clay structure, thereby influencing the hydraulic conductivity of the liner. Depending on the cation type and the clay mineral, an increased presence of such cations can cause the clay minerals to form clusters and increase the permeability of the clay. Therefore, before selecting a compacted clay liner material, it is important to develop a good understanding of the composition of the waste that will be placed in the waste management unit. EPA's Method 9100, in publication SW-846, measures the hydraulic conductivity of soil samples before and after exposure to permeants.[6]

Locating and Testing Material

Although the selection process for compacted clay liner construction materials can vary from project to project, some common material selection steps include locating and testing materials at a potential borrow or commercial pit before construction, and observing and testing material performance throughout construction. First, investigate a potential borrow or commercial pit to determine the volume of materials available. The next step is to test a representative sample of soil to determine material properties such as plasticity characteristics, percent gravel, and percent fines. To confirm the suitability of the materials once construction begins, you should consider requesting that representative samples from the materials in the borrow or commercial pit be tested periodically after work has started.

Material selection steps will vary, depending on the origin of the materials for the project. For example, if a commercial pit provides the materials, locating an appropriate onsite borrow pit is not necessary. In addition to the tests performed on the material, it is recommended that a qualified inspector make visual observations throughout the construction process to ensure that harmful materials, such as stones or other large matter, are not present in the liner material.

What issues should be considered in the construction of a liner and the operation of a unit?

You should develop test pads to demonstrate construction techniques and material performance on a small scale. During unit construction and operation, some additional factors influencing the performance of the liner include: preprocessing, subgrade preparation, method of compaction, and protection against desiccation and cracking. Each of these steps, from preprocessing through protection against desiccation and cracking, should be repeated for each lift or layer of soil.

Test Pads

Preparing a test pad for the compacted clay liner helps verify that the materials and methods proposed will yield a liner that meets the desired hydraulic conductivity. A test pad also provides an opportunity to

[6] SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods.*

demonstrate the performance of alternative materials or methods of construction. A test pad should be constructed with the soil liner materials proposed for a particular project, using the same preprocessing procedures, compaction equipment, and construction practices proposed for the actual liner. A complete discussion of test pads (covering dimensions, materials, and construction) can be found in Chapter 2 of EPA's 1993 technical guidance document *Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c). A discussion of commonly used methods to measure in-situ hydraulic conductivity is also contained in that chapter.

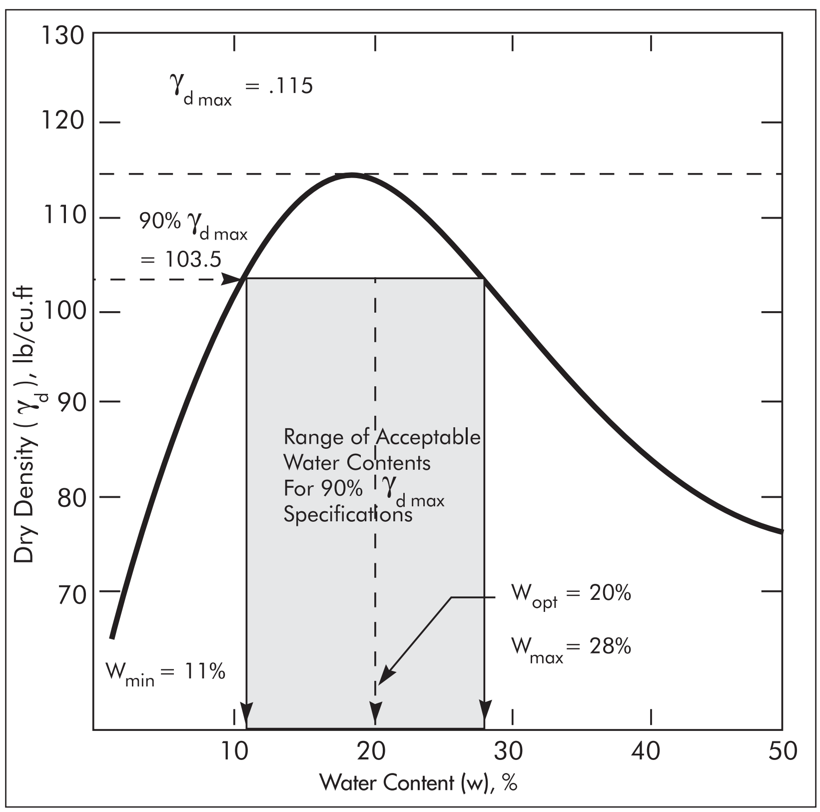
Preprocessing

Although some liner materials can be ready for use in construction immediately after they are excavated, many materials will require some degree of preprocessing. Preprocessing methods include: water content adjustment, removal of oversized particles, pulverization of any clumps, homogenization of the soils, and introduction of additives, such as bentonite.

Water content adjustment. For natural soils, the degree of saturation of the soil liner at the time of compaction, known as molding water content, influences the engineering properties of the compacted material. Soils compacted at water contents less than optimum tend to have a relatively high hydraulic conductivity. Soils compacted at water contents greater than optimum tend to have low hydraulic conductivity and low strength.

Proper soil water content revolves around achieving a minimum dry density, which is expressed as a percentage of the soil's maximum dry density. The minimum dry density typically falls in the range of 90 to 95 percent of the soil's maximum dry density value. From the minimum dry density range, the required water content range can be calculated, as shown in Figure 1. In this example the soil has a maximum dry density of 115 lb/cu ft. Based upon a required minimum dry density value of 90 percent of maximum dry density,

Figure 1.
Water Content for Achieving a Specific Density



Source: U.S. EPA, 1988.

which is equal to 103.5 lb/cu ft, the required water content ranges from 10 to 28 percent.

It is less problematic to compact clay soil at the lower end of the required water content range because it is easier to add water to the clay soil than to remove it. Thus, if precipitation occurs during construction of a site which is being placed at the lower end of the required water content range, the additional water might not result in a soil water content greater than the required range. Conversely, if the site is being placed at the upper end of the range, for example at 25 percent, any additional moisture will be excessive, resulting in water content over 28 percent and making the 90 percent maximum dry density unattainable. Under such conditions construction should halt while the soil is aerated and excess moisture is allowed to evaporate.

Removal of oversized particles. Preprocessing clay materials, to remove cobbles or large stones that exceed the maximum allowable particle size, can improve the soil's compactibility and protect any adjacent geomembrane from puncture. Particle size should be small (e.g., 3/4 inch in diameter) for compaction purposes. If a geomembrane will be placed over the compacted clay, only the upper lift of clay needs to address concerns regarding puncture resistance. Observation by quality assurance and quality control personnel is the most effective method to identify areas where oversized particles need to be removed. Cobbles and stones are not the only materials that can interfere with compactive efforts. Chunks of dry, hard clay, also known as clods, often need to be broken into smaller pieces to be properly hydrated, remolded, and compacted. In wet clay, clods are less of a concern since wet clods can often be remolded with a reasonable compactive effort.

Soil amendments. If the soils at a unit do not have a sufficient percentage of clay, a common practice is to blend bentonite with them to reduce the hydraulic conductivity. Bentonite is a clay mineral that expands when it comes into contact with water. Relatively small amounts of bentonite, on the order of 5 to 10 percent, can be added to sand or other noncohesive soils to increase the cohesion of the material and reduce hydraulic conductivity.

Sodium bentonite is a common additive used to amend soils. However, this additive is vulnerable to degradation as a result of contact with certain chemicals and waste leachates. Calcium bentonite, a more permeable material than sodium bentonite, is another common additive used to amend soils. Approximately twice as much calcium bentonite is needed to achieve a hydraulic conductivity comparable to that of sodium bentonite. Amended soil mixtures generally require mixing in a pug mill, cement mixer, or other mixing equipment that allows water to be added during the mixing process. Throughout the mixing and placement processes, water content, bentonite content, and particle distribution should be controlled. Other materials that can be used as soil additives include lime cement and other clay minerals, such as atapulgite. It can be difficult to mix additives thoroughly with cohesive soils, or clays; the resultant mixture might not achieve the desired level of hydraulic conductivity throughout the entire liner.

Subgrade Preparation

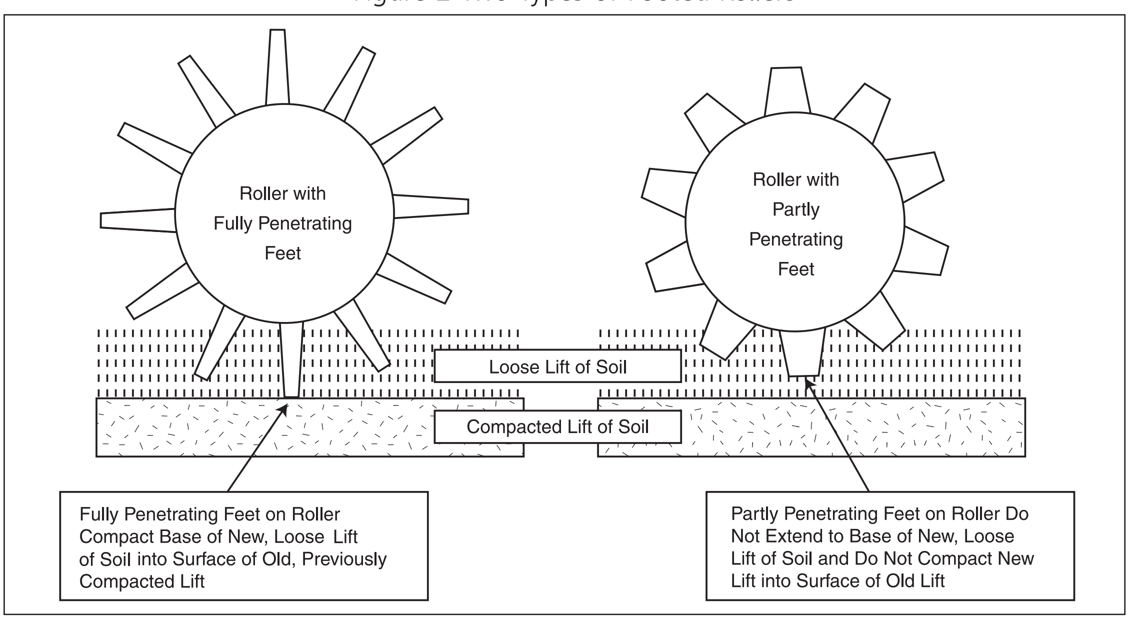
It is important to ensure that the subgrade on which a compacted clay liner will be constructed is properly prepared. When a compacted clay liner is the lowest component of a liner system, the subgrade consists of native soil or rock. Subgrade preparation for these systems involves compacting the native soil to remove any soft spots and adding water to or removing water from the native soil to obtain a specified firmness. Alternatively, in some cases, the compacted clay liner can be placed on top of a geosynthetic material, such as a geotextile. In such cases, subgrade preparation involves ensuring the smoothness of the geosynthetic on which the clay liner will be placed and the conformity of the geosynthetic material to the underlying material.

Compaction

The main purpose of compaction is to densify the clay materials by breaking and remolding clods of material into a uniform mass. Since amended soils usually do not develop clumps, the primary objective of compaction for such materials is to increase the material's density. Proper compaction of liner materials is essential to ensure that a compacted clay liner meets specified hydraulic conductivity standards. Factors influencing the effectiveness of compaction efforts include: the type of equipment selected, the number of passes made over the materials by such equipment, the lift thickness, and the bonding between the lifts. Molding water content, described earlier under preprocessing, is another factor influencing the effectiveness of compaction.

Type of equipment. Factors to consider when selecting compaction equipment include: the type and weight of the compactor, the characteristics of any feet on the drum, and the weight of the roller per unit length of drummed surface. Heavy compactors, weighing more than 50,000 pounds, with feet long enough to penetrate a loose lift of soil, are often the best types of compactor for clay liners. For bentonite-soil mixtures, a footed roller might not be appropriate. For these mixtures, where densification of the material is more important than kneading or remolding it to meet low hydraulic conductivity specifications, a smooth-drum roller or a rubber- tired roller might produce better results. Figure 2 depicts two types of footed rollers, a fully penetrating footed roller and a partially-penetrating footed roller.

Figure 2 Two Types of Footed Rollers



Source: U.S. EPA, 1993c.

For placement of liners on side slopes, consider the angle and length of the slope. Placing continuous lifts on a gradually inclined slope will provide better continuity between the bottom and sidewalls of the liner. Since continuous lifts might be impossible to construct on steeper slopes due to the difficulties of operating heavy compaction equipment on these slopes, materials might need to be placed and compacted in horizontal lifts. When sidewalls are compacted horizontally, it is important to avoid creating seepage planes, by securely connecting the edges of the horizontal lift with the bottom of the liner. Because the lift needs to be wide enough to accommodate compaction equipment, the thickness of the horizontal lift is often greater than the thickness specified in the design. In such cases, you should consider trimming soil material from the constructed side slopes and sealing the trimmed surface using a sealed drum roller.

It is common for contractors to use several different types of compaction equipment during liner construction. Initial lifts might need the use of a footed roller to fully penetrate a loose lift. Final lifts also might need the use of a footed roller for compaction, however, they might be formed better by using a smooth roller after the lift has been compacted to smooth the surface of the lift in preparation for placement of an overlying geomembrane.

Number of passes. The number of passes made by a compactor over clay materials can influence the overall hydraulic conductivity of the liner. The minimum number of passes that is reasonable depends on a variety of site-specific factors and cannot be generalized. In some cases, where a minimum coverage is specified, it might be possible to calculate the minimum number of passes to meet such a specification. At least 5 to 15 passes with a compactor over a given point are usually necessary to remold and compact clay liner materials thoroughly.

An equipment pass can be defined as one pass of the compaction equipment or as one pass of a drum over a given area of soil. It is important to clearly define what is meant by a pass in any quality assurance or quality control plans. It does not matter which definition is agreed upon, as long as the definition is used consistently throughout the project.

Lift thickness. You should determine the appropriate thickness (as measured before compaction) of each of the several lifts that will make up the clay liner. The initial thickness of a loose lift will affect the compactive effort needed to reach the lower portions of the lift. Thinner lifts allow compactive efforts to reach the bottom of a lift and provide greater assurance that compaction will be sufficient to allow homogenous bonding between subsequent lifts. Loose lift thicknesses typically range between 13 and 25 cm (5 and 10 in.). Factors influencing lift thickness are: soil characteristics, compaction equipment, firmness of the foundation materials, and the anticipated compaction necessary to meet hydraulic conductivity requirements.

Bonding between lifts. Since it is inevitable that some zones of higher and lower hydraulic conductivity, also known as preferential pathways, will be present within each lift, lifts should be joined or bonded in a way that minimizes extending these zones or pathways between lifts. If good bonding is achieved, the preferential pathways will be truncated by the bonded zone between the lifts. At least two recommended methods exist for preparing proper bonds. The first method involves kneading, or blending the new lift with the previously compacted lift using a footed roller. Using a roller with feet long enough to fully penetrate through the top lift and knead the previous lift improves the quality of the bond. A second method involves using a disc harrow or similar equipment to scarify, or roughen, and wet the top inch of the recently placed lift, prior to placing the next lift.

Protection Against Desiccation and Cracking

You should consider how to protect compacted clay liners against desiccation and freezing during and after construction. Protection against desiccation is important, because clay soil shrinks as it dries. Depending on the extent of shrinkage, it can crack. Deep cracks, extending through more than one lift, can cause problems. You should measure water content to determine whether desiccation is occurring.

There are several ways to protect compacted clay liners from desiccation. One preventive measure is to smooth roll the surface with a steel drummed roller to produce a thin, dense skin of soil; this layer can help minimize the movement of water into or out of the compacted material. Another option is to wet the clay periodically in a uniform manner; however, it is important to make sure to avoid creating areas of excessive wetness. A third measure involves covering compacted clay liner materials with a sheet of white or clear plastic or tarp to help prevent against desiccation and cracking. The cover should be weighted down with sandbags or other material to minimize exposure of the underlying materials to air. Using a light-colored plastic will help prevent overheating, which can dry out the clay materials. If the clay liner is not being covered with a geosynthetic, another method to prevent desiccation involves covering the clay with a layer of protective cover soil or intentionally overbuilding the clay liner and shaving it down to liner grade.

Protection against freezing is another important consideration, because freezing can increase the hydraulic conductivity of a liner. It is important to avoid construction during freezing weather. If freezing does occur and the damage affects only a shallow depth, the liner can be repaired by rerolling the surface. If deeper freezing occurs, the repairs might be more complicated. For a general guide to frost depths, see Figure 1 of Chapter 11—Performing Closure and Post-Closure Care.

B. Geomembranes or Flexible Membrane Liners

Geomembranes or flexible membrane liners are used to contain or prevent waste constituents and leachate from escaping a waste management unit. Geomembranes are made by combining one or more plastic polymers with ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, crosslinking chemicals, anti-degradants, and biocides. A wide range of plastic resins are used for geomembranes, including high density polyethylene (HDPE), linear low density polyethylene (LLDPE), low density linear polyethlene (LDLPE), very low density polyethlene (VLDPE), polyvinyl chloride (PVC), flexible polypropylene (fPP), chlorosulfonated polyethylene (CSPE or Hypalon), and ethylene propylene diene termonomer (EPDM). Most manufacturers produce geomembranes through extrusion or calendering. In the extrusion process, a molten polymer is stretched into a nonreinforced sheet; extruded geomembranes are usually made of HDPE and LLDPE. During the calendering process, a heated polymeric compound is passed through a series of rollers. In this process, a geomembrane can be reinforced with a woven fabric or fibers. Calendered geomembranes are usually made of PVC and CSPE.

What are the thickness recommendations for geomembrane liners?

Geomembranes range in thicknesses from 20 to 120 mil (1 mil = 0.001 in.). A good design should include a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. These recommended minimum thicknesses ensure that the liner material will withstand the stress of construction and the weight load of the waste, and allow adequate seaming to bind separate geomembrane panels. Reducing the potential for tearing or puncture, through proper construction and quality control, is essential for a geomembrane to perform effectively.

What issues should be considered in the design of a geomembrane liner?

Several factors to address in the design include: determining appropriate material properties and testing to ensure these properties are met, understanding how the liner will interact with the intended waste stream, accounting for all stresses imposed by the design, and ensuring adequate friction.

Material Properties and Selection

When designing a geomembrane liner, you should examine several properties of the geomembrane material in addition to thickness, including: tensile behavior, tear resistance, puncture resistance, susceptibility to environmental stress cracks, ultraviolet resistance, and carbon black content.

Tensile behavior. Tensile behavior refers to the tensile strength of a material and its ability to elongate under strain. Tensile strength is the ability of a material to resist pulling stresses without tearing. The tensile properties of a geomembrane must be sufficient to satisfy the stresses anticipated during its service life. These stresses include the self-weight of the geomembrane and any down drag caused by waste settlement on side slope liners.

Puncture and tear resistance. Geomembrane liners can be subject to tearing during installation due to high winds or handling. Puncture resistance is also important to consider since geomembranes are often placed above or below materials that might have jagged or angular edges. For example, geomembranes might be installed above a granular drainage system that includes gravel.

Susceptibility to environmental stress cracks. Environmental factors can cause cracks or failures before a liner is stressed to its manufactured strength. These imperfections, referred to as environmental stress cracks, often occur in areas where a liner has been scratched or stressed by fatigue. These cracks can also result in areas where excess surface wetting agents have been applied. In surface impoundments, where the geomembrane liner has greater exposure to the atmosphere and temperature changes, such exposure can increase the potential for environmental stress cracking.

Ultraviolet resistance. Ultraviolet resistance is another factor to consider in the design of geomembrane liners, especially in cases where the liner might be exposed to ultraviolet radiation for prolonged periods of time. In such cases, which often occur in surface impoundments, ultraviolet radiation can cause degradation and cracking in the geomembrane. Adding carbon black or other additives during the manufacturing process can increase a geomembrane's ultraviolet resistance. Backfilling over the exposed geomembrane also works to prevent degradation due to ultraviolet radiation.

Interactions With Waste

Since the main purpose of a geomembrane is to provide a barrier and prevent contaminants from penetrating through the geomembrane, chemical resistance is a critical consideration. Testing for chemical resistance might be warranted depending on the type, volumes, and characteristics of waste managed at a particular unit and the type of geomembrane to be used. An established method for testing the chemical resistance of geomembranes, EPA Method 9090, can be found in SW-846. ASTM has also adopted standards for testing the chemical compatibility of various geosynthetics, including geomembranes, with leachates from waste management units. ASTM D-5747 provides a standard for testing the chemical compatibility of geomembranes.[7]

Stresses Imposed by Liner Design

A liner design should take into account the stresses imposed on the liner by the design configuration. These stresses include: the differential settlement in foundation soil, strain requirements at the anchor trench, strain requirements over long, steep side slopes, stresses resulting from compaction, and seismic stresses. Often an anchor trench designed to secure the geomembrane during construction is prepared along the perimeter of a unit cell. This action can help prevent the geomembrane from slipping down the interior side slopes. Trench designs should include a depth of burial sufficient to hold the specified length of liner. If forces larger than the tensile strength of the liner are inadvertently developed, then the liner could tear. For this reason, the geomembrane liner should be allowed to slip or give in the trench after construction to prevent such tearing. To help reduce unnecessary stresses in the liner design, it is advisable to avoid using horizontal seams. For more information on design stresses, consult *Geosynthetic Guidance for Hazardous Waste Landfill Cells and Surface Impoundments* (U.S. EPA, 1987).

Designing for Adequate Friction

Adequate friction between the geomembrane liner and the soil subgrade, as well as between any geosynthetic components, is necessary to prevent extensive slippage or sloughing on the slopes of a unit. Design equations for such components should evaluate: 1) the ability of a liner to support its own weight on side slopes, 2) the ability of a liner to withstand down-dragging during and after waste placement, 3) the best anchorage configuration for the liner, 4) the stability of soil cover on top of a liner, and 5) the stability of other geosynthetic components, such as geotextiles or geonets, on top of a liner. An evaluation of these issues can affect the choice of geomembrane material, polymer type, fabric reinforcement, thickness, and texture necessary to achieve the design requirements. Interface strengths can be significantly improved by using textured geomembranes.

What issues should be considered in the construction of a geomembrane liner?

When preparing to construct a geomembrane liner, you should plan appropriate shipment and handling procedures, perform testing prior to construction, prepare the subgrade, consider temperature effects, and account for wind effects. In addition, you should select a seaming process, determine a material for and method of backfilling, and plan for testing during construction.

Shipment, Handling, and Site Storage

You should follow quality assurance and quality control procedures to ensure proper handling of geomembranes. Different types of geomembrane liners require different types of packaging for shipment and storage. Typically a geomembrane manufacturer will provide specific instructions outlining the

[7] ASTM D-5747, Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids.

handling, storage, and construction specifications for a product. In general, HDPE and LLDPE geomembrane liners are packaged in a roll form, while PVC and CSPE-R liners (CSPE-R refers to a CSPE geomembrane liner reinforced with a fabric layer) are packaged in panels, accordion-folded in two directions, and placed onto pallets. Whether the liner is shipped in rolls or panels, you should provide for proper storage. The rolls and panels should be packaged so that fork lifts or other equipment can safely transport them. For rolls, this involves preparing the roll to have a sufficient inside diameter so that a fork lift with a long rod, known as a stinger, can be used for lifting and moving. For accordion panels, proper packaging involves using a structurally-sound pallet, wrapping panels in treated cardboard or plastic wrapping to protect against ultraviolet exposure, and using banding straps with appropriate cushioning. Once the liners have been transported to the site, the rolls or panels can be stored until the subgrade or subbase (either natural soils or another geosynthetic) is prepared.

Subgrade Preparation

Before a geomembrane liner is installed, you should prepare the subgrade or subbase. The subgrade material should meet specified grading, moisture content, and density requirements. In the case of a soil subgrade, it is important to prevent construction equipment used to place the liner from deforming the underlying materials. If the underlying materials are geosynthetics, such as geonets or geotextiles, you should remove all folds and wrinkles before the liner is placed. For further information on geomembrane placement, see Chapter 3 of EPA's *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c).

Testing Prior to Construction

Before any construction begins, is it recommended that you test both the geomembrane materials from the manufacturer and the installation procedures. Acceptance and conformance testing is used to evaluate the performance of the manufactured geomembranes. Constructing test strips can help evaluate how well the intended construction process and quality control procedures will work.

Acceptance and conformance testing. You should perform acceptance and conformance testing on the geomembrane liner received from the manufacturer to determine whether the materials meet the specifications requested. While the specific ASTM test methods vary depending on geomembrane type, recommended acceptance and conformance testing for geomembranes includes evaluations of thickness, tensile strength and elongation, and puncture and tear resistance testing, as appropriate. For most geomembrane liner types, the recommended ASTM method for testing thickness is ASTM D-5199.[8] For measuring the thickness of textured geomembranes, you should use ASTM D-5994.[9] For tensile strength and elongation, ASTM D-638 is recommended for the HDPE and LLDPE sheets, while ASTM D-882 and ASTM D-751 are recommended for PVC and CSPE geomembranes, respectively.[10] Puncture resistance testing is typically recommended for HDPE and LLDPE geomembranes using ASTM D-4833.[11] To evaluate tear resistance for HDPE, LLDPE, and PVC geomembrane

[8] ASTM D-5199, Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes.

[9] ASTM D-5994, Measuring Core Thickness of Textured Geomembranes.

[10] ASTM D-638, Standard Test Method for Tensile Properties of Plastics.
ASTM D-882, Standard Test Methods for Tensile Properties of Thin Plastic Sheeting.
ASTM D-751, Standard Test Methods for Coated Fabrics.

[11] ASTM D-4833, Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products.

liners, the recommended testing method is ASTM D-1004, Die C.[12] For CSPE-R geomembranes, ply adhesion is more of a concern than tear or puncture resistance and can be evaluated using ASTM D-413, Machine Method, Type A.[13]

Test strips. In preparation for liner placement and field seaming, you should develop test strips and trial seams as part of the construction process. Construction of such samples should be performed in a manner that reproduces all aspects of field production. Providing an opportunity to test seaming methods and workmanship helps ensure that the quality of the seams remains constant and meets specifications throughout the entire seaming process.

Temperature Effects

Liner material properties can be altered by extreme temperatures. High temperatures can cause geomembrane liner surfaces to stick together, a process commonly referred to as blocking. On the other hand, low temperature can cause the liner to crack when unrolled or unfolded. Recommended maximum and minimum allowable sheet temperatures for unrolling or unfolding geomembrane liners are 50°C (122°F) and 0°C (32°F), respectively. In addition to sticking and cracking, extreme temperatures can cause geomembranes to contract or expand. Polyethylene geomembranes expand when heated and contract when cooled. Other geomembranes can contract slightly when heated. Those responsible for placing the liner should take temperature effects into account as they place, seam, and backfill in the field.

Wind Effects

It is recommended that you take measures to protect geomembrane liners from wind damage. Windy conditions can increase the potential for tearing as a result of uplift. If wind uplift is a potential problem, panels can be weighted down with sand bags.

Seaming Processes

Once panels or rolls have been placed, another critical step involves field-seaming the separate panels or rolls together. The selected seaming process, such as thermal or chemical seaming, will depend on the chemical composition of the liner. To ensure the integrity of the seam, you should use the seaming method recommended by the manufacturer. Thermal seaming uses heat to bond together the geomembrane panels. Examples of thermal seaming processes include extrusion welding and thermal fusion (or melt bonding). Chemical seaming involves the use of solvents, cement, or an adhesive. Chemical seaming processes include chemical fusion and adhesive seaming. For more information on seaming methods, *Technical Guidance Document: Inspection Techniques for the Fabrication of Geomembrane Field Seams* (U.S. EPA, 1991c), contains a full chapter on each of the traditional seaming methods and additional discussion of emerging techniques, such as ultrasonic, electrical conduction, and magnetic energy source methods.

Consistent quality in fabricating field seams is paramount to liner performance. Conditions that could affect seaming should be monitored and controlled during installation. Factors influencing seam construction and performance include: ambient temperature, relative humidity, wind uplift, changes in geomembrane temperature, subsurface water content, type of supporting surface used, skill of the seaming crew, quality and consistency of chemical or welding materials, preparation of liner surfaces to be joined, moisture at the seam interface, and cleanliness of the seam interface.

[12] ASTM D-1004, Standard Test Method for Initial Tear Resistance of Plastic Film and Sheeting.

[13] ASTM D-413, Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.

To help control some of these factors, no more than the amount of sheeting that can be used during a shift or a work day should be deployed at one time. To prevent erosion of the underlying soil surface or washout of the geomembrane, proper storm water control measures should be employed. Ambient temperature can become a concern, if the geomembrane liner has a high percentage of carbon black. Although the carbon black will help to prevent damage resulting from ultraviolet radiation, because its dark color absorbs heat, it can increase the ambient temperature of the geomembrane, making installation more complicated. To avoid surface moisture or high subsurface water content, geomembranes should not be deployed when the subgrade is wet.

Regardless of how well a geomembrane liner is designed, its ability to meet performance standards depends on proper quality assurance and quality control during installation. Geomembrane sheets and seams are subject to tearing and puncture during installation; punctures or tears can result from contact with jagged edges or underlying materials or by applying stresses greater than the geomembrane sheet can handle. Proper quality assurance and quality control can help minimize the occurrence of pinhole or seam leaks. For example, properly preparing the underlying layer and ensuring that the gravel is of an acceptable size reduces the potential for punctures.

Protection and Backfilling

Geomembrane liners that can be damaged by exposure to weather or work activities should be covered with a layer of soil or a geosynthetic as soon as possible after quality assurance activities associated with geomembrane testing are completed. If the backfill layer is a soil material, it will typically be a drainage material like sand or gravel. If the cover layer is a geosynthetic, it will typically be a geonet or geocomposite drain placed directly over the geomembrane. Careful placement of backfill materials is critical to avoid puncturing or tearing the geomembrane material.

For soil covers, three considerations determine the amount of slack to be placed in the underlying geomembrane. These considerations include selecting the appropriate type of soil, using the proper type of equipment, and establishing a placement procedure for the soil. When selecting a soil for backfilling, characteristics to consider include particle size, hardness, and angularity, as each of these can affect the potential for tearing or puncturing the liner. To prevent wrinkling, soil covers should be placed over the geomembrane in such a way that construction vehicles do not drive directly on the liner. Care should be taken not to push heavy loads of soil over the geomembrane in a continuous manner. Forward pushing can cause localized wrinkles to develop and overturn in the direction of movement. Overturned wrinkles create sharp creases and localized stress in the liner and can lead to premature failure. A recommended method for placing soil involves continually placing small amounts of soil or drainage material and working outward over the toe of the previously placed material.

Another recommended method involves placing soil over the liner with a large backhoe and spreading it with a bulldozer or similar equipment. If a predetermined amount of slack is to be placed in the geomembrane, the temperature of the liner becomes an important factor, as it will effect the ability of the liner to contract and expand. Although the recommended methods for covering geomembrane liners with soil can take more time than backfilling with larger amounts of soil, these methods are designed to prevent damage caused by covering the liner with too much soil too quickly. In the long run, preventing premature liner failure can be faster and more cost-effective than having to repair a damaged liner.

The types of geosynthetics that are often used as protective covering include geotextiles and geonets. Geogrids and drainage geocomposites can be used for cover soil reinforcement on slopes. The appendix at the end of this chapter provides additional information on geosynthetic materials. For geosynthetic protective covers, as with soil backfilling, to prevent tearing or puncturing, most construction vehicles should not be permitted to move directly on the geomembrane. Some possible exceptions include small, 4-wheel, all terrain vehicles or other types of low ground pressure equipment. Even with these types of vehicles, drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, which can damage the geomembrane. Seaming-related equipment should be allowed on the geomembrane liner, as long as it does not damage the liner. Geosynthetic materials are placed directly on the liner and are not bonded to it.

Testing During Construction

Testing during construction enables assessment of the integrity of the seams connecting the geomembrane panels. Tests performed on the geomembrane seams are categorized as either destructive or nondestructive.

Destructive testing. Destructive testing refers to removing a sample from the liner seam or sheet and performing tests on the sample. For liner seams, destructive testing includes shear testing and peel testing; for liner sheets, it involves tensile testing. While quality control procedures often require destructive testing prior to construction, in order to ensure that the installed seams and sheets meet performance standards, destructive testing should be performed during construction also. For increased quality assurance, it is recommended that peel and shear tests on samples from the installed geomembrane be performed by an independent laboratory. Testing methods for shear testing, peel testing, and tensile testing vary for different geomembrane liner types.

Determining the number of samples to take is a difficult step. Taking too few samples results in a poor statistical representation of the geomembrane quality. On the other hand, taking too many samples requires additional costs and increases the potential for defects. Defects can result from the repair patches used to cover the areas from which samples were taken.

A common sampling strategy is "fixed increment sampling" where samples are taken at a fixed increment along the length of the geomembrane. Increments range from 80 to 300 m (250 to 1,000 ft). The type of welding, such as extrusion or fusion welding, used to connect the seams and the type of geomembrane liner can also help determine the appropriate sampling interval. For example, extrusion seams on HDPE require grinding prior to welding and if extensive grinding occurs, the strength of the HDPE might decrease. In such cases, sampling at closer intervals, such as 90 to 120 m (300 to 400 ft), might provide a more accurate description of material properties. If the seam is a dual hot edge seam, both the inner and outer seams might need to be sampled and tested.

If test results for the seam or sheet samples do not meet the acceptance criteria for the destructive tests, you should continue testing the area surrounding the rejected sample to determine the limits of the low quality seam. Once the area of low quality has been identified, then corrective measures, such as seaming a cap over the length of the seam or reseaming the affected area, might be necessary.

Nondestructive testing. Unlike destructive tests, which examine samples taken from the geomembrane liner in the containment area, nondestructive tests are designed to evaluate the integrity of larger portions of geomembrane seams without removing pieces of the geomembrane for testing. Common nondestructive testing methods include: the probe test, air lance, vacuum box, ultrasonic methods (pulse echo, shadow, and impedance planes), electrical spark test, pressurized dual seam, and electrical resistivity. You should select the test method most appropriate for the material and seaming method. If sections of a seam fail to meet the acceptable criteria of the appropriate nondestructive test, then those sections need to be delineated and patched, reseamed, or retested. If repairing such sections results in large patches or areas of reseaming, then destructive test methods are recommended to verify the integrity of such pieces.

C. Geosynthetic Clay Liners

If a risk evaluation recommended the use of a single liner, another option to consider is a geosynthetic clay liner (GCL). GCLs are factory-manufactured, hydraulic barriers typically consisting of bentonite clay (or other very low permeability materials), supported by geotextiles or geomembranes held together by needling, stitching, or chemical adhesives. GCLs can be used to augment or replace compacted clay liners or geomembranes, or they can be used in a composite manner to augment the more traditional compacted clay or geomembrane materials. GCLs are typically used in areas where clay is not readily available or where conserving air space is an important factor. As GCLs do not have the level of long-term field performance data that geomembranes or compacted clay liners do, states might request a demonstration that performance of the GCL design will be comparable to that of compacted clay or geomembrane liners.

What are the mass per unit area and hydraulic conductivity recommendations for geosynthetic clay liners?

Geosynthetic clay liners are often designed to perform the same function as compacted clay and geomembrane liner components. For geosynthetic clay liners, you should design for a minimum of 3.7 kg/m^2 (0.75 lb/ft^2) dry weight (oven dried at 105°C) of bentonite clay with a hydrated hydraulic conductivity of no more than 5 x 10^{-9} cm/sec (2 x 10^{-9} in/sec). It is important to follow manufacturer specifications for proper GCL installation.

What issues should be considered in the design of a geosynthetic clay liner?

Factors to consider in GCL design are the specific material properties needed for the liner and the chemical interaction or compatibility of the waste with the GCL. When considering material properties, it is important to keep in mind that bentonite has a low shear strength when it is hydrated. Manufacturers have developed products designed to increase shear strength.

Materials Selection and Properties

For an effective GCL design, material properties should be clearly defined in the specifications used during both manufacture and construction. The properties that should be specified include: type of bonds, thickness, moisture content, mass per unit area, shear strength, and tensile strength. Each of these properties is described below.

Type of bonds. Geosynthetic clay liners are available with a variety of bonding designs, which include a combination of clay, adhesives, and geomembranes or geotextiles. The type of adhesives, geotextiles, and geomembranes used as components of GCLs varies widely. One type of available GCL design uses a bentonite clay mixed with an adhesive bound on each side by geotextiles. A variation on this design involves stitching the upper and lower geotextiles together through the clay layer. Alternatively, another option is to use a GCL where geotextiles on each side of adhesive or nonadhesive bentonite clay are connected by needle punching. A fourth variation uses a clay mixed with an adhesive bound to a geomembrane on one side; the geomembrane can be either the lower or the upper surface. Figure 3 displays cross section sketches of the four variations of GCL bonds. While these options describe GCLs available at the time of this Guide, emerging technologies in GCL designs should also be reviewed and considered.

Thickness. The thickness of the various available GCL products ranges from 4 to 6 mm (160 to 320 mil). Thickness measurements are product dependent. Some GCLs can be quality controlled for thickness while others cannot.

Moisture content. GCLs are delivered to the job site at moisture contents ranging from 5 to 23 percent, referred to as the “dry” state. GCLs are delivered dry to prevent premature hydration, which can cause unwanted variations in the thickness of the clay component as a result of uneven swelling.

Stability and shear strength. GCLs should be manufactured and selected to meet the shear strength requirements specified in design plans. In this context, shear strength is the ability of two layers to resist forces moving them in opposite directions. Since hydrated bentonite clay has low shear strength, bentonite clay can be placed between geotextiles and stitch bonded or needle- punched to provide additional stability. For example, a GCL with geotextiles supported by stitch bonding has greater internal resistance to shear in the clay layer than a GCL without any stitching. Needle-punched GCLs tend to provide greater resistance than stitch-bonded GCLs and can also provide increased friction resistance against an adjoining layer, because they require the use of nonwoven geotextiles. Increased friction is an important consideration on side slopes.

Mass per unit area. Mass per unit area refers to the bentonite content of a GCL. It is important to distribute bentonite evenly throughout the GCL in order to meet desired hydraulic conductivity specifications. All GCL products available in North America use a sodium bentonite clay with a mass per unit area ranging from 3.2 to 6.0 kg/m^2 (0.66 to 1.2 lb/ft^2), as manufactured.

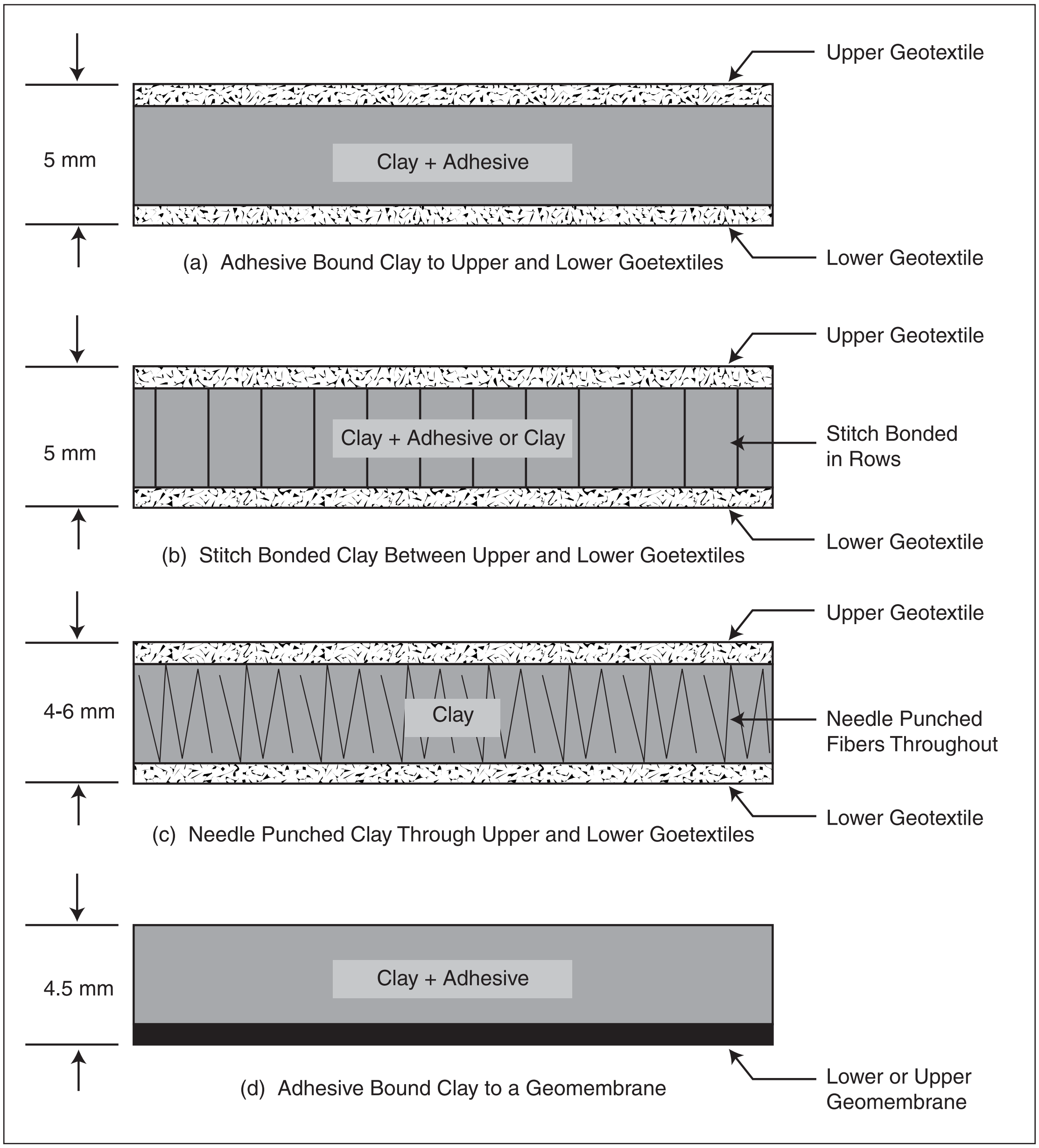
Interaction With Waste

During the selection process for a GCL liner, you should evaluate the chemical compatibility of the liner materials with the types of waste that are expected to be placed in the unit. Certain chemicals, such as calcium, can have an adverse effect on GCLs, resulting in a loss of liner integrity. Specific information on GCL compatibilities should be available from the manufacturer.

What issues should be considered in the construction of a geosynthetic clay liner?

Prior to and during construction, it is recommended that a qualified professional should prepare construction specifications for the GCL. In these specifications, procedures for shipping and storing materials, as well as performing acceptance testing on delivered

Figure 3
Four Variations of GCL Bonding Methods



Source: U.S. EPA, 1993c.

materials, should be identified. The specifications should also address methods for subgrade preparation, joining panels, repairing sections, and protective backfilling.

Shipment, Handling, and Site Storage

GCLs are manufactured in widths of approximately 2 to 5 m (7 to 17 ft) and lengths of 30 to 60 m (100 to 200 ft). Directly after manufacturing, GCLs are rolled around a core and covered with a thin plastic protective covering. This waterproof covering serves to protect the material from premature hydration. GCLs should be stored at the factory with these protective coverings. Typical storage lengths range from a few days to 6 months. To ensure protection of the plastic covering and the rolls themselves during loading and unloading, it is recommended that qualified professionals specify the equipment needed at the site to lift and deploy the rolls properly.

To reduce the potential for accidental damage or for GCLs to absorb moisture at the site, you should try to arrange for "just-in-time-delivery" for GCLs transported from the factory to the field. Even with "just-in-time-delivery," it might be necessary to store GCLs for short periods of time at the site. Often the rolls can be delivered in trailers, which can then serve as temporary storage. To help protect the GCLs prior to deployment, you should use wooden pallets to keep the rolls off the ground, placing heavy, waterproof tarps over the GCL rolls to protect them from precipitation, and using sandbags to help keep the tarps in place.

Manufacturer specifications should also indicate how high rolls of GCLs can be stacked horizontally during storage. Overstacking can cause compression of the core around which the GCL is wrapped. A damaged core makes deployment more difficult and can lead to other problems. For example, rolls are sometimes handled by a fork lift with a stinger attached. The stinger is a long tapered rod that fits inside the core. If the core is crushed, the stinger can damage the liner during deployment.

Acceptance and Conformance Testing

Acceptance and conformance testing is recommended either upon delivery of the GCL rolls or at the manufacturer's facility prior to delivery. Conformance test samples are used to ensure that the GCL meets the project plans and specifications. GCLs should be rewrapped and replaced in dry storage areas immediately after test samples are removed. Liner specifications should prescribe sampling frequencies based on either total area or on number of rolls. Since variability in GCLs can exist between individual rolls, it is important for acceptance and conformance testing to account for this. Conformance testing can include the following.

Mass per unit area test. The purpose of evaluating mass per unit area is to ensure an even distribution of bentonite throughout the GCL panel. Although mass per unit area varies from manufacturer to manufacturer, a typical minimum value for oven dry weight is 3.7 kg/m^2 (0.75 lb/ft^2). Mass per unit area should be tested using ASTM D-5993.[14] This test measures the mass of bentonite per unit area of GCL. Sampling frequencies should be determined using ASTM D- 4354.[15]

Free swell test. Free swell refers to the ability of the clay to absorb liquid. Either ASTM D-5890 or GRI-GCL1, a test method developed by the Geosynthetic Research Institute, can be used to evaluate the free swell of the material.[16]

[14] ASTM D-5993, Standard Test Method for Measuring Mass per Unit Area of Geosynthetic Clay Liners.

[15] ASTM D-4354, Standard Practice for Sampling of Geosynthetics for Testing.

[16] ASTM D-5890, Test Method for Swell Index of Clay Mineral Components of Geosynthetic Clay Liners. GRI-GCL1, Swell Measurement of the Clay Component of Geosynthetic Clay Liners.

Direct shear test. Shear strength of the GCLs can be evaluated using ASTM D-5321.[17] The sampling frequency for this performance-oriented test is often based on area, such as one test per 10,000 m^2 (100,000 ft^2).

Hydraulic conductivity test. Either ASTM D-5084 (modified) or GRI-GCL2 will measure the ease with which liquids can move through the GCL.[18]

Other tests. Testing of any geotextiles or geomembranes should be made on the original rolls of the geotextiles or geomembranes and before they are fabricated into the GCL product. Once these materials have been made part of the GCL product, their properties can change as a result of any needling, stitching, or gluing. Additionally, any peel tests performed on needle punched or stitch bonded GCLs should use the modified ASTM D-413 with a recommended sampling frequency of one test per 2,000 m^2 (20,000 ft^2).[19]

Subgrade Preparation

Because the GCL layer is relatively thin, the first foot of soil underlying the GCL should have a hydraulic conductivity of 1 x 10^{-5} cm/sec or less. Proper subgrade preparation is essential to prevent damage to the GCL layer as it is installed. This includes clearing away any roots or large particles that could potentially puncture the GCL and its geotextile or geomembrane components. The soil subgrade should be of the specified grading, moisture content, and density required by the installer and approved by a construction quality assurance engineer for placement of the GCL. Construction equipment deploying the rolls should not deform or rut the soil subgrade excessively. To help ensure this, the soil subgrade should be smooth rolled with a smooth-wheel roller and maintained in a smooth condition prior to deployment.

Joining Panels

GCLs are typically joined by overlapping panels, without sewing or mechanically connecting pieces together. To ensure proper joints, you should specify minimum and maximum overlap distances. Typical overlap distances range from 150 to 300 mm (6 to 12 in.). For some GCLs, such as needle punched GCLs with nonwoven geotextiles, it might be necessary to place bentonite on the area of overlap. If this is necessary, you should take steps to prevent fugitive bentonite particles from coming into contact with the leachate collection system, as they can cause physical clogging.

Repair of Sections Damaged During Liner Placement

During installation, GCLs might incur some damage to either the clay component or to any geotextiles or geomembranes. For damage to geotextile or geomembrane components, repairs include patching using geotextile or geomembrane materials. If the clay component is disturbed, a patch made from the same GCL product should be used to perform any repairs.

Protective Backfilling

As soon as possible after completion of quality assurance and quality control activities, you should cover GCLs with either a soil layer or a geosynthetic layer to prevent hydration. The soil layer can be a compacted clay liner or a layer of coarse drainage material. The geosynthetic layer is typically a

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[17] ASTM D-5321, Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

[18] ASTM D-5084, Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.
GRI-GCL2, Permeability of Geosynthetic Clay Liners (GCLs).

[19] ASTM D-413, Standard Test Methods for Rubber Property-Adhesion to Flexible Substrate.

geomembrane; however, depending on site-specific designs, it can be a geotextile. As noted earlier, premature hydration before covering can lead to uneven swelling, resulting in a GCL with varied thickness. Therefore, a GCL should be covered with its subsequent soil or geosynthetic layer before a rainfall or snowfall occurs. Premature hydration is less of a concern for GCLs, where the geosynthetic components are needle punched or stitch bonded, because these types of connections can better limit clay expansion.

III. Composite Liners

A composite liner consists of both a geomembrane liner and natural soil. The geomembrane forms the upper component with the natural soil being the lower component. The ususal variations are:

- Geomembrane over compacted clay liner (GM/CCL).
- Geomembrane over geosynthetic clay liner (GM/GCL).
- Geomembrane over geosynthetic clay liner over compacted clay liner (GM/GCL/CCL).

A composite liner provides an effective hydraulic barrier by combining the complementary properties of the two different liners into one system. The geomembrane provides a highly impermeable layer to maximize leachate collection and removal. The natural soil liner serves as a backup in the event of any leakage from the geomembrane. With a composite liner design, you should construct a leachate collection and removal system above the geomembrane. Information on design and construction of leachate collection and removal systems is provided in Section V below.

What are the thickness and hydraulic conductivity recommendations for composite liners?

Each component of the composite liner should follow the recommendations for geomembranes, geosynthetic clay liners, and compacted clay liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, you should use materials with maximum hydraulic conductivities of 1×10^{-7} cm/sec (4×10^{-8} in/sec) and 5×10^{-9} cm/sec (2×10^{-9} in/sec), respectively.

What issues should be considered in the design of a composite liner?

As a starting point, you should follow the design considerations discussed previously for single liners. In addition, to achieve the benefits of a combined liner system, you should install the geomembrane to ensure good contact with the compacted clay layer. The uniformity of contact between the geomembrane and the compacted clay layer helps control the flow of leachate. Porous material, such as drainage sand or a geonet, should not be placed between the geomembrane and the clay layer. Porous materials will create a layer of higher hydraulic conductivity, which will increase the amount of leakage below any geomembrane imperfection.

You should consider the friction or shear strength between a compacted clay layer and a geomembrane. The friction or shear stress at this surface is often low and can form a weak plane on which sliding can occur.

ASTM D-5321 provides a test method for determining the friction coefficient of soil and geomembranes.[20] When using bentonite-amended soils, it is important to account for how the percentage of bentonite added and the degree of saturation affect interface friction. To provide for stable slopes, it is important to control both the bentonite and moisture contents. A textured geomembrane can increase the friction with the clay layer and improve stability.

What issues should be considered in the construction of a composite liner?

To achieve good composite bonding, the geomembrane and the compacted clay layer should have good hydraulic contact. To improve good contact, you should smooth-roll the surface of the compacted clay layer using a smooth, steel-drummed roller and remove any stones. In addition, you should place and backfill the geomembrane so as to minimize wrinkles.

The placement of geomembranes onto a compacted clay layer poses a challenge, because workers cannot drive heavy machines over the clay surface without potentially damaging the compacted clay component. Even inappropriate footwear can leave imprints in the clay layer. It might be possible to drive some types of low ground pressure equipment or small, 4-wheel, all terrain vehicles over the clay surface, but drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, that could damage the surface. To avoid damaging the clay layer, it is recommended that you unroll geomembranes by lifting the rolls onto jacks at a cell side and pulling down on the geomembrane manually. Also, the entire roll with its core can be unrolled onto the cell (with auxiliary support using ropes on embankments).

To minimize desiccation of the compacted clay layer, you should place the geomembrane over the clay layer as soon as possible. Additional cover materials should also be placed over the geomembrane. Exposed geomembranes absorb heat, and high temperatures can dry out and crack an underlying compacted clay layer. Daily cyclic changes in temperature can draw water from the clay layer and cause this water to condense on the underside of the geomembrane. This withdrawal of water can lead to desiccation cracking and potential interface stability concerns.

IV. Double Liners (Primary and Secondary Lined Systems)

In a double-lined waste management unit, there are two distinct liners—one primary (top) liner and one secondary (bottom) liner. Each liner might consist of compacted clay, a geomembrane, or a composite (consisting of a geomembrane and a compacted clay layer or GCL). Above the primary liner, it is recommended that you construct a leachate collection and removal system to collect and convey liquids out of the waste management unit and to control the depth of liquids above the primary liner. In addition, you should place a leak detection, collection, and removal system between the primary and secondary liner. This leak detection system will provide leak warning, as well as collect and remove any liquid or leachate that has escaped the primary liner. See section V below for information on the design of leachate collection and removal systems and leak detection, collection, and removal systems.

[20] ASTM D-5321, Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.

What are the thickness and hydraulic conductivity recommendations for double liners?

Each component of the double liner should follow the recommendations for geomembranes, compacted clay liners, or composite liners described earlier. Geomembrane liners should have a minimum thickness of 30 mil, except for HDPE liners, which should have a minimum thickness of 60 mil. Similarly, compacted clay liners should be at least 2 feet thick and are typically 2 to 5 feet thick. For compacted clay liners and geosynthetic clay liners, use materials with maximum hydraulic conductivities of 1 x 10^{-7} cm/sec (4 x 10^{-8} in/sec) and 5 x 10^{-9} cm/sec (2 x 10^{-9} in/sec), respectively.

What issues should be considered in the design and construction of a double liner?

Like composite liners, double liners are composed of a combination of single liners. When planning to design and construct a double liner, you should consult the sections on composite and single liners first. In addition, you should consult the sections on leachate collection and removal systems and leak detection systems.

V. Leachate Collection and Leak Detection Systems

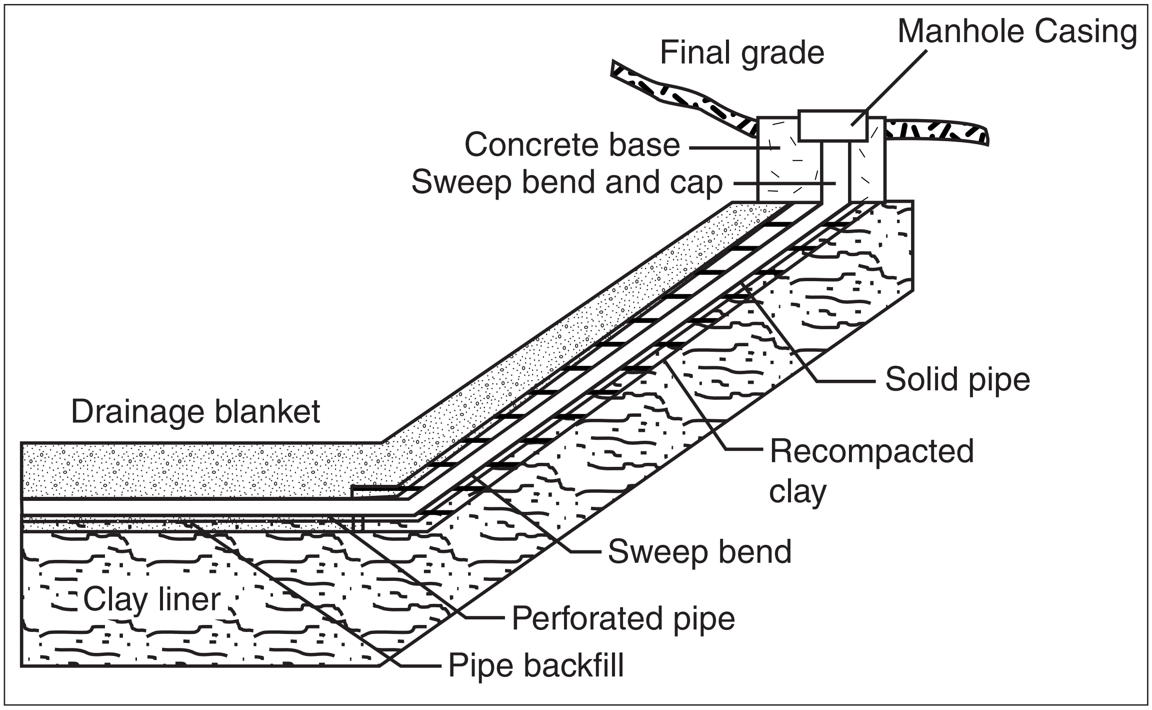
One of the most important functions of a waste management unit is controlling leachate and preventing contamination of the underlying ground water. Both leachate collection and removal systems and leak detection systems serve this purpose. You should consult with the state agency too determine if such systems are required. The primary function of a leachate collection and removal system is to collect and convey leachate out of a unit and to control the depth of leachate above a liner. The primary function of a leak detection system is to detect leachate that has escaped the primary liner. A leak detection system refers to drainage material located below the primary liner and above a secondary liner (if there is one); it acts as a secondary leachate collection and removal system. After the leachate has been removed and collected, a leachate treatment system might be incorporated to process the leachate and remove harmful constituents.

The information in this section on leachate collection and leak detection systems is applicable if the unit is a landfill or a waste pile. Surface impoundments, which manage liquid wastes, usually will not have leachate collection and removal systems unless they will be closed in-place as landfills; they might have leak detection systems to detect liquid wastes that have escaped the primary liner. Leachate collection or leak detection systems generally are not used with land application.

A. Leachate Collection System

A typical leachate collection system includes a drainage layer, collection pipes, a removal system, and a protective filter layer. Leachate collection systems are designed to collect leachate for treatment or alternate disposal and to reduce the buildup of leachate above the liner system. Figure 4 shows a cross section of a typical leachate collection system showing access to pipes for cleaning.

Figure 4
Typical Leachate Collection System



Source: U.S. EPA, 1995b

What are the recommendations for leachate collection and removal systems?

You should design a leachate collection and removal system to maintain less than 30 cm (12 in.) depth of leachate, or "head," above the liner if granular soil or a geosynthetic material is used. The reason for maintaining this level is to prevent excessive leachate from building up above the liner, which could jeopardize the liner's performance. This should be the underlying factor guiding the design, construction, and operation of the leachate collection and removal system.

You should design a leachate collection and removal system capable of controlling the estimated volume of leachate. To determine potential leachate generation, you should use water balance equations or models. The most commonly used method to estimate leachate generation is EPA's Hydrogeologic Evaluation of Landfill Performance (HELP) model.[21] This model uses weather, soil, and waste management unit design data to determine leachate generation rates.

What issues should be considered in the design of a leachate collection and removal system?

You should design a leachate collection and removal system to include the following elements: a low-permeability base, a high-permeability drainage layer, perforated leachate collection pipes, a protective filter layer, and a leachate removal system. During

[21] Available on the CD-ROM version of the Guide, as well as from the U.S. Army Corps of Engineers Web site **<www.wes.army.mil/el/elmodels/index.html#landfill>**

design, you should consider the stability of the base, the transmissivity of the drainage layers, and the strength of the collection pipes. It is also prudent to consider methods to minimize physical, biological, and chemical clogging within the system.

Low-Permeability Base

A leachate collection system is placed over the unit's liner system. The bottom liner should have a minimum slope of 2 percent to allow the leachate collection system to gravity flow to a collection sump. This grade is necessary to provide proper leachate drainage throughout the operation, closure, and post-closure of the unit. Estimates of foundation soil settlement should include this 2 percent grade as a post-settlement design.

High-Permeability Drainage Layer

A high-permeability drainage layer consists of drainage materials placed directly over the low-permeability base, at the same minimum 2 percent grade. The drainage materials can be either granular soil or geosynthetic materials. For soil drainage materials, a maximum of 12 inches of materials with a hydraulic conductivity of at least 1×10^{-2} cm/sec (4×10^{-3} in/sec) is recommended. For this reason, sand and gravel are the most common soil materials used. If the drainage layer is going to incorporate sand or gravel, it should be demonstrated that the layer will have sufficient bearing capacity to withstand the waste load of the full unit. Additionally, if the waste management unit is designed on grades of 15 percent or higher, it should be demonstrated that the soil drainage materials will be stable on the steepest slope in the design.

Geosynthetic drainage materials such as geonets can be used in addition to, or in place of, soil materials. Geonets promote rapid transmission of liquids and are most effective when used in conjunction with a filter layer or geotextile to prevent clogging. Geonets consist of integrally connected parallel sets of plastic ribs overlying similar sets at various angles. Geonets are often used on the side walls of waste management units because of their ease of installation. Figure 5 depicts a typical geonet material configuration.

The most critical factor involved with using geonets in a high-permeability drainage layer is the material's ability to transmit fluids under load. The flow rate of a geonet can be evaluated by ASTM D-4716.[22] Several additional measures for determining the transmissivity of geonets are discussed in the *Solid Waste Disposal Facility Criteria: Technical Manual* (U.S. EPA, 1993b).

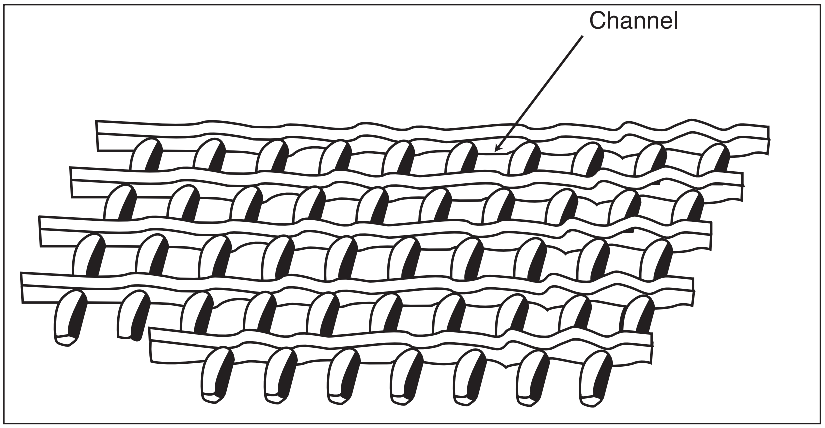
Perforated Leachate Collection Pipes

Whenever the leachate collection system is a natural soil, a perforated piping system should be located within it to rapidly transmit the leachate to a sump and removal system. Through the piping system, leachate flows gravitationally to a low point where the sump and removal system is located. The design of perforated leachate collection pipes, therefore, should consider necessary flow rates, pipe sizing, and pipe structural strength. After estimating the amount of leachate using the HELP model or a similar water balance model, it is possible to calculate the appropriate pipe diameter and spacing. For the leachate collection system design, you should select piping material that can withstand the anticipated weight of the waste, construction and operating equipment stresses, and foundation settling. Most leachate collection pipes used in modern waste management units are constructed of HDPE. HDPE pipes provide great structural strength, while allowing significant chemical resistance to the many constituents found in leachate. PVC pipes are also used in waste

[22] ASTM D-4716, Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plane Flow) of Geotextiles and Geotextile Related Products.

Figure 5

Typical Geonet Configuration



management units, but they are not as chemically resistant as HDPE pipes.

Protective Filter Layer

To protect the drainage layer and perforated leachate collection piping from clogging, you should place a filter layer over the high-permeability drainage layer. To prevent waste material from moving into the drainage layer, the filter layer should consist of a material with smaller pore space than the drainage layer materials or the perforation openings in the collection pipes. Sand and geotextiles are the two most common materials used for filtration. You should select sand that allows adequate flow of liquids, prevents migration of overlying solids or soils into the drainage layer, and minimizes clogging during the service life. In designing the sand filter, you should consider particle size and hydraulic conductivity. The advantages of using sand materials include common usage, traditional design, and durability.

Any evaluation of geotextile materials should address the same concerns but with a few differences. To begin with, the average pore size of the geotextile should be large enough to allow the finer soil particles to pass but small enough to retain larger soil particles. The number of openings in the geotextile should be large enough that, even if some of the openings clog, the remaining openings will be sufficient to pass the design flow rate. In addition to pore size, geotextile filter specifications should include durability requirements. The advantages of geotextile materials include vertical space savings and easy placement. Chapter 5 of *Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities* (U.S. EPA, 1993c) offers guidance on protection of drainage layers.

Leachate Removal System

Leachate removal often involves housing a sump within the leachate collection drainage layer. A sump is a low point in the liner constructed to collect leachate. Modern waste management unit sumps often consist of prefabricated polyethylene structures supported on a steel plate above the liner. Especially with geomembrane liners, the steel plate serves to support the weight of the sump and protect the liner from puncture. Gravel filled earthen depressions can serve as the sump. Reinforced concrete pipe and concrete flooring also can be used in place of the polyethylene structure but are considerably heavier.

To remove leachate that has collected in the sump, you should use a submersible pump. Ideally, the sump should be placed at a depth of 1 to 1.5 m (3 to 5 ft) to allow enough leachate collection to prevent the pump from running dry. You should consider installing a level control, backup pump, and warning system to ensure proper sump operation. Also consider using a backup pump as an alternate to the primary pump and to assist it during high flow periods. A warning system should be used to indicate pump malfunction.

Standpipes, vertical pipes extending through the waste and cover system, offer one method of removing leachate from a sump without puncturing the liner. Alternatively, you can remove leachate from a sump using pipes that are designed to penetrate the liner. When installing pipe penetrations through the liner, you should proceed with extreme caution to prevent any liner damage that could result in uncontained leachate. Both of these options rely on gravity to direct leachate to a leachate collection pond or to an external pumping station.

Minimizing Clogging

Leachate collection and removal systems are susceptible to physical, biological, and chemical clogging. Physical clogging can occur through the migration of finer-grained materials into coarser-grained materials, thus reducing the hydraulic conductivity of the coarser-grained material. Biological clogging can occur through bacterial growth in the system due to the organic and nutrient materials in leachate. Chemical clogging can be caused by chemical precipitates, such as calcium carbonates, causing blockage or cementation of granular drainage material.

Proper selection of drainage and filter materials is essential to minimize clogging in the high-permeability drainage layer. Soil and geotextile filters can be used to minimize physical clogging of both granular drainage material and leachate collection pipes. When placed above granular drainage material, these filters can also double as an operations layer to prevent sharp waste from damaging the liner or leachate collection and removal systems. To minimize chemical and biological clogging for granular drainage material, the best procedure is to keep the interstices of the granular drainage material as open as possible.

The leachate collection pipes are also susceptible to similar clogging. To prevent this, you should incorporate measures into the design to allow for routine pipe cleaning, using either mechanical or hydraulic methods. The cleaning components can include pipes with a 15 cm (6 in) minimum diameter to facilitate cleaning; access located at major pipe intersections or bends to allow for inspections and cleaning; and valves, ports, or other appurtenances to introduce biocides and cleaning solutions. Also, you should check that the design does not include wrapping perforated leachate collection pipes directly with geotextile filters. If the geotextile becomes clogged, it can block flow into the pipe.

B. Leak Detection System

The leak detection system (LDS) is also known as the secondary leachate collection and removal system. It uses the same drainage and collection components as the primary leachate collection and removal system and identifies, collects, and removes any leakage from the primary system. The LDS should be located directly below the primary liner and above the secondary liner.

What are the recommendations for leak detection systems?

The LDS should be designed to assess the adequacy of the primary liner against leachate leakage; it should cover both the bottom and side walls of a waste management unit. The LDS should be designed to collect leakage through the primary layer and transport it to a sump within 24 hours.

The LDS should allow for monitoring and collection of leachate escaping the primary liner system. You should monitor the LDS on a regular basis. If the volume of leachate detected by the LDS appears to be increasing or is significant, you should consider a closer examination to determine possible remediation measures. A good rule of thumb is that if the LDS indicates a seepage level greater than 20 gallons per acre per day, the system might need closer monitoring or remediation.

C. Leachate Treatment System

Once the leachate has been removed from the unit and collected, you should consider taking measures to characterize the leachate in order to ensure proper management. There are several methods of disposal for leachate, and the treatment strategy will vary according to the disposal method chosen. Leachate disposal options include discharging to or pumping and hauling to a publicly owned treatment works or to an onsite treatment system; treating and discharging to the environment; land application; and natural or mechanical evaporation.

When discharging to or pumping and hauling leachate to a publicly owned treatment works, a typical treatment strategy includes pretreatment. Pretreatment could involve equalization, aeration, sedimentation, pH adjustment, or metals removal.[23] If the plan for leachate disposal does not involve a remote treatment facility, pretreatment alone usually is not sufficient.

There are two categories of leachate treatment, biological and physical/chemical. The most common method of biological treatment is activated sludge. Activated sludge is a "suspended-growth process that uses aerobic microorganisms to biodegrade organic contaminants in leachate."[24] Among physical/chemical treatment techniques, the carbon absorption process and reverse osmosis are the two most common methods. Carbon absorption uses carbon to remove dissolved organics from leachate and is very expensive. Reverse osmosis involves feeding leachate into a tubular chamber whose wall acts as a synthetic membrane, allowing water molecules to pass through but not pollutant molecules, thereby separating clean water from waste constituents.

What are the recommendations for leachate treatment systems?

You should review all applicable federal and state regulations and discharge standards to determine which treatment system will ensure long-term compliance and flexibility for the unit. Site-specific factors will also play a fundamental role in determining the proper leachate treatment system. For some facilities, onsite storage and treatment might not be an option due to space constraints. For other facilities, having a nearby, publicly owned treatment works might make pretreatment and discharge to the treatment works an attractive alternative.

VI. Construction Quality Assurance and Quality Control

Even the best unit design will not translate into a structure that is protective of human health and the environment, if the unit is not properly constructed. Manufacturing quality assurance and manufacturing quality control (MQA and MQC) are also important issues for the overall project; however, they are discussed only briefly here since they are primarily the responsibility of a manufacturer. Nonetheless, it is best to select a manufactur-

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[23] Arts, Tom. "Alternative Approaches For Leachate Treatment." *World Wastes*.

[24] Ibid.

er who incorporates appropriate quality assurance and quality control (QA and QC) mechanisms as part of the manufacturing process. The remainder of this section provides a general description of the components of a construction quality assurance and construction quality control (CQA and CQC) program for a project. CQA and CQC are critical factors for waste management units. They are not interchangeable, and the distinction between them should be kept in mind when preparing plans. CQA is third party verification of quality, while CQC consists of in-process measures taken by the contractor or installer to maintain quality. You should establish clear protocols for identifying and addressing issues of concern throughout every stage of construction.

What is manufacturing quality assurance?

The desired characteristics of liner materials should be specified in the unit's contract with the manufacturer. The manufacturer should be responsible for certifying that materials delivered conform to those specifications. MQC implemented to ensure such conformance might take the form of process quality control or computer-aided quality control. If requested, the manufacturer should provide information on the MQC measures used, allow unit personnel or engineers to visit the manufacturing facility, and provide liner samples for testing. It is good practice for the manufacturer to have a dedicated individual in charge of MQC who would work with unit personnel in these areas.

What is construction quality assurance?

CQA is a verification tool employed by the facility manager or regulatory agency, consisting of a planned series of observations and tests designed to ensure that the final product meets project specifications. CQA testing, often referred to as acceptance inspection, provides a measure of the final product quality and its conformance with project plans and specifications. Performing acceptance inspections routinely, as portions of the project become complete, allows early detection and correction of deficiencies, before they become large and costly.

On routine construction projects, CQA is normally the concern of the facility manager and is usually performed by an independent, third-party testing firm. The independence of the testing firm is important, particularly when a facility manager has the capacity to perform the CQA activities. Although the

MQC, MQA, CQC, and CQA

Manufacturing quality control (MQC) is measures taken by the manufacturer to ensure compliance with the material and workmanship specifications of the facility manager.

Manufacturer quality assurance (MQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the manufacturer is in compliance with the specifications of the facility manager.

Construction quality control (CQC) is measures taken by the installer or contractor to ensure compliance with the installation specifications of the facility manager.

Construction quality assurance (CQA) is measures taken by facility personnel, or by an impartial party brought in expressly for the purpose, to determine if the installer or contractor is in compliance with the installation specifications of the facility manager.

facility's in-house CQA personnel might be registered professional engineers, a perception of misrepresentation might arise if CQA is not performed by an independent third party.

The independent party should designate a CQA officer and fully disclose any activities or relationships that the officer has with the facility manager that might impact his or her impartiality or objectivity. If such activities or relationships exist, the CQA officer should describe actions that have been or can be taken to avoid, mitigate, or neutralize the possibility they might affect the CQA officer's objectivity. State regulatory representatives can help evaluate whether these mechanisms are sufficient to ensure acceptable CQA.

What is construction quality control?

CQC is an ongoing process of measuring and controlling the characteristics of the product in order to meet manufacturer's or project specifications. CQC inspections are typically performed by the contractor to provide an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans. Since CQC is a production tool employed by the manufacturer of materials and by the contractor installing the materials at the site, the Guide does not cover CQC in detail. CQC is performed independently of CQA. For example, while a geomembrane liner installer will perform CQC testing of field seams, the CQA program should require independent testing of those same seams by a third-party inspector.

How can implementation of CQA and CQC plans be ensured?

When preparing to design and construct a waste management unit, regardless of design, you should develop CQA and CQC plans customized to the project. To help the project run smoothly, the CQA plan should be easy to follow. You should organize the CQA plan to reflect the sequence of construction and write it in language that will be familiar to an average field technician. For a more detailed discussion of specific CQA and CQC activities recommended for each type of waste management unit, you should consult *Technical Guidance Document: Quality Assurance and Quality Control for Waste Management Containment Facilities* (U.S. EPA, 1993c). This document provides information to develop comprehensive QA plans and to carry out QC procedures at waste management units.

CQA and CQC plans can be implemented through a series of meetings and inspections, which should be documented thoroughly. Communication among all parties involved in design and construction of a waste management unit is essential to ensuring a quality product. You should define responsibility and authority in written QA and QC plans and ensure that each party involved understands its role. Pre-construction meetings are one way to help clarify roles and responsibilities. During construction, meetings can continue to be useful to help resolve misunderstandings and to identify solutions to unanticipated problems that might develop. Some examples of typical meetings during the course of any construction project include pre-bid meetings, resolution meetings, pre-construction meetings, and progress meetings.

A. Compacted Clay Liner Quality Assurance and Quality Control

Although manufacturing quality control and quality assurance are often the responsibility of the materials manufacturer, in the case of soil components, manufacturing and construction quality control testing can be the responsibility of the facility manager. The CQA and CQC plans should specify procedures for quality assurance and quality control during construction of the compacted clay liners.

How can implementation of QA and QC be ensured for a compacted clay liner?

QC testing is typically performed by the contractor on materials used in construction of the liner. This testing examines material properties such as moisture content, soil density, Atterberg limits, grain size, and laboratory hydraulic conductivity. Additional testing of soil moisture content, density, lift thickness, and hydraulic conductivity helps ensure that the waste management unit has been constructed in accordance with the plans and technical specifications.

CQA testing for soil liners includes the same tests described for QC testing in the paragraph above. Generally, the tests are performed less frequently. CQA testing is performed by an individual or an entity independent of the contractor. Activities of the CQA officer are essential to document quality of construction. The responsibilities of the CQA officer and his or her staff might include communicating with the contractor; interpreting and clarifying project drawings and specifications with the designer, facility manager, and contractor; recommending acceptance or rejection by the facility manager of work completed by the construction contractor; and submitting blind samples, such as duplicates and blanks, for analysis by the contractor's testing staff or independent laboratories.

You should also consider constructing a test pad prior to full-scale construction as a CQA tool. As described earlier in the section on compacted clay liners, pilot construction or test fill of a small-scale test pad can be used to verify that the soil, equipment, and construction procedures can produce a liner that performs according to the construction drawings and specifications.

Specific factors to examine or test during construction of a test fill include: preparation and compaction of foundation material to the required bearing strength; methods of controlling uniformity of the soil material; compactive effort, such as type of equipment and number of passes needed to achieve required soil density and hydraulic conductivity; and lift thickness and placement procedures needed to achieve uniformity of density throughout a lift and prevent boundary effects between lifts or between placements in the same lift. Test pads can also provide a means to evaluate the ability of different types of soil to meet hydraulic conductivity requirements in the field. In addition to allowing an opportunity to evaluate material performance, test pads also allow evaluation of the skill and competence of the construction team, including equipment operators and QC specialists.

B. Geomembrane Liner Quality Assurance and Quality Control

As with the construction of soil liners, installation of geomembrane liners should be in conformance with a CQA and CQC plan. The responsibilities of the CQA personnel for the installation of the geomembrane are generally the same as the responsibilities for the construction of a compacted clay liner, with the addition of certain activities including observations of the liner storage area and liners in storage, and handling of the liner as the panels are positioned in the cell. Geomembrane CQA staff should also observe seam preparation, seam overlap, and materials underlying the liner.

How can implementation of QA and QC be ensured for a geomembrane liner?

Prior to installation, you should work with the geomembrane manufacturer to ensure the labeling system for the geomembrane rolls is clear and logical, allowing easy tracking of the placement of the rolls within the unit. It is important to examine the subgrade surface with both the subgrade contractor and the liner installer to ensure it conforms to specifications.

Once liner installation is underway, CQA staff might be responsible for observations of destructive testing conducted on scrap test welds prior to seaming. Geomembrane CQA staff might also be responsible for sending destructive seam sampling to an independent testing laboratory and reviewing the results for conformance to specifications. Other observations for which the CQA staff are typically responsible include observations of all seams and panels for defects due to manufacturing and handling, and placement and observations of all pipe penetrations through a liner.

Test methods, test parameters, and testing frequencies should be specified in the CQA plan to provide context for any data collected. It is prudent to allow for testing frequency to change, based on the performance of the geomembrane installer. If test results indicate poor workmanship, you should increase testing. If test results indicate high quality installation work, you can consider reducing testing frequencies. When varying testing frequency, you should establish well-defined procedures for modifying testing frequency. It is also important to evaluate testing methods, understand the differences among testing methods, and request those methods appropriate for the material and seaming method be used. Nondestructive testing methods are preferrable when possible to help reduce the number of holes cut into the geomembrane.

Geomembrane CQA staff also should document the results of their observations and prepare reports indicating the types of sampling conducted and sampling results, locations of destructive samples, locations of patches, locations of seams constructed, and any problems encountered. In some cases, they might need to prepare drawings of the liner installation. Record drawing preparation is frequently assigned to the contractor, to a representative of the facility manager, or to the engineer. You should request complete reports from any CQA staff and the installers. To ensure complete CQA documentation, it is important to maintain daily CQA reports and prepare weekly summaries.

C. Geosynthetic Clay Liner Quality Assurance and Quality Control

Construction quality assurance for geosynthetic clay liners is still a developing area; the GCL industry is continuing to establish standardized quality assurance and quality control procedures. The CQA recommendation for GCLs can serve as a starting point. You should check with the GCL manufacturer and installer for more specific information.

How can implementation of QA and QC be ensured for a geosynthetic clay liner?

It is recommended that you develop a detailed CQA plan, including product specifications; shipping, handling, and storage procedures; seaming methods; and placement of overlying material. It is important to work with the manufacturer to verify that the product meets specifications. Upon receipt of the GCL product, you should also verify that it has arrived in good condition.

During construction, CQA staff should ensure that seams are overlapped properly and conform to specifications. CQA staff should also check that panels, not deployed within a short period of time, are stored properly. In addition, as overlying material is placed on the GCL, it is important to restrict vehicle traffic directly on the GCL. You should prohibit direct vehicle traffic, with the exception of small, 4-wheel, all terrain vehicles. Even with the small all-terrain vehicles, drivers should take extreme care to avoid movements, such as sudden starts, stops, and turns, which can damage the GCL.

As part of the CQA documentation, it is important to maintain records of weather conditions, subgrade conditions, and GCL panel locations. Also, you should document any repairs that were necessary or other problems identified and addressed.

D. Leachate Collection System Quality Assurance and Quality Control

Leachate collection system CQC should be performed by the contractor. Similar activities should be performed for CQA by an independent party acting on behalf of the facility manager. The purpose of leachate collection system CQA is to document that the system is constructed in accordance with design specifications.

How can implementation of QA and QC be ensured for a leachate collection system?

Prior to construction, CQA staff should inspect all materials to confirm that they meet the construction plans and specifications. These materials include: geonets; geotextiles; pipes; granular material; mechanical, electrical, and monitoring equipment; concrete forms and reinforcements; and prefabricated structures such as sumps and manholes. The leachate collection system foundation, either a geomembrane or compacted clay liner, should also be inspected, upon its completion, to ensure that it has proper grading and is free of debris and liquids.

During construction, CQA staff should observe and document, as appropriate, the placement and installation of pipes, filter layers, drainage layers, geonets and geotextiles, sumps, and mechanical and electrical equipment. For pipes, observations might include descriptions of pipe bedding material, quality and thickness, as well as the total area covered by the bedding material. Observations of pipe installations should focus on the location, configuration, and grading of the pipes, as well as the quality of connections at joints.

For granular filter layers, CQA activities might include observing and documenting material thickness and quality during placement. For granular drainage layers, CQA might focus on the protection of underlying liners, material thickness, proper overlap with filter fabrics and geonets (if applicable), and documentation of any weather conditions that might affect the overall performance of the drainage layer. For geonets and other geosynthetics, CQA observations should focus on the area of coverage and layout pattern, as well as the overlap between panels. For geonets, CQA staff might want to make sure that the materials do not become clogged by granular material that can be carried over, as a result of either wind or runoff during construction.

Upon completion of construction, each component should be inspected to identify any damage that might have occurred during its installation or during construction of another component. For example, a leachate collection pipe can be crushed during placement of a granular drainage layer. Any damage that does occur should be repaired, and the repairs should be documented in the CQA records.

Designing and Installing Liners Activity List

- ❑ Review the recommended location considerations and operating practices for the unit.
- ❑ Select appropriate liner type—single, composite, or double liner—or in-situ soils, based on risk characterization.
- ❑ Evaluate liner material properties and select appropriate clay, geosynthetic, or combination of materials; consider interactions of liner and soil material with waste.
- ❑ Develop a construction quality assurance (CQA) plan defining staff roles and responsibilities and specifying test methods, storage procedures, and construction protocols.
- ❑ Ensure a stable in-situ soil foundation, for nonengineered liners.
- ❑ Prepare and inspect subgrade for engineered liners.
- ❑ Work with manufacturer to ensure protective shipping, handling, and storage of all materials.
- ❑ Construct a test pad for compacted clay liners.
- ❑ Test compacted clay liner material before and during construction.
- ❑ Preprocess clay material to ensure proper water content, remove oversized particles, and add soil amendments, as applicable.
- ❑ Use proper lift thickness and number of equipment passes to achieve adequate compaction.
- ❑ Protect clay material from drying and cracking.
- ❑ Develop test strips and trial seams to evaluate geomembrane seaming method.
- ❑ Verify integrity of factory and field seams for geomembrane materials before and during construction.
- ❑ Backfill with soil or geosynthetics to protect geomembranes and geosynthetic clay liners during construction.
- ❑ Place backfill materials carefully to avoid damaging the underlying materials.
- ❑ Install geosynthetic clay liner with proper overlap.
- ❑ Patch any damage that occurs during geomembrane or geosynthetic clay liner installation.
- ❑ Design leachate collection and removal system to allow adequate flow and to minimize clogging; include leachate treatment and leak detection systems, as appropriate.
- ❑ Document all CQA activities, including meetings, inspections, and repairs.

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Appendix

Geosynthetic Materials[25]

Geotextiles

Geotextiles form one of the two largest group of geosynthetics. Their rise in growth during the past fifteen years has been nothing short of awesome. They are indeed textiles in the traditional sense, but consist of synthetic fibers rather than natural ones such as cotton, wool, or silk. Thus biodegradation is not a problem. These synthetic fibers are made into a flexible, porous fabric by standard weaving machinery or are matted together in a random, or nonwoven, manner. Some are also knit. The major point is that they are porous to water flow across their manufactured plane and also within their plane, but to a widely varying degree. There are at least 80 specific application areas for geotextiles that have been developed; however, the fabric always performs at least one of five discrete functions:

1. Separation
2. Reinforcement
3. Filtration
4. Drainage
5. Moisture barrier (when impregnated)

Geogrids

Geogrids represent a rapidly growing segment within the geosynthetics area. Rather than being a woven, nonwoven or knit textile (or even a textile-like) fabric, geogrids are plastics formed into a very open, gridlike configuration (i.e., they have large apertures). Geogrids are either stretched in one or two directions for improved physical properties or made on weaving machinery by unique methods. By themselves, there are at least 25 application areas, however, they function almost exclusively as reinforcement materials.

Geonets

Geonets, called geospacers by some, constitute another specialized segment within the geosynthetic area. They are usually formed by a continuous extrusion of parallel sets of polymeric ribs at acute angles to one another. When the ribs are opened, relatively large apertures are formed into a netlike configuration. Their design function is completely within the drainage area where they have been used to convey fluids of all types.

Geomembranes

Geomembranes represent the other largest group of geosynthetics and in dollar volume their sales are probably larger than that of geotextiles. Their growth has been stimulated by governmental regulations originally enacted in 1982. The materials themselves are "impervious" thin sheets of rubber or plastic material used primarily for linings and covers of liquid- or solid-storage facilities. Thus the primary function is always as a liquid or vapor barrier. The range of applications, however, is very great, and at least 30 individual applications in civil engineering have been developed.

Geosynthetic Clay Liners

Geosynthetic clay liners (or GCLs) are the newest subset within geosynthetic materials. They are rolls of factory fabricated thin layers of bentonite clay sandwiched between two geotextiles or bonded to a geomembrane. Structural integrity is maintained by needle punching, stitching or physical bonding. They are seeing use as a composite compo-

[25] Created by Geosynthetic Research Institute. Accessed from the Internet on October 16, 2001 at **<www.drexel.edu/gri/gmat.html>**.

nent beneath a geomembrane or by themselves as primary or secondary liners.

Geopipe (aka Buried Plastic Pipe)

Perhaps the original geosynthetic material still available today is buried plastic pipe. This "orphan" of the Civil Engineering curriculum was included due to an awareness that plastic pipe is being used in all aspects of geotechnical, transportation, and environmental engineering with little design and testing awareness. This is felt to be due to a general lack of formalized training. The critical nature of leachate collection pipes coupled with high compressive loads makes geopipe a bona-fide member of the geosynthetics family. The function is clearly drainage.

Geocomposites

A geocomposite consists of a combination of geotextile and geogrid; or geogrid and geomembrane; or geotextile, geogrid, and geomembrane; or any one of these three materials with another material (e.g., deformed plastic sheets, steel cables, or steel anchors). This exciting area brings out the best creative efforts of the engineer, manufacturer, and contractor. The application areas are numerous and growing steadily. The major functions encompass the entire range of functions listed for geosynthetics discussed previously: separation, reinforcement, filtration, drainage, and liquid barrier.

"Geo-Others"

The general area of geosynthetics has exhibited such innovation that many systems defy categorization. For want of a better phrase, geo-others, describes items such as threaded soil masses, polymeric anchors, and encapsulated soil cells. As with geocomposites their primary function is product-dependent and can be any of the five major functions of geosynthetics.

Part IV
Protecting Ground Water

Chapter 7: Section C
Designing A Land Application Program

Contents

Designing A Land Application Program

This chapter will help you:

- *Assess the risks associated with waste constituents when considering application directly to the land as a soil amendment, or for treatment, or disposal.*
- *Account for the designated ground-water constituents identified in Chapter 7, Section A—Assessing Risk, as well as other waste parameters such as soil properties and plant and microbial interactions.*
- *Evaluate the capacity of the soil, vegetation, and microbial life to safely assimilate the waste when developing an application rate.*

Land application can be a beneficial and practical method for treating and disposing of some wastes. Because land application does not rely on liners to contain waste, however, there are some associated risks. With proper planning and design, a land application program can meet waste management and land preservation goals, and avoid negative impacts such as noxious odors, long-term damage to soil, and releases of contaminants to ground water, surface water, or the air. This chapter describes and recommends a framework for addressing a variety of waste parameters, in addition to the constituents outlined in Chapter 7, Section A—Assessing Risk,[1] and other factors such as soil properties and plant and microbial nutrient use[2] that can affect the ability of the land to safely assimilate directly applied waste. Successful land application programs address the interactions among all these factors.

Some of the benefits of land application include:

- **Biodegradation of waste.** If a waste stream contains sufficient organic material, plants and microorganisms can significantly biodegrade the waste, assimilating its organic components into the soil. After allowing sufficient time for assimilation of the waste, more waste can be applied to a given site without significantly increasing the total volume of waste at the site. This is in contrast to landfills and waste piles, in which waste accumulates continually and generally does not biodegrade quickly enough to reduce its volume significantly.
- **Inclusion of liquids.** Land application units can accept bulk, non-containerized liquid waste. The water

[1] The constituents incorporated in IWEM, including the heavy metals and synthetic organic chemicals, typically have little or no agricultural value and can threaten human health and the environment even in small quantities. The term "waste parameters" as used in this section refers to some additional constituents such as nitrogen and biodegradable organic matter and other site-specific properties such as pH, that can have considerable agricultural significance and that can significantly impact human health and the environment.

[2] 40 CFR Part 503 specifies requirements for land application of sludge from municipal sewage treatment plants. The Part 503 regulations apply to sewage sludge (now generally referred to as "biosolids") or mixtures of sewage sludge and industrial process wastes, not to industrial wastes alone. Some of the specifications in Part 503, for example those concerning pathogens, might be helpful in evaluating land application of industrial wastes. For mixtures of sewage sludge and industrial waste, the ground-water and air risk assessments and the framework laid out in the Guide can help address constituents that are not covered under the Part 503 regulations.

content of some liquid wastes make them desirable at land application sites in arid climates. When managing liquid waste, land application can reduce the need for expensive dewatering processes.

- **Improvement of soil.** Applying waste directly to land can improve soil quality if the waste contains appropriate levels of biodegradable organic matter and nutrients. Nutrients can improve the chemical composition of the soil to the extent that it can better support vegetation, while biodegradable organic matter can improve its physical properties and increase its water retention capacity. This potential for chemical and physical improvements through land application have led to its use in conditioning soil for agricultural use.

Figure 1 outlines a framework for evaluating land application. This framework incorporates both the ground-water risk assessment methodology recommended in Chapter 7, Section A–Assessing Risk, as well as the other waste parameters and factors important to land application.

I. Identifying Waste Constituents for Land Application

If a waste leachate contains any of the constituents covered in the IWEM ground-water model, you should first check with a federal, state, or other regulatory agency to see if the waste constituents identified in the waste are covered by any permits, MOUs, or other agreements concerning land application. The Guide does not supersede or modify conditions established in regulatory or other binding mechanisms, such as MOUs or agreements.[3]

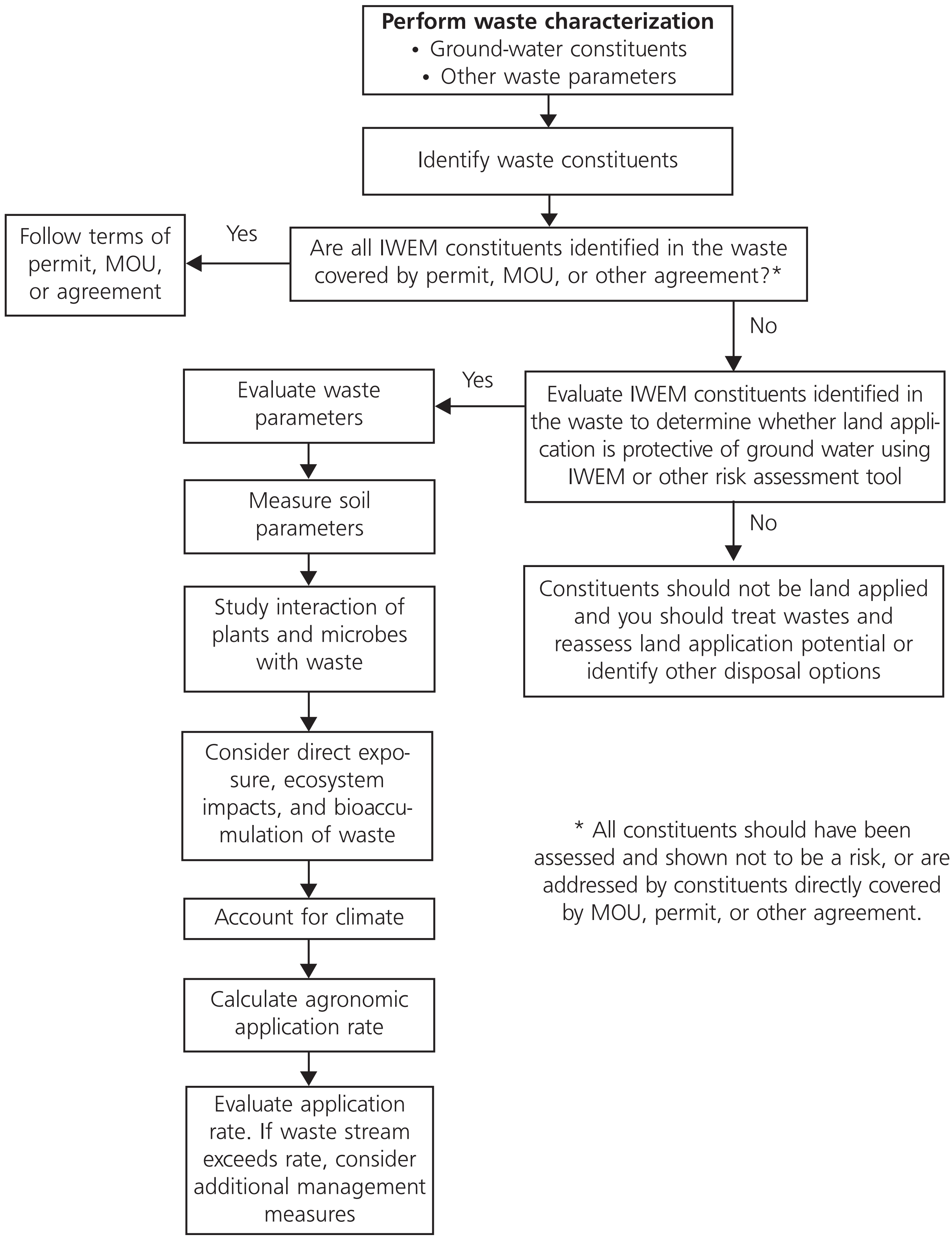
Some wastes might be designated by state or local regulators as essentially equivalent to a manufactured product or raw material. Such designations usually are granted only when use of the designated waste would not present a greater environmental and health risk than would use of the manufactured or raw material it replaces. Equivalence designations are included in the category of "other agreements" above. If there are no designated ground-water constituents other than those on which the designation is based, then the guidelines described in this chapter can help you to determine an appropriate application rate.

If the constituent(s) identified in the waste is not currently covered under an agreement, IWEM or another site-specific model can help you determine whether land application of the constituent(s) will be protective of ground water. In some cases, pollution prevention or treatment can lower constituents levels so that a waste can be land applied. In other cases, land application might not be feasible. In this event, you should pursue other waste management options. If your modeling results indicate that the constituents can be land applied, then the guidelines described in this chapter can once again help you to determine an appropriate application rate.

Your modeling efforts should consider both the direct exposure and ecosystem pathways. These pathways are extremely important in land application since waste is placed on the land and attenuated by the natural environment rather than contained by an engineered structure.

[3] EPA has signed agreements with states, industries, and individual sites concerning land application. One example is EPA's Memorandum of Understanding (MOU) between the American Forest and Paper Association (AFPA) and the U.S. EPA Regarding the Implementation of the Land Application Agreements Among AF&PA Member Pulp and Paper Mills and the U.S. EPA, January 1994. For more information on this MOU contact either AFPA's Director of Industrial Waste Programs at 111 19th Street, N.W., Washington, D.C. 20036 or EPA's Director of the Office of Pollution Prevention and Toxics.

Figure 1. A Recommended Framework for Evaluating Land Application



II. Evaluating Waste Parameters

In addition to the ground-water constituents designated in Chapter 7, Section A–Assessing Risk, you should evaluate the waste's total solids content, pH, biodegradable matter, pathogens, nutrients, metals, carbon to nitrogen ratio, soluble salts, and calcium carbonate equivalent when considering land application. These parameters provide the basis for determining an initial waste application rate and are summarized in Table 1. After the initial evaluation, you should sample and characterize the waste on a regular basis and after process changes that might affect waste characteristics to help determine whether you should change application practices or consider other waste management options.

A. Total Solids Content

Total solids content indicates the ratio of solids to water in a waste. It includes both suspended and dissolved solids, and is usually expressed as a percentage of the waste.

Table 1
Summary of Important Waste Parameters

Waste Parameter	Significance
Total solids content	Indicates ratio of solids to water in waste and influences application method.
pH	Controls metals solubility (and therefore mobility of metals toward ground water) and affects biological processes.
Biodegradable organic matter	Influences soil's water holding capacity, cation exchange, and other physical and chemical properties, including odor.
Nutrients (nitrogen, phosphorus, and potassium)	Affect plant growth; nitrogen is a major determinant of application rate; can contaminate ground water or cause phytotoxicity if applied in excess.
Carbon to nitrogen ratio	Influences availability of nitrogen to plants.
Soluble salts	Can inhibit plant growth, reduce soil permeability, and contaminate ground water.
Calcium carbonate equivalent	Measures a waste's ability to neutralize soil acidity.
Pathogens	Can threaten public health by migrating to ground water or being carried by surface water, wind, or other vectors.
Ground-water constituents designated in Chapter 7, Section A–Risk Assessment including metals and organic chemicals	Can present public health risk through ground-water contamination, direct contact with waste-soil mix, transport by surface water, and accumulation in plants. Metals inhibit plant growth and can be phytotoxic at elevated concentrations. Zinc, copper, and nickel are micronutrients essential to plant growth, but can inhibit growth at high levels.

Total solids content depends on the type of waste, as well as whether the waste has been treated prior to land application. If waste is dried, composted, dewatered, thickened, or conditioned prior to land application, water content is decreased, thereby increasing the total solids content (for some dry, fine, particulate wastes, such as cement kiln dust, conditioning might involve adding water).[4]

Understanding the total solids content will help you develop appropriate storage and handling procedures and establish an application rate. Total solids content also can affect your choice of application method and equipment. Some methods, such as spray irrigation, might not work effectively if the solids content is too high. If it is low, meaning liquid content is correspondingly high, waste transportation costs could increase. If the total solids content of the waste is expected to vary, you can select equipment to accommodate materials with a range of solids content. For example, selecting spreaders that will not clog if the waste is slightly drier than usual will help operations run more efficiently and reduce equipment problems.

B. pH

A waste's pH is a measure of its acidic or alkaline quality. Most grasses and legumes, as well as many shrubs and deciduous trees, grow best in soils with a pH range from 5.5 to 7.5. If a waste is sufficiently acidic or alkaline[5] to move soil pH out of that range, it can hamper plant growth. Acidic waste promotes leaching of metals, because most metals are more soluble under acidic conditions than neutral or alkaline conditions. Once in solution, the metals would be available for plant uptake or could migrate to ground water. Alkaline conditions inhibit movement of most metals. Extreme alkalinity, where pH is greater than 11, impairs growth of most soil microorganisms and can increase the mobility of zinc, cadmium, and lead.

Source: Ag-Chem Equipment Co., Inc.
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Aqueous waste with a pH of 2 or less or a pH of 12.5 or more meets the definition of hazardous waste under federal regulations (40 CFR 261.22(a)). If the pH of a waste makes it too acidic for land application, you can consider adjusting waste pH before application. Lime is often used to raise pH, but other materials are also available. The pH is also important to consider when developing waste handling and storage procedures.

[4] Some states consider composted materials to no longer be wastes. Consult with the regulatory agency for applicable definitions.

[5] A pH of 7 is neutral. Materials with pH less than 7 are acidic, while those with pH greater than 7 are alkaline.

C. Biodegradable Organic Matter

Wastes containing a relatively high percentage of biodegradable organic matter have greater potential as conditioners to improve the physical properties of soil. The percentage of biodegradable organic matter in soil is important to soil fertility, as organic matter can add nutrients; serve as an absorption and retention site for nutrients; and provide chemical compounds, such as chelating agents, that help change nutrients into more plant-available forms. The content of biodegradable organic matter is typically expressed as a percentage of sample dry weight.

Biodegradable organic matter also influences soil characteristics. Soils with high organic matter content often have a darker color (ranging from brown to black), increased cation exchange capacity—capacity to take up and give off positively charged ions—and greater water holding capacity. Biodegradable organic matter also can help stabilize and improve the soil structure, decrease the density of the material, and improve aeration in the soil. In addition, organic nutrients are less likely than inorganic nutrients to leach.

How can biodegradable organic matter affect the waste application rate?

While organic materials provide a significant source of nutrients for plant growth, decomposition rates can vary significantly among materials. Food processing residues, for example, generally decompose faster than denser organic materials, such as wood chips. It is important to account for the decomposition rate when determining the volume, rate and frequency of waste application. Loading the soil with too much decomposing organic matter (such as by applying new waste before a previous application of slowly decomposing waste has broken down) can induce nitrogen deficiency (see section D. below) or lead to anaerobic conditions.

D. Nutrients

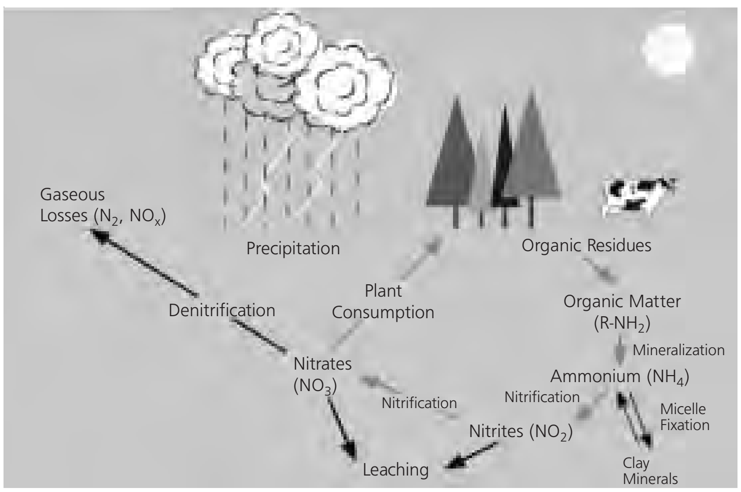
Nitrogen, phosphorus, and potassium are often referred to as primary or macro-nutrients and plants use them in large amounts. Plants use secondary nutrients, including sulfur, magnesium, and calcium, in intermediate quantities. They use micronutrients, including iron, manganese, boron, chlorine, zinc, copper, and molybdenum, in very small quantities. Land application is often used to increase the supply of these nutrients, especially the primary nutrients, in an effort to improve plant growth.

Nutrient levels are key determinants of application rates. Excessive soil nutrient levels, caused by high waste application rates, can be phytotoxic or result in contamination of ground water, soil, and surface water. Nutrient loading is dependent on nutrient levels in both the waste and the soil, making characterization of the soil, as well as of the waste, important.

Nitrogen. Nitrogen content is often the primary factor determining whether a waste is agriculturally suitable for land application, and, if so, at what rate to apply it. Nitrogen deficiency is detrimental to the most basic plant processes, as nitrogen is an essential element for photosynthesis. Sufficient nitrogen promotes healthy growth and imparts a dark green color in vegetation. Lack of nitrogen can be identified by stunted plant growth and pale green or yellowish colored vegetation. Extreme nitrogen deficiency can cause plants to turn brown and die. On the other extreme, excessive nitrogen levels can result in nitrate leaching, which can contaminate ground-water supplies.

Although nitrate poses the greatest threat to ground water, nitrogen occurs in a variety of forms including ammonium, nitrate, nitrite, and organic nitrogen. These forms taken together are measured as total nitrogen. You should account for the ever-occurring nitrogen transformations that take place in the soil before and after waste is applied. These transformations are commonly described as the nitrogen cycle and are illustrated below in Figure 2.

Figure 2. The Nitrogen Cycle



Phosphorus. Phosphorus plays a role in the metabolic processes and reproduction of plants. When soil contains sufficient quantities of phosphorus, root growth and plant maturation improve. Conversely, phosphorus-deficient soils can cause stunted plant growth. Excessive phosphorus can lead to inefficient use of other nutrients and, at extreme levels, zinc deficiency. High phosphorus usage on crops and its associated runoff into surface water bodies has increased the biological productivity of surface waters by accelerating eutrophication, which is the natural aging of lakes or streams brought on by nutrient enrichment.[6] Eutrophication has been identified as the main cause of impaired surface water quality in the United States.

Potassium. Potassium is an essential nutrient for protein synthesis and plays an important role in plant hardiness and disease tolerance. In its ionic form (K^+), potassium helps to regulate the hydration of plants. It also works in the ion transport system across cell membranes and activates many plant enzymes. Like other nutrients, symptoms of deficiencies include yellowing, burnt or dying leaves, as well as stunted plant growth. Symptoms of potassium deficiency also, in certain plants, can include reduced disease resistance and winter hardiness.

How can I take nutrient levels into account?

You should develop a nutrient management plan that accounts for the amount of nitrogen, phosphorus, and potassium being supplied by all sources at a site. The U.S. Department of Agriculture, Natural Resources Conservation Service has developed a conservation practice standard "Nutrient Management" Code 590 that can be used as the basis for your nutrient management plan. The purpose of this standard is to budget and supply nutrients for plant production, to properly utilize manure or organic by-products as a plant nutrient source, to minimize agricultural nonpoint source pollution of surface and ground-water resources, and to maintain or improve the physical, chemical, and biological condition of the soil. Updated versions of this standard can be obtained from the Internet at **<www.nrcs.usda.gov/technical/ECS/nutrient/documents.html>**.

Nitrogen is generally the most limiting nutrient in crop production systems and is added to the soil environment in the greatest

6 U.S. Department of Agriculture, Agricultural Research Service. *Agricultural Phosphorus and Eutrophication*, 1999. Washington, DC.

amount of any of the plant nutrients. If, however, waste application rates are based solely on nitrogen levels, resulting levels of other nutrients such as phosphorus and potassium can exceed crop needs or threaten ground water or surface water bodies. You should avoid excessive nutrient levels by monitoring waste concentrations and soil buildup of nutrients and reducing the application rate as necessary, or by spacing applications to allow plant uptake between applications. Your local, state, or regional agricultural extension service might have already developed materials on or identified software for nutrient management planning. Consult with them about the availability of such information. Northeast Regional Agricultural Engineering Services (NRAES) Cooperative Extension, for example, has compiled information on nutrient management software programs.[7]

E. Metals

A number of metals are included in IWEM for evaluating ground-water risk. Some metals, such as zinc, copper, and manganese, are essential soil micronutrients for plant growth. These are often added to inorganic commercial fertilizers. At excessive concentrations, however, some of these metals can be toxic to humans, animals, and plants. High concentrations of copper, nickel, and zinc, for example, can cause phytotoxicity or inhibit plant growth. Also, the uptake and accumulation of metals in plants depends on a variety of plant and soil factors, including pH, biodegradable organic matter content, and cation exchange capacity. Therefore, it is important to evaluate levels of these metals in waste, soil, and plants from the standpoint of agricultural significance as well as health and environmental risk.

How can I determine acceptable metal concentrations?

The Tier I and II ground-water models can help you identify acceptable metals concentrations for land application. Also it is important to consult with your local, state, or regional agriculture extension center on appropriate nutrient concentrations for plant growth. If the risk evaluation indicates that a waste is appropriate for land application, but subsequent soil or plant tissue testing finds excessive levels of metals, you can consider pretreating the waste with a physical or chemical process, such as chemical precipitation to remove some metals before application.

F. Carbon-to-Nitrogen Ratio

The carbon-to-nitrogen ratio refers to the relative quantities of these two elements in a waste or soil. Carbon is associated with organic matter, and the carbon-to-nitrogen ratio reflects the level of inorganic nitrogen available. Plants cannot use organic nitrogen, but they can absorb inorganic nitrogen such as ammonium. For many wastes, the carbon-to-nitrogen ratio is computed as the dry weight content of organic carbon divided by the total nitrogen content of waste.

Some wastes rich in organic materials (carbon) can actually induce nitrogen deficiencies. This occurs when wastes provide carbon in quantities that microbes cannot process without depleting available nitrogen. Soil microbes use carbon to build cells and nitrogen to synthesize proteins. Any excess organic nitrogen is then converted to inorganic nitrogen, which plants can use. The carbon-to-nitrogen ratio tells whether excess organic nitrogen will be available for this conversion.

When the carbon-to-nitrogen ratio is less than 20 to 1—indicating a high nitrogen content—organic nitrogen is mineralized, or con-

[7] Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop. To order, call NRAES at 607 255-7654 and request publication number NRAES-100.

verted from organic nitrogen to inorganic ammonium, and becomes available for plant growth. For maximal plant growth, the literature recommends maintaining a ratio below 20 to 1. When the carbon-to-nitrogen ratio is in the range of 20 to 1 to 30 to 1—a low nitrogen content—soil micro-organisms use much of the organic nitrogen to synthesize proteins, leaving only small excess amounts to be mineralized. This phenomenon, known as immobilization, leaves little inorganic nitrogen available for plant uptake. When the carbon-to-nitrogen ratio is greater than 30 to 1, immobilization is the dominant process, causing stunted plant growth. The period of immobilization, also known as nitrogen or nitrate depression, will vary in length depending on the decay rate of the organic matter in the waste. As a result, plant growth within that range might not be stunted, but is not likely to be maximized.

How can I manage changing carbon-to-nitrogen ratios?

The cycle of nitrogen conversions within the soil is a complex, continually changing process (see Figure 2). As a result, if applying waste based only on assumed nitrogen mineralization rates, it is often difficult to ensure that the soil contains sufficient inorganic nitrogen for plants at appropriate times. If you are concerned about reductions in crop yield, you should monitor the soil's carbon-to-nitrogen ratio and, when it exceeds 20 to 1, reduce organic waste application and/or supplement the naturally mineralized nitrogen with an inorganic nitrogen fertilizer, such as ammonium nitrate. Methods to measure soil carbon include EPA Method 9060 in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846*. Nitrogen content can be measured with simple laboratory titrations.

G. Soluble Salts

The term soluble salts refers to the inorganic soil constituents (ions) that are dissolved in the soil water. Major soluble salt ions include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), and nitrate (NO_3^{-}). Total dissolved solids (TDS) refers to the total amount of all minerals, organic matter, and nutrients that are dissolved in water. The soluble salt content of a material can be determined by analyzing the concentration of the individual constituent ions and summing them, but this is a lengthy procedure. TDS of soil or waste can reasonably be estimated by measuring the electrical conductivity (EC) of a mixture of the material and water. EC can be measured directly on liquid samples. TDS is found by multiplying the electrical conductivity reading in millimhos/cm (mmhos/cm) by 700 to give TDS in parts per million (ppm) or mg/l.

Soluble salts are important for several reasons. First, saline soil, or soil with excessive salt concentrations, can reduce plant growth and seed germination. As salt concentration in soil increases, osmotic pressure effects make it increasingly difficult for plant roots to extract water from the soil. Through a certain range, this will result in reduced crop yield, up to a maximum beyond which crops will be unable to grow. The range and maximum for a few representative crops are shown in Table 2. For this reason, the salt content of the waste, rather than its nitrogen content, can be the primary determinant of its agricultural suitability for land application, especially on irrigated soils in arid regions.

The second reason soluble salts are important is that sodic soil, or soil with excessive levels of sodium ions (Na^{+}) relative to divalent ions (Ca^{2+}, Mg^{2+}), can alter soil structure and reduce soil permeability. The sodium absorption rate (SAR) of a waste is an indicator of its sodicity. To calculate the SAR of a

Table 2:
Salinity Tolerance of Selected Crops

Crop	Soil Salinity (mmhos/cm)[a] that will result in:		
	0% yield reduction[b]	50% yield reduction[b]	100% yield reduction[b]
Alfalfa	2.0	8.8	16
Bermuda grass	6.9	14.7	23
Clover	1.5	10.3	19
Perennial rye	5.6	12.1	19
Tall fescue	3.9	13.3	32

Source: Borrelli, J. and D. Brosz. 1986. Effects of Soil Salinity on Crop Yields.

[a] A rule of thumb from the irrigation industry holds that soil salinity will be 1½ times the salinity of applied irrigation water. The effect that waste salinity will have on soil salinity, however, is not as easily predicted and depends on the waste's water content and other properties and on the application rate.

[b] Reductions are stated as a percentage of maximum expected yield.

waste or soil, determine the Na^+, Ca^{2+}, and Mg^{2+} concentrations in milliequivalents per liter[8] for use in the following equation:[9]

$$SAR = \frac{Na^+}{\sqrt{\tfrac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Soils characterized by both high salts (excessive TDS as indicated by EC) and excessive sodium ions (excessive Na^+ as indicated by SAR) are called saline-sodic soils, and can be expected to have the negative characteristics of both saline soils and sodic soils described above. Table 3 displays EC and SAR levels indicative of saline, sodic, and saline-sodic soils.

The third reason soluble salts are important is that specific ions can induce plant toxicities or contaminate ground water. Sodium and chloride ions, for example, can become phytotoxic at high concentrations. To assess sodic- or toxic-inducing characteristics, you should conduct an analysis of specific ions in addition to measuring EC.

What can I do if a waste is either saline or sodic?

Saline waste. If a waste is saline, careful attention to soil texture, plant selection, and application rate and timing can help. Coarse soils often have a lower clay content and are less subject to sodium-induced soil structure

[8] The term milliequivalents per liter (meq/l) expresses the concentration of a dissolved substance in terms of its combining weight. Milliequivalents are calculated for elemental ions such as Na^+, Ca^{2+}, and Mg^{2+} by multiplying the concentration in mg/l by the valence number (1 for Na^+, 2 for Ca^2+ or Mg^{2+}) and dividing by the atomic weight (22.99 for Na^+, 40.08 for Ca^{2+}, or 24.31 for Mg^{2+}).

[9] If the proper equipment to measure these concentrations is not available, consider sending soil and waste samples to a soil testing laboratory, such as that of the local extension service (visit **<www.reeusda.gov/statepartners/usa.htm>** for contact information) or nearby university. Such a laboratory will be able to perform the necessary tests and calculate the SAR.

Table 3
EC and SAR Levels Indicative of Saline, Sodic, and Saline-Sodic Soils

Soil Characterization			
Normal	**Saline**	**Sodic**	**Saline-Sodic**
EC[a] < 4 and SAR[b] < 13	EC > 4	SAR> 13	EC > 4 and SAR > 13

Source: Fipps, G. Managing Irrigation Water Salinity In the Lower Rio Grande Valley.
[a]In units of mmhos/cm [b]dimensionless

problems. While coarse soils help minimize soil structural problems associated with salinity, they also have higher infiltration and permeability rates, which allow for more rapid percolation or flushing of the root zone. This can increase the risk of waste constituents being transported to ground water.

Since plants vary in their tolerance to saline environments, plant selection also is important. Some plant species, such as rye grass, canary grass, and bromegrass, are only moderately tolerant and exhibit decreased growth and yields as salinity increases. Other plants, such as barley and bermuda grass, are more saline-tolerant species.

You should avoid applying high salt content waste as much as possible. For saline wastes, a lower application rate, and thorough tilling or plowing can help dilute the overall salt content of the waste by mixing it with a greater soil volume. To avoid the inhibited germination associated with saline soils, it also can help to time applications of high-salt wastes well in advance of seedings.

Sodic waste. SAR alone will not tell how sodium in a waste will affect soil permeability; it is important to investigate the EC of a waste as well. Even if a waste has a high SAR, plants might be able to tolerate this level if the waste also has an elevated EC. As with saline waste, for sodic waste select a coarser-textured soil to help address sodium concerns. Adding gypsum ($CaSO_4$) to irrigation water can also help to reduce the SAR, by increasing soil calcium levels. Although this might help address sodium-induced soil structure problems, if choosing to add constituents to alter the SAR, the EC should also be monitored to ensure salinity levels are not increased too much.

H. Calcium Carbonate Equivalent

Calcium carbonate equivalent (CCE) is used to measure a waste's ability to neutralize soil acidity—its buffering capacity—as compared with pure calcium carbonate. Buffering capacity refers to how much the pH changes when a strong acid or base is added to a solution. A highly buffered solution will show only a slight change in pH when strong acids or bases are added. Conversely, if a solution has a low buffering capacity, its pH will change rapidly when a base or acid is added to it. If a waste has a 50 percent CCE, it would need to be applied at twice the rate of pure calcium carbonate to achieve the same buffering effect.

I. Pathogens

Potential disease-causing microorganisms or pathogens, such as bacteria, viruses, protozoa, and the eggs of parasitic worms, might be present in certain wastes. Standardized testing procedures are available to help determine whether a waste contains pathogens. You should consider using such tests especially if your process knowledge indicates that a waste might contain pathogens. Fecal coliform bacteria can be quantified, for example, by using a membrane filtering technique, which involves passing liquid waste through a filter, incubating the filtrate (which contains the bacteria) on a culture medium for 24 hours, and then counting the number of bacterial colonies formed.

How can I reduce pathogenic risks?

Methods to reduce pathogenic risk include disinfecting or stabilizing a waste prior to land application. Examples of treatment methods recognized for sewage sludge stabilization are included in the sidebar. Pathogens present a public health hazard if they are transferred to food or feed crops, contained in runoff to surface waters, or transported away from a land application site by vectors. If pathogen-carrying vectors are a concern at a site, it is important to establish measures to control them. For examples of methods to control vectors, refer to Chapter 8–Operating the Waste Management System. Additional information on pathogen reduction and methods to control vectors can be obtained from 40 CFR 503.15 and 40 CFR 503.32 (EPA's Sewage Sludge Rule.) A discussion of these alternatives is available in EPA's guidance document *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503* (U.S. EPA, 1994a).

The services of a qualified engineer might be necessary to design an appropriate process for reducing pathogens in a waste. You should consult with the state to determine whether there are any state-specific requirements for pathogen reductions for specific waste types.

What are methods for stabilizing waste prior to land application?

The following methods, recommended for stabilizing sewage sludge, can also be useful for reducing pathogens in waste:

- Aerobic digestion
- Air drying
- Anaerobic digestion
- Composting
- Lime stabilization

More detailed information on each of these and other methods can be found in EPA's *Control of Pathogens and Vector Attraction in Sewage Sludge* (U.S. EPA, 1992).

III. Measuring Soil Properties

Physical, biological, and chemical characteristics of the soil are key factors in determining its capacity for waste attenuation. If the soil is overloaded, rapid oxygen depletion, extended anaerobic conditions, and the accumulation of odorous and phytotoxic end-products can impair soil productivity and negatively impact adjacent properties. With proper design and operation, waste can be successfully applied to almost any soil; however, sites with highly permeable soil (e.g., sand), highly impermeable soil (e.g., clay), poorly drained soils, or steep slopes can present special design issues. Therefore, it is advisable to give such sites lower priority during the site selection process.

How can I evaluate the soil at a site?

To help evaluate the soil properties of a site, you should consult the U.S. Department of Agriculture (USDA) soil survey for the prospective area. These surveys provide information on properties such as soil type and permeability. USDA has prepared soil surveys for most counties in each state. To obtain a copy of the survey for an area, contact the Natural Resource Conservation Service offices, the county conservation district, the state agricultural cooperative extension service, or local health authorities/planning agency. These soils surveys will help during site selection; however, conditions they describe can differ from the actual soil conditions.

Several guidance documents on soil surveys are also available from USDA. These documents include the *National Soil Survey Handbook* and the guide *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. The *National Soil Survey Handbook* provides an abundance of information including help on interpreting soil surveys, a primer on soil properties and soil quality, and guides for predicting the permeability of your soil. Both of these documents are available over the Internet and can be obtained from **<www.ftw.nrcs.usda.gov/tech_ref.html>**.

For more site-specific data on actual soil conditions, you can sample and characterize the soil. It might be desirable to have a qualified soil scientist perform this characterization, which often includes soil texture, percentage of organic matter, depth to water table, soil pH, and cation exchange capacity. At a minimum, you should characterize samples from an upper soil layer, 0 to 6 inches, and a deeper soil layer, 18 to 30 inches, and follow established soil sampling procedures to obtain meaningful results. If a detailed characterization is desired, or if it is suspected soil types vary considerably, further subdivision of soil horizons or collection of samples over a greater variety of depths might be appropriate. For more information about how to obtain representative soil samples and to submit them for analysis, you can consult EPA's *Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs* (U.S. EPA, 1995d), or state guides, such as Nebraska's *Guidelines for Soil Sampling*, G91-1000.

Why are chemical and biological properties of soil important?

Chemical and biological properties of the soil, like those of the waste, influence the attenuation of waste constituents. These properties include pH, percentage of organic matter, and cation exchange capacity. Affected attenuation processes in the soil include absorption, adsorption, microbial degradation, biological uptake, and chemical precipitation. For example, adsorption—the process by which molecules adhere to the surface of other particles, such as clay—increases as the cation exchange capacity and pH of the soil increase. Cation exchange capacity, in turn, is dependent on soil composition, increasing as the clay content of the soil increases. Adsorption through cation exchange is an important means of immobilizing metals in the soil. Organic chemicals, on the other hand, are negatively charged and can be adsorbed through anion exchange, or the exchange of negative ions. A soil's capacity for anion exchange increases as its pH decreases.

Why are physical properties of soil important?

Physical properties of the soil such as texture, structure, and pore-size distribution affect infiltration rates and the ability of soil to filter or entrap waste constituents. Infiltration and permeability rates decrease as clay content increases. Sites with soils with permeabilities that are too high or too low have lower land application potential. Soils with high permeability can allow wastes to move through without adequate attenuation. Soils with low permeability can cause pooling or excessive surface runoff during intense rainstorms. Excessive runoff conditions can be compensated for somewhat by minimizing surface slope during site selection. Soils with low permeability are also prone to hydraulic overloading.

The amount of liquid that can be assimilated by a soil system is referred to as its hydraulic loading capacity. In addition to a soil's permeability, hydraulic loading capacity is dependent on other factors such as climate, vegetation, site characteristics, and other site-specific soil properties such as soil type, depth to seasonally high water table, slope and erodibility, water intake rate, and underlying geology and hydrogeology. Exceeding the hydraulic loading capacity of a site, can lead to rapid leaching of waste constituents into ground water, reduction in biological activity, sustained anaerobic conditions, soil erosion, and possible contamination of surface waters. It can also result in excessive evaporation, which can cause excessive odor and unwanted airborne emissions. In order to avoid hydraulic overloading at a site, application of liquid or semi-liquid waste or wastewater should be managed so uncontrolled runoff or prolonged saturation of the soil does not occur.

An important indicator of soil properties is its topography, which affects the potential for soil erosion and contaminated surface-water runoff. Soils on ridge tops and steep slopes are typically well drained, well aerated, and shallow. Steep slopes, however, increase the likelihood of surface runoff of waste and of soil erosion into surface waters. State guidelines, therefore, often specify the maximum slopes allowable for land application sites for various waste characteristics, application techniques, and application rates. The agencies that regulate land application in a state can provide specific guidance concerning slopes. Soils on concave land and broad flat lands, on the other hand, frequently are poorly drained and can be waterlogged during part of the year. Soils in relatively flat areas can have intermediate properties with respect to drainage and runoff and could be more suitable for land application.

IV. Studying the Interaction of Plants and Microbes with Waste

The next step in the design of a land application unit is to consider the plants and microbes at the site and how they will interact with the waste. This interaction includes the uptake and degradation of waste constituents, the effects of the wastes on plant and microbial growth, and changes that can occur in plants or crops affecting their use as food or feed. The uptake of nutrients by plants and microbes on plant roots or in soil affects the rate of waste assimilation and biodegradation, usually increasing it.

It might be necessary to conduct greenhouse or field studies or other tests of plants, soil, and microbes to understand and quantify these interactions. You should consult with the state agricultural department, the local health department, and other appropriate agencies if considering land application of wastes containing designated ground-water constituents or other properties that are potentially harmful to food or feed crops. Industry groups might also be able to provide information about plants with which they have land application experience.

A. Greenhouse and Field Studies

State agricultural extension services, departments of environmental protection, or public universities might have previous studies about plant uptake of nutrients, especially nitrogen, phosphorus, and potassium, but it is important to recognize that the results of studies conducted under different conditions (such as different waste type, application rate, plant type, or climate) are only partially relevant to a specific situation. Furthermore, most studies to date have focused on relatively few plant species, such as corn, and only a handful of constituents, typically metals. Greenhouse studies or pilot-scale field studies attempt to model site-specific conditions by growing the intended crops in soil from the prospective application site. These studies are useful because individual parameters can be varied, such as plant type and waste application rate, to determine the effects of each factor. Additionally, greenhouse or field studies might be required by some states to certify that a waste has agricultural benefits. Generally, the first point of contact for assistance with studies is the state agricultural extension service. Many state extensions can conduct these studies; others might be able to provide guidance or expertise but will recommend engaging a private consultant to conduct the studies.

How do I conduct greenhouse or field studies?

Currently, no national guidelines exist for conducting greenhouse or field studies,[10] but check to see if the state has guidance on accepted practices. Working with a state agricultural extension service or a local university will provide the benefit of their expertise and experience with local conditions, such as which plants are suitable for local soils and climate. If a particular industry sector has a large presence in a state, the state agricultural extension service might have previous experience with that specific type of waste.

Greenhouse studies. Aside from their smaller scale, greenhouse studies differ from field studies primarily in that they are conducted indoors under controlled conditions, while field studies are conducted under natural environmental conditions. A greenhouse study typically involves distributing representative soil samples from the site into several pots to test different application rates, application methods, and crops. Using several duplicate pots for each rate, method, or crop allows averaging and statistical aggregating of results. It is also important to establish control pots, some with no waste and no plants, others with waste but no plants (to observe the extent to which waste assimilation effects are due to soil and pre-existing microbes) and still others with plants but without waste (as a baseline for comparison with waste-amended plant growth).

To the extent feasible, temperature, moisture, and other parameters should simulate actual site conditions. There should be a series of several duplicate pots grown with each combination of plant type, application rate, and other parameters. Pots should be arranged to avoid environmental conditions disproportionately affecting one series of pots. For example, you should avoid placing a whole series of pots in a row closest to a light source; instead, it is better to place one pot from each of several series in that row or randomize placement of pots.

The controlled greenhouse environment allows the study of a wide range of waste-soil

[10] Based on conversations with Dr. Rufus L. Chaney and Patricia Milner, U.S. Department of Agriculture.

interactions without risking the loss of plants due to weather, animal hazards, and other environmental influences. At the same time, this can introduce differences from actual conditions. Root confinement, elevated soil temperature, and rapidly changing moisture levels, for example, can increase the uptake of pollutants by potted plants compared to uptake under field conditions.[11]

Field studies. Field studies, on the other hand, can test application rates and crops on plots at the actual proposed site. As with greenhouse studies, duplicate plots are useful for statistical purposes, and controls are needed. Field study data can be more useful because it more closely reflects real-world conditions, but it also can be more difficult to obtain because of uncontrollable circumstances such as flooding or unusual pest damage that can occur at the time of the study. Field studies also can be subject to siting, health and safety, and permitting requirements.

Field studies also help determine the actual land area required for land application and the quality of runoff generated. Soil and ground-water monitoring help to confirm that waste constituents are being taken up by plants and not leaching into the ground water. Results from field studies, however, might not be duplicated on actual working plots after multiple waste applications, due to long-term soil changes. Crop yields also can vary by as much as 15 to 25 percent under field conditions, even with good fertility and management.

Both greenhouse and field studies typically include extensive sampling of waste, soil before application, plants or representative parts of plants, soil after application, growth of plants, and, to the extent feasible, water. You should sample soil at the surface and in lower horizons using core sampling. Some soil tests require mixing samples with water to form a paste or slurry. Plant tissue tests often require dry-weight samples, made by drying cut plants at about 65°C. Water can be collected in lysimeters (buried chambers made from wide perforated pipe) and removed using hand pumps.

The effects of waste on organisms in the soil can also be monitored during greenhouse and field studies. The literature suggests, that the effects of waste on earthworms are a good indicator of effects on soil organisms in general. It might be worthwhile, therefore, to stock greenhouse pots or field study plots with earthworms at the beginning of a study and monitor the waste constituent levels and the effects on the worms during and at the end of the study. Although these brief studies will not effectively model long-term exposure to waste constituents, it is possible to gauge short-term and acute effects.

B. Assessing Plant and Microbial Uptake Rates

Plants. After performing studies, you should measure the amounts of various nutrients, metals, and other constituents in tissue samples from plants grown in the greenhouses or on test plots. This tells approximately how much of these constituents the plants extracted from the soil-waste mix. By measuring plant-extracted quantities under these various conditions, you can determine a relationship between

[11] If a waste contains VOCs, ensure the possibility of VOCs accumulating within the enclosed greenhouse is addressed.

plant type, application rate, and nutrient extraction. From this, you can choose the conditions which result in the desired uptake rate while avoiding uptake of designated ground-water constituents at undesirable concentrations. Plant uptake is often measured as a ratio of the pollutant load found in the plants to the pollutant load applied to the land as illustrated below:

$$\frac{\mu g \text{ pollutant}}{g \text{ dry plant tissue}} \text{ per } \frac{kg \text{ pollutant}}{\text{hectare}}$$

This ratio serves to place pollutant uptake in the context of the original amount of pollutant applied.

In choosing plants for a land application unit, you should also consider growing seasons in relation to periods of waste application rate. Specific waste application rates associated with corresponding uptakes of nutrients by plants, as indicated in greenhouse or field studies, are applicable only during the growing phases covered by the study. At other times, waste application might be infeasible because plants are not present to help assimilate waste, or because plants are too large to permit passage of application equipment without sustaining damage.

Microbes. Certain microbes can biodegrade organic chemicals and other waste constituents. Some accomplish this by directly using the constituents as a source of carbon and energy, while others co-metabolize constituents in the process of using other compounds as an energy source. Aerobic microorganisms require oxygen to metabolize waste and produce carbon dioxide and water as end products. Anaerobic microbes function without oxygen but produce methane and hydrogen sulfide as end products. These gases can present a safety risk as well as environmental threats, and hydrogen sulfide is malodorous. For these reasons, it is recommended that you maintain conditions that favor aerobic microbes.

For many microorganisms, these conditions include a pH of 6 to 8 and temperatures of 10°C to 30°C. In addition, microbes might be unable to transfer oxygen from soil efficiently if the moisture content is near saturation, or they might be unable to obtain sufficient water if the soil is too dry. A water content of 25 to 85 percent of the soil's water holding capacity is recommended in the literature. Oxygen generally is available through diffusion from the atmosphere, but this mechanism might provide insufficient oxygen if there is too little pore space (less than 10 percent of soil volume) or if so much organic matter is applied that oxygen is consumed faster than it is replaced.

C. Effects of Waste on Plant and Microbe Growth

Greenhouse and field studies can tell what effect the waste will have on plant growth patterns. A typical method of quantifying plant growth is to state it in terms of biomass production, which is the dry weight of the cut plants (or representative parts of the plants). If the plants grown with waste applications show greater mass than the control plants,[12] the waste might be providing useful nutrients or otherwise improving the soil. If the plants grown with waste applied at a certain rate

[12] Trends detected in studies assume that results have been subjected to tests of statistical validity before finding a trend significant.

weigh less than the controls, some constituent(s) in the waste might be excessive at the studied application rate. Comparing the results from several different application rates can help find the rate that maximizes growth and avoids detrimental and phytotoxic effects.

Analyzing soil and water after plant growth allows for a comparison between the planted pots or plots against the control to discern the differences due to plant action. If water samples show excessive nutrient (especially nitrogen) levels at a certain application rate, this might indicate that the plants were unable to use all the nutrients in the waste applied at that rate, suggesting that the application was excessive. If soil and water tests show that constituents are consumed, and if other possible causes can be ruled out, microbes might be responsible. Further investigation of microbial action might involve sampling of microbes in soil, counting their population, and direct measurement of waste constituents and degradation byproducts.

D. Grazing and Harvesting Restrictions

If a waste might contain pathogens or designated ground-water constituents, and the established vegetative cover on the land application site is intended for animal consumption, it is important to take precautions to minimize exposure of animals to these contaminants. This is important because animals can transport pathogens and ground-water constituents from one site to another, and can be a point of entry for waste constituents and pathogens into the food chain.

If harvesting crops from a unit for use as animal fodder, you should test plants for the presence of undesirable levels of the designated ground-water constituents before feeding. Grazing animals directly on a unit is discouraged by some states.[13] If considering direct grazing, you should consult with the state to see if there are any restrictions on this practice. Growing crops for human consumption on soil amended with waste calls for even greater caution. In some states, this practice is prohibited or regulated, and in states where it is allowed, finding food processors or distributors willing to purchase such crops can be difficult.

When testing crops before feeding them to animals, local agricultural extension services might be able to help determine what levels are appropriate for animal consumption. If plant tissue samples or findings of a fate and transport model indicate waste constituent levels inappropriate for animal consumption, it is important that you not use harvested plants as fodder or allow grazing on the site. Additionally, plants with high constituent levels will probably be inappropriate for other agricultural use, and thus would likely necessitate disposal of such crops as a waste after harvest.

V. Considering Direct Exposure, Ecosystem Impacts, & Bioaccumulation of Waste

You should evaluate the impacts that your land application unit will have on direct exposure and ecological pathways as well as the potential for bioaccumulation of land-applied waste. During the land application unit's active life, direct human exposure to waste or waste-amended soil is primarily a risk to personnel involved in the operation. You should follow OSHA standards and ensure that personnel are properly trained and use proper protective clothing and equip-

[13] Grazing can also be unwise due to potential effects on soil physical structure. The weight of heavy animals can compact soil, decreasing pore space, which can reduce the soil's waste attenuation capacity.

ment when working onsite. You should limit direct exposure to others through steps such as access control and vehicle washing to prevent tracking waste and waste amended soil off site.

Access control will also limit exposure of some animals. If crops will be used for animal fodder or grazing, you should test harvested fodder for the designated ground-water constituents before use and restrict grazing times. After a site is closed, there might be long-term access risks to future land uses and the general public. To minimize these risks, long-term access controls or deed restrictions might be appropriate. Consult Chapter 11—Performing Closure and Post-Closure Care for further information.

Direct exposure of native animals is often impossible to control and might be an entry point for the ground-water constituents into the food chain. Worms, for example, might be present in the soil and take in these constituents. Birds or other animals could then consume the worms, bioaccumulate, or be transported off site. Furthermore, animals can ingest plants grown on waste-amended soil. Therefore, you should also consider pathways such as these in evaluating your plans for land application.

VI. Accounting for Climate

Local climate considerations should also enter into your land application planning process. For example, wastes that are high in soluble salts are less appropriate and can have deleterious effects in arid climates due to the osmotic pressure from the salts inhibiting root uptake of water. On the other hand, the downward movement of water in the soil is minimal in arid climates, making the migration of waste constituents to ground water less likely.

Climate also determines which plants can grow in a region and the length of the growing season. If the local climate cannot support the plants that might be most helpful in assimilating the particular constituents in a given waste, the use of land application might be limited to other crops at a lower application rate. If the climate dictates that the part of the growing cycle during which land application is appropriate is short, a larger area for land application might be necessary.

There are also operating considerations associated with climate. Since waste should not be applied to frozen or very wet soil, the application times can be limited in cold or rainy climates. In climates where the ground can freeze, winter application poses particular problems even when the ground is not frozen, because if the ground freezes soon after application, the waste that remained near the soil surface can run off into surface waters during subsequent thaw periods. Waste nutrients are also more likely to leach through the soil and into the ground water following spring thaw, prior to crop growth and nutrient uptake. These problems can be partially solved by providing sufficient waste storage capacity for periods of freezing or rainy weather.

VII. Calculating An Agronomic Application Rate

The purpose of a land application unit (i.e., waste disposal versus beneficial use) helps determine the waste application rate best suited for that unit. When agricultural benefits are to be maximized, the application rate is governed by the agronomic rate. The objective for determining an agronomic application rate is to match, as closely as possible, the amount of available nutrients in the waste with the amount required by the crop. One example of an equation for calculating agronomic application rates is:

Agronomic application rate = (Crop nutrient uptake × Crop yield)-Nutrient credits

Where:

Crop nutrient uptake = Amount of nutrients absorbed by a particular crop. These requirements are readily available from your state and local Cooperative Extension Offices

Crop yield = Amount of plant available for harvest. Methods for calculating expected yields include past crop yields for that unit, county yield records, soil productivity tables, or local research.

Nutrient credits = Nitrogen residual from past waste applications, irrigation water nitrate nitrogen, nutrients from commercial fertilizer, and other nitrogen credits from atmospheric deposition from dust and ammonia in rainwater.

In addition, many states and universities have developed their own worksheets or calculations for developing an agronomic application rate. You should check with your state agency to see if you are subject to an existing regulation. In setting a preliminary application rate the crop's nitrogen requirements often serve as a ceiling, but in some cases, phosphorus, potassium, or salt content, rather than nitrogen, will be the limiting factor.

How do I determine the agronomic rate?

Computer models can help determine site-specific agronomic rates. Modeling nitrogen levels in waste and soil-plant systems can help provide information about physical and hydrologic conditions and about climatic influences on nitrogen transformations. Models recommended for use with sewage sludge include Nitrogen Leaching and Economic Analysis Package (NLEAP); DECOMPOSITION; Chemicals, Run-Off, and Erosion from Agricultural Management Systems (CREAMS); and Ground-Water Loading Effects of Agricultural Management Systems (GLEAMS).[14] NLEAP is a moderately complex, field scale model that assesses the potential for nitrate leaching under agricultural fields. NLEAP can be used to compare nitrate leaching potential under different soils and climates, different cropping systems, and different management scenarios. The computer model DECOMPOSITION is specifically designed to help predict sewage sludge nitrogen transformations based on sludge characteristics, as well as climate and soil properties (organic matter content, mean soil temperature, and water potential). Finally, the CREAMS and GLEAMS models, developed by the USDA, are other potentially useful models to assist with site-specific management of land application operations. Additional computer models include Cornell Nutrient Management Planning System (NMPS), Fertrec Plus v 2.1, and Michigan State University Nutrient

[14] All of these models are referenced in EPA's *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage* (U.S. EPA, 1995b). According to that source, the NLEAP software, developed by Shaffer et al., is included in the purchase of *Managing Nitrogen for Groundwater Quality and Farm Profitability* by Follet, et al., which also serves as reference for information on parameters required for nitrogen calculations. Four regional soil and climatic databases (Upper Midwest, Southern, Northeastern, and Western) also are available on disk for use with NLEAP. These materials can be obtained from: Soil Science Society of America Attn: Book Order Department, 677 S. Segoe Road, Madison, WI 53711, 608/273-2021; Book $36.00; Regional Databases $10.00 each. Current updates of the NLEAP program can be obtained by sending original diskettes to: Mary Brodahl, USDA-ARS-GPSR, Box E, Fort Collins, CO 80522. Additional information on the DECOMPOSITION model, developed by Gilmour and Clark, can be obtained from: Mark D. Clark, Predictive Modeling, P.O. Box 610, Fayetteville, AR 72702. The CREAMS and GLEAMS models were developed by USDA.

Management v1.1.[15] If assistance is required in determining an appropriate agronomic rate for a waste, you should contact the regional, state, or county agricultural cooperative extensions, or a similar organization.

VIII. Monitoring

Monitoring ground water can be helpful to verify whether waste constituents have migrated to ground water. Some state, tribal, or other regulatory authorities require ground-water monitoring at certain types of land application units; you should consult with the appropriate regulatory agency to determine whether such a requirement applies to the unit. Even if the unit is not required to monitor ground water, instituting a ground-water monitoring program is recommended for long-term, multiple application units where wastes contain the designated ground-water constituents. Such units are more likely to pose a threat to ground water than are single-application units or units receiving waste without these constituents.

In most cases, lysimeters should be sufficient to monitor ground water. A lysimeter is a contained unit of soil, often a box or cylinder in the ground which is filled with soil, open on the top, and closed at the bottom, so that the water that runs through it can be collected. It is usually more simple and economical to construct and operate than a monitoring well. You can consult with a qualified professional to develop an appropriate ground-water monitoring program for your land application unit.

If ground-water results indicate unacceptable constituent levels, you should suspend land application until the cause is identified. You should then correct the situation that led to the high readings. If a long-term change in the industrial process, rather than a one-time incident, caused the elevated levels, you should reevaluate your use of land application. Adjusting the application rate, adding pretreatment, or switching to another means of waste management might be necessary. After reevaluation, you should examine whether corrective action might be necessary to remediate the contaminated ground water. You should pay particular attention to ensure that applications are not exceeding the soil's assimilative capacity.

You should also consider testing soil samples periodically during the active life of a land application unit. For this testing to be meaningful, it is important that you first determine baseline conditions by sampling the soil before waste application begins. This might already have been done in preparation for greenhouse/field studies or for site characterization. Later, when applying waste to the unit, you should collect and analyze samples at regular intervals (such as annually or after a certain number of applications). Consider analyzing samples for macronutrients, micronutrients, and any of the designated ground-water constituents reasonably expected to be present in the waste. The location and number of sampling points, frequency of sampling, and constituents to be analyzed will depend on site-specific soil, water, plant, and waste characteristics. Local agricultural extension services, which have experience with monitoring, especially when coupled with ground-water monitoring, can detect contamination problems. Early detection allows time to change processes to remedy the problems, and to conduct corrective action if necessary before contamination becomes widespread.

Testing soils after the active life of a unit ends might also be appropriate, especially if the waste is likely to have left residues in the soil. The duration of monitoring after closure, like the location and frequency of monitoring during active life, is site-specific and depends on similar factors. For further information

[15] These models are referenced in the Northeast Regional Agricultural Engineering Cooperative Extension's Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop from December 11, 1996.

about testing soil after the active life of a unit ends, refer to Chapte 11—Performing Closure and Post-Closure Care.

IX. Odor Controls

Odors are sometimes a common problem at land application facilities and an odor management plan can allow facility managers to respond quickly and effectively to deal with odor complaints. A plan should involve working to prevent odors from occurring, working with neighbors to resolve odor complaints, and making changes if odors become an unacceptable condition. The plan should also identify the chemical odor constituents, determine the best method for monitoring odor, and develop acceptable odor thresholds. These odor management plans can be stand-alone plans or part of your company's environmental management system.

To effectively deal with odor complaints, it is important to consider creating an odor detection and response team to identify the source of, and quickly respond to, potential nuisance odor conditions. Document the problem as well as how it was or was not resolved, and notify facility managers as soon as possible. Odor complaints should be documented immediately in terms of the odor's location, characteristics, the time and date, existing meteorological conditions, suspected specific source, information that indicates relative strength compared to other events, and when during the day the odors are noticed.

Measuring odors can be accomplished in two manners: olfactometry and analytical. The olfactometry method uses trained individuals who determine the strength of an odor. Both of these methods have advantages and disadvantages. Some of the advantages of the olfactometry method are that it is accurately correlated with human response, it is fast at providing a general chemical classification, and it is usually cost effective as a field screening method. Disadvantages include the requirement of highly trained individuals, and it does not address the chemistry of the odor problem. Analytical methods use gas chromatographs and mass spectrophotometers to analyze vapor concentrations captured from a sample. Some of the advantages of the analytical method are that it allows detection of odorants at levels near human detection, it is precise and repetitive, and it provides chemical specificity. Disadvantages include a very high capital cost which might not accurately correlate with human responses. You should contact your state for more information on odor management plans and measuring odors.

Designing a Land Application Program Activity List

- ❑ Use the framework to design and evaluate a land application program and to help determine a preliminary waste application rate.
- ❑ Be familiar with waste parameters, such as total solids content, pH, organic matter, nutrients, carbon and nitrogen levels, salts, soil buffering capacity, and pathogens.
- ❑ When examining potential application sites, give special consideration to physical and chemical properties of soil, topography, and any site characteristics that might encourage runoff or odor.
- ❑ Choose crops for the unit considering plant uptake of nutrients and constituents.
- ❑ Account for climate and its effects.
- ❑ Determine an agronomic application rate.
- ❑ Evaluate ground-water and air risks from land application units and consider potential exposure pathways.
- ❑ Consider implementing a ground-water monitoring program and periodic sampling of unit soils.

Resources

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Part V
Ensuring Long-Term Protection

Chapter 8
Operating The Waste Management System

Contents

Operating the Waste Management System

This chapter will help you:

- *Develop a waste management system that includes procedures for monitoring performance and measuring progress towards environmental goals. The waste management system should identify operational procedures that are necessary to achieve those environmental goals and to make continual improvements in waste management operations.*

Implementing a waste management system that achieves protective environmental operations requires incorporating performance monitoring and measurement of progress towards environmental goals. An effective waste management system can help ensure proper operation of the many interrelated systems on which a unit depends for waste containment, leachate management, and other important functions. If the elements of an overall waste management system are not regularly inspected, maintained, improved, and evaluated for efficiency, even the best-designed unit might not operate efficiently. Implementing an effective waste management system can also reduce long- and short-term costs, protect workers and local communities, and maintain good community relations.

This chapter will address the following questions.

- What is an effective waste management system?
- What maintenance and operational aspects should be developed as part of a waste management system?

I. An Effective Waste Management System

Having an effective waste management system requires an understanding of environmental laws and an understanding of how to comply with these laws. An effective waste management system also requires that procedures be in place to monitor performance and measure progress towards clearly articulated and well understood environmental goals. Lastly, an effective waste management system involves operational procedures that integrate continual improvements in waste management operations to ensure continued compliance with environmental laws. In addition to what is discussed in this chapter, you can consider reviewing and implementing, as appropriate, the draft voluntary standards for good environmental practices developed by the International Standards Organization (ISO). The ISO 14000 series of standards identify management system elements that are intended to lead to improved performance. These include: a method to identify significant environmental aspects; a policy that includes a commitment to regulatory compliance, the prevention of pollution, and continual improvement; environmental objectives and targets for all relevant levels and functions in the organization; procedures to ensure performance, as well as compliance procedures to monitor and measure performance; and a systematic management review process.

The ISO 14000 series of standards include a "specification" standard, ISO 14001. The rest are standards that provide optional guidance for companies developing and implementing management systems and product standards. The ISO 14001 specification standard contains only those requirements that can be objectively audited for certification, registration, and self-declaration purposes. For more information about EPA's involvement in the ISO 14000 and 14001 standards, refer to the ISO 14000 Resource Directory, October 1997, (U.S. EPA, 1997). Information on obtaining the ISO 14000 series of standards is provided in the text box above. An example of an integrated EMS can be found at **<www.epa.gov/dfe/tools/iems.htm>**.

Additional Information on ISO 14000

The ISO 14000 series of standards are copyrighted and can be obtained by contacting any of the following organizations:

American National Standards Institute (ANSI)
1819 L Street, NW, 6th Floor
Washington, DC 20026
202 293-8020
<www.ansi.org>

American Society of Testing and Materials (ASTM)
100 Bar Harbor Drive
West Conshohocken, PA 19428-2959
610 832-9585
<www.astm.org>

American Society for Quality Control (ASQC)
611 East Wisconsin Avenue
P.O. Box 3005
Milwaukee, WI 53201
800 248-1946
<www.asqc.org>

NSF International
P.O. Box 130140
789 N. Dixboro Road
Ann Arbor, MI 48113-0140
800 NSF-MARK or 734 769-8010
<www.nsf.org>

II. Maintenance and Operation of Waste Management System Components

All of the time and money invested in planning, designing, and developing a unit will be jeopardized if proper operational procedures are not carried out. Effective operation is important for environmental protection, and for reasons of economy, efficiency, and aesthetics. Operating control systems, therefore, should be developed and maintained by the facility operator to ensure efficient and protective operation of a waste management system. These controls consist of the operator conducting frequent inspections, performing routine maintenance, reporting inspection results, and making necessary improvements to keep the system functioning.

Unit inspections can help identify deterioration of or malfunction in control systems. Surface impoundments should be inspected for evidence of overtopping, sudden drops in liquid levels, ice formation, and deterioration of dikes or other containment devices. Overtopping, or the flowing of waste over the top of the walls of an impoundment, can occur as a result of insufficient freeboard, wind or wave action, or other unusual conditions including the formation and movement of ice within a surface impoundment which can also puncture or tear synthetic liners.

One method of protecting liners from ice damage is to install a liner cover consisting of sand and rip rap along the edge of the liner. Another option is the use of a double liner system. The higher cost of a double liner is offset by reducing the need for rip rap and offers enhanced ground-water protection. Regardless of which method is implemented, liner systems should be inspected for damage and be repaired if necessary after periods of ice formation. Also, make visual inspections periodically to check waste levels, weather conditions, or draining during periods of heavy precipitation. In addition, it is important to consider devising a contingency plan to reinforce dikes when failure is imminent.

Waste piles and landfills should be inspected for adequate surface-water protection systems, leachate seeps, dust suppression methods, and daily covers, where applicable. Land application sites should be inspected for adequate surface-water protection systems and dust suppression methods, as applicable. Inspections of pipes, monitoring of mechanical equipment, and safety, emergency, and security devices will help to ensure that a unit operates in a safe manner. In addition, inspections often prevent small problems from growing into more costly ones.

How should effective inspections be conducted?

To help ensure that routine inspections are performed regularly and consistently, consider developing a written inspection schedule and ensure that staff follow the schedule. The schedule could state the type of inspections to be conducted, the inspection methods to be used, the frequency of the inspections, and a plan of action highlighting preventative measures to address potential problems. Consider conducting additional inspections after extraordinary site-specific circumstances, such as storms or other extreme weather conditions.

Staff conducting the inspections should look for malfunctioning or deteriorating equipment, such as broken sump pumps, leaking fittings, eroding dikes, or corroded pipes or tanks; discharges or leaks from valves or pipes; and operator errors. A written schedule for inspections should be maintained at the facility, and inspections should be recorded in a log containing information such as date of inspection, name of inspector, conditions found, and recommended corrective action. Inspection personnel should be familiar with the inspection log to identify any malfunctions or deficiencies that remain uncorrected from previous inspections.

When designing an inspection form for a unit, add appropriate items for the unit type. You can check with the appropriate state regulatory agency to see if it has an inspection form that can be used. For example, a landfill form would include a section about waste placement and a surface impoundment form might have an entry for sufficient freeboard. If ground water is monitored, you can make ground-water monitoring part of the unit inspection, and add check boxes for each monitoring point to ensure that inspectors collect samples from all monitoring points according to the specified schedule. After an inspection, it is important that all inspection reports are reviewed in a timely manner so that any necessary repairs and improvements can quickly be identified and implemented. You should consult with your state agency to help determine if improvements are necessary.

A. Ground-Water Controls

Ground-water protection controls, such as ground-water monitoring systems, unit covers, leachate collection and removal systems, and leak detection systems should be incorporated into the design and construction of a unit.

Ground-water monitoring wells require continued maintenance. A major reason for maintenance is plugging of the gravel pack or screen. (See Chapter 9–Monitoring Performance for a discussion on the construction of ground-water monitoring wells.) The most common plugging problems are caused by precipitation of calcium or magnesium carbonates and iron compounds. Acid is most commonly used to clean screens clogged with calcium carbonate. In many instances, however, the cost of attempted restoration of a monitoring well can be more than the installation of a new well. Because many wells are installed in unconsolidated sand formations, silt and clay can be pumped through the system and cause it to fail. Silt and sand grains are abrasive and can damage well screens, pumps (if present), flow meters, and other components.

In some cases, the well can fill with sediment and must be cleaned out. The most frequent method of cleaning is to pull the pump from the well, circulate clean water down the well bore through a drop, and flush the sediment out. If large amounts of sediments are expected to enter a monitoring well, consider incorporating a sediment sump (also called a silt trap or sediment trap) into the monitoring well construction. The sump consists of a blank section of pipe placed below the base of the screen. Its purpose is to provide a catch-trap for fine sand and silt which bypasses the filter pack and screen and settles out within the well. This sediment collects within the sump rather than within the screen, and therefore, does not reduce the functional screened length of the well and minimizes the need for periodic cleanouts of the screen. Regardless of the type of ground-water monitoring well installed, the well should be protected with a cap or plug at the upper end to prevent condensation, rust, and dirt from entering into the manhole or protective casing. In addition, it is important to inspect the outer portion of the wells to ensure that they have not been damaged by trucks or other unit operations, and to ensure that the cap or plug is intact.

You also should inspect and maintain unit covers to ensure that they are intact. For optimal performance, covers should be designed to minimize permeability, surface ponding, and the erosion of cover material. The cover should also prevent the buildup of liquids within the unit. Consult Chapter 11–Performing Closure and Post-Closure Care for a more detailed discussion on maintaining cover systems.

It is essential that all components of a leachate collection and removal system and a leak detection system be maintained properly. The main components include the leachate collection pipes, manholes, leachate collection tanks and accessories, and pumps. You should consider cleaning the leachate pipes once a year to remove any organic growth and visually inspecting the manholes, tanks, and pumps once a year as leachate can corrode metallic parts. Annual inspections and necessary repairs will prevent many future emergency problems such as leachate overflow from the tank due to pump failure. Maintain a record of all repair activities as necessary to assess (or claim) long-term warranties on pumps and other equipment.

In surface impoundments, monitor waste liquid levels. An unexpected decrease in liquid levels can be an indication of a release from the impoundment. If a surface impoundment fails, it is important to discontinue adding waste to the impoundment and contain any discharge that has occurred or is occurring. Repair leaks as soon as possible. If leaks cannot be stopped, empty the impoundment if possible. If the size of the unit or amount of waste present prohibits emptying, see Chapter 9–Monitoring Performance and consult with state officials about beginning an assessment monitoring program. Clean up any released waste (see Chapter 10–Taking Corrective Action) and notify the appropriate state authorities of the failure and the remedial actions taken.

B. Surface-Water Controls

If a unit has a point source discharge, the unit must have a National Pollutant Discharge Elimination System (NPDES) permit (or equivalent) and, in some states, might require a state discharge permit. Point source discharges include the release of leachate from a leachate collection or onsite treatment system into surface waters, disposal of industrial waste into surface waters, or release of surface-water runoff (e.g., storm water) that is directed by a runoff control system into surface waters. Even if there are no point source discharges, surface-water controls might be necessary to prevent pollutants from being discharged or leached into surface waters, such as lakes and rivers. If a facility is discharging wastewater to a local publicly owned treatment works (POTW), check with the POTW and local regulatory authorities to determine whether pretreatment standards exist for the facility.

Soil erosion and sedimentation controls, such as ditches, berms, dikes, drains, and silt fences, should be incorporated into the design and construction of a unit. Berms or dikes are often constructed from earthen materials, concrete, or other materials designed to be safely traversed during inspection or monitoring activities. Vegetation also is often used for erosion control. Trees or other deep rooted vegetation, however, should not be used near liners or other structures that could be damaged by roots. Grass is often used for soil stabilization around surface impoundments. For a more detailed discussion of storm-water issues, consult Chapter 6–Protecting Surface Water.

Most if not all of these surface-water controls should be inspected by the operator regularly, especially after large storm events. Structures should be maintained as installed and any structural damage should be repaired as soon as possible to prevent further damage or erosion. Any trapped sediments should be removed and disposed of properly. Vegetative controls frequently need watering after planting and during periods of intense heat or lack of rain.

C. Air Controls

Gases, including methane, carbon dioxide, and hydrogen, are often produced at waste management units as byproducts of the microbial decomposition of wastes containing organic material. Additionally, volatile organic compounds (VOCs) can be present in the waste, and particulate emissions and dust can be generated during unit operations. It is important to analyze wastes carefully prior to designing a waste management unit to determine what airborne emissions are likely to come from these wastes. If airborne emission controls are needed in the design of a unit, maintenance of these controls should be considered as part of a waste management system. For further information on airborne emission controls, consult Chapter 5–Protecting Air Quality.

Methane is a particular concern at some waste management units. Methane is odorless and can cause fires or explosions that can endanger employees and damage structures both on and off site. Hydrogen gas can also form, and is also explosive, but it readily reacts with carbon or sulfur to form methane or hydrogen sulfide. Hydrogen sulfide can be easily identified by its sulfur or "rotten egg" smell. Methane, if not captured, will either escape to the atmosphere or migrate underground. Underground methane can enter structures, where it can reach explosive concentrations or displace oxygen, creating the danger of asphyxiation. Methane in the soil profile can damage the vegetation on the surface of the landfill or on the land surrounding the landfill, thereby exposing the unit to increased erosion. Finally, methane is a potent "greenhouse" gas that contributes to global warming.

Methane is explosive when present in the ranges of 5 to 15 percent by volume in the air. The 5 percent level is known as the lower explosive limit (LEL) and 15 percent as the upper explosive limit (UEL). At levels above 15 percent by volume, methane will not explode when exposed to a source of ignition. Levels above the UEL remain a concern, however, as methane will burn at these concentrations and can still cause asphyxiation.

In the event that methane gas levels exceed 25 percent of the LEL in facility structures or other closed spaces, initiate safety measures, such as evacuating the site and structures. In such cases, or when the methane level exceeds 25 percent of the LEL in the soil at a monitoring point, implement a remediation plan to decrease gas levels and prevent future buildup of gases.

Gas control systems generally include mechanisms designed to control gas migration and to minimize the venting of gas emissions into the atmosphere. Passive gas control systems use natural pressure and convection mechanisms to remove gas from the waste management unit. Examples of passive gas control system elements include ditches, trenches, vent walls, perforated pipes surrounded by coarse soil, synthetic membranes, and high moisture, fine-grained soil. Active gas control systems use mechanical means to remove gas from the unit. Gas extraction wells are an example of an active gas control system.

Gas monitoring and extraction systems require regular maintenance to operate efficiently. As wastes settle over time, pipes can fail and condensate outlets can become blocked. Extracted gas is saturated, which causes moisture to collect within the pipes. Therefore, the condensate within the pipes must be dealt with, otherwise it will affect the pumping suction pressure. Since the plumbing on the top of the unit is quite involved, develop and adhere to a gas maintenance schedule to ensure the efficient operation of gas systems.

If generated gas is not removed from a unit, uplift pressure can cause bubbles within the unit that displace the cover soil at the surface. Gas bubbles also can decrease the normal stress between the geomembrane and its underlying material leading to slippage of the geomembrane and all overlying materials. This creates high tensile stresses evidenced by folding at the toe of the slope and tension cracks near the top.

III. Operational Aspects of a Waste Management System

This section identifies and briefly discusses some of the important operational aspects of a waste management system, including developing an operating plan, performing waste analyses and inspections, installing daily covers, placing wastes in a unit, removing sludge, considering climate, implementing security and access control measures, providing employee training, addressing nuisance concerns, developing emergency response plans and procedures, and maintaining important records. Consider developing practices to ensure compliance with applicable laws and regulations, to train workers how to handle potential problems, and to ensure that all necessary improvements or changes are made to a waste management system. Proper planning and implementation of these operating practices are important elements in the efficient and protective operation of a unit.

A. Operating Plan

An operating plan should serve as the primary resource document for operating a waste management unit. It should include the technical details necessary for a unit to operate as designed throughout its intended working life. At a landfill, for example, the operating plan should illustrate the chronological sequence for filling the unit, and it should be detailed enough to allow the facility manager to know what to do at any point in the active life of the unit.

An operating plan should include:

- A daily procedures component.
- Lists of current equipment holdings and of future equipment needs.
- Procedures to inspect for inappropriate wastes and to respond when their presence is suspected.
- Procedures for addressing extreme weather conditions.
- Personnel needs and equipment utilization, including backup.
- Procedures to address emergencies, such as medical crises, fires, and spills.
- Quality control standards.
- Record keeping protocols.
- Means of compliance with local, state, and federal regulations.

The daily procedures component of the plan outlines the day-to-day activities necessary to place waste, operate environmental controls, and inspect and maintain the waste management unit in accordance with its design. Daily procedures should be concise enough to be circulated among all employees at the unit and flexible enough to allow for any adjustments necessary to accommodate weather variability, changing waste volume, and other contingencies. You should revise and update daily procedures as needed to ensure the unit's continued safe operation within the parameters of the overall operating plan.

Since a unit will likely operate for several years, it is important that staff periodically review the operating plan to refresh their memories and to ensure long-term conformity with the plan. If modifications to the operating plan are necessary, the changes and the date they were made should be noted within the plan itself. Documented operating procedures can be crucial, especially if questions arise in the future regarding the adequacy of site construction and management.

B. Waste Analysis

To effectively manage waste and ensure proper handling (e.g., preventing the mixing of incompatible wastes, use of incompatible liners or containers), knowledge of the chemical and physical composition of the wastes is imperative. Determining waste characteristics can be done by performing a comprehensive waste analysis or through process knowledge. To ensure that this information remains accurate, it might be necessary to repeat the analysis whenever there is a change in the industrial process generating the waste. For further information, consult Chapter 2–Characterizing Waste.

C. Waste Inspections

The purpose of performing waste inspections is to identify waste that might be inappropriate for the waste management unit, and to prevent problems and accidents before they happen. Hazardous wastes, PCBs, liquids (in landfills and waste piles), and state-designated wastes are prohibited from disposal in units designated solely for industrial nonhazardous waste. Some states have developed more stringent screening requirements that require a spotter to be present at a unit to detect unauthorized wastes and to weigh and record incoming wastes.

As part of a waste management system, screening procedures should be implemented to prevent inappropriate wastes from entering a unit. For units receiving waste exclusively from on site, only limited waste screening might be necessary. For facilities receiving waste from off site, screening procedures typically call for screening waste as it enters a unit. Ideally, all wastes entering a unit should be screened, but this is not always practical or necessary. A decision might be made, therefore, to screen a percentage of incoming waste. It might be practical to use spot inspections, such as checking random loads of waste on a random day each week or every incoming load on one random day each month. Base the frequency of random inspections on the type and quantity of wastes expected to be received, the accuracy and confidence desired, and any state inspection requirements. Inspections need to be performed prior to placement of wastes in a unit.

An effective waste management system relies on accurate knowledge of the waste being handled.

Training employees to recognize inappropriate wastes during routine operations increases the chances that inappropriate waste arriving on non-inspection days will be detected. Some indications of inappropriate wastes are color, texture, or odor different from those of the waste a unit normally receives. Also, laboratory testing can be performed to identify different wastes.

A waste management system should include procedures to address suspected inappropriate waste. The procedures to implement, when inappropriate wastes are found, should include the following:

- Segregate the suspicious wastes.
- Use appropriate personal protective equipment.
- Contact the part of the industrial facility that generated the waste to find out more about it.

- Contact laboratory support to analyze the waste, if required.
- Call the appropriate state, tribal or federal agencies in accordance with the opertaing plan.
- Notify a response agency, if necessary.

Should liquids be restricted from being placed in some units?

Bulk or containerized liquids should not be placed in landfills or waste piles, as liquids increase the potential for leachate generation. Liquid waste includes any waste material determined to contain free liquids as defined by Method 9095 (also known as the paint filter test) in EPA's *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (SW-846). Sludges are a common waste that can contain significant quantities of liquids. You should consider methods such as drying beds to dewater sludges prior to placement in landfills and waste piles.[1]

D. Daily Cover

It might be necessary to apply a daily cover to operating landfills and waste piles. Covering the waste helps control nuisance factors, such as the escape of odors, dust, and airborne emissions, and can control the population of disease vectors where necessary. Some cover materials, due to their ability to hold moisture, can reduce the infiltration of rain water, decreasing the generation of leachate and the potential for surface-water and ground-water contamination.

How is daily cover applied?

Covers most often consist of earthen material, although there are several alternative daily covers being used in the industry today, including coproducts,[2] foam, geotextiles, and plastic sheets or tarps. Examples of coproducts that have been used as daily cover include granular wastes, automobile shredder fluff, foundry sand, dewatered sludges, and synthetic soils. When using coproduct covers that can themselves contain contaminants, ensure that run-on is either diverted before it contacts the cover material or captured and handled appropriately after contacting it. Granular wastes used as daily cover should be low in fine-grained particles to avoid waste being transported by wind. Before using alternative covers, especially coproducts, you should consult the state to determine what, if any, regulations apply.

Inspect waste to ensure that hazardous waste is not placed in a unit.

Daily cover should be applied after the waste has been placed, spread, and compacted. Cover frequency is most often determined by the type of industrial waste disposed of at the landfill or waste pile. Frequent application of earthen material might be required if undesirable conditions persist. A typical daily soil cover thickness is 6 inches, but different thicknesses might be sufficient. When using earthen cover, it is important to avoid soils with high clay content. Clay, due to its low permeability, can block vertical movement of water and channel it horizontally through the landfill or waste pile.

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[1] EPA is investigating the potential of bioreactor landfills as the concept applies to the operation of a municipal landfill. The idea of a bioreactor landfill might be considered appropriate in select cases for an industrial landfill at some time in the future.

[2] In Pennsylvania a coproduct is defined as "materials which are essentially equivalent to and used in place of an intentionally manufactured product or produced raw material and...[which present] no greater risk to the public or the environment."

Using alternative daily cover materials can save valuable space in a waste management unit. Some types of commercially available daily cover materials include foam that usually is sprayed on the working face at the end of the day, and geosynthetic products, such as a tarp or fabric panel that is applied at the end of the working day and removed at the beginning of the following working day. Some of these materials require specially designed application equipment, while others use equipment generally available at most units. Criteria to consider when selecting an alternative daily cover material include availability and suitability of the material, precipitation, chemical compatibility with waste, equipment requirements, and cost.

E. Placing Wastes

To protect the integrity of liner systems, the waste management system should prescribe proper waste placement practices. The primary physical compatibility issue is puncture of the liner by sharp objects in the waste. Ensure that the liner is protected from items angular and sharp enough to puncture it. Similarly, facility employees should be instructed to keep heavy equipment off the liner. Another physical compatibility issue is keeping fine-grained waste materials away from drainage layers that could be clogged by such materials.

Differential settlement of wastes is another problem that can be associated with waste placement. To avoid differential settlement, focus on how the waste is placed on the liner material or on the protective layer above the liner. Uneven placement of waste, or uneven compaction can result in differential settlement of succeeding waste layers or of final cover. Differential settlement, in turn, can lead to ponding and infiltration of water and damage to liners or leachate collection systems. In extreme cases, failure of waste slopes can occur. To avoid these problems, it is important to ensure that waste is properly placed and, if possible, compacted to ensure stability of the final cover.

To protect liner integrity in lined surface impoundments, consider placing an erosion guard or a concrete pad on the liner at the point where waste discharges into the unit. Otherwise, pressure from the waste hitting the liner can accelerate liner deterioration in that area. Inlet pipes can also be arranged so that liquid waste being discharged into the unit is diffused upward or to the side. Although inlet pipes can enter the surface impoundment above the water level, the point of discharge should be submerged to avoid generating odor and disturbing the circulation of stratified ponds. Discharging liquid waste straight into the unit without diffusion is not recommended as this can disrupt the intended treatment.

F. Sludge Removal

If significant amounts of sludge accumulate on the bottom of an impoundment, it might be necessary to remove the sludge and dispose of it periodically. There are two ways to remove the sludge: dewater the cell and remove the sludge after it has dried, or dredge the impoundment. Many different methods exist for dredging an impoundment. Examples include a tanker truck outfitted with a vacuum hose, manned and remote dredges, and submersible pumps on steel pontoons used as a floating dredge or dragged on the pond bottom. You should work with your state and sludge removal professionals to choose or create a method that works best at your facility.

There are two main concerns regarding sludge management: protecting the liner while cleaning out sludge from the impoundment (if a liner is used) and properly disposing of any removed sludge. During dredging, heavy equipment can damage the liner. You can avoid this by selecting equipment and methods that protect the liner during sludge removal. Further, any sludge removed should be evaluated and managed in an appropriate manner, based on its chemical properties.

G. Climate Considerations

Waste management operations can be affected by weather conditions, especially rain, snow, or wind. Rainy or snowy weather can create a variety of problems, such as hindered vehicle access and difficulty in spreading and compacting waste. To combat these difficulties, consider altering drainage patterns, maintaining storm-water controls, maintaining all-weather access roads (if appropriate), or designating a wet-weather disposal area.

Extremely cold conditions can prevent efficient excavation of soil from a borrow pit and can also inhibit the spreading and compaction of soil cover on the waste. Freezing temperatures can also inflict excessive wear on equipment. To combat these problems, you can use coarse-textured soil during winter operations, stockpile cover soil for winter use, and protect cover soil with leaves, plastics, or other insulating materials.

Consider using special inclement weather disposal areas during extreme wet and windy weather. In wet weather, placing waste in a part of the unit near the entrance reduces the likelihood of trucks causing ruts on site roadways or being stranded in mud. Under windy conditions, waste might need to be wetted or placed in downwind areas of a unit to reduce blowing waste or particulates.

H. Security Measures, Access Control, and Traffic Management

To prevent injury to members of the public, consider implementing security and access control measures to block unauthorized entry to a unit. These measures can also help to prevent scavenging, vandalism, and illegal dumping of unauthorized wastes. Providing access controls for the facility within which the unit is located is an example of providing such measures for the unit.

Examples of access control measures include fences, locked gates, security guards, and surveillance systems; and natural barriers such as, berms, trees, hedges, ditches, and embankments. The site perimeter should be clearly marked or fenced. Additionally, consider posting signs that warn of restricted access and alert the public to the potential for harm associated with heavy equipment operations.

How can onsite traffic best be managed?

Even though access to the unit is limited, it is important to provide clear transportation routes for emergency response equipment to access the waste management unit. Traffic management is often overlooked as part of waste management unit operations. Proper traffic routing can help a unit operate more smoothly and prevent injuries and deter intruders. Access roads should be designed and built to be safe and efficient, and blind spots or unmarked intersections should be minimized. They should also be located to provide long-term service without requiring relocation. Posting clear directional signs can help direct traffic and reduce the potential for vehicle accidents. Providing all-weather access roads (if appropriate) and temporary storage areas can improve waste transport to and from a unit and allow equipment to move about more freely. In addition, you can consider imposing onsite speed limits or constructing speed bumps.

Access roads should be maintained properly at all times. Adequate drainage of road beds is essential for proper operation of a unit. Heavy, loaded vehicles traveling to and from a unit deteriorate the roads on which they travel. Equipment without rubber tires should be restricted from the paved stretches of roads as they can damage the roads. Sufficient funds should be allocated up front for the maintenance of access roads.

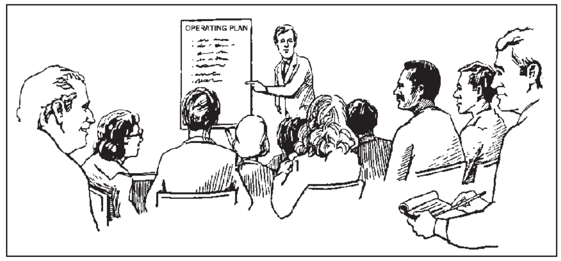
What are some other prudent safety measures?

There are a number of safety considerations associated with ground-water monitoring wells. The tops of monitoring wells should be clearly marked and accessible. In traffic areas, posts and bumper guards around monitoring wells can help protect aboveground installations from damage. Posts and bumper guards come in various sizes and strengths and are typically constructed for high visibility and trimmed with reflective tape or highly visible paint containing reflective material.

Proper labeling of monitoring wells is also important for several reasons. Monitoring wells should be distinguished from underground storage tank fill lines, for example. Also, different monitoring wells should be distinguished from each other. Monitoring wells, therefore, should be labeled on immovable parts of the well.

I. Providing Employee Training

One of the most important aspects of a waste management system is employee training. Employees should be trained before their initial assignment, upon changing assignments, and any time a new health or safety hazard is introduced into the work area. A good training program uses concrete examples to improve and maintain employee skill, safety, and teamwork. Training can be provided by in-house trainers, trade associations, computer programs, or specialized consultants. In some states, proactive safety and training programs are required by law.



Classroom training helps familiarize employees with operating procedures.

What types of training can be provided for employees?

Safety is a primary concern because waste management operations can present a variety of risks to workers. In addition, employee right-to-know laws require employers to provide training and information about safety issues pertinent to a given occupation. Furthermore, accidents can be expensive, with hidden costs often amounting to several times the apparent costs. Accidents at waste management units can include injury from explosions or fire, inhalation of contaminants and dust, asphyxiation from poorly vented leachate collection system manholes or tanks, falls from vehicles, injury associated with operating heavy earth-moving equipment, exposure to extreme cold or heat, and onsite traffic accidents.

To minimize risks to workers, it is recommended that you provide an ongoing safety training program to ensure all staff are properly and regularly trained on safety issues. A safety training program should be consistent with the requirements specified by the U.S. Occupational Safety and Health Administration (OSHA) and include initial training and frequent refresher sessions on at least the following topics:

- Waste management operations.
- Hazardous waste identification.
- Monitoring equipment operations.
- Emergency shut-off procedures.
- Overview of safety, health, and other hazards present at the site.
- Symptoms and signs of overexposure to hazards.
- Proper lifting methods, material handling procedures, equipment operation, and safe driving practices.
- Emergency response topics, such as spill response, fire suppression, hazard analysis, and location and operation of emergency equipment.
- Requirements for personal protective gear, such as hard hats, gloves, goggles, safety shoes, and high-visibility vests.

Weave a common thread of teamwork into every training program. Breaks in communication between site engineers and field operations personnel can occur. Bridging this gap is an important step toward building an effective unit team that can work together. Consider periodic special training to update employees on new equipment and technologies, to improve and broaden their range of job-related skills, and to keep them fresh on the basics. Training can also include such peripheral topics as liability concerns, first aid, avoidance of substance abuse, and stress management.

Sample Manager and Supervisor Training Agenda

- Introduction
- Unit basics:
  —Siting
  —Waste containment
  —Daily operations
- Owning and operating costs
- Machine types
- Equipment maintenance
- Maximizing airspace
- Labor management
- Production analysis
- Application of production rate data
- Budgets and data tracking:
  —Operating budget
  —Cover soil budget
  —Airspace budget
- Waste handling techniques
- Waste management techniques
- Cover soil placement
- Safety issues and safety meetings
- Record keeping
- Emergency response plan
- State requirements for operation

Bolton, N. 1995. *The Handbook of Landfill Operations: a Practical Guide for Landfill Engineers, Owners, and Operators*. (ISBN 0-9646956-0-X). Reprinted by permission.

Equipment Operator Training Agenda

- Introduction
- Unit basics:
  - —Siting
  - —Waste containment
  - —Daily operations
- Heavy equipment types and applications:
  - —Scraper, dozer, and compactor operations
  - —Support equipment
  - —Fluids
  - —Fueling, maintenance and its hazards, and fuel spill prevention
- Cover operations:
  - —Types of cover soil
  - —Placement of cover soil
- Drainage control
- Surveying and staking
- Unit safety:
  - —Emergency response plans
  - —Safe operating techniques
- Owning and operating costs

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How should training programs be conducted?

You should keep records of the type and amount of training provided to employees, and obtain documentation (employee signatures) whenever training is given. Consider establishing regular (at least monthly) safety meetings, during which specific topics can be addressed and employees can voice concerns, ask questions, and present ideas. Keep meetings short and to the point, and steer discussion toward topics that are applicable to those employees present. In addition, do not waste time talking about issues not applicable to a site. If a site experiences extreme weather conditions, develop safety meeting topics that address weather-related safety. Many safety-related videos are available and can add variety to meetings.

Closely monitor worker accident and injury reports to try to identify conditions that warrant corrective or preventive measures. In addition, it is wise to document all safety meetings. Assistance in establishing a safety program is available from insurance companies with worker's compensation programs, the National Safety Council, safety consultants, and federal and state government safety organizations. The overall cost of an aggressive, preventive safety program is almost certain to be offset by the savings from a decrease in lost work time and injuries.

J. Emergency Response Plan and Procedures

There are three major types of waste management emergencies: accidents, spills, and fires/explosions. A waste management system should include emergency response plans for each of these scenarios that considers not only the waste management unit but also all surrounding facility areas. The plans should be reviewed and revised periodically to keep the procedures fresh in employees' minds and to reflect any changes in such items as the unit operating procedures, facility operations, physical and chemical changes in the wastes, generated volumes, addition or replacement of emergency equipment, and personnel changes. If an emergency does arise, or if hazardous waste is inadvertently disposed of in a unit, notify appropriate agencies, adjacent land owners, and emergency response personnel, if needed. After emergency conditions have been cleared, review the waste management system and revise it, if necessary, to prevent similar mishaps in the future.

A facility might be required to prepare similar emergency response or contingency plans under other regulatory programs [e.g., Spill Prevention Control and Countermeasures and Response Plan requirements (40 CFR Part 112.7(d) and 112.20-21); Risk Management Program regulations (40 CFR Part 68); and HAZWOPER regulations (29 CFR 1910.120)]. EPA encourages facilities to consolidate emergency response plans whenever possible to elimante redundancy and confusion. The National Response Team, chaired by EPA, has prepared its Integrated Contingency Plan Guidance (61 *FR* 28642; June 5, 1996) as a model for integrating such plans.

How should an appropriate emergency response plan be developed?

An emergency response plan should consider the following:

- Description of types of emergencies that would necessitate a response action.
- Names, roles, and duties of primary and alternate emergency coordinators.
- Spill notification procedures.
- Who should be notified.
- Fire department or emergency response telephone number.
- Hospital telephone number.
- Primary and secondary emergency staging areas.
- Location of first aid supplies.
- Designation and training of several first aid administrators.
- Location of and operating procedures for all fire control, spill control, and decontamination equipment.
- Location of hoses, sprinklers, or water spray systems and adequate water supplies.
- Description and listing of emergency response equipment.

Sample Laborer Training Agenda

- Introduction
- Unit basics:
  —Siting
  —Waste containment
  —Daily operations
- Traffic management and safety
- Interacting with the public
- Load segregation and placement
- Hazardous material identification procedure
- Unit equipment types and applications
- Cover operations
- Equipment maintenance
- Unit safety:
  —Heavy equipment safety
  —Traffic safety
  —Personal protective equipment
- Emergency response plans

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- Maintenance and testing log of emergency equipment.
- Plans to familiarize local authorities, local emergency response organizations, and neighbors with the characteristics of the unit and appropriate and inappropriate responses to various emergency situations.
- Information on state emergency response teams, response contractors, and equipment suppliers.
- Properties of the waste being handled at the unit, and types of injuries that could result from fires, explosions, releases, or other mishaps.
- An evacuation plan for unit personnel (if applicable).
- Prominent posting of the above information.

The emergency plan should instruct all employees what to do if an emergency arises, and all employees should be familiar with the plan and their responsibilities under it. In order to ensure that everyone knows what to do in an emergency, EPA recommends conducting periodic drills. These practice responses could be planned ahead of time or they could be unannounced. Either way, the drills are treated as real emergencies and serve to hone the skills of the employees who might have to respond to actual emergencies. The key to responding effectively to an emergency is knowing in advance what to do.

Communication is vital during an emergency and should be an inherent component of any emergency response plan. Two-way radios and bullhorns can prove invaluable in the event of an emergency, and an alarm system can let employees know that an emergency situation is at hand. It is recommended that you designate one or more employees who will not be essential to the emergency response to handle public affairs during a major emergency. These employees should work with the press to ensure that the public receives an accurate account of the emergency.

K. Record Keeping

Record keeping is a vital part of cost-effective, efficient waste management unit operations. Records should be maintained for an appropriate period of time, but it is a good idea to keep a set of core records indefinitely. Some facilities have instituted policies that records are to be maintained for up to 30 years while other facilities maintain records for only 3 years. Some states have record keeping requirements for certain waste management units and associated practices. You should check with state authorities to determine what, if any, record keeping is required by law and to determine how long records should be kept.

Besides being required by some states, records help evaluate and optimize unit performance. Over time, these records can serve as a valuable almanac of activities, as well as a source of cost information to help fine tune future expenditures and operating budgets. Data on waste volume, for example, can allow a prediction of remaining site life, any special equipment that might be needed, and personnel requirements. Furthermore, if a

Keeping accurate records is an essential part of unit operations.

facility is ever involved in litigation, accurate, dated records can be invaluable in establishing a case.

What type of records should be kept?

Operational records that should be maintained include the following, as appropriate:

- Waste analysis results.
- Liner compatibility testing (where a liner system is considered appropriate).
- Waste volume.
- Location of waste placement, including a map.
- Depth of waste below the final cover surface.
- Inventory of daily cover material used and stockpile.
- Frequency of waste application.
- Equipment operation and maintenance statistics.
- Environmental monitoring data and results.
- Inspection reports, including photographs.
- Design documents, including drawings and certifications.
- Cost estimates and other financial data.
- Plans for unit closure and post-closure care.
- Information on financial assurance mechanisms.
- Daily log of activities.
- Calendar of events.

Health and safety records that should be maintained include the following:

- Personal information and work history for each employee, including health information such as illness reports.
- Accident records.
- Work environmental records.
- Occupational safety records, including safety training and safety surveys.

L. Addressing Nuisance Concerns

Minimizing nuisances, such as noise, odor, and disease vectors, is of great importance for the health of personnel working in the industrial facility and of neighbors that live or work near a unit. This section describes many of the nuisance concerns typical of waste management units and offers measures to address them. Measures besides those listed can also be used to achieve the same objective.

How can noises be minimized?

Noise resulting from the operation of heavy equipment can be a concern for waste management units located near residential areas. Noise can also disrupt animal habitats and behavior. In addition, workers' hearing and stress levels can be adversely affected by long-term exposure to noise. At waste management units where noise is a concern, limiting hours of operation can reduce potential problems. Design access routes to minimize the impact of site traffic noise on nearby neighborhoods. Equipment should also be maintained to minimize unnecessary noise, and affected workers should wear ear protection (plugs or muffs). Berms, wind breaks, or other barriers can be erected to help mute sounds. OSHA has established standards for occupational exposure to noise (see 29 CFR §1910.95).

How can odor be minimized?

Increased urbanization has led to industrial facilities being situated in close proximity to residential areas and commercial developments. This has resulted in numerous complaints about odors from industrial waste management units and industrial processes such as poultry processing, slaughtering and rendering, tanning, and manufacture of volatile organics. Some of the major sources of odors are hydrogen sulfide and organic compounds generated by anaerobic decomposition. The latter can include mercaptans, indole, skatole, amines, and fatty acids. Odor might be a concern at a unit, depending on proximity to neighbors and the nature of the wastes being managed. In addition to causing complaints, odors can be a sign of toxic or irritating gases or anaerobic conditions in a unit that could have adverse health effects or environmental impacts. Plan to be proactive in minimizing odors, and establish procedures to respond to citizen complaints about odor problems and to correct the problems.

Odors can be seasonal in nature and, therefore, can often be anticipated. Some odors at landfills, waste piles, and land application units arise either from waste being unloaded or from improperly covered in-place waste. If odor from waste being unloaded becomes a problem, it might be necessary to place these loads in a portion of the unit where they can be immediately covered with soil. At land application units, quick incorporation or injection of waste can help prevent odor. It also might be prudent to establish a system whereby unit personnel are notified when odorous wastes are coming to the unit to allow them to prepare accordingly. Odors from in-place waste can effectively be minimized by maintaining the integrity of cover material over everything but the currently active face. Proper waste compaction also helps to control odors. Consider implementing gas controls if odors are associated with gases generated from a unit.

If odors emanate from surface impoundments, there are several options available for control, including biological and chemical treatment. The type of treatment for an impoundment should be determined on a site-specific basis, taking into account the chemistry of the waste.

Practices to control odor are especially important at land application units. If land application is used, it is important to apply waste at appropriate rates for site conditions, and design and locate waste storage facilities to minimize odor problems. Make it a priority to minimize potential odors by applying wastes as soon as possible after delivery and incorporating wastes into the soil as soon as possible after application. Cleaning trucks, tanks, and other equipment daily (or more frequently, if necessary) can also help reduce odor. Avoid applying waste when soils are wet or frozen or when other soil or slope conditions would cause ponding or poor drainage. Chapter 7 Section C– Designing a Land Application Program presents information concerning an odor management plan for land application facilities.

Other methods of controlling odors include:

- Covering or enclosing the unit.
- Adding chemicals such as chlorine, lime, and ferric chloride to reduce bacterial activity and oxidize many products of anaerobic decomposition.
- Using biofilters.
- Applying a deep soil cover, whose upper layers consist of silty soils or soils containing a large percentage of carbon or humic material.
- Applying a layer of relatively impermeable soil, so as to reduce gas gen-

eration rates by reducing the amount of rainfall water percolating into the waste.

- Restoring landfill surface covers when subsidence and cracks occur.

Choosing a method for controlling odors involves a comprehensive understanding of wastes and how they react under certain circumstances. Consult with state agencies to determine the most effective odor control method for the wastes in question.

In addition to these steps to control odor generation, consider steps to manage those odors that are generated. When designing a waste management unit, consider installing barriers such as walls, berms, embankments, and dense plantings of trees set at right angles to the flow of cold, odorous nighttime air. These measures can help to impede the odor and dilute it through mixture with higher layers of fresh air. Alternatively, consider placing an impermeable fence or wall on top of a berm or embankment, on its downwind side. This will increase odor plume height, and odors will be diluted on the steep downslope side of the barrier as a result of turbulent mixing of air layers as the cold air flows over it. Try to locate such barriers as close to the unit as possible.

Another design suggestion is to plant fast-growing evergreen trees which have good windbreak properties in buffer-zones around a unit. In addition to dispersing odors, dense plantings of evergreen trees will also help to protect the unit itself from strong winds, reducing the possibility of windblown soil erosion.

How can disease vectors be controlled?

Disease vectors are animals or insects, such as rodents, birds, flies, and mosquitos, that can transmit disease to humans. Burrowing animals, such as gophers, moles, and groundhogs, can also damage vital unit structures, such as liners, final cover materials, drainage ditches, and sedimentation ponds. As a result, these animals can create costly problems.

Consider the following methods to control disease vectors:

- Apply adequate daily cover. This simple action is often all that is needed to control many disease vectors.
- Make sure the unit is properly drained, reducing the amount of standing water that acts as a breeding medium for insects.
- As a last resort, or when the application of cover material is impractical, consider using repellents, insecticides, rodenticides, or pest reproductive control. Care must be taken to make sure that pesticides are used only in accordance with specified uses and application methods. Follow the instructions carefully when using these products. Trapping animals might also be considered, but trapping alone rarely eliminates the problem.

If land applying wastes, subsurface injection and prompt incorporation of waste can help control vectors. Both of these methods work by using the soil as a barrier between the waste and the vectors. If a waste storage facility exists, these can attract vectors as well and should not be overlooked in the implementation of vector control. If vector problems arise

Operating the Waste Management System Activity List

- ❑ Develop a waste management system identifying the standard procedures necessary for a unit to operate according to its design throughout the intended working life.
- ❑ Provide proper maintenance and operation of ground-water, surface-water, and air controls.
- ❑ Develop daily procedures to place waste, operate environmental controls, and inspect and maintain the unit.
- ❑ Review at a regular interval, such as annually, whether the waste management system needs to be updated.
- ❑ Develop a waste analysis procedure to ensure an understanding of the physical and chemical composition of the waste to be managed.
- ❑ Develop regular schedules for waste screening and for unit inspections.
- ❑ If daily cover is recommended, select an appropriate daily cover and establish processes for placing and covering waste.
- ❑ Consider how operations can be affected by climate conditions.
- ❑ Implement security measures to prevent unauthorized entry.
- ❑ Provide personnel with proper training.
- ❑ Establish emergency response procedures and familiarize employees with emergency equipment.
- ❑ Develop procedures for maintaining records.
- ❑ Establish nuisance controls to minimize dust, noise, odor, and disease vectors.

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Part V
Ensuring Long-Term Protection

Chapter 9
Monitoring Performance

Contents

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Monitoring Performance

This chapter will help you:

- *Carefully design and implement a monitoring program that is essential to evaluating whether a unit meets performance objectives and whether there are releases to, and impacts on, the surrounding environment that need to be corrected.*
- *Design effective monitoring programs that protect the environment, improve unit performance, and help reduce long-term costs and liabilities associated with industrial waste management.*

Monitoring the performance of a waste management unit is an integral part of a comprehensive waste management system. A properly implemented monitoring program provides an indication of whether a waste management unit is functioning in accordance with its design, and detects any changes in the quality of the environment caused by the unit. The detection information obtained from a monitoring program can be used to ensure that the proper types of wastes are being managed in the unit, discover and repair any damaged area(s) of the unit, and determine if an alternative management approach might be appropriate. By implementing a monitoring program, facility managers can identify problems or releases in a timely fashion and take the appropriate measures to limit contamination. Continued detection of contamination in the environment could result in the implementation of more aggressive corrective action measures to remediate releases.

> This chapter will address the following questions.
>
> - What site characterizations are needed to develop an effective monitoring program?
> - What are the basic elements of a monitoring program?
> - How should sampling and analytical protocols be used in a monitoring program?
> - What procedures should be used to evaluate monitoring data?
> - What elements of the basic monitoring program can be modified to address site conditions?

This chapter highlights issues associated with establishing a ground-water monitoring program because most industrial waste management units need to have such a program. The chapter also provides a discussion of air, surface water, and soil monitoring that might be applicable to some units managing industrial waste. You should consult with qualified professionals, such as engineers and ground-water specialists,[1] for technical assistance in making decisions about the design and operation of a ground-water monitoring program. In

[1] For the purpose of this chapter, a qualified "ground-water specialist" refers to a scientist or engineer who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

addition when questions arise concerning soil, air, or surface-water monitoring, you should also consult specialists in these areas as each media requires different expertise.

I. Ground-Water Monitoring

The basic elements of a ground-water monitoring program include:

- The monitoring method.
- The number of wells.
- Location and screened intervals of wells.
- Well design, installation, and development.
- The duration and frequency of monitoring.
- Sampling parameters to be monitored.

The remainder of this section provides a brief overview of the six basic elements of a ground-water monitoring program, along with a discussion of the importance of a hydrogeological characterization.

A. Hydrogeological Characterization

An accurate hydrogeological characterization is the foundation of an effective ground-water monitoring system. The goal of a hydrogeological characterization is to acquire site-specific data to enable the development of an appropriate ground-water monitoring program for a site. In some instances, a complete hydrogeological characterization might not be necessary due to the type of unit being considered, the type of waste being managed, or the climate. The design of the ground-water monitoring program should be based upon the following site-specific data:

- The lateral and vertical extent of the uppermost aquifer.
- The lateral and vertical extent of the upper and lower confining units/layers.
- The geology at the waste management unit's site, such as stratigraphy, lithology, and structural setting.
- The chemical properties of the uppermost aquifer and its confining layers

Why is it important to use a qualified professional?

- Site characterizations can be extremely complex.
- Incorrect or incomplete characterizations could result in inaccurate detection of contamination in the ground water due to improper placement of ground-water monitoring wells and can cost a significant amount of money. Incorrect or incomplete characterizations could also result in the installation of unnecessary monitoring wells at significant cost.
- You should always use a qualified professional to conduct site characterizations. Check to see if the professional has sufficient training and experience in ground-water hydrology and related fields, as demonstrated by state registration, professional certification, or completion of accredited university programs. These professionals should be experienced at analyzing ground-water flow and contaminant fate and transport and at designing ground-water monitoring systems. Ensure that these professionals are familiar with the contaminants in the waste and thoroughly check their references.

relative to local ground-water chemistry and wastes managed at the unit.

- Ground-water flow, including:
  - The vertical and horizontal directions of ground-water flow in the uppermost aquifer.
  - The vertical and horizontal components of the hydraulic gradient in the uppermost aquifer and any hydraulically connected aquifer.
  - The hydraulic conductivities of the materials that comprise the uppermost aquifer and its confining units/layers.
  - The average linear horizontal velocity of ground-water flow in the uppermost aquifer.

To perform a hydrogeological characterization and develop an understanding of a site's hydrogeology, a variety of sources and kinds of information should be considered.

- **Existing information.** This can include the history of the site, including documented records describing wastes managed on site and releases. This information can help you characterize the area of the waste management unit and better understand background conditions. Some hydrogeological information might also have been developed in the past, for example during the siting process (see Chapter 4–Considering the Site). It might be useful to conduct literature reviews for research performed in the area of the unit and examine federal and state geological and environmental reports related to the site or to the region where the site is to be located. This review can often assist in better understanding the overall site geology and ground-water flow beneath the unit.
- **Site geology.** A geologic unit is typically considered to be any distinct or definable native rock or soil stratum. Characterize thickness, stratigraphy, lithology, and hydraulic characteristics of saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, in the uppermost aquifer, and in the lower confining unit of the uppermost aquifer using soil borings, drilling, or geophysical methods. Conventional soil borings are typically used to characterize onsite soils through direct sampling. Geophysical equipment, such as ground-penetrating radar, electromagnetic detection equipment, and electrical resistivity arrays, can provide non-invasive measurements of physical, electrical, or geochemical properties of the site. Understanding the different strata can help identify the appropriate ground-water monitoring well locations and screen depths.
- **Ground-water flow beneath the site.** Across the United States, ground-water flow velocities range from several feet to over 2,000 feet per year. To determine hydraulic gradient and flow rate, you should implement a water-level monitoring program and estimate hydraulic conductivity. This program should include measurements of seasonal and temporal fluctuations in flow, the effect of site construction and operations on ground-water flow direction, and variations in ground-water elevation. Information on water-level monitoring programs and procedures for obtaining accurate water level measurements can be found in EPA's *Municipal Solid Waste Landfill Technical Guidance Document* (U.S. EPA, 1988).

The level of effort one employs to characterize a site sufficiently to design an adequate ground-water monitoring system depends on the geologic and hydrogeologic complexity of the site. The complexity of a site should not be assumed; a soil boring program can help determine the complexity of a site's hydrogeology. The American Society for Testing and Materials' (ASTM) *Annual Book of ASTM Standards*[2] provides more than 80 guides and practices related to waste and site characterization and sampling. For additional information on ground-water monitoring, see EPA's *Ground-Water Monitoring: Draft Technical Guidance* (U.S. EPA, 1993a) and *Solid Waste Disposal Facility Criteria: Technical Manual* (U.S. EPA, 1993b).

B. Monitoring Methods

Ground-water monitoring usually involves the installation of permanent monitoring wells for periodic collection of ground-water samples. Waste constituent migration can be monitored by sampling ground water for either contaminants or geophysical parameters. Ground water also can be sampled through semi-permanent conventional monitoring wells or by temporary direct-push sampling. Conventional monitoring wells, direct-push sampling, and geophysical methods are described below.

1. Conventional Monitoring Wells

The conventional monitoring well is the most common type used to target a single screened interval. Figure 1 presents an illustration of a single screened interval. Specific construction features are described in more detail below. The conventional monitoring well is semi-permanent, meaning it can be used for sampling over an extended period of time and should be located by professionally surveyed reference points. To monitor more than one depth at a single location, you should install conventional monitoring wells in clusters or with multilevel sampling devices.

2. Direct-Push Ground-Water Sampling

Using the direct-push technique, ground water is sampled by hydraulically pressing and/or vibrating a probe to the desired depth and retrieving a ground-water sample through the probe. The probe is removed for reuse elsewhere after the desired volume of ground water is extracted. It is important to clean the probe with an appropriate decontamination protocol after each use to avoid potential cross-contamination.

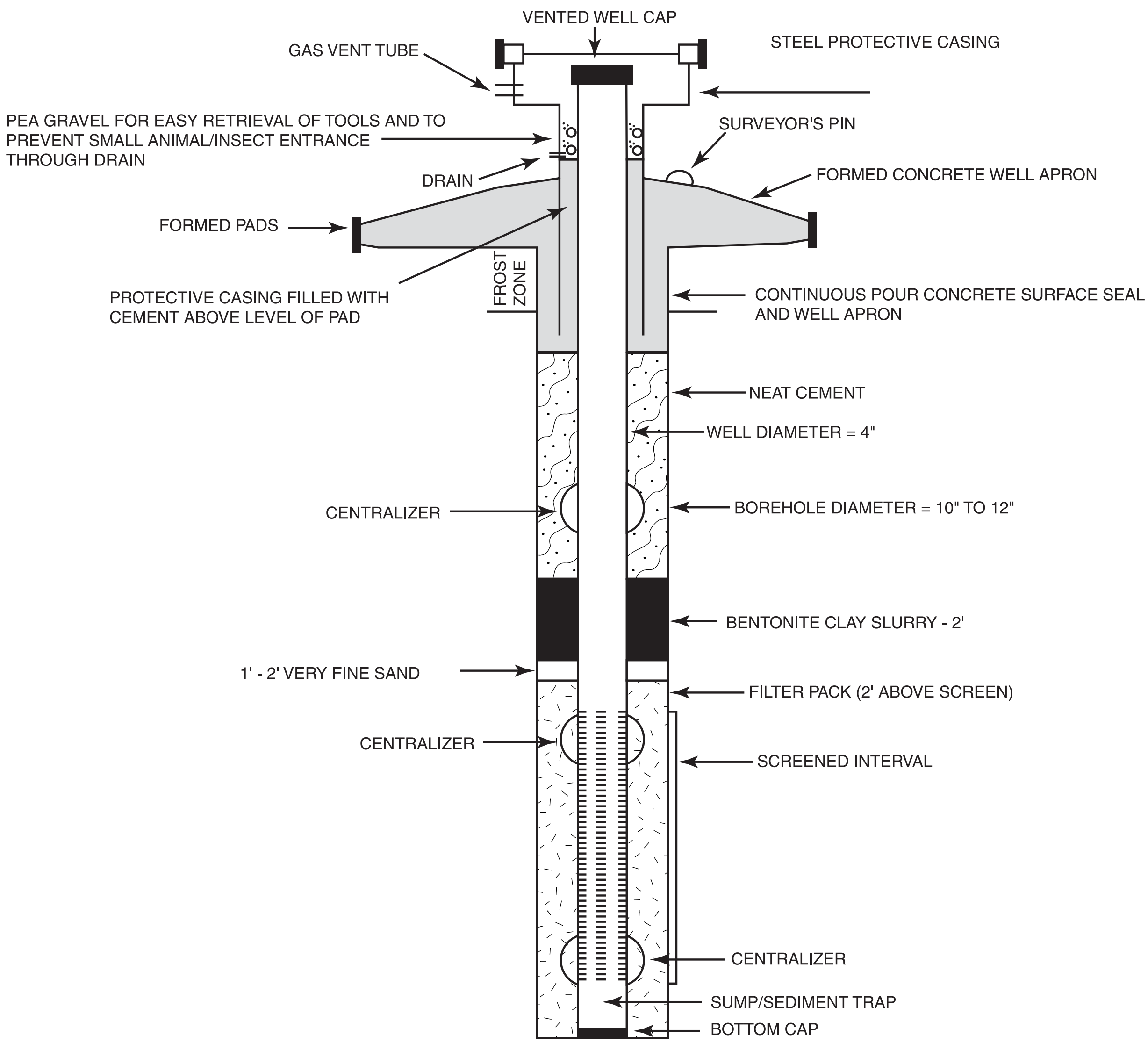
What are the benefits of direct-push sampling?

Given favorable geology, the direct-push method of ground-water sampling can be a simpler and less expensive alternative to conventional wells. Conventional monitoring wells, because they are semi-permanent, generally cost more and take longer to install. Direct-push technology, however, does not provide a semi-permanent structure from which to sample the ground water over an extended period of time, as do conventional wells. Also, some states only allow the use of direct-push technology as an initial screening technique or as a complement to conventional monitoring wells.

In sandy aquifers, however, the direct-push technology can be used to install a well similar to a conventional monitoring well. Relatively recent advances in direct-push technology use pre-packed screens with grouts and seals attached to a metal pipe that are driven into the ground, forming an assembly similar to a conventional well. The appropriate state agency will be able to tell you whether direct-push well installations are acceptable.

[2] ASTM's *Annual Book of ASTM Standards* is available in hard copy or on CD-ROM through ASTM's online bookstore at **<www.astm.org>**.

Figure 1. Cross-Section of a Generic Monitoring Well



Source: U.S. EPA, 1993a

3. Geophysical Methods

Geophysical methods measure potential changes in ground-water quality by measuring changes in the geophysical characteristics of the sub-surface soils, and in some cases, in the ground water itself. For example, increases in the levels of certain soluble metals in ground water can change the resistive properties of the ground water, which can be measured using surface resistive technologies. Similarly, changes in the resistive properties of the vadose zone might indicate the migration of leachate toward ground water.

Geophysical characteristics, such as DC-resistivity, electromagnetic induction, pH, and temperature, can provide important preliminary indications of the performance of the liner system design. You should consult with the appropriate state agency regarding the use of a geophysical method. (See *Subsurface Characterization and Monitoring Techniques* (U.S. EPA, 1993) for additional information on the use of geophysical methods).

How useful is geophysical method data?

Geophysical methods are more commonly used to map the initial extent of contamination at waste management units than for ongoing monitoring. Initial monitoring data can guide the placement of permanent monitoring wells for ongoing monitoring. As discussed later, geophysical methods, used in conjunction with ground-water monitoring, can reduce the frequency of well sampling, which could reduce monitoring costs. The usefulness of geophysical methods, however, will depend on the local hydrogeology, the contaminant concentration levels, and type of contaminants.

C. Number of Wells

It is recommended that a ground-water monitoring system have a minimum of one upgradient (or background) monitoring well, and three downgradient monitoring wells to make statistically meaningful comparisons of ground-water quality. The upgradient or background well(s) permit the assessment of the background quality of onsite ground water. The downgradient wells permit detection of any contaminant plumes from a waste management unit. The actual number of upgradient and downgradient wells will vary from unit to unit depending on the actual site-specific conditions. The actual number of upgradient and downgradient monitoring wells and their distribution will influence the selection of appropriate statistical method. If an insufficient number of background wells are used, the use of an inter-well evaluation might not be possible. Site-specific conditions that influence the number of upgradient and downgradient wells include:

- Geology of the waste management unit site.
- Ground-water flow direction and velocity, including seasonal and temporal fluctuations.
- Permeability or hydraulic conductivity of any water-bearing formations.
- Physical and chemical characteristics of contaminants.
- Area of waste management unit.

The number of wells is dependent on the lateral and vertical placement of monitoring wells, which is determined by the geology and hydrogeology of the site. Other factors influencing the number of wells include the number of potential contaminant migration pathways; the spatial distribution of potential contaminant migration pathways; and the depth and thickness of stratigraphic horizons that can serve as contaminant migration pathways. The number of wells needed will also vary according to the need for samples from different depths in the aquifer. This is a function of hydrogeologic factors and the chemical and physical characteristics of contaminants. The next section provides a detailed discussion of the lateral and vertical placement of monitoring wells.

A larger number of monitoring wells might be needed at sites with complex hydrogeology. If a site has multiple waste management units, use of a multi-unit ground-water monitoring system can reduce the necessary number of wells. You should consult with the appropriate state agency when determining a site's ground-water monitoring well requirements.

D. Lateral and Vertical Placement of Wells

The lateral and vertical placement of monitoring wells is very site-specific. (Monitoring wells should yield ground-water samples from the targeted aquifer(s) that are representative of both the quality of background ground water and the quality of ground water at a downgradient monitoring point.) Locate monitoring wells at the closest practicable distance from the waste management unit boundary to detect contaminants before they migrate away from the unit. Early detection provides a warning of potential waste management unit design failure and allows time to implement appropriate abatement measures and potentially eliminate the need for more extensive corrective action. It also reduces the area exposed and can limit overall liability.

1. Lateral Placement

Monitoring wells should be placed laterally along the down-gradient edge of the waste management unit to intercept potential contaminant migration pathways. Ground-water flow direction and hydraulic gradient are two major determining factors in monitoring well placement. Placement of monitoring wells should also take into account the number and spatial distribution of potential contaminant migration pathways and the depths and thickness of stratigraphic horizons that can serve as contaminant migration pathways. In homogeneous, isotropic hydrogeologic sites, ground-water flow direction and hydraulic gradient, along with the potential contaminant's chemical and physical characteristics, will primarily determine lateral well placement. In a more complex site where hydrogeology and geology are variable and preferential pathways exist, (a heterogeneous, anisotropic hydrogeologic site, for example) the well placement determination becomes more complex. Potential migration pathways are influenced by site geology including changes in hydraulic conductivity, fractured or faulted zones, and soil chemistry. Human-made features that influence ground-water flow should also be considered. These features include ditches, filled areas, buried piping, buildings, leachate collection systems, and other adjacent disposal units.

Another point of consideration is seasonal change in ground-water flow. Seasonal changes in ground-water flow can result from seasonal changes in precipitation patterns, tidal influences, lake or river stage fluctuations, well pumping, or land use pattern changes. At some sites it might even be possible that ground water flows in all directions from a waste management unit. These contingencies might call for placement of monitoring wells in a circular pattern to monitor on all sides of the waste management unit. Seasonal fluctuations might cause certain wells to be downgradient only part of the time, but such configurations ensure that releases will be detected.

Lateral placement of monitoring wells also depends upon the chemical and physical characteristics of a waste management unit's constituents. Consider potential contaminant characteristics such as solubility, Henry's law constant, partition coefficients, specific gravity (density), potential for natural attenuation and the resulting reaction or degradation products, and the potential for contaminants to degrade confining layers. A dense non-aqueous phase liquid (DNAPL), for instance, because of its density might not necessarily migrate only in the direction of the ground-water flow. The presence of DNAPLs, therefore, can result in placing wells in more locations than just the normal downgradient sites.

2. Vertical Placement and Screen Lengths

Similar to lateral placement, vertical well placement in the ground water around a waste management unit is determined by geologic and hydrogeologic factors, as well as the chemical and physical characteristics of the potential contaminants. The vertical placement of each well and its screen lengths will be determined by the number and spatial distribution of potential contaminant migration pathways and the depth and thickness of potential migration pathways. Site-specific geology, hydrogeology, and constituent characteristics influence the location, size, and geometry of potential contaminant plumes, which in turn determine monitoring well depths and screen lengths.

The chemical and physical characteristics of potential contaminants from a waste management unit play a significant role in determining vertical placement. The specific properties of a particular contaminant will determine what potential migration pathway it might take in an aquifer. The specific characteristics of a contaminant, such as its solubility, Henry's law constant, partition coefficients, specific gravity (density), potential for natural attenuation and the resulting reaction or degradation products, and the potential for contaminants to degrade confining layers, will all influence the vertical placement and screen lengths of a unit's monitoring wells. A DNAPL, for instance, will sink to the bottom of an aquifer and migrate along geologic gradients (rather than hydrogeologic gradients), thus a monitoring well's vertical placement should correspond with the depth of the appropriate geologic feature. LNAPLs (light non-aqueous phase liquids), on the other hand, would move along the top of an aquifer, and result in placement of wells and wells screens at the surface of the aquifer.

Well screen lengths are also determined by site- and constituent-specific parameters. These parameters and the importance of taking vertically discrete ground-water samples, factor into the determination of well screen size. Highly heterogeneous (complex) geologic sites require shorter well screen lengths to allow for the sampling of discrete migration pathway. Screens that span more than a single contaminant migration pathway can cause cross contamination, possibly increasing the extent of contamination. Shorter screen lengths allow for more precise monitoring of the aquifer or the portion of the aquifer of concern. Excessively large well screens can lead to the dilution of samples making contaminant detection more difficult.

The depth or thickness of an aquifer also influences the length of the well screen. Sites with highly complex geology or relatively thick aquifers might require multiple screens at varying depths. Conversely, a relatively thin and homogenous aquifer might allow for fewer wells with longer screen lengths. Table 1 below summarizes the recommended factors to consider when determining the number of wells needed per sampling location.

You should consult with state officials on the lateral and vertical placement of monitoring wells including well screening lengths. In the absence of specific state requirements, it is recommended that the monitoring points be no more than 150 meters downgradient from a waste management unit boundary, on facility property, and placed in potential contamination migration pathways. This maximum distance is consistent with the approach taken in many states in order to protect waters of the state.

Table 1
Factors Affecting Number of Wells Per Location (CLUSTER)

One Well per Sampling Location	More Than One Well Per Sampling Location
No light non-aqueous phase liquids (LNAPLs) or dense non-aqueous phase liquids (DNAPLs) (immiscible liquid phases)	Presence of LNAPLs or DNAPLs
Thin flow zone (relative to screen length) Horizontal flow predominates	Thick flow zones Vertical gradients present
Homogeneous isotropic uppermost aquifier, simple geology	Heterogeneous anisotropic uppermost aquifier, complicated geology - multiple, interconnected aquifiers - variable lithology - perched water zones - discontinuous structures Discrete fracture zones in bedrock Solution conduits, such as caves, in karst terrains Cavernous basalts

E. Monitoring Well Design, Installation, and Development

Ground-water monitoring wells are tailored to suit the hydrogeologic setting, the type of constituents to be monitored, the overall purpose of the monitoring program, and other site-specific variables. You should consult with the appropriate state agency and qualified professionals to discuss the design specifications for ground-water monitoring wells before beginning construction. Figure 1 illustrates the design components that are discussed in this section. The *Annual Book of ASTM Standards* includes guides and practices related to monitoring well design, construction, development, maintenance, and decommissioning. EPA's *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (U.S. EPA, 1989) also contains this information.

1. Well Design

The typical components of a monitoring well include a well casing, a well intake, a filter pack, an annular and surface seal, and surface completion. Each of these components is briefly described below.

Well Casing

The well casing is a pipe which is installed temporarily or permanently to counteract caving and to isolate the zone being monitored. The well casing provides access from the surface of the ground to some point in the subsurface. The casing, associated seals, and grout prevent borehole collapse and interzonal hydraulic communication. Access to the monitored zone is through the casing and either the screened intake or the open borehole. (Note: some states do not allow the use of open borehole monitoring wells. Check with the state agency to determine whether this type of monitoring well design is acceptable.) The casing thus permits piezometric head measurements and ground-water quality sampling.

A well casing can be made of an appropriate rigid tubular material. The most frequently evaluated characteristics that directly influence the performance of casing material in ground-water monitoring applications are strength, chemical resistance, and interference. The monitoring well casing should be strong enough to resist the forces exerted on it by the surrounding geologic materials and the forces imposed on it during installation. Casings should exhibit structural integrity for the expected duration of the monitoring program under natural and man-induced subsurface conditions. Well casing materials should also be durable enough to withstand galvanic or electrochemical corrosion and chemical degradation. Metallic casing materials are most subject to corrosion and thermoplastic casing materials are most subject to chemical degradation. In addition, casing materials should not exhibit a tendency to either sorb chemical constituents from (i.e., take constituents out of solution by either adsorption or absorption) or leach chemical constituents into the water that is sampled from the well. If casing materials sorb selected constituents, the water-quality sample will not be representative.

The three most common types of casing materials are fluoropolymer materials, including polytetrafluoroethylene (PTFE) and tetrafluoroethylene (TFE); metallic materials, including carbon steel, galvanized steel, and stainless steel; and thermoplastic materials, including polyvinyl chloride (PVC) and acrylonitrile butadiene styrene (ABS). Threaded, flush casing joints that do not require glue should be used. Another option is the use of PTFE tape or o-rings at the threaded joints.

Well Screen

A well screen is a filtering device used to retain the primary or natural filter pack; it is usually a cylindrical pipe with openings of a uniform width, orientation, and spacing. It is often important to design the monitoring well with a well intake (well screen) placed opposite the zone to be monitored. The intake should be surrounded by materials that are coarser, have a uniform grain size, and have a higher permeability than natural formation material. This allows ground water to flow freely into the well from the adjacent formation material while minimizing or eliminating the entrance of fine-grained materials, such as clay or sand, into the well.

A well screen design should consider: intake opening (slot) size, intake length, intake type, and corrosion and chemical-degradation resistance. Proper sizing of monitoring well intake openings is one of the most important aspects of monitoring well design. The selection of the length of a monitoring well intake depends on the purpose of the well. Most monitoring wells function as both ground-water sampling points and piezometers[3] for a discrete interval. To accomplish these objectives, well intakes are typically 2 to 10 feet in length and only rarely equal or exceed 20 feet in length. The hydraulic efficiency of a well intake depends primarily on the amount of open area available per unit length of intake. The amount of open area in

[3] A piezometer is a non-pumping well, generally of small diameter, used to measure the elevation of the water table.

a well intake is controlled by the type of well intake it is and its opening size. Many types of well intakes have been used in monitoring wells, including: the louvered (shutter-type) intake, the bridge-slot intake, the machine-slotted well casing, and the continuous-slot wire-wound intake.

Filter Pack

Filter pack is the material placed between the well screen and the borehole wall that allows ground water to flow freely into the well while filtering out fine-grained materials. It is important to minimize the distortion of the natural stratigraphic setting during construction of a monitoring well. Hence, it might be necessary to filter-pack boreholes that are over-sized with regard to the casing and well intake diameter. The filter pack prevents formation material from entering the well intake and helps stabilize the adjacent formation. The filter-pack materials should be chemically inert to avoid the potential for alteration of ground-water sample quality. Commonly used filter-pack materials include clean quartz sand, gravel, and glass beads. You should check with the state regulatory agency to determine if state regulations specify filter pack grain size, either in absolute terms or relative to the grain size of the water bearing zone, or a uniformity coefficient.

The filter pack should generally extend from the bottom of the well intake to approximately two to five feet above the top of the well intake, provided the interval above the well intake does not result in a hydraulic connection with an overlying zone. To ensure that filter pack material completely surrounds the screen and casing without bridging, the filter pack can be placed with a tremie pipe (a small diameter pipe that carries the filter pack material directly to the filter screen without creating air pockets within the filter pack). A layer of fine sand can also be placed on top of the filter pack to minimize migration of annular seal material (see below) into the filter pack.

Annular Seal

Annular space is the space between the casing and the borehole wall. Any annular space that is produced as a result of the installation of well casing in a borehole provides a channel for vertical movement of water and/or contaminants unless the space is sealed. The annular seal in a monitoring well is placed above the filter pack in the annulus between the borehole and the well casing. The seal serves several purposes: to provide protection against infiltration of surface water and potential contaminants from the ground surface down the casing/borehole annulus; to seal off discrete sampling zones, both hydraulically and chemically; and to prohibit vertical migration of water. Such vertical movement can cause “cross contamination” which can influence the representativeness of ground-water samples. The annular seal can be comprised of several different types of permanent, stable, low-permeability materials including pelletized, granular, or powdered bentonite; neat cement grout; and combinations of both. The most effective seals are obtained by using expanding materials that will not shrink away from either the casing or the borehole wall after curing or setting.

Surface Seal

A surface seal is an above-ground seal that protects a monitoring well from surface water and contaminant infiltration. Monitoring wells should have a surface seal of neat cement or concrete surrounding the well casing and filling the annular space between the casing and the borehole at the surface. The surface seal can be an extension of the annular seal installed above the filter pack, or it can be a separate seal placed on top of the annular seal. The surface seal will generally extend to at least three feet away from the well casing at the surface and taper down to the size of the borehole within a few feet of the surface. In climates with alternating freezing and thawing conditions, the cement surface should extend below the frost depth to prevent potential well damage caused by frost heaving.

Surface Completions

Surface completions are protective casings installed around the well casing. Two types of surface completions are common for ground-water monitoring wells: above-ground completion, and flush-to- ground completion. The primary purposes of either type of completion are to prevent surface runoff from entering and infiltrating down the annulus of the well and to protect the well from accidental damage or vandalism.

In an above-ground completion, which is the preferred alternative, a protective casing is generally installed around the well casing by placing the protective casing into the cement surface seal while it is still wet and uncured. The protective casing discourages unauthorized entry into the well, prevents damage by contact with vehicles, and reduces degradation caused by direct exposure to sunlight. The protective casing should be fitted with a locking cap and installed so that there are at least one to two inches clearance between the top of the in-place, inner well, casing cap and the bottom of the protective casing locking cap when in the locked position.

Like the inner well casing, the outer protective casing should be vented near the top to prevent the accumulation and entrapment of potentially explosive gases and to allow water levels in the well to respond naturally to barometric pressure changes. Additionally, the outer protective casing should have a drain hole installed just above the top of the cement level in the space between the protective casing and the well casing. This drain allows trapped water to drain away from the casing. In high-traffic areas or in areas where heavy equipment might be working, consider the installation of additional protection such as "bumper guards." Bumper guards are brightly-painted posts of wood, steel, or some other durable material set in cement and located within three or four feet of the well.

2. Well Installation

To ensure collection of representative ground-water samples, the well intake, filter pack, and annular seal need to be properly installed. In cohesive unconsolidated material or consolidated formations, well intakes should be installed as an integral part of the casing string by lowering the entire unit into the open borehole and placing the well intake opposite the interval to be monitored. Centralizing devices are typically used to center the casing and intake in the borehole to allow uniform installation of the filter pack material around the well intake. In non-cohesive, unconsolidated materials there are other standardized techniques to ensure the proper installation of wells, such as the use of a casing hammer, a cable tool technique, the dual-wall reverse-circulation method, or installation through the hollow stem of a hollow-stem auger.

3. Well Development

Monitoring well development is the removal of fine particulate matter, commonly clay and silt, from the geologic formation near the well intake. If particulate matter is not removed, as water moves through the formation into the well, the water sampled will be turbid, and the viability of the water quality analyses will be impaired. When pumping during well development, the movement of water is unidirectional toward the well. Therefore, there is a tendency for the particulates moving toward the well to "bridge" together or form blockages that restrict subsequent particulate movement. These blockages can prevent the complete development of the well capacity. This effect potentially impacts the quality of the water entering the well. Development techniques should remove such bridges and encourage the movement of particulates into the well. These particulates can then be removed from the well by bailer or pump and, in most cases, the water produced will subsequently be clear and non-turbid.

In most instances, monitoring wells installed in consolidated formations can be developed without great difficulty. Monitoring wells also can usually be developed rapidly and without great difficulty in sand and gravel deposits. However, many installations are made in thin, silty, and/or clayey zones. It is not uncommon for these zones to be difficult to develop sufficiently for adequate samples to be collected.

F. Duration and Frequency of Monitoring

The duration of ground-water monitoring will depend on the length of the active life of the waste management unit and its post-closure care period. Continued monitoring after a waste management unit has closed is important because the potential for contaminant releases remains even after a unit has stopped receiving waste. Monitoring frequency should be sufficient to allow detection of ground-water contamination. This frequency usually ranges from quarterly to annually.

What site characteristics should be evaluated to determine the frequency of monitoring?

Ground-water flow velocity is important in establishing an appropriate ground-water monitoring frequency to ensure that samples collected are physically and statistically independent. For example, in areas with high ground-water flow velocity, more frequent monitoring might be necessary to detect a release before it migrates and contaminates large areas. In areas with low flow velocity, less frequent monitoring might be appropriate. It is important to analyze background ground-water conditions, such as flow direction, velocity, and seasonal fluctuations to help determine a suitable monitoring frequency for a site. You should consult with the appropriate state agency to determine an appropriate monitoring frequency. In the absence of state requirements, it is recommended that semi-annual monitoring be conducted to detect contamination as part of a basic monitoring program.

G. Sampling Parameters

Selection of parameters to be monitored in a ground-water monitoring program should be based on the characteristics of waste in the management unit. Additional sampling and analysis information can be found in EPA *SW-846 Test Methods for Evaluating Solid Waste* (U.S. EPA, 1986) and in ASTM's standards. The *Annual Book of ASTM Standards* also identifies 18 ASTM guides and practices for performing waste characterization and sampling.

What are sampling parameters?

Analyzing a large number of ground-water quality parameters in each sampling episode can be costly. To minimize expense, select only contaminants and geochemical indicators that can be reasonably expected to migrate to the ground water. These are called sampling parameters. Sampling parameters should provide an early indication of a release from a waste management unit. Once contamination is detected, consider expanding the original sampling parameters and monitor for additional constituents to fully characterize the chemical makeup of the release.

What sampling parameters should be used?

Due to the broad universe of industrial solid waste, it is not possible to recommend a list of indicator papameters that are capable of identifying every possible release. It is recommended to begin by analyzing for a broad range of parameters to establish background ground-water quality, and then use the results to select the sampling parameters to be monitored subsequently at a site. Table 2 lists potential parameters for a basic ground-water monitoring program, by different categories. Modify these parameters, as appropriate, to address site-specific circumstances. Your knowledge of the actual waste streams or existing analytical data is a preliminary guide for what should be monitored, and leachate sampling data is also useful to select or adjust sampling parameters. Where there is uncertainty concerning the chemistry of the waste, you should perform metal and organic scans at a minimum. You should consult with the appropriate state agency to ensure that appropriate sampling parameters are selected.

What are the minimum components of a basic monitoring program?

Table 3 summarizes the recommended minimum components of a basic ground-water monitoring program described above. Potential modifications to the basic monitoring program that might be appropriate based on site-specific waste management unit conditions are discussed later in this chapter.

H. Potential Modifications to a Basic Ground-Water Monitoring Program

It might be appropriate to modify certain elements of the basic ground-water monitoring program described above to accommodate site-specific circumstances. When using the IWEM software to evaluate the need for a liner system, if the recommendation is to use a composite liner, then the basic ground-water monitoring program should probably be enhanced. If the recommendation using the software is that no liner is appropriate, then it might be possible to scale back some aspects of the basic ground-water monitoring program.

Components that might be subject to modification include the duration and frequency of monitoring, sampling parameters, and the use of vadose zone monitoring. Possible modifications of these elements are discussed further below. You should consult with the appropriate state officials on their requirements for ground-water monitoring programs. In some states, a unit might be eligible for a no-migration exemption from the state's ground-water monitoring requirements.

1. Duration and Frequency of Monitoring

The duration of monitoring (active life plus post-closure care) is not likely to be modified in either a reduced or an enhanced ground-water monitoring program. Adjustments to the frequency of monitoring, however, might be appropriate, based primarily on the mobility of contaminants and ground- water velocity. For example, if the sampling parameters are slow moving metals, annual rather than semi-annual monitoring might be appropriate. Conversely, quarterly monitoring might be considered at a unit with a rapid ground-water flow rate or a

Table 2
Potential Parameters for Basic Ground-Water Monitoring
(Potential Parameters Should be Selected Based on Site-Specific Circumstances)

Category	Specific Parameters
Field-Measured Parameters	Temperature pH Specific electrical conductance Dissolved oxygen Eh oxidation-reduction potential Turbidity
Leachate Indicators	Total organic carbon (TOC-filtered) pH Specific conductance Manganese (Mn) Iron (Fe) Ammonium (NH_4) Chloride (Cl) Sodium (Na) Biochemical oxygen demand (BOD) Chemical oxygen demand (COD) Volatile organic compounds (VOCs) Total Halogenated Compounds (TOX) Total Petroleum Hydrocarbons (TPH) Total dissolved solids (TDS)
Additional Major Water Quality Parameters	Bicarbonate (HCO_3) Boron (Bo) Carbonate (CO_3) Calcium (Ca) Fluoride (Fl) Magnesium (Mg) Nitrate (NO_3) Nitrogen (disolved N_2) Potassium (K) Sulfate (SO_4) Silicon (H_2SiO_4) Strontium (Sr) Total dissolved solids (TDS)
Minor and Trace Inorganics	Initial background sampling of inorganics for which drinking water standards exist (arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver); ongoing monitoring of any constituents showing background near or above drinking water standards.
Waste-Specific Constituents	Selected based on knowledge of waste characteristics (initial metals and organic scans at a minimum).

Table 3 Recommended Components of a Basic Ground-Water Monitoring Program

Monitoring Component	Recommended Minimum
Number of Wells	Minimum 1 upgradient and 3 downgradient.[4]
Point of Monitoring	Waste management unit boundary or out to 150 meters down gradient of the waste management unit area.[5]
Duration of Monitoring	Active life plus post-closure care.
Frequency of Monitoring	Semi-annual during active life.[6]
Sampling Parameters	Metal and organic scans, use of indicators, leachate analysis, and/or knowledge of the waste. See the categories listed in Table 2.

mobile contaminant such as cyanide over a permeable sand and gravel aquifer.

2. *Sampling Parameters*

The basic recommended ground-water monitoring program already recommends the use of a parameter list that is tailored to the waste characteristics and site hydrogeology. Where the use of the IWEM software indicates no liner is appropriate, it might be possible to reduce the list of parameters routinely analyzed in downgradient wells to only a few indicator parameters. More complete analysis would only be initiated if a significant change in the concentration of an indicator parameter had occurred.

3. *Vadose-Zone Monitoring*

The vadose zone is the region between the ground surface and the saturated zone. Depending on climate, soils, and geology, it can range in thickness from several feet to hundreds of feet. Vadose-zone monitoring can detect migration of contaminants before they reach ground water, serving as an early warning system if a waste management unit is not functioning as designed. It can also reduce the time and cost of remediation, and the extent of subsequent ground-water monitoring efforts.

If site conditions permit, it might be desirable to include vadose-zone monitoring as part of the overall ground-water program. If vadose-zone monitoring is incorporated, the recommended number of ground-water monitoring wells would be determined by the basic ground-water monitoring program, and background quality would still need to be characterized with ground-water monitoring. The ground-water monitoring program becomes a backup, however, with full use only being initiated if contaminant migration is detected in the vadose zone. The sections

[4] The actual number of both upgradient and downgradient wells will vary from unit-to-unit and will depend on the actual site-specific conditions.

[5] Discussion of EPA's rationale for the point of monitoring being out to 150 meters from a unit's boundary can be found in 40 CFR Part 258 criteria.

[6] Ground-water flow rate might dictate that more or less frequent monitoring might be appropriate. More frequent monitoring might be appropriate at the start of a monitoring program to establish background. Less frequent and/or reduced in scope monitoring might also be appropriate during the post-closure care period.

below describe some of the commonly used methods for vadose zone monitoring, vadose zone characterization, and elements to consider in the design of a vadose zone monitoring system.

Vadose-Zone Monitoring Methods

There are dozens of specific techniques for indirect measurement and direct sampling of the vadose zone. The more commonly used methods with potential value for waste management units are described briefly below.

Soil-Water and Tension Monitoring

Measuring changes over time in soil-water content or soil-water tension is a relatively simple and inexpensive method for leak detection. Periodic measurements of soil water content or soil moisture tension beneath a lined waste management unit, for example, should show only small changes. Significant increases in water content or decreases in moisture tension would indicate a leak.

What method should be used to measure soil moisture?

Soil-moisture characteristics can be measured in two main ways: 1) water content, usually expressed as weight percentage, and 2) soil-moisture tension, or suction, which measures how strongly water is held by soil particles due to capillary effects. As soil-water content increases, soil-moisture tension decreases. Measurements will not indicate, however, whether contaminants are present.

Figure 2 shows three major methods that are available for insitu monitoring of soil-moisture changes. Porous-cup tensiometers (Figure 2a) measure soil-moisture tension, with the pressure measurements indicated by using either a mercury manometer, a vacuum gauge, or pressure transducers. Soil-moisture resistivity sensors (Figure 2b) measure either

water content or soil-moisture tension, depending on how they are calibrated. Time-domain reflectometry probes (Figure 2c) measure water content using induced electromagnetic currents. For vadose-zone monitoring applications, the devices are usually placed during construction of a waste management unit and electrical cables run to one or more central locations for periodic measurement. The other commonly used method for monitoring soil-water content is to use neutron or dielectric probes. These require placement of access tubes, through which probes are lowered or pulled, and allow continuous measurement of changes in water content along the length of the tubes.

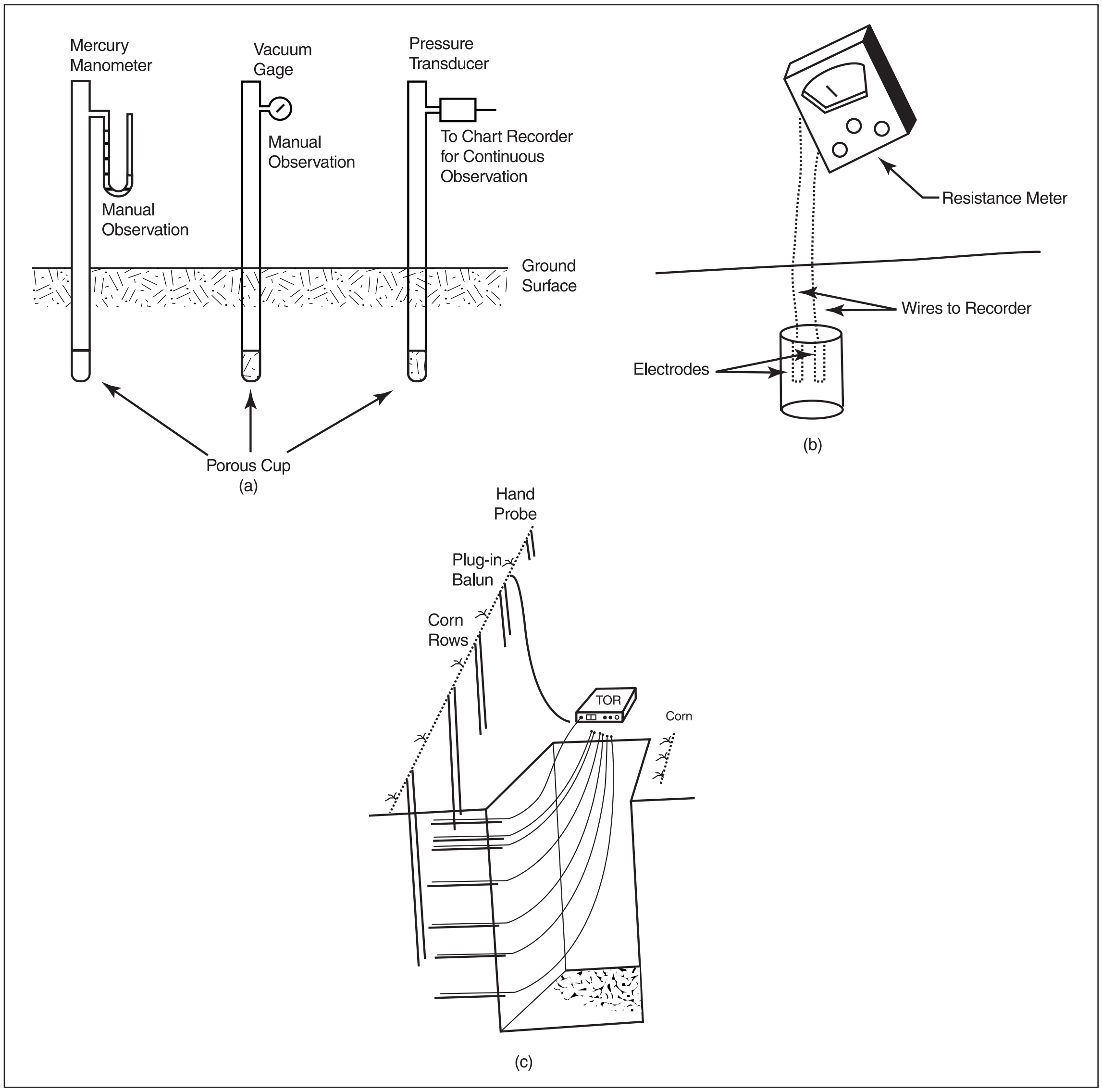
Soil-Pore Liquid Sampling

Sampling and analysis of soil-pore liquids can determine the type and concentration of contaminants that might be moving through the vadose zone. Soil-pore liquids can be collected by applying either a vacuum that exceeds the soil moisture tension, commonly done using vacuum or pressure-vacuum lysimeters, or by burying collectors that intercept drain water. Figures 3a and 3b illustrate different methods for collecting soil-pore liquids.

Soil-Gas Sampling

Soil-gas sampling is a relatively easy and inexpensive way to detect the presence or movement of volatile contaminants and gases associated with degradation of waste within a

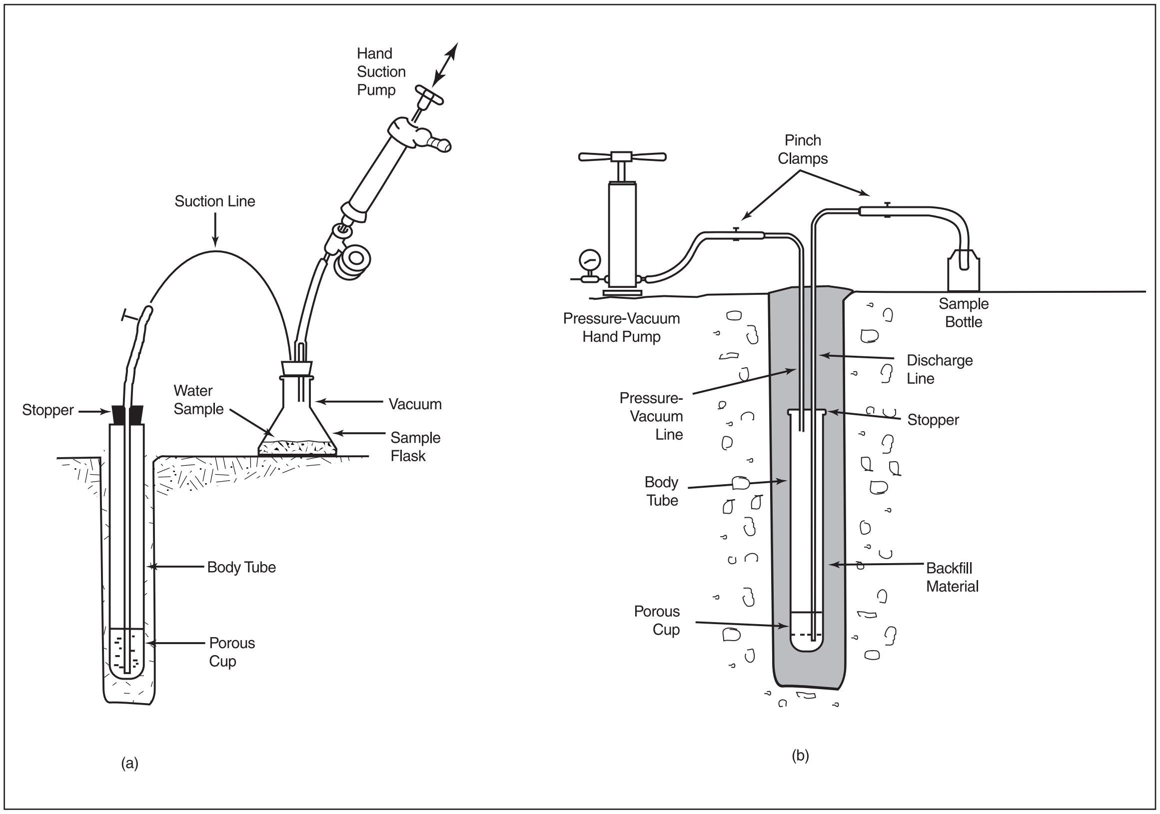
Figure 2. Major Methods for In Situ Monitoring of Soil Moisture or Matrix Potential



(a) Three Types of Porous Cup Tensiometers, (b) Resistance Sensors, and (c) Time Domain Reflectometry Probes
Sources: (a) Morrison, 1983. (b) U.S. EPA, 1993. (c) Topp and Davis, 1985, by permission.

waste management unit, such as carbon dioxide and methane. Of particular concern are gases associated with the breakdown of organic materials and toxic organic compounds. Permanent soil-gas monitoring installations consist of a probe point placed above the water table, a vacuum pump which draws soil-gas to the surface, and a syringe used to extract the gas sample, as shown in Figure 4a. Installing soil-gas probes at multiple levels, as shown in Figure 4b, allows detection of downward or upward migration of soil gases. It is important to note, however, that the performance of soil-gas sampling can

Figure 3. Example Methods for Collecting Soil-Pore Samples



(a) Vacuum Lysimeter, (b) Pressure-Vacuum Lysimeter
Source: ASTM, 1994. Copyright ASTM. Reprinted with permission.

be limited by some types of soil, such as tight clays or tight, saturated clays.

Vadose Zone Characterization

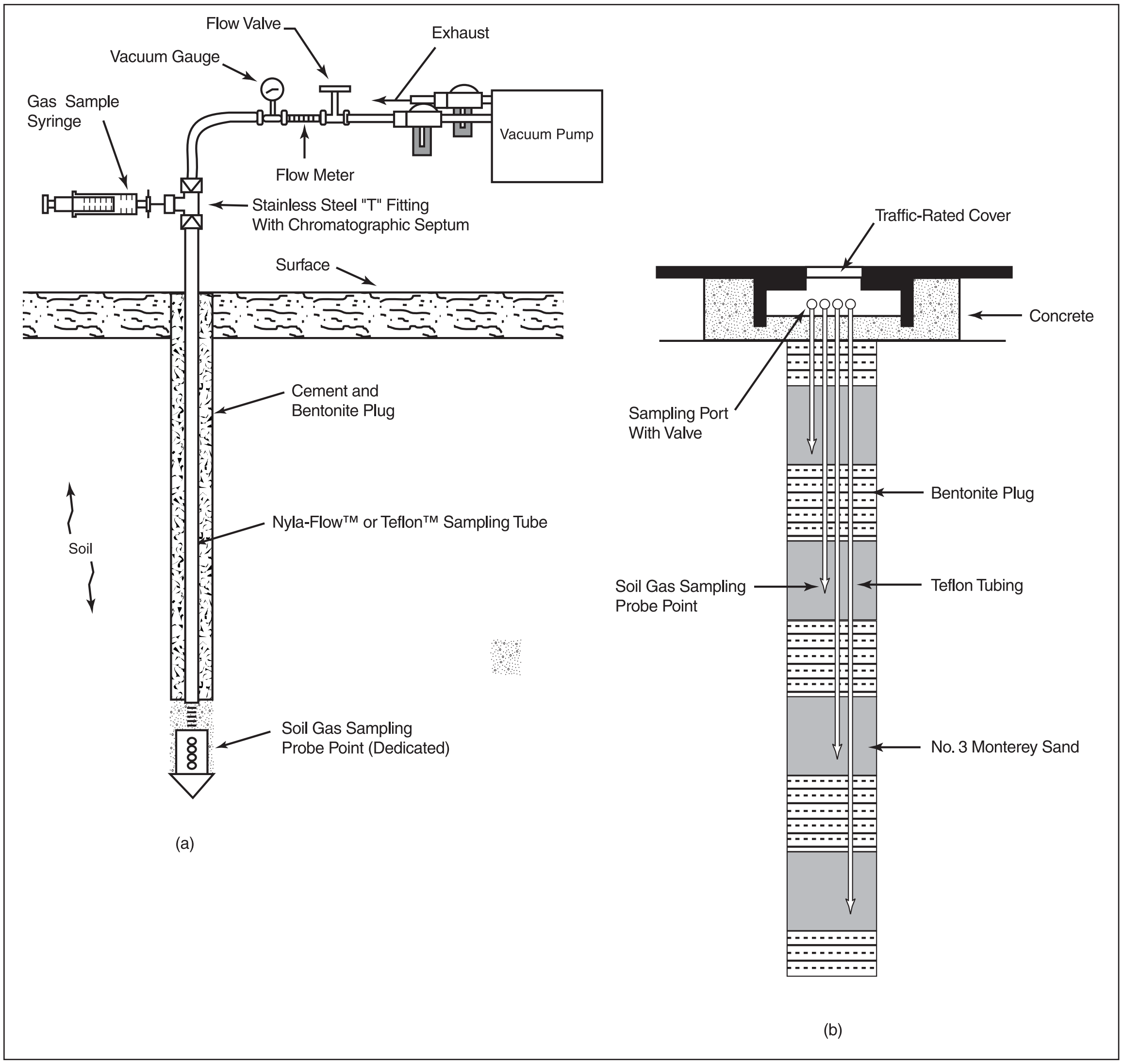
Just as the design of ground-water monitoring systems requires an understanding of the ground-water flow system, the design of vadose zone monitoring systems requires an understanding of the vadose zone flow system. For example, in ground water systems, hydraulic conductivity does not change over time at a particular-location, whereas in the vadose zone, hydraulic conductivity changes with soil-water content and soil-moisture tension. To estimate the speed with which water will move through the vadose zone, the relationship between soil-water content, soil-moisture tension, and hydraulic conductivity should be measured or estimated. Unsaturated zone numerical modeling programs, such as HYDRUS 2-D or Seep (2-D) are designed to characterize the vadose zone.

Vadose-Zone Monitoring System Design

A vadose zone monitoring system combined with a ground-water monitoring system can reduce the cost of corrective measures in the event of a release. Remedial action is usually easier and less expensive if employed before contaminants reach the ground-water flow system.

The design and installation of a vadose-zone monitoring system are easiest with new waste

Figure 4. Soil Gas Sampling Systems



(a) Gas Sampling Probe and Sample Collection Systems, (b) Typical Installation of Nested Soil Gas Probes
Source: Reprinted with permission from Wilson, et al., *Handbook of Vadose Zone Characterization and Monitoring*, 1995. Copyright CRC Press, Boca Raton, Florida.

management facilities, where soil-water monitoring and sampling devices can be placed below the site. Relatively recent improvements in horizontal drilling technology, however, now allow installation of access tubes for soil-moisture monitoring beneath existing facilities. Important factors in choosing the location and depth of monitoring points in a leak-detection network include: 1) consideration of the potential area of downward leakage, and 2) determination of the effective detection area of the monitoring device.

Cullen et al. (1995) suggest an approach to vadose zone monitoring that includes the following:

- Identification and prioritization of critical areas most vulnerable to contaminant migration.
- Selection of indirect monitoring methods that provide reasonably comprehensive coverage and cost-effective, early warning of contaminant migration.
- Selection of direct monitoring methods that provide diagnostic confirmation of the presence and migration of contaminants.
- Identification of background monitoring points that will provide hydrogeologic monitoring data representative of preexisting site conditions.
- Identification of a cost-efficient, temporal monitoring plan that will provide early warning of contaminant migration in the vadose zone.

This approach is very similar to what is described for the basic ground-water monitoring program.

II. Surface-Water Monitoring

Controlling constituent discharges to surface water from industrial waste management units is another component of responsible waste management. Monitoring can be conducted for many purposes, such as:

- Characterizing surface-water conditions and identifying changes or trends in water quality over time.
- Identifying existing or emerging water quality problems.
- Identifying the types and amounts of constituents present in the water body.
- Designing a pollution prevention program or establishing best management practices (BMPs).
- Determining whether surface-water regulations and permit conditions are being satisfied.
- Responding to emergencies, such as accidental discharges or spills.

Some types of monitoring activities meet several of these purposes simultaneously, while others are specifically designed for one purpose, such as to determine compliance with permit conditions.

If your facility is subject to a federal, state, or local permit that requires monitoring and sampling, you must collect and analyze samples according to the permit requirements. Otherwise, you should consider implementing a sampling program to monitor the quality of runoff, the performance of BMPs, and any impacts on surface waters. For further information on BMPs relating to surface-water quality, refer to Chapter 6–Protecting Surface Water. Implementation of BMPs, along with regular maintenance inspections and upkeep, will greatly reduce the potential for surface-water contamination.

When establishing any type of sampling and monitoring program, there are certain common sense guidelines to follow. Inadequate frequency of data collection and incomplete monitoring might be useless while high-frequency monitoring and sampling for numerous constituents can be costly and could create a backlog of unusable data. The following discussion summarizes what you should consider when establishing sampling programs to effectively perform surface water monitoring.

A. Monitoring Storm-Water Discharges

As discussed in Chapter 6–Protecting Surface Water, NPDES permits establish limits on what constituents (and at what amounts or concentrations) facilities may discharge to receiving surface waters. Some waste management units, such as surface impoundments, might have an NPDES permit to discharge wastewaters directly to surface waters. Other units might need an NPDES permit for storm-water discharges. An NPDES permit will also contain limits on what can be discharged, monitoring and reporting requirements, and other provisions to ensure that the discharge does not impair surface-water quality or human health. Due to the variable nature of storm-water flows during a rainfall event and the different analytical considerations for certain constituents, the sampling requirements for different waste management unit types and sampling locations will vary as well. The guidelines and general sampling procedures outlined below should be considered when developing a storm-water sampling program to comply with permit requirements or to monitor the quality of runoff and determine the effectiveness of BMPs.

Sampling a representative storm. Using climatic data, you can determine the average rainfall depth and duration of rainfall events at the waste management unit site. You should sample during a representative storm event. The representative storm should be preceded by at least 72 hours of dry weather and, when possible, should be between 50 and 150 percent of the average depth and duration. The time to collect individual grab samples is during the first flush (i.e., the first 30 minutes of the event), and composite samples should then be collected over the first 3 hours, or the entire event if less than 3 hours. These guidelines help ensure that constituents in the sampled runoff will not be so concentrated or so dilute as to be unrepresentative of the overall runoff.

Determining the sample type. A grab sample is a discrete, individual sample taken within a short period of time, usually less than 15 minutes. Analysis of a grab sample characterizes the quality of a storm water-discharge at the time the sample was taken. These types of samples can be used to characterize the maximum concentration of a constituent in the discharge.

A composite sample is a mixed or combined sample that is formed by combining a series of individual and discrete samples of specific volumes at specified intervals. These intervals can be either time-weighted or flow-weighted. Time-weighted composite samples are collected and combined in proportion to time, while flow-weighted composite samples are combined in proportion to flow. Composite samples characterize the quality of a storm-water discharge over a specific period of time, such as the duration of a storm event.

Determining the sample techniques. Grab and composite samples can be collected by either manual or automatic sampling techniques. Manual samples are simply collected by hand, while automatic samples are collected by powered devices according to preprogrammed criteria. Both techniques have advantages and disadvantages that need to be weighed when choosing a sampling technique for a specific site. The advantages of manual sampling include its appropriateness for all constituents and its lower cost compared to automatic sampling. Manual sampling, however, can be labor intensive, can expose personnel to potentially hazardous conditions, and is subject to human error.

The advantages of automatic sampling are the convenience it offers, its minimum labor requirements, its reduction of personnel exposure to hazardous conditions, and its low risk of human error. Unfortunately, automatic sampling is not suitable for all constituent types. Volatile organic compounds (VOC), for example, can not be sampled automatically due to the agitation during sample collection. This agitation can cause the VOC constituents to completely volatilize from the sample. Other constituents such as fecal streptococcus, fecal coliform, and chlorine might also not be amenable to automatic sampling due to their short holding times. Since sample temperature and pH need to be measured immediately, the option for using automatic sampling for these parameters is limited as well. Automatic sampling can also be expensive, and does require a certain amount of training. Table 4 presents a comparison of manual and automatic sampling techniques.

Sampling at the outfall point. Stormwater samples should be taken at a stormwater point source. A "point source" is defined as any discernible, confined, and discrete conveyance. The ideal sampling location is often the lowest point in a drainage area where a conveyance discharges, such as the discharge at the end of a pipe or ditch. The sample point should be easily accessible on foot and in a location that will not cause hazardous sampling conditions. You should not sample during dangerous wind, lightning, flooding, or other unsafe conditions. If these conditions are unavoidable during an event, then the sampling should be delayed until a less hazardous event occurs. Preferably, the sampling location will be located onsite, but if it is not, obtain permission from the owner of the property where the discharge is located. Inaccessible discharge points, numerous small point discharges, run-on from other properties, and infinite other scenarios can cause logistical problems with sampling locations. If the discharge is inaccessible or not likely to be representative of the runoff, samples might need to be taken at a point further upstream of the discharge pipe or at several locations to best characterize site runoff.

Coordinating with the laboratory. It is important to collect adequate sample volumes to complete all necessary analyses. When testing for certain constituents, samples might need to be cooled or otherwise preserved until analyzed to yield meaningful results. Section 3.5 of EPA's *NPDES Storm Water Sampling Guidance Document* (U.S. EPA, 1992) contains information on proper sample handling and preservation procedures. Submitting the proper information to the laboratory is important in ensuring proper sample handling by the laboratory. Proper sample documentation guidelines are outlined in Section 3.7 of the *NPDES Storm Water Sampling Guidance Document*. Coordination with the laboratory that will be performing the analysis will help ensure that these issues are adequately addressed.

You are required to follow all sampling and monitoring requirements in an NPDES permit. If there are no sampling requirements, analyze runoff for basic constituents, such as oil and grease, pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), phosphorus, and nitrogen, as well as any other constituents known or suspected to be present in the waste, such as heavy metals or other toxic constituents.

Additional sampling guidance can be obtained from EPA's *NPDES Storm Water Sampling Guidance Document* (U.S. EPA, 1992) and *Interim Final RCRA Facility Investigation (RFI) Guidance: Volume III* (U.S. EPA, 1989). In addition, state and local environmental agencies also have guidance on appropriate sampling methods.

There is a national system that provides permitting information for facilities holding

Table 4
Comparison of Manual and Automatic Sampling Techniques

Sample Method	Advantages	Disadvantages
Manual Grabs	• Generally appropriate for all constituents • Minimum equipment required	• Labor-intensive • Environment possibly dangerous to field personnel • Might be difficult to get personnel and equipment to the storm water outfall within the first 30 minutes of the event • Possible human error
Manual Flow-Weighted Composites (multiple grabs)	• Generally appropriate for all constituents • Minimum equipment required	• Labor-intensive • Environment possibly dangerous to field personnel • Human error can have significant impact on sample representativeness • Requires that flow measurements be taken during sampling
Automatic Grabs	• Minimizes labor requirements • Low risk of human error • Reduced personnel exposure to unsafe conditions • Sampling can be triggered remotely or initiated according to present conditions	• Samples not collected for oil and grease, might not be representative • Automatic samplers generally cannot properly collect samples for VOC analysis • Costly if numerous sampling sites require the purchase of equipment • Can require equipment installation and maintenance; can malfunction • Can require operator training • Might not be appropriate for pH and temperature • Might not be appropriate for parameters with short holding times (e.g., fecal streptococcus, fecal coliform, chlorine) • Cross-contamination of aliquot if tubing/bottles not washed
Automatic Flow-Weighted Composites	• Minimizes labor requirements • Low risk of human error • Reduced personnel exposure to unsafe conditions • Can eliminate the need for manual compositing of aliquots • Sampling can be triggered remotely or initiated according to onsite conditions	• Generally not acceptable for VOC sampling • Costly if numerous sampling sites require the purchase of equipment • Can require equipment installation and maintenance; can malfunction • Can require operator training • Can require that flow measures be taken during sampling • Cross-contamination of aliquot if tubing/bottles not washed

Source: U.S. EPA, 1992.

NPDES permits. This system is called the Permits Compliance System (PCS) and it allows users to retrieve information regarding facilities holding NPDES permits, including permit limits and actual monitoring data. You can specify the desired information by using any combination of facility name, geographic location, standard industrial classification (SIC) code, and chemical names. The PCS database can be accessed at <**www.epa.gov/enviro/html/water.html#PCS**>.

B. Monitoring Discharges to POTWs

As discussed in the Chapter 6–Protecting Surface Water, industrial facilities discharging to a POTW might have to meet "pretreatment standards." If so,, they will be subject to certain requirements under a local pretreatment program. The National Pretreatment Program requires certain POTWs in defined circumstances to develop a local pretreatment program (see 40 CFR Section 403.8(a)). The actual requirement for a POTW to develop and implement a local program is a condition of the POTW's NPDES permit.

Sampling is the most common method for verifying compliance with pretreatment standards. Monitoring locations are usually designated by the local municipality administering the pretreatment program and will be such that compliance with permitted discharge limits can be determined. Monitoring locations should be appropriate for waste stream conditions, be representative of the discharge, have no bypass capabilities, and allow for unrestricted access at all times (see 40 CFR Section 403.12).

EPA's General Pretreatment Regulations require POTWs to monitor each significant industrial user (SIU) at least annually (see 40 CFR Section 403.8 (f)(2)(v)) and each SIU to self-monitor semi-annually, although permits issued by the local control authority might require more frequent monitoring (see 40 CFR Section 403.12 (g) and (h)). The local municipality will develop and implement standard operating procedures and policies that specify the sample collection and handling protocols in accordance with 40 CFR Part 136.

Sampling for constituents such as pH, cyanide, oil and grease, flashpoint, and VOCs will require manual collection of grab samples (see 40 CFR Section 403.12 (b)(5)). Similar to composite samples, grab samples must be representative (see 40 CFR Section 403.12 (g)(4)) of the discharge and must be collected from actively flowing waste streams. Fluctuations in flow or the nature of the discharge might require collection and hand-compositing of more than one grab sample to accurately access compliance. Flow-weighted composite samples are preferred over time-weighted composite samples, particularly where the monitored discharge is intermittent or variable. The local authorities can waive flow-weighted composite sampling if an industrial user demonstrates that flow-weighted sampling is not feasible. In these cases, time-weighted composite samples can be collected (see 40 CFR Section 403.12 (b)(5)(iii)). Refer to EPA's *Industrial User Inspection and Sampling Manual for POTWs* (U.S. EPA, 1994a) for additional information on sample collection and analysis procedures for the pretreatment program.

If you are subject to pretreatment requirements and must conduct sampling to demonstrate compliance, the requirements established for your site by the local control authority apply. These include following the proper sample collection and handling protocols and being able to prove that you did so (i.e., by keeping sampling records; noting location, date, and time of sample collection; maintaining chain of custody forms showing the link between field personnel and the laboratory) (see 40 CFR Section 403.12(o)). Consult EPA's *Introduction to the National Pretreatment Program* document (U.S. EPA, 1999) for further information on monitoring requirements under the National Pretreatment Program.

C. Monitoring Surface Water Conditions

In order to determine if runoff from your waste management unit is impacting adjacent surface waters you might want to consider establishing a surface-water quality monitoring program. Chemical, physical, and biological data can provide information about the effectiveness of BMPs. The data collected will help you to characterize any overall water quality at the selected monitoring sites, identify problem areas, and document any changes in water quality.

In designing your program, one of the most important things to consider is what types of parameters to monitor (chemical, physical, and/or biological) that will enable you to determine how your waste management unit might be impacting the aquatic ecosystem. Determining where you should set-up a monitoring station is also very important and will depend on relevant hydrologic, geologic, and meteorologic factors. For assistance and more information on establishing water quality sampling stations and a sampling program you should consult with state and local water quality planning agencies. Additional guidance on establishing sampling and monitoring programs can be obtained from EPA's *Volunteer Stream Monitoring Document* (U.S. EPA, 1997) and *Volunteer Lake Monitoring Document* (U.S. EPA, 1991). Monitoring can be conducted at regular sites on a continuous basis ("fixed station" monitoring); at selected sites on an as needed basis or to answer specific questions ("intensive surveys"); on a temporary or seasonal basis (e.g., during periods of intense rainfall); or on an emergency basis (i.e., an accidental spill or discharge).

Why is the monitoring taking place?

You should first determine the purpose of establishing a surface-water monitoring program. Reasons for monitoring surface water can include developing baseline characterization data prior to a waste management unit being constructed, documenting water quality changes over time, screening for potential water quality problems, determining the effectiveness of BMPs, or determining the impact of the waste management unit on surface waters.

How will the data be used?

The data collected will help you to identify constituents of concern, the impacts of pollution and pollution control activities (i.e., BMPs), and trends in water quality. Note that the data you collect might also be useful to regional or local water quality planning offices that might already be collecting similar data in other parts of the watershed.

What parameters or conditions will be monitored?

The basic parameters that are indicators of general water quality health, include dissolved oxygen (DO), pH, total suspended solids (TSS), nitrogen, hardness, temperature, and phosphorous. In addition, you might choose to monitor parameters that would indicate whether the designated use (e.g., fisheries, recreation) of the water body is being met (as discussed in Chapter 6–Protecting Surface Water). Further, based on the types of constituents associated with the waste management unit, you should also sample for contaminants that would indicate whether your surface-water protection measures are functioning properly (e.g., heavy metals, organics, or other materials associated with the unit). In many cases, a few surrogate constituents can be selected instead of analyzing a complete spectrum of constituents. For example, lead, zinc, or cadmium are often selected to indicate pollution by toxic metals. Instead of analyzing for every possible pathogenic microorganism, total and fecal coliform bacteria analyses are commonly used to indicate bacterial and viral contamination. Chemical oxygen demand (COD) and total organic carbon (TOC) are used in high-frequency grab sampling programs as indicators of pollution by organics.

Where should the monitoring sites/stations be located?

In order to determine if the waste management unit is having an impact on surface water it is important to determine the quality of the water upstream from the unit as well as downstream. You should also consider the number of sites to establish how accessible, safe, and convenient potential sites are. In addition, it is important to determine if potential sites are near tributary inflows, dams, bridges, or other structures that might affect the sampling results. You should also determine if you will establish permanent sampling stations (i.e., structures or buildings) or if the stations will simply be designated points within the watershed.

What sampling methods should be used?

You must decide how the samples will be collected, what sampling equipment will be used (e.g., automatic samplers or by hand), what equipment preparation methods are necessary (e.g., container sterilization, meter calibration), and what protocols will be followed. Refer to Part II, Section A of this chapter for a discussion of determining sampling methods. EPA's SW-846 also provides guidance on selecting the appropriate sampling methods.

When will the monitoring occur?

You need to establish how frequently monitoring will take place, what time of year is best for sampling, and what time of day is best for sampling. Monitoring at the same time of day and at regular intervals helps ensure comparability of data over time. In general, monthly chemical sampling and twice yearly biological sampling are considered adequate to identify water quality changes over time. If you are conducting biological sampling, it should be conducted at the same time each year because of natural seasonal variations in the aquatic ecosystem. Note that the frequency of sampling should be increased during the rainy season as this is when contamination from waste management units is expected to increase due to stormwater runoff.

How can the quality of the data collected be ensured?

You should develop a quality assurance plan to ensure that quality assurance and quality control procedures are implemented at all times. In addition, the personnel conducting the sampling should be properly trained and consider how to manage the data after the data have been collected.

Hydrologic and water quality information is also collected and published regularly by EPA and the U.S. Geological Survey (USGS). Both agencies have computerized systems for storing and retrieving information on water quality that are available on the Internet. Water quantity and flow data in streams is also available from USGS which has offices in every state. USGS also operates two national stream water quality networks, the Hydrologic Benchmark Network (HBN) and

EPA's Water Quality Data Management Systems

EPA maintains two data management systems containing water quality information: the Legacy Data Center (LDC) and STORET. The LDC contains historical water quality data dating back to the early part of the 20th century and collected up to the end of 1998. STORET (short for STOrage and RETrieval) contains data collected beginning in 1999, along with older data that has been properly documented and migrated from the LDC.

Both systems contain biological, chemical, and physical data on surface and ground water collected by federal, state and local agencies, Indian Tribes, volunteer groups, academics, and others. All 50 states, territories, and jurisdictions of the U.S. are represented.

Each sampling result in these databases is accompanied by information on where the sample was taken (e.g., latitude, longitude, state, county, Hydrologic Unit Code), when the sample was gathered, the medium sampled (e.g., water, sediment, fish tissue), and the name of the organization that sponsored the monitoring. In addition, STORET contains information on why the data were gathered; the sampling and analytical methods used; and the quality control checks used when sampling, handling, and analyzing the data.

The LDC and STORET databases are Web-enabled. With a standard Web browser, you can browse both systems interactively or create files to be downloaded to your computer. For more information on the LDC and STORET data management systems and how the water quality data can be obtained visit EPA's STORET Web site at **<www.epa.gov/storet>**.

the National Stream Quality Accounting Network (NASQAN). These networks were established to provide national and regional descriptions of stream water quality conditions and trends, based on uniform monitoring of selected watersheds throughout the United States, and to improve our understanding of the effects of the natural environment and human activities on water quality. Stream water quality measurements are available for the approximate periods 1973 to 1995 for NASQAN and 1962 to 1995 for HBN. For more information on how to obtain this water quality information, visit the USGS Web site at **<water.usgs.gov/pubs/FS/fs-014-00/index.html>**.

III. Soil Monitoring

This section focuses primarily on establishing a soil monitoring program for land application purposes. Much of the following discussion concerning sampling methods, protocols, and quality assurance and quality control, however, also is applicable to soil monitoring for corrective action site assessments. Part I of Chapter 10–Taking Corrective Action outlines which parameters to consider when performing soil investigations for corrective action purposes. For more information on corrective action unit assessments, refer to the North Carolina Cooperative Extension Service's *Soil facts: Careful Soil Sampling - The Key to Reliable Soil Test Information* (AG-439-30), the University of Nebraska Cooperative Extension Institute of Agriculture and Natural Resources' *Guidelines for Soil Sampling* (G91-1000-A), and EPA's *RCRA Facility Investigation Guidance: Volume II: Soil, Ground Water and Subsurface Gas Releases* (U.S. EPA, 1989). As discussed in Part I of this chapter, soil monitoring can be used to detect the presence of waste constituents in the soil and track their migration before they reach ground water. Characterizing the soil properties at a land application site can also help you determine the application rates that will maximize waste assimilation.

To obtain site-specific data on actual soil conditions, the soil should be sampled and characterized. The number and location of samples necessary for adequate soil characterization is primarily a function of the variability of the soils at a site. If the soil types occur in simple patterns, a composite sample of each major soil type can provide an accurate picture of the soil characteristics. The depth to which the soil profile is sampled, and the extent to which each horizon is vertically subdivided, will depend on the parameters to be analyzed, the vertical variations in soil character, and the objectives of the soil sampling program. You should rely on a qualified soil scientist to perform this characterization. Poorly conducted soil sampling can result in an inaccurate soil characterization which could lead to improper application of waste and failure of the unit to properly assimilate the applied waste.

A. Determining the Quality of Soil

Soil quality is an assessment of how well soil performs all of its functions, not just how well it assimilates waste. Measuring crop yield, nutrient levels, water quality, or any other single outcome alone will not give you a complete assessment of a soil's quality. The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including those applied to the land and deposited by the atmosphere. Determining the quality of a soil is an assessment of how it performs all of these functions in addition to waste assimilation. For assessing soil quality in relation to land application units, it will be

Examples of Indicators of Soil Quality

Indicator	Relationship to Soil Health
Soil organic matter (SOM).	Soil fertility, structure, stability, nutrient retention, soil erosion.
PHYSICAL: soil structure, depth of soil, infiltration and bulk density, water holding capacity.	Retention and transport of water and nutrients, habitat for microbes, estimate of crop productivity potential, compaction, water movement, porosity, workability.
CHEMICAL: pH, electrical conductivity, extractable nitrogen-phosphorous-potassium.	Biological and chemical activity thresholds, plant and microbial activity thresholds, plant available nutrients and potential for nitrogen and phosphorous loss.
BIOLOGICAL: microbial biomass, carbon and nitrogen, potentially mineralizable nitrogen, soil supplying potential, microbial activity measure.	Microbial catalytic potential and repository for carbon and nitrogen, soil productivity and respiration.

important for the soil to be able to filter the waste constituents and cycle nutrients such as carbon, nitrogen, and phosphorus.

Measuring soil quality requires the use of physical, chemical, and biological indicators, which can be assessed by qualitative or quantitative techniques. After measurements are collected, they can be evaluated by looking for patterns and comparing results to measurements taken at a different time or field. For more information, consult the *Guidelines for Soil Quality Assessment* prepared by the Soil Quality Institute of the Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service).

B. Sampling Location and Frequency

Prior to sampling, divide the land application unit into uniform areas, then collect representative samples from each area. These divisions should be based upon soil type, slope, degree of erosion, cropping history, known crop growth differences, and any other factors that might influence nutrient levels in the soil. One recommended approach is to divide the unit into areas no larger than 20 acres and to collect at least one sample from each of these areas.

Each sample for a designated area consists of a predetermined number of soil cores. A soil core is an individual boring at one spot in the field. The recommended number of cores per sample are 15-20 cores for a surface soil sample and 6-8 cores for a subsurface sample. If using a soil probe, a single core can be separated into its horizontal layers to provide samples for each layer being analyzed. For example, a single core could be divided into four predefined layers such as surface soil, subsurface soil, and two deep subsurface soil. For a designated area, all the individual cores are combined according to soil level and mixed to provide a composite sample for the area. From the mixed cores a composite subsample should be taken and analyzed. Each grab sample can be analyzed individually, rather than combined, as part of a composite sample (discussed below), but composite samples generally provide reliable data for soil characterization.

Soil core grab samples can be collected at random or in a grid pattern. Random collection generally requires the least amount of time, but cores must be collected from the entire area to ensure reliable site characterization. When performed properly, random sampling will provide an accurate assessment of average soil nutrient and constituent levels. While the preparation required for collecting core samples in a grid pattern can be more costly and time consuming, it does ensure that the entire area is sampled. An advantage of grid sampling is the ability to generate detailed nutrient level maps for a land application unit. This requires analysis of each individual grab sample from an area, rather than compositing samples. Analyzing each individual grab sample is time consuming and expensive, but software and computerized applicators are becoming available that can use these data to tailor nutrient application to soil needs.

You should determine baseline conditions by sampling the soil before waste application begins. Subsequent sampling will depend on land use and any state or local soil monitoring requirements. After waste is applied to the land application unit, you should collect and analyze samples at regular intervals, or after a certain number of applications. You should sample annually, at a minimum, or more frequently, if appropriate.

The frequency of sampling, the micronutrients, the macronutrients, and the constituents to be analyzed will depend on site-specific soil, water, plant, and waste characteristics. Local agricultural extension services, which have experience with designing soil-sampling programs, can assist in this area. Soil monitoring, especially when coupled with ground-water monitoring, can detect contamination problems. Early detection allows changes to be made to the land application process to remedy the problems and to conduct corrective action if necessary. Finally, soil testing after the active life of the unit has ended is recommended to determine if any residues remain in the soil.

C. Sampling Equipment

There are a number of soil sampling devices available. A soil probe or tube is the most desirable, as it provides a continuous core with minimal disturbance of the soil. Sample cores from a soil probe can be divided by depth and provide surface, subsurface, and deep subsurface samples from a single boring. When the soil is too wet, too dry, or frozen, however, soil probes are not very effective. The presence of gravel in the soil will also prevent the use of a soil probe.

When sampling excessively wet, dry, or frozen soils, or soils with gravel, a soil auger can be used in place of a soil probe. Because of their tendency to mix soils from different depths during sample collection, a soil auger should only be used when the use of a soil probe is not possible. A spade can also be used for surface samples, but it is not effective for subsurface sampling. Post-hole diggers can be used for collecting deeper subsurface samples, but they present the same mixing problem as soil augers. EPA's *Description and Sampling of Contaminated Soils: A Field Pocket Guide* (U.S. EPA, 1991) contains a description of various hand-held and power-driven tube samplers. The guide also outlines the recommended applications and limitations for each sampling device.

D. Sample Collection

Initial soil characterization samples are typically taken from each distinct soil horizon down to a depth of 4-5 feet (120-150 cm). For example, a single core sample might provide the following four horizon samples: surface (0-6 inches), subsurface (6-18 inches), and two deep subsurface (18-30 inches and 30-42 inches). For subsequent evaluations, it is important to sample more than just the surface layer to determine if the land application rate is appropriate and that the quality of soil is not being detrimentally affected. Sampling subsurface layers will indicate whether waste constituents are being removed and assimilated as expected and are not leaching into subsurface layers or the groundwater. As a minimum practice, sample at least the upper soil layer (0-6 inches) and at least one deeper soil layer (e.g., 18-30 inches). You should consult the local agricultural extension service, the county agricultural agent, or other soil professionals for recommended soil sampling depths for the specific area in which your land application unit is located.

Once the samples have been obtained, they must be prepared for chemical analysis. This typically is done by having the sample air dried, ground, and mixed, and then passed through a 2 millimeter sieve as soon as possible after collection. If the samples are to be analyzed for nitrate, ammonia, or pathogens, then they should be refrigerated under moist field conditions and analyzed as soon as possible. For more information on handling and preparing soil samples, refer to the "General Protocol for Soil Sample Handling and Preparation" section in EPA's *Description and Sampling of Contaminated Soils: A Field Pocket Guide* (U.S. EPA,1991). ASTM method D-4220 *Practices for Preserving and Transporting Soil Samples* also addresses proper soil sample handling protocols.

The exact procedure for drying is not critical as long as contamination is minimized and excessive temperatures are avoided. The recommended drying procedure for routine soil analysis is to dry the samples overnight, using forced air at ambient temperatures. Supplemental heating can be used, but it is recommended that soil samples to be used for routine analyses not be dried at greater than 36°C. Microwave drying can alter the analytical results and should be avoided.

Because soil is defined as having a particle size of less than 2 millimeters, this sieve size (# 10 mesh) is recommended for routine soil testing. Commercial soil grinders and crushers, such as mortar and pestles, hammermills, or roller-crushers, are typically long and motorized. The amount of coarse fragments common in some samples limits the use of some of these. In general, it is desirable to get most of the sample to less than 2 mm with the least amount of grinding. If the sample is to be analyzed for micronutrients, all contact with metal surfaces should be avoided during crushing and sieving unless it has been clearly demonstrated that the metal is not a source of contamination. Cross-contamination between samples can be avoided by minimizing soil-particle carry over on the crushing and sieving apparatus. For macronutrient analysis, removal of particles by brushing or jarring should be adequate. If micronutrient or trace element analysis is to be performed, a more thorough cleaning of the apparatus by brushing or wiping between samples might be required.

The bulk soil sample should be thoroughly homogenized by mixing with a spatula, stirring rod, or other implement. As much of the sample as possible should be loosened and mixed together. No segregation of the sample by aggregate size should be apparent after mixing. You should dip into the center of the mixed sample to obtain a subsample for analysis.

Prior to sampling, all containers and equipment that are to be used for soil collection (i.e., those that will come in contact with the soil being sampled) should be rinsed in warm tap water to remove any residual soil particles from previous sampling runs. They should then be rinsed with an aluminum chloride solution. Avoid using anhydrous aluminum chloride due to its violent reaction with water. A four percent hydrogen chloride solution can also be used if the soil is not to be analyzed for chlorine. The containers and equipment should be rinsed twice in distilled or deionized water and allowed to dry prior to use.

You should obtain professional assistance from qualified soil scientists and laboratories to properly interpret the soil-sample results. For more information about how to obtain representative soil samples and submit them for analysis, you can consult various federal manuals, such as EPA's *Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs* (U.S. EPA, 1995b), or state guides, such as Nebraska's *Guidelines for Soil Sampling* (G91-1000-A). The following ASTM methods might also prove useful when conducting soil sampling: D-1452 *Practice for Soil Investigation and Sampling by Auger Borings*; D-1586 *Test Method for Penetration Test and Split-Barrel Sampling of Soils*; D-1587 *Practice for Thin-Walled Tube Sampling of Soils*; and D-3550 *Practice for Ring-Lined Barrel Sampling of Soils.*

IV. Air Monitoring

The development of appropriate air-monitoring data can be technically complex and resource intensive. The Industrial Waste Air (IWAIR) Model on the CD ROM version of this Guide provides a simple tool that relies on waste characterization information, rather than actual air monitoring data, to evaluate risks from VOC emissions at a unit. The air-modeling tool uses an emissions model to estimate emissions from a waste management unit based on the waste characterization. You should review Chapter 5–Protecting Air Quality, and the supporting background document developed for the IWAIR model to understand the limitations of the model and determine whether it is applicable to a specific unit. If the model is not appropriate for a specific site or if it indicates that there is a problem with VOC emissions, use an alternative (emissions) model that is more appropriate for the site or consider air monitoring to gather more site-specific data.

A. Types of Air Emissions Monitoring

There are generally four different types of air emissions monitoring: source, ambient, fugitive, and indoor. Source, ambient, and fugitive monitoring can provide data for use in emission and dispersion modeling. In addition, the monitoring of meteorological conditions at sites is generally conducted whenever source emissions or ambient monitoring is performed, as discussed below. As the vast majority of industrial waste management units are located outdoors, indoor air quality and monitoring issues typically will not apply. Consequently, this guide does not address this issue. For more information on indoor air quality and monitoring visit the Occupational Safety and Health Administration's (OSHA) Web site at **<www.osha-slc.gov/SLTC/indoorair quality/index.html>**.

1. Emissions Monitoring

Stationary-source emissions monitoring involves the direct sampling of an air stream in a duct, stack, or pipe that is the end source of an emission release point. A stationary source is an immobile unit from which air pollutants are released. Examples include incinerators, boilers, industrial furnaces, landfills, waste piles, surface impoundments, and other waste management units. The purpose of source sampling is to obtain as accurate a sample as possible of the material entering the atmosphere. The major reasons for which source testing is required are to demonstrate compliance with regulations or permit conditions, to collect engineering data (e.g., to evaluate the performance of air pollution control equipment), to support performance guarantees (e.g., checking to confirm that the air pollution control equipment is meeting the guaranteed degree of performance), and to provide data for air modeling.

2. Ambient Monitoring

The second type of air monitoring involves ambient air monitoring at selected locations around the waste management unit or site. The data are used to monitor dispersion of airborne contaminants to the surrounding areas. Ambient testing usually involves "fenceline" testing. Typically, the air is monitored at the four fenceline compass points. At least one additional measuring station is placed either in the predominant upwind (or downwind) location or in a direct line between your site and a neighboring facility or property. The resulting data should yield information concerning the concentration of ambient emissions leaving your property (minus the emissions from adjacent facilities).

In many areas of the country, several facilities share property boundaries delineated by a fenceline. Since each facility is regulated according to total emissions, it is critical that a neighboring facility's "drifting" emissions be qualified and quantified. Depending on the neighboring facility's production rate, the atmospheric conditions, and the seasonal climate, the neighboring facility's emissions could impact the operation of your facility. For example, many facilities are required to continuously monitor downwind fenceline emission of hydrocarbons. If a neighboring facility's emissions of hydrocarbons or adjacent freeway hydrocarbon emissions drift across your fenceline and combine with your own hydrocarbon emissions, your total facility hydrocarbon emission limit could be violated.

3. *Fugitive Monitoring*

Fugitive testing is a hybrid of ambient and source testing and generally involves the monitoring of either particulate or gaseous emissions from sources open to the atmosphere. It can involve testing sources such as valves, flanges, pumps, and similar equipment and hardware for leaks, and it can include quantifying emissions from open drums, open vats, landfills, waste piles, and surface impoundments such as lagoons, pits, and settling ponds. It is typically conducted using one or more of the following techniques: use of a handheld organic analyzer; "bagging" suspect sources for subsequent analysis; capturing and scrubbing fugitive emissions using a floating flux chamber/summa canister; or measuring particulate matter greater than or less than 10 microns in diameter (PM10) following promulgated EPA test methods.

Selection of the test method depends on factors such as the type of emissions, source type, temperature, pressure, constituent concentration, etc. (test methods are discussed later in this chapter). For example, a plant operator who suspects that a valve is leaking might use a handheld organic analyzer to verify the presence of a leak. If the analyzer is not able to quantify the concentration of the leaking gas, then the bagging technique can be employed. To determine the amount and type of organic emissions escaping from a settling pond or wastewater treatment tank, a floating flux chamber/summa canister might be preferred. This is a box that isolates a portion of the pond to determine volumetric flow. The box acts as a floating stack in which emissions are captured into a canister for analysis. For material transfer operations or vehicular traffic from unpaved roads, it is obviously not practical to use a handheld analyzer or to "bag" the source (especially something as large as a waste pile). In such cases of particulate matter fugitive emissions, a high-volume ambient PM10 sampling system is used, or the emissions are ducted through a temporary stack for direct measurement using a sampling train (see Figure 6).

4. *Meteorological Monitoring*

Another form of air monitoring measures meteorological conditions at a site. Site-specific meteorological information can be collected for use in air emission and dispersion modeling. This type of monitoring involves measurement of wind speed, wind direction, temperature, etc., and can be performed when other offsite meteorological information might not adequately characterize the weather conditions at the site. Local wind systems are usually quite significant in terms of the transport and dispersion of air constituents. Therefore, local meteorological monitoring will most likely be important for mountainous or hilly terrain (where solar heating and radiational cooling influence how wind moves) or for a site near a large body of water (where the differential heating of land and water can result in thermals and subsidence over water). Also, the initial direction of transport of constituents from their source is determined by the wind direction at the source.

To make meteorological measurements, three components are typically needed: a detector or sensor, an encoder or digitizer, and a data logger. Most detectors are analog, providing a continuous output as a function of varying meteorological conditions. The output signal must then be sampled to produce a discrete digital record, using some sort of encoder or analog-to-digital converter. The resulting discrete series of data must be recorded, often on magnetic tape, magnetic disks, or optical disks. "Instrument system" or "instrument package" is the name given to the set of all three components listed above.

Additional components might also be necessary including: an instrument platform, a means of calibration, and display devices. Platforms, such as a tower, can often hold many instrument systems. Calibration against known standards should be performed periodically during the measuring program, or should be accomplished continuously as a function of the sensor or instrument package. All data must be calibrated. Finally, the measured values should be displayed on printers, plotters, or video displays in order to confirm the proper operation of the instrument.

A large variety of sensors have been developed to measure various meteorologic parameters. Direct sensors are ones that are placed on an instrument platform to make in situ measurements of the air at the location of the sensor. Remote sensors measure waves that are generated by, or modified by, the atmosphere at locations distant from the sensor. These waves propagate from the generation or modification point back to the sensor. Disadvantages of direct sensors include modification of the flow by the sensor or its platform and the requirement to physically position the sensor where the measurement is to be made. Disadvantages of remote sensors include their size, cost, and complexity. Advantages of direct sensors include sensitivity, accuracy, and simplicity. Advantages of remote sensors include the fact that they can quickly scan a large area while remaining stationary on the ground.

Sensors Used To Measure Meteorologic Parameters

The following types of sensors can be used to monitor meteorological conditions at a site (note that this list is not meant to be exhaustive):

Temperature—thermometers.

Direct sensors:	*Remote sensors:*
wax thermostat	microwave sounders
thermistor	sodar
bimetallic strip thermistor	
thermocouple	
liquid (mercury or alcohol) in glass	
radiometers	

Humidity—hygrometers.

Direct sensors:	*Remote sensors:*
psychrometers	lidar
hair hygrometer	radar
chilled mirror (dew pointer)	
hygristor	

Wind—velocity (anemometers) and direction (vanes).

Direct senors:	*Remote sensors:*
cup	Doppler radar
propellar	
wind vane	
bivane	

Pressure—barometers and microbarographs.

Direct sensors:
aneroid elements
capacitive elements
mercury in glass

Remote sensors:
None that use wave propagation directly, but some that measure temperature and velocity fluctuations as mentioned above, and infer pressure perturbations as residual from governing equations.

Radiation—radiometers.
Radiometers can be designed to measure radiation in specific frequency bands coming from specific directions: radiometer, net radiometer, pyranometer, and net pyranometer.

B. Air Monitoring and Sampling Equipment

1. Ambient Air Monitoring

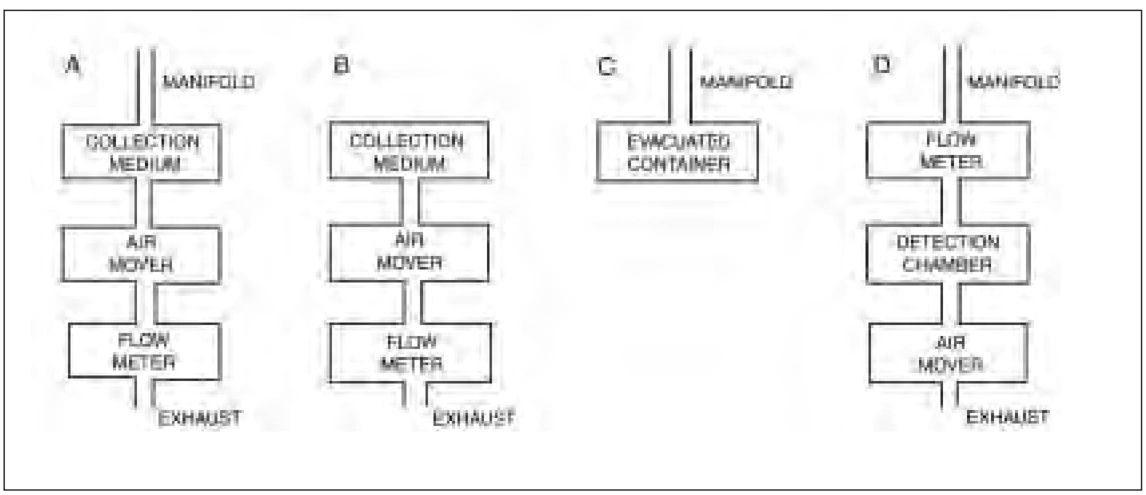
For ambient air monitoring, the principal requirement of a sampling system is to obtain a sample that is representative of the atmosphere at a particular place and time. The major components of most sampling systems are an inlet manifold, an air mover, a collection medium, and a flow measurement device. The inlet manifold transports material from the ambient atmosphere to the collection medium, or analytical device, preferably in an unaltered condition. The inlet opening can be designed for a specific purpose. All inlets for ambient sampling must be rainproof. Inlet manifolds are made out of glass, Teflon, stainless steel, or other inert materials and permit the remaining components of the system to be located at a distance from the sample manifold inlet. The air mover (i.e., pump) provides the force to create a vacuum or lower pressure at the end of the sampling system. The collection medium for a sampling system can be a liquid or solid sorbent for dissolving gases, a filter surface for collecting particles, or a chamber to contain an aliquot of air for analysis. The flow device measures the volume of air associated with the sampling system. Examples of flow devices include mass flow meters and rotameters.

Gaseous Constituents

Sampling systems for gaseous constituents can take several forms and might not necessarily have all four components as shown in Figure 5. The sampling manifold's only function is to transport the gas from the manifold inlet to the collection medium. The manifold must be made of nonreactive material and no condensation should be allowed to occur in the sampling manifold. The volume of the manifold and the sampling flow rate determine the time required for the gas to move from the inlet to the collection medium. This residence time can be minimized to decrease the loss of reactive species in the manifold by keeping the manifold as short as possible.

The collection medium for gases can be liquid or solid sorbents, and evacuated flask,

Figure 5. Schematic Diagram of Various Types of Sampling Systems



Source: *Fundamentals of Air Pollution.*

or a cryogenic trap. Each design is an attempt to optimize gas flow rate and collection efficiency. Higher flow rates permit shorter sampling times. Liquid collection systems take the form of bubblers which are designed to maximize the gas-liquid interface. However, excessive flow rates can result in lower collection efficiency.

Diagram A is typical of many extractive sampling techniques (e.g., SO_2 in liquid sorbents and polynuclear aromatic hydrocarbons on solid sorbents). Diagram B is used for "open-face" filter collection, in which the filter is directly exposed to the atmosphere being sampled. Diagram C is an evacuated container used to collect an aliquot of air or gas to be transported to the laboratory for chemical analysis, (e.g., polished stainless steel canisters are used to collect ambient hydrocarbons for air toxic analysis). Diagram D is the basis for many of the automated continuous analyzers, which combine the sampling and analytical processes in one piece of equipment (e.g., continuous ambient air monitors for SO_2, O_3, and NOx).

Particulate Constituents

Sampling for particulate constituents in the atmosphere involves a different set of parameters from those used for gases. Particles are inherently larger than the molecules of N_2 and O_2 in the surrounding air and behave differently with increasing diameter. When sampling for particulate matter in the atmosphere, three pieces of information are of particular interest: the concentration, the size, and the chemical composition of the particles. Particle size is important in determining adverse effects and atmospheric removal processes.

The primary approach is to separate the particles from a known volume of air and subject them to weight determination and chemical analysis. The principle methods for extracting particles from an airstream are filtration and impaction.[7] All sampling techniques must be concerned with the behavior of particles in a moving airstream. Care must be taken to move the particles through the manifold to the collection medium in an unaltered form. Potential problems arise if manifold systems are too long or too twisted. Gravitational settling in the manifold will remove a fraction of the very large particles. Larger particles are also subject to loss by impaction on walls at bends in a manifold. Particles can also be subject to electrostatic forces which will cause them to migrate to the walls of nonconducting manifolds. Other potential problems include condensation or agglomeration during transit time in the manifold. These constraints require particulate sampling manifolds to be as short as possible and to have as few bends as possible.

2. Source Emissions Monitoring

For source emissions monitoring, the sampling system is tailored to the unique properties of the emissions from a particular process. It is necessary to take into account the specific process, the nature of the control devices, the peculiarities of the source, and the use of the data obtained. In source monitoring, the sample is obtained from a stack that is discharging to the atmosphere using a "sampling train". A typical sample train is shown in Figure 6. The figure shows the minimum number of components, but in some systems the components can be combined. Extreme care must be exercised to assure that no leaks occur in the train and that the components of the train are identical for both calibration and sampling. Standard sampling trains are specified for some tests. Continuous emission monitors (CEMs) are also available to monitor opacity and certain gaseous emissions.

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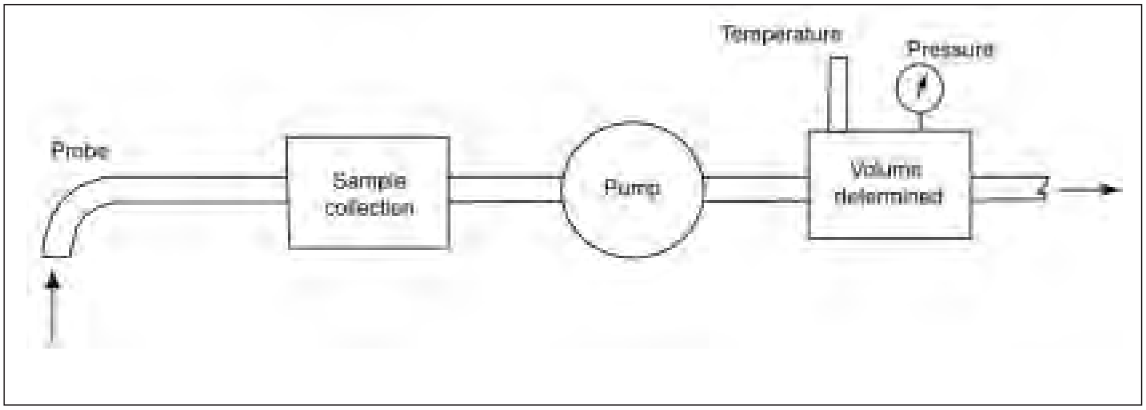
[7] Filtration consists of collecting particles on a filter surface by three processes: direct interception, inertial impaction, and diffusion. Filtration attempts to remove a very high percentage of the mass and number of particles by these processes. Any size classification is done by a preclassifier, such as an impactor, before the particle stream reaches the surface of the filter

Figure 6. Sampling Train



Source: *Fundamentals of Air Pollution.*

C. Test Method Selection

Correct method selection is both scientific and subjective. Knowing when to utilize the appropriate method for a given circumstance is very important, since incorrect or inaccurate measurement can lead to incorrect results. The test methods to be used for air emission monitoring are typically specified by applicable regulations; and the type of facility will often determine the regulations or standards which are applicable. In general, most EPA test methods applicable to a facility will be contained in the Code of Federal Regulations (40 CFR Parts 60, 61, 63, and 51). Other test methods might be specified by the EPA Office of Solid Waste or the National Institute for Occupational Safety and Health (primarily for indoor air monitoring). Additionally, some states and local air pollution control agencies have their own test methods that differ from EPA methods, the use of which might be required in lieu of EPA methods. The CFR specifies test methods for testing for numerous compounds and various parameters necessary for determining constituent concentrations and emission rates. New regulations, however, are being developed for many compounds that, as yet, have no promulgated test methods. Air emission testing specialists or consultants can often determine appropriate test methods for most of these compounds. Usually, the testing involves adapting an existing method to the constituent of interest. It is best to use an existing method whenever possible. If using an existing method is impractical, you can develop a test method particular to that constituent to monitor for it. You should seek the advice or assistance of a professional if this is the case and consult your state and local air quality offices.

D. Sampling Site Selection

Sampling activities are typically undertaken to determine the ambient air quality for compliance with air quality standards, to evaluate the effectiveness of air pollution control techniques being implemented at the site, to evaluate hazards associated with accidental spills, and to collect data for air emissions and dispersion modeling. The purpose or use of the results of the monitoring program determines the sampling site selection. The fundamental reason for controlling air pollution sources is to limit the concentration of contaminants in the atmosphere so that adverse effects do not occur. Sampling sites should therefore be selected to measure constituent levels close to or representative of exposed populations of people, plants, trees, materials, or structures. As a result, ambient air monitoring sites are typically located near ground level, about 3 meters above ground (Boubel, p. 192.), in a place where the results are not influenced by a nearby source such as a roadway. Sampling sites might require electrical power and adequate protection (which can be as simple as a fence). A shelter, such as a small building, might be necessary. Permanent sampling sites (when necessary) will require adequate heating and air conditioning to provide a stable environment for the sampling and monitoring equipment.

EPA Test Methods

EPA test methods are available for a variety of compounds and parameters, including but not limited to the following examples:

- Particulate Matter
- Volatile Organic Compounds (VOC)
- Sulfur Dioxide
- Nitrogen Oxide
- Visible Emissions
- Carbon Monoxide
- Hydrogen Sulfide
- Inorganic Lead
- Total Fluoride
- Landfill Gas (gas production flow rate)
- Nonmethane Organic Compounds (NMOC) (in landfill gases)
- Hydrogen Chloride
- Gaseous Organic Compounds
- Polychlorinated Dibenzo-p-dioxins and Polychlorinated Dibenzofurans
- Stack Gas Velocity and Volumetric Flow Rate
- Gas Analysis for Carbon Dioxide, Excess Air, and Dry Molecular Weight
- Moisture Content in Stack Gases

V. Sampling and Analytical Protocols and Quality Assurance and Quality Control

The best designed monitoring program will not provide useful data in the absence of sound sampling and analytical protocols. Sampling and analytical protocols are generally contaminant specific. A correctly designed and implemented sampling and analysis protocol helps ensure that sampling results accurately represent media quality and can be compared over time. The accurate representation is demonstrated through statistical analysis.

Whether or not an established quality assurance and quality control (QA/QC) program is required on a federal, state, or local level, it is a good management practice to develop and strictly implement such a plan. The sampling protocol should incorporate federal, state, and local QA/QC requirements. Sampling QA/QC procedures detail steps for collection and handling of samples. Sample collection, preservation, shipment, storage, and analysis should be performed in accordance with an approved QA/QC program to ensure data of known quality are generated.

You should rely on qualified professionals who are properly trained to conduct sampling. Poorly-conducted sampling can give false evidence of a contamination problem or can miss early warnings of contaminant leaching. Erring in either direction is an avoidable and costly mistake.

At a minimum, you should include the following in your sampling protocol:

- Data quality objectives including lists of important tracking parameters, such as the date and name of samples.
- Sample collection procedures, including description of sample collection methods, and lists of necessary field analyses.
- Instructions for sample preservation and handling.
- Other QA/QC procedures such as chain-of-custody.
- The name of the person who conducted the sampling.

Quality control operations are defined by operational procedures and might contain the following components for an air monitoring program:

- Description of the methods used for sampling and analysis.
- Sampling manifold and instrument configuration.
- Appropriate multipoint calibration procedures.
- Zero/span checks and record of adjustments.
- Control specification checks and their frequency.
- Control limits for zero, span, and other control limits.
- The corrective actions to be taken when control limits are exceeded.
- Preventative maintenance.
- Recording and validation of data.
- Documentation of quality assurance activities.

States have developed guidance documents addressing sampling plans, protocols, and reports. You should work with the state to develop an effective sampling protocol.

- You should consult with soil specialists at the state and local environmental/planning offices, your local cooperative extension service office, or the county conservation district office before implementing a soil monitoring program for your unit. (For more information, visit the USDA Cooperative State Research, Education, and Extension Service Web site at: **<www.reeusda.gov/ 1700/statepartners/usa.htm**>). These agencies likely will be able to provide you with maps showing the location and extent of soils, data about the physical and chemical properties of soils, and information derived from the soil data about potentialities and problems of use for the soils in your area. You can also consult the Natural Resources Conservation Service (NRCS) Web site at **<www.wv.nrcs.usda.gov>**. The NRCS manages the national cooperative soil survey program which is a partnership of federal land management agencies, state agricultural experiment stations, and state and local agencies that provide soil survey information necessary for understanding, managing, conserving, and sustaining soil resources. The NRCS maintains various on-line databases that can help you to characterize local soil.

- You should consult with air modeling professionals, state and local air quality offices, EPA Regional air program offices, or EPA's Office of Air Quality Planning and Standards (OAQPS) in Research Triangle Park, North Carolina, before implementing an air monitoring program for your unit or choosing alternative emission and dispersion models to evaluate risks associated with air emissions. For information concerning emission test methods, you can contact the Emission Measurement Center (EMC) within the Office of Air Quality Planning and Standards. The EMC is EPA's point of contact for providing expert technical assistance for EPA, state, and local officials and industrial representatives involved in emission testing. The Center has produced numerous methods of measuring air constituents emitted from a multitude of industries. A 24-hour automated telephone information hotline known as the "SOURCE" at 919 541-0200, provides callers with a variety of technical emission testing information. The SOURCE also includes connections to technical material through an automatic facsimile link and with technical staff during working hours. For more information concerning the EMC, visit EPA's Web site at: **<www.epa.gov/ttn/emc>**.

  OAQPS also maintains the Support Center for Regulatory Air Models (SCRAM). The SCRAM Web site <www.epa.gov/scram001> is a source of information on various atmospheric dispersion (air quality) models that support regulatory programs required by the Clean Air Act. The computer code, data, and technical documents provided by SCRAM deal with mathematical modeling for the dispersion of air constituents. Documentation and guidance for these computerized models are a major feature of the Web site.

A. Data Quality Objectives

In any sampling and analysis plan, it is important to understand the data needs for a monitoring program. Tailoring sampling protocol and analytical work to data needs ensures cost-efficient sampling. A sampling and analysis plan should specify: 1) clear objective, such as what data are needed and how the data are to be used, 2) target contaminants, and 3) level of accuracy requirements for data to be conclusive. Chapter 1 of EPA SW-846 *Test Methods for Evaluating Solid Waste* (U.S. EPA, 1986) and ASTM Guide D5792 provide guidance on developing data quality objectives for waste management activities.

B. Sample Collection

Sample collection techniques should be carefully designed to ensure sampling quality and avoid cross-contamination or background contamination of samples. (As an example of some of the sample collection guidance available, Section A.4 of the *Annual Book of ASTM Standards* lists guides for ground-water sampling.) You should consider the following factors when preparing for sample collection.

- **Sample collection.** The equipment used to collect samples should be appropriate for the monitoring parameters. Sampling equipment should cause minimal agitation of the sample and reduce or eliminate contact between the sample and environmental contaminants during transfer to ensure it is representative.
- **Field analysis.** Some constituents or parameters can be physically or chemically unstable and should be tested in the field rather than waiting for shipment to a laboratory. Examples of unstable parameters include pH, redox (oxidation-reduction) potential, dissolved oxygen, temperature, and specific conductance.

C. Sample Preservation and Handling

Sample preservation and handling protocols are designed to minimize alterations of the chemistry of samples between the time the sample is collected and when it is analyzed. You should consider the following.

- **Sample containers.** To avoid altering sample quality, transfer samples from the sampling equipment directly into a contaminant free container. SW-846, identifies proper sample containers for different constituents and media. Samples should not be combined in a common sample container and then split later in the field.
- **Sample preservation.** The time between sampling and sample analysis can range from several hours to several weeks. Immediate sample preservation and storage assists in maintaining the natural chemistry of the samples. The latest edition of SW-846 provides specific preservation methods and holding times for each constituent analyzed. SW- 846 recommends preservation methods, such as pH adjustment, chemical addition, and refrigeration.
- **Sample transport.** To document sample possession from the time of collection to the laboratory, include a chain-of-custody record in every sample shipment. A chain-of- custody record generally includes the date and time of collection, signatures of those involved in the chain of possession, time and dates of possession, and other notations to trace samples.

D. Quality Assurance and Quality Control

To verify the accuracy of field sampling procedures, you should collect field quality control samples, such as trip blanks, field blank, equipment blanks, spilt samples, blinds, and duplicates. Table 5 below summarizes these common types of QA/QC samples. Analyze quality control samples for the required monitoring parameters. Other QA/QC practices include sampling equipment calibration, equipment decontamination, and use of chain-of-custody forms. ASTM Guide D-5283 *Standard Practice for Generation of Environmental Data Related to Waste Management Activities: Quality Assurance and Quality Control Planning and Implementation* provides guidance on QA/QC

Table 5 Types of QA/QC Samples

Type of Sample	Purpose	Frequency
Trip Blank Used for volatile organic compounds (VOCs) only. Trip blanks are prepared at the analyzing laboratory and transported to the field with the empty vials to be used in the VOC field sampling. They consist of a sealed vial filled with analyte-free water (i.e., de-ionized water). The water should be the same as the water the laboratory will use in analyzing the actual samples collected in the field, and include any preservatives or additives that will be used. They are handled, stored, and transported in the exact same manner as the field samples. Trip blanks should never be opened in the field.	Trip blanks provide a quality assurance test for detecting contamination from improper sample container (vial) cleaning prior to shipping to the field, the use of contaminated water in analyzing the samples in the laboratory, VOC contamination occurring during sample storage or transport, and any other environmental conditions that could result in VOC contamination of samples during the sampling event.	One trip blank for each cooler used during a sampling episode should be prepared for each volatile organic method to be used in the field. For example, if 2 volatile organic methods are to be used over 2 days with samples being sent to the lab at the end of each day, then a total of 4 trip blanks would be needed (i.e., Day 1: 1 cooler with samples from 2 methods = 2 trip blanks; Day 2: 1 cooler with samples from 2 methods = 2 trip blanks; total trip blanks = 4).
Field Blank A sample collected in the field by filling a vial with analyte-free water and all preservatives or additives that will be added to actual samples. Field blanks should be prepared under the exact same conditions in the same location as actual samples either in the middle or at the end of each sampling episode. They also should be handled, stored, and transported in the exact same manner as the actual samples.	Field blanks are used to evaluate the effects of onsite environmental contaminants, the purity of the preservatives and additives used, and general sample collecting and container filling.	One field blank should be prepared for each parameter being sampled and analyzed per day, or at a rate of 5 percent of the samples in a parameter group per day, whichever is larger. For example if 3 parameter groups were to be sampled over 2 days then 6 field blanks would be required (i.e., 3 parameter groups x 2 days = 6 field blanks).
Equipment Blank A sample prepared by pouring analyte-free water through or over a decontaminated piece of sampling equipment. The blank should be prepared on site. Equipment blanks should be handled, stored, and transported in the exact same manner as the actual samples.	Equipment blanks are used to determine the effectiveness of the field cleaning of sampling equipment. Generally, they are necessary when sampling equipment must be cleaned in the field and reused for subsequent sampling.	At least one equipment blank should be prepared for each piece of equipment used in sampling that must be field cleaned. Each time an equipment blank is required, a sample should be prepared for each parameter group being assessed. For example, if samples are taken for 3 parameter groups, and a piece of sampling equipment requires cleaning then a total of 3 equipment blanks will be required for each required cleaning (i.e., 1 piece of equipment x 3 parameter groups = 3 equipment blanks per cleaning).

Table 5 Types of QA/QC Samples (cont.)

Type of Sample	Purpose	Frequency
Split (Replicate) Sample A sample that is divided into 2 or more containers and sent for analysis by separate laboratories.	Split samples are used to assess sampling and analytical techniques. Samples can be divided into portions (split) at different points in the sampling and analysis process to assess the precision of various components of the sampling and analysis system. For example, a sample split in the field (field replicate) is used to assess sample storage, shipment, preparation, analysis, and data reduction. A sample split just prior to laboratory analysis (analysis replicate) is used to assess the precision of analytical instrumentation.	(No guidance on frequency provided)
Duplicates Samples collected simultaneously from the same source under identical conditions (e.g., same type of sampling techniques and equipment).	Duplicate samples are used to assess the precision of sampling techniques and laboratory equipment.	(No guidance on frequency provided)
Blinds A sample prepared prior to a sampling episode by the laboratory or an independent source. The blind contains a specific amount of analyte known by the preparer, but that is unknown to the analyst at the time of analysis.	Blinds are used to validate the accuracy and precision of the analyzing laboratories sample analyses.	(No guidance on frequency provided)

planning and implementation for waste management activities. Chapter 1 of SW-846 also provides guidance on QA/QC practices.

E. Analytical Protocols

Monitoring programs should employ analytical methods that accurately measure the constituents being monitored. SW-846 recommends specific analytical methods to test for various constituents. Similarly, individual states might recommend other analytical methods for analysis.

Ensure the reliability and validity of analytical laboratory data as part of the monitoring program. Most facility managers use commercial laboratories to conduct analyses of samples; others might use their own internal laboratories if they are equipped and qualified to perform such analyses. In selecting an analytical laboratory, check for the following: laboratory certification by a state or professional association for the type of analyses needed; qualified lab personnel; good quality analytical equipment with back-up instrumentation; a laboratory QA/QC program; proper lab documentation; and adherence to standard procedures for data handling, reporting, and record keeping. Laboratory QA/QC programs should describe chain-of-custody procedures, calibration procedures and frequency, analytical standard operating procedures, and data validation and reporting procedures. A good QA/QC program helps ensure the accuracy of laboratory data.

VI. Analysis of Monitoring Data, Contingency Planning, and Assessment Monitoring

Once monitoring data have been collected, the data are analyzed to determine whether contaminants are migrating from a waste management unit. You should develop a contingency plan to address the situations where contamination is detected.

A. Statistical Approaches

Statistical procedures should be used to evaluate monitoring data and determine if there is evidence of a release from a waste management unit. Anomalous data can result from sampling uncertainty, laboratory error, or seasonal changes in natural site conditions. Qualified statistical professionals can determine if statistically significant changes have occurred or whether the quantified differences could have arisen solely because of one of the above-listed factors. Selecting the appropriate statistical method is very important to avoid generating false positive or false negatives. In monitoring groundwater, for example, the selection of the appropriate statistical method will be contingent upon an adequate review and evaluation of the background groundwater data. These data should be evaluated for properties such as independence, trends, detection frequency and distribution (e.g., normal or lognormal). Examples of two statistical approaches include inter-well (upgradient vs. downgradient) or intra-well comparisons. After consulting with the state agency and statistical professional and selecting a statistical approach, continue to use the selected method in all statistical analyses. Do not switch to a different test when the first method generates unfavorable results.

What is important in selecting a statistical approach?

An appropriate statistical approach will minimize false positives or negatives in terms of potential releases. The approach should account for historical data, site conditions, site operating practices, and seasonal variations. While there are numerous statistical approaches used to evaluate monitoring data, check with the state to determine if a specific statistical approach is recommended.

Common methods for evaluating monitoring data include the following statistical approaches:

- **Tolerance intervals.** Tolerance intervals are statistical intervals constructed from data designed to contain a portion of a population, such as 95 percent of all sample measurements.
- **Prediction intervals.** These intervals approximate future sample values from a population or distribution with a specific probability. Prediction

intervals can be used both for comparison of current monitoring data to previous data for the same site.

- **Control charts.** These charts use historical data for comparison purposes and are, therefore, only appropriate for initially uncontaminated sites.

There are many different ways to select an appropriate statistical method. For more detailed guidance on statistical methods for ground-water contaminant detection monitoring, consult *Addendum to Interim Final Guidance Document on Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities* (U.S. EPA, 1993); *Guidance Document on Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities-Interim Final Guidance* (U.S. EPA, 1989); and ASTM provisional guide PS 64- 96 in the *Annual Book of ASTM Standards*.

B. Contingency Planning

Contingency plans identify the procedures to follow if a statistically significant change in one or more constituents has been detected. A contingency plan should include procedures to determine whether a change in sample concentrations was caused by the waste management unit or by unrelated factors; procedures for developing and conducting an assessment monitoring program; procedures for remediating the waste management unit to stop the release of contaminants; and a determination of the magnitude of contamination that would require initiation of corrective action, such as a statistical exceedance of an HBN, an MCL for surface or ground water, or a site-specific risk-based number.

C. Assessment Monitoring

The purpose of assessment monitoring is to evaluate the rate, extent, and concentrations of contamination. Once a statistically significant change has been confirmed for one or more of the sampling parameters, you should determine whether the change was caused by factors unrelated to the unit. Factors unrelated to the unit that might cause a change in the detected concentration(s) are:

- Contaminant sources other than the waste management unit being monitored.
- Natural variations in the quality of the media being monitored.
- Analytical errors.
- Statistical errors.
- Sampling errors.

If the change was caused by a factor unrelated to the unit, then additional measures might not be necessary and the original monitoring program can be resumed. If, however, these factors have been ruled out, you should begin an assessment monitoring program. You should consult with the state agency to determine the type of assessment monitoring to conduct at the unit. Assessment monitoring typically involves resampling at all sites, and analyzing the samples for a larger list of parameters than used during the basic monitoring program. More than one sampling event might be necessary and additional monitoring might need to be performed to adequately determine the scope or extent of any contamination. It is recommended that you work with state officials to establish background concentrations and protection standards for all additional constituents that were detected during assessment monitoring.

If assessment monitoring results indicate there is not a statistically significant change in the concentrations of one or more of the constituents over the established protection standards, then you can resume the original monitoring program. If, however, there is a statistically significant change in any of these constituents, consult with state officials to identify the next steps. It might be necessary to perform additional monitoring to characterize the nature and extent of the contamination and to notify persons who own or reside on any land directly impacted by the contamination if it has migrated beyond the facility boundary.

Detection of contamination can be an indicator that the waste management unit's containment system is not working properly. During this assessment phase, component(s) of the unit (cover, liner, or leachate collection system) that are not working properly should be identified and, if possible, remediated. For example, sometimes sealing a hole in the liner of a small surface impoundment can be sufficient to stop the source of contamination. Other times, more extensive response might be required. One example could be the extensive subsidence of a unit's final cover creating the need for repair. In some cases, liner and leachate collection system repairs might not be possible, such as in a large surface impoundment or a landfill with several tons of waste already in place. If remediation is not possible, consult with state officials about beginning assessment monitoring and consult Chapter 10–Taking Corrective Action.

Monitoring Performance Activity List

You should consider the following for each media when developing a monitoring program for industrial waste management units:

Ground Water

- ❑ Perform a site characterization, including investigation of the site's geology, hydrology, and subsurface hydrogeology to determine areas for ground-water monitoring; select parameters to be monitored based on the characteristics of the waste managed.
- ❑ Identify qualified engineers and ground-water specialists to assist in designing and operating the ground-water monitoring program.
- ❑ Consult with qualified professionals to identify necessary program components including the monitoring well design, the number of monitoring wells, the lateral and vertical placement of the wells, the duration and frequency of monitoring, and the appropriate sampling parameters.
- ❑ Determine the appropriate method(s) of ground-water monitoring, including conventional well monitoring, direct push sampling, geophysical monitoring, and vadose zone monitoring as possibilities.
- ❑ Use qualified laboratories to analyze samples.

Surface Water

- ❑ Collect and analyze samples according to the requirements of a site's federal or state storm-water permit.
- ❑ If not subject to permit requirements, implement a storm-water sampling program to monitor the quality of runoff and determine the effectiveness of BMPs.
- ❑ If applicable, collect and analyze discharges to POTWs according to any requirements of a local pretreatment program.
- ❑ Implement a surface-water sampling program to monitor water quality and determine the effectiveness of BMPs.
- ❑ Perform regular inspections and maintenance of surface-water protection measures and BMPs to reduce the potential for surface-water contamination.
- ❑ Use qualified laboratories to analyze samples.

Soil Monitoring

- ❑ Determine the number and location of samples needed to adequately characterize soil according to the variability of the soil at a site.
- ❑ Follow established soil-sampling procedures to obtain meaningful results.
- ❑ Use qualified laboratories to analyze samples.

Monitoring Performance Activity List (cont.)

- ❑ Determine baseline soil conditions by sampling prior to waste application.
- ❑ Collect and analyze samples at regular intervals to detect contaminant problems.

Air Monitoring

- ❑ Use the Industrial Waste Air (IWAIR) Model to evaluate risks from VOC emissions.
- ❑ Use an alternative emissions model if the IWAIR Model indicates a problem with VOC emission or is not appropriate for your site.
- ❑ If collecting air monitoring data, determine the type of monitoring necessary to evaluate the effectiveness of air pollution control techniques employed on site or for input into air emissions and dispersion models.
- ❑ Select the proper test methods.
- ❑ Establish guidelines to ensure the quality of the data collected prior to implementing an air monitoring program.
- ❑ Consult with air modeling professionals, state and local air quality offices, EPA regional air program offices, or EPA's Office of Air Quality Planning and Standards before implementing an air monitoring program or choosing an alternative emission model to evaluate risks.
- ❑ Use qualified laboratories to analyze samples.

Sampling and Analytical Protocols QA/QC

- ❑ Develop sample collection, preservation, storage, transport, and handling protocols tailored to data needs, and establish quality assurance and quality control procedures to check the accuracy of the monitoring samples.
- ❑ Eliminate cross-contamination or background contamination of any samples by purging the wells, using appropriate sampling equipment, and ensuring that any unstable parameters, such as pH, dissolved oxygen, and temperature, have been tested at the site.
- ❑ Identify the appropriate analytical methods and statistical approach for the sampling data including parametric analysis of variance (ANOVA), tolerance intervals, prediction intervals, and control charts as possibilities.
- ❑ Evaluate the need for assessment monitoring and abatement.

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Part V
Ensuring Long-Term Protection

Chapter 10
Taking Corrective Action

Contents

Taking Corrective Action

This chapter will help you:

- *Monitor the performance of a waste management unit and take appropriate steps to remediate any contamination associated with its operation.*
- *Locate and characterize the source of any contamination.*
- *Identify and evaluate potential corrective measures.*
- *Select and implement corrective measures to achieve attainment of the established cleanup standard.*
- *Work closely with the state and community representatives.*

Effective operation of a waste management unit involves checking the performance of the waste management system components. When components are not operating effectively or when a problem develops, corrective action might be needed to protect human health and the environment. Corrective action involves identifying exposure pathways of concern, selecting the best corrective measure to achieve the appropriate cleanup standard, and consulting with state and community representatives.

This chapter will help address the following questions.

- What steps are associated with corrective action?
- What information should be collected during investigations?
- What factors should be considered in selecting an appropriate corrective measure?
- What is involved in implementing the selected remedy?

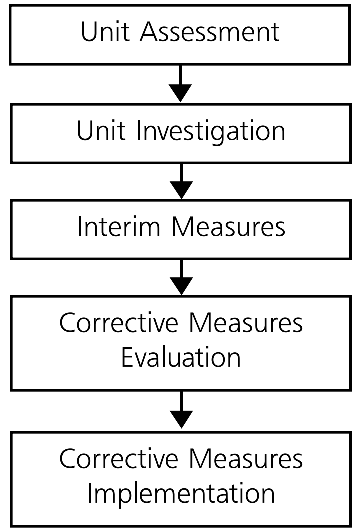
I. Corrective Action Process

The purpose of a corrective action program is to assess the nature and extent of the releases of waste or constituents from the waste management unit(s); to evaluate unit characteristics; and to identify, evaluate, and implement appropriate corrective measures to protect human health and the environment. The overall goal of any corrective action should be to achieve a technically and economically feasible cleanup standard at a specified point on the facility property. For new facilities this point should be on facility property, no more than 150 meters from the waste management unit boundary (as established in Chapter 9–Monitoring Performance). Existing facilities can either use this same 150 meter monitoring point standard or work with their state agencies to determine an alternate set of acceptable monitoring and cleanup criteria. Using the ground-water pathway as an example, the corrective action goal should be to reduce constituent concentration levels to the applicable maximum contaminant levels (MCLs) or health based numbers at the monitoring point (i.e., for new units, no more than 150 meters from the waste management unit).

A corrective action program generally has the components outlined here and in Figure 1 (and explained in greater detail below). The detail required in each of these components varies depending on the unit and its complexity and only those tasks appropriate for your site should be conducted. We recommend that you coordinate with the state during all phases of corrective action.

- Perform a unit assessment to locate the actual or potential source(s) of the release(s) of contaminants based on waste management unit monitoring information and the use of other existing information.
- Perform a unit investigation to characterize the nature and extent of contamination from the unit and any contamination that might be migrating beyond the facility boundary, identify areas and populations threatened by releases from the unit, and determine short- and long-term threats of releases from the unit to human health and the environment.
- Identify, evaluate, and implement interim measures, if needed. Interim measures are short-term actions taken to protect human health and the environment while a unit assessment or a unit investigation is being performed or before a corrective measure is selected.
- Identify, evaluate, and implement corrective measures to abate the further spread of contaminants, control the source of contamination, and to remediate releases from the unit.
- Design a program to monitor the maintenance and performance of any interim or final corrective measures to ensure that human health and the environment are being protected.

Figure 1 Corrective Action Process



A. Unit Assessment

Often the first activity in the corrective action process is the unit assessment. A unit assessment identifies potential and actual releases from the unit and makes preliminary determinations about release pathways, the need for corrective action, and interim measures. If appropriate, evaluate the possibility of addressing multiple units as the corrective action process proceeds. Table 1 identifies a number of factors to consider during a unit assessment. Tables 2 and 3 present some useful properties and parameters that define chemical

Table 1
Factors To Consider in Conducting a Unit Assessment

Unit/Site Characteristics	Chemical Characteristics	Migration Pathways	Evidence of Release Potential	Exposure
Contamination Parameters – Concentrations – Depth and location of contamination Physical Parameters – Geology – Depth to ground water – Flow characteristics – Climate Historical Information – History of unit – Knowledge of waste generation practices	Type of waste placed in the unit Volatilization parameters Toxicological characteristics Physical and chemical properties Chemical class Soil sorption/ degradation parameters	Facility's geological setting Facility's hydrogeological setting Atmospheric conditions Topographic characteristics Manmade features (e.g., pipelines, underground utility lines)	Prior inspection reports Citizen complaints Monitoring data Visual evidence, such as discolored soil, seepage, discolored surface water or runoff Other physical evidence such as fish kills, worker illness, or odors Sampling data Offsite water wells	Proximity to affected population Proximity to sensitive environments Likelihood of migration to potential receptors

Table 2
Chemical Characteristics

Property/Parameter	Characteristics
Chemical properties	Density, viscosity
Chemical class	Acid, base, polar neutral, nonpolar neutral, inorganic
Chemical reactivity	Oxidation, reduction, hydrolysis, polymerization, precipitation, biotic/abiotic
Soil sorption parameters	Cation exchange capacity, anion exchange capacity, soil/water partition coefficient (K_d), octanol/water partition coefficient (K_{ow})
Soil degradation parameters	Half-life, intermediate products of degradation
Volatilization parameters	Henry's law constant, vapor pressure

Table 3
Site Characteristics

Parameter/Information	Characteristics
Contamination parameters	Concentration in soil, water, and subsurface gas; depth and location of contamination
Physical parameters	Permeability, particle size distribution, organic matter, geology, moisture content, flow characteristics, depth to ground water, pH, wind directions, climate
Historical information	History of the waste management unit, knowledge of waste generation processes, waste quantity

Additional information on performing unit assessments can be found in RCRA Facility Assessment Guidance (U.S. EPA, 1986).

and site characteristics that you should consider when characterizing your site and environmental setting.

A beginning step is to review available site information regarding unit characteristics, waste characteristics, contaminant migration pathways, evidence of release, and exposure potential. Much of this information should have been gathered in the site assessment (see Chapter 4–Considering the Site) and waste characterization phases (see Chapter 2–Characterizing Waste). Conducting a visual site inspection of the unit will re-affirm available information and enable you to note any visual evidence of releases. If necessary, perform sampling to confirm or disprove suspected releases before performing an extensive unit investigation.

B. Unit Investigation

A unit investigation is conducted after a release from the operating unit has been confirmed. The purpose of the investigation is to gather enough data to fully characterize the nature, extent, and rate of migration of contaminants to determine and support the selection of the appropriate response action. It is important to tailor unit investigations to specific conditions and circumstances at the unit and focus on releases and potential pathways. Although each medium will require specific data and methodologies to investigate a release, a general strategy for this investigation, consisting of two elements, can be described as follows.

- Collect and review monitoring data, data which can be gathered from outside information sources on parameters affecting the release, or new information such as aerial photography or waste characterization.
- Formulate and implement field investigations and sampling and analysis or monitoring procedures designed to verify suspected releases. Evaluate the nature, extent, and rate of migration of verified releases. Refer to Chapter 9–Monitoring Performance to help design a monitoring program.

Detailed knowledge of source characteristics is valuable in identifying constituents for which to monitor, indicator parameters, and

Guidance on Performing Unit Investigations

Additional guidance on performing unit inspections can be found in the following EPA documents:

- *RCRA Facility Investigation Guidance Volume I: Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations* (U.S. EPA, 1989a)
- *RCRA Facility Investigation Guidance Volume II: Soil, Ground Water, and Subsurface Gas Releases* (U.S. EPA, 1989b)
- *RCRA Facility Investigation Guidance Volume III: Air and Surface Water Releases* (U.S. EPA, 1989c)
- *RCRA Facility Investigation Guidance Volume IV: Case Study Examples* (U.S. EPA, 1989d)
- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA, 1988a)
- *Draft Practical Guide for Assessing and Remediating Contaminated Sites* (U.S. EPA, 1989f)
- *Site Characterization for Subsurface Remediation* (U.S. EPA, 1991c)

possible release pathways. It is also helpful in linking releases to a particular unit. Monitoring information collected by a program described in Chapter 9–Monitoring Performance can be helpful. Waste and unit characteristics can also provide information for determining release rates and for determining the nature and scope of any corrective measures which might be applied. Refer to Chapter 2–Characterizing Waste for information on how to characterize a waste.

Unit investigations can result in significant amounts of data, including the results of chemical, physical, or biological analyses. This can involve analyses of many constituents, in different media, at various sampling locations, and at different times. Data management procedures should be established to effectively process these data such that relevant data descriptions, such as sample numbers, locations, procedures, and methods, are readily accessible and accurately maintained.

1. *Specific Considerations for Ground-Water Investigations*

To facilitate ground-water investigations consider the following parameters:

- Ability of the waste to be dissolved or to appear as a distinct phase.
- Degradability of the waste and its decomposition products.
- Geologic and hydrologic factors which affect the release pathway.

- Regional and site-specific ground-water flow regimes that might affect the potential magnitude of the release pathways and possible exposure routes.

Exposure routes of concern include ingestion of ground water as drinking water and near-surface flow of contaminated ground water into basements of residences or other structures. It is important to also address the potential for the transfer of contaminants in ground water to other environmental media through processes such as discharge to surface water and volatilization to the atmosphere.

Use existing ground-water monitoring information, where it exists, to determine the nature, extent, and rate of contaminant release from the unit(s) to the ground water. Investigation of a suspected release might be terminated based on results from an initial monitoring phase if these results show that an actual release has not, in fact, occurred. If, however, contamination is found, you should characterize the release through subsequent monitoring to help determine the detailed constituent composition and concentrations, the horizontal and vertical extent of the contaminant release, as well as its rate of migration as appropriate to assess the risk. This should be accomplished through direct sampling and analysis and, when appropriate, can be supplemented by indirect means such as geophysical assessment and fate and transport modeling.

2. *Specific Considerations for Soil Investigations*

When performing soil investigations, consider the following parameters:

- Ability of the waste to be dissolved by infiltrating precipitation.

- The waste's affinity for soil particles.
- The waste's degradability and its decomposition products.
- Surface features such as topography, erosion potential, land-use potential, and vegetation.
- Stratigraphic/hydrologic features such as soil profile, particle-size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity.
- Meteorological factors such as temperature, precipitation, runoff, and evapotranspiration.

Relevant physical and chemical properties of the soil should be assessed to help determine potential mobility of any contaminants in the soil. Also, consider the potential for transfer of contaminants in the soil to other environmental media such as overland runoff to surface water, leaching to ground water, and volatilization to the atmosphere. In addition, you should establish whether a potential release involved a point source (localized) or a non-point source. Point sources might include container handling and storage areas, tanks, waste piles, and bulk chemical transfer areas. Non-point sources might include airborne particulate contamination originating from a land application unit and widespread leachate seeps from a landfill. Table 4 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

3. *Specific Considerations for Surface-Water Investigations*

When conducting surface-water investigations, the following factors should be considered:

- The release mechanism, such as overtopping of an impoundment.

Table 4
Potential Release Mechanisms for Various Unit Types

Unit Type	Release Mechanism
Surface impoundment	Releases from overtopping Leakage through dikes or unlined portions to surrounding soils
Landfill	Migration of releases outside the unit's runoff collection and containment system Seepage through underlying soils
Waste pile	Migration of releases outside the unit's runoff collection and containment system Seepage through underlying soils
Land application unit	Migration of runoff outside the application area Passage of leachate into the soil horizon

- The nature of the source area, such as point or non-point.
- Waste type and degradability.
- Local climate.
- Hydrologic factors such as stream flow conditions.
- The ability for a contaminant to accumulate in stream bottom sediments.

Also, address the potential for the transfer of contaminants in surface water to other environmental media such as soil contamination as a result of flooding of a contaminated creek on the facility property.

During the initial investigation, particular attention should be given to sampling runoff from contaminated areas, leachate seeps, and other similar sources of surface-water contamination, as these are the primary overland release pathways for surface water. Releases to surface water via ground-water discharge should be addressed as part of the ground-water investigation for greater efficiency. See Chapter 9–Monitoring Performance, Section II: Surface-Water Monitoring for information on proper surface-water monitoring techniques.

4. *Specific Consideration for Air-Release Investigations*

The intent of an air-release investigation is to determine any actual or potential effects at a nearby receptor. This might involve emission modeling to estimate unit-specific emission rates, air monitoring to determine concentrations at a nearby receptor, emission monitoring at the source to determine emission rates, and dispersion modeling to estimate concentrations at a nearby receptor. See Chapter 9–Monitoring Performance, Section IV: Air Monitoring for more information on air monitoring and Chapter 5–Protecting Air for more information on air modeling.

As in other media-specific investigations, the first step is to collect, review, and evaluate available waste, unit, environmental setting, and release data. Evaluation of these data can indicate the need for corrective measures or that no further action is required. For example, the source might involve a large, active storage surface impoundment containing volatile constituents adjacent to residential housing. Action, therefore, instead of further studies, might be appropriate. Another case might involve a unit in an isolated location, where an acceptable modeling or monitoring database indicates that the air release can be considered insignificant and, therefore, further studies are not warranted. In many cases, however, further release characterization might be necessary.

C. Interim Measures

Many cleanup programs recognize the need for interim measures while site characterization is underway or before a final remedy is selected. Typically, interim measures are used to control or abate ongoing risks before final remedy selection. Examples of interim measures for various types of waste management units and various release types are listed in Table 5. More information is available through the *RCRA Corrective Action Interim Measures Guidance—Interim Final* (U.S. EPA,

Table 5
Examples of Interim Corrective Measures

Unit/Release	Interim Measure
Containers	Overpack or redrum Construct storage area Move to new storage area Segregation Sampling and analysis Treatment or storage Temporary cover
Tanks	Construct overflow/secondary containment Leak detection or repair Partial or complete removal
Surface Impoundments	Reduce head Remove free liquids and highly mobile wastes Stabilize or repair side walls, dikes, or liner(s) Temporary cover Run-on or runoff control (diversion or collection devices) Sample and analyze to document the concentration of constituents Interim ground-water measures

Table 5
Examples of Interim Corrective Measures (cont.)

Unit/Release	Interim Measure
Landfills	Run-on or runoff control (diversion or collection devices) Reduce head on liner or leachate collection and removal system Inspect leachate collection and removal system, or french drain Repair leachate collection and removal system, or french drain Temporary cap Waste removal Interim ground-water measures
Waste Piles	Run-on or runoff control (diversion or collection devices) Temporary cover Waste removal Interim ground-water measures
Soils	Sampling or analysis Removal and disposal Run-on or runoff control (diversion or collection devices) Temporary cap or cover
Ground Water	Delineation or verification of gross contamination Sampling and analysis Interceptor trench, sump, or subsurface drain Pump-and-treat In situ treatment Temporary cap or cover
Surface-Water Releases (Point and Non-Point)	Overflow or underflow dams Filter fences Run-on or runoff control (diversion or collection devices) Regrading or revegetation Sample and analyze surface waters and sediments or point source discharges
Gas Mitigation Control	Barriers Collection Treatment Monitoring
Particulate Emissions	Truck wash (decontamination unit) Revegetation Application of dust suppressant
Other Actions	Fencing to prevent direct contact Sampling offsite areas Alternate water supply to replace contaminated drinking water Temporary relocation of exposed population Temporary or permanent injunction

1988b) and *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992b). Interim measures can be separate from the comprehensive corrective action plan, but should be consistent with and integrated into any longer term corrective measure. To the extent possible, interim measures should not seriously complicate the ultimate physical management of wastes or constituents, nor should they present or exacerbate a health or environmental threat.

D. Evaluating Potential Corrective Measures

The corrective measure or measures selected should meet the corrective action goals, such as a state or local cleanup standard, and control or remove the source of contamination to reduce or eliminate further releases. Most corrective measures fall into one of three technology categories—containment technologies, extraction or removal technologies, or treatment technologies. The performance objectives of the corrective measures relate to source reduction, cleanup goals, and cleanup timeframe. These measures might include the repair or upgrade of existing unit components, such as liner systems, leachate collection systems, or covers.

You should base selection of corrective measures on the following considerations and contact the state and community representatives before finalizing the selection:

- The ability to meet appropriate cleanup standards.
- The appropriateness and effectiveness of the treatment technology in relation to waste and site characteristics.
- The long- and short-term effectiveness including economic, technical feasibility, and protectiveness of the remedy.
- The effectiveness of the remedy in reducing further releases.
- The ease of implementing the remedy.
- The degree to which local community concerns have been addressed.

Potential Corrective Measures

Additional guidance on potential corrective measures is available from the following documents:

- *Corrective Action: Technologies and Applications* (U.S. EPA, 1989c)
- *Handbook: Stabilization Technologies for RCRA Corrective Actions* (U.S. EPA, 1991b)
- *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992b)
- *Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners* (U.S. EPA, 1996c)
- *Handbook: Remediation of Contaminated Sediments* (U.S. EPA, 1991a)
- *Abstracts of Remediation Case Studies* (U.S. EPA, 1995)
- *Bioremediation Resource Guide* (U.S. EPA, 1993)
- *Groundwater Treatment Technology Resource Guide* (U.S. EPA, 1994a)
- *Physical/Chemical Treatment Technology Resource Guide* (U.S. EPA, 1994b)
- *Soil Vapor Extraction Treatment Technology Resource Guide* (U.S. EPA, 1994d)

1. *Meeting Cleanup Standards*

Work with your state and community representatives to establish risk-based cleanup standards for the media of concern before identifying potential corrective measures. For example, if there is a statistically significant increase of constituent concentrations over background in the ground water, cleanup standards would include reducing contaminant concentrations to the MCL or health-based level at the point of monitoring.

Several approaches have been developed to identify appropriate cleanup standards. One of the more recent approaches is the Risk-Based Corrective Action (RBCA) standard developed by some states and the American Society for Testing and Materials (ASTM) Committee. The RBCA standard provides guidance on how to integrate ecological and human-health, risk-based, decision-making into the traditional corrective action process described above. RBCA is a decision-making process for the assessment and response to chemical releases. This standard is applicable to all types of chemical-release sites, which can vary greatly in terms of their complexity, physical and chemical characteristics, and the risk they pose to human health and the environment. RBCA uses a tiered approach that begins with simple analyses and moves to more complex evaluations when necessary. The foundation of the RBCA process is that technical policy decisions are identified in the front-end of the process to ensure that data collected are of sufficient quantity and quality to answer questions posed at each tier of the investigation. The RBCA standard is not intended to replace existing regulatory programs, but rather to provide an enhancement to these programs. The RBCA process allows for a three-tiered approach as described below.

In recent years, many states have adopted similar risk-based guidance or rules. The Louisiana Department of Environmental Quality, for instance, promulgated its Risk Evaluation/Corrective Action Program (RECAP) final rule, on June 20, 2000. Likewise, the Texas Natural Resource Conservation Commission (TNRCC) finalized the Texas Risk Reduction Program in 1999 (Title 30 Texas Administrative Code (TAC) Chapter 350). Your state and community representatives can tell you whether similar RBCA standards exist in your state and the appropriateness of such an approach. ASTM also offers two training courses on RBCA: Risk-Based Corrective Action for Chemical Releases, and Risk Based Corrective Action Applied at Petroleum Release Sites. These courses are open to all individuals from federal, state, tribal, and local regulatory agencies as well as professionals from the private sector.

RBCA Tier 1 Evaluation

A Tier 1 evaluation classifies a site according to the urgency for corrective action using broad measures of release and exposure. This tier is used to identify the source(s) of the chemical release, obvious environmental impacts, potential receptors, and significant exposure pathways. During a Tier 1 evaluation, site-specific contaminant concentrations are compared against a standard table of risk-based screening levels (RBSLs) that have been developed using conservative, nonsite-specific exposure assumptions. If a site’s contaminant concentrations are found to be above the RBSLs, then corrective action or further evaluation would be considered. Continued monitoring might be the only requirement if site-specific contaminant concentrations are below the RBSLs.

At the end of the Tier 1 evaluation, initial corrective action responses are selected while additional analysis is conducted to determine final remedial action, if necessary. The standard includes an exposure scenario evaluation flowchart to help identify appropriate receptors and exposure scenarios based on current and projected reasonable land use scenarios, and appropriate response actions. Site conditions should also be compared to relevant ecological screening criteria (RESC) applicable to the site which might include qualitative or quantitative benchmarks, comparison of site conditions to local biological and environmental conditions, or considerations related to the exposed habitat areas.

RBCA Tier 2 Evaluation

The user might decide to conduct a Tier 2 evaluation after selecting and implementing the appropriate initial response action to the Tier 1 evaluation. The purpose of this tier is to determine site-specific target levels (SSTLs) and appropriate points of compliance when it is determined that Tier 1 RBSLs have been exceeded. While a Tier 2 evaluation is based on similar screening levels as those used in the Tier 1 evaluation, some of the generic assumptions used in the earlier evaluation are replaced with site-specific measurements to develop the SSTLs. The intent of Tier 2 is to incorporate the concept that measured levels of contamination can decline over the distance from source to receptor. Thus, simple environmental fate and transport modeling is used to predict attenuation over that distance. If site-specific contaminant concentrations are above the SSTLs, corrective action is needed and further analysis might be required.

RBCA Tier 3 Evaluation

A Tier 3 evaluation involves the same steps as those taken during the Tier 1 and Tier 2 evaluations, except that a significant increase in effort is employed to better define the scope of the contamination. Actual levels of contamination are compared to SSTLs that are developed for this Tier. The Tier 3 SSTLs differ from Tier 2 SSTLs in the level of sophistication used to develop site-specific measures of the fate and transport of contaminants. Where simplified, site-specific measures of the fate and transport are used in the Tier 2 evaluation, much more sophisticated models and data will be used in this Tier. These models might rely on probabilistic approaches and on alternative toxicity and biodegradability data.

2. Evaluating Treatment Technologies

In nearly every phase of the corrective action process, some information about treatment technologies is important. Many documents exist that describe candidate technologies in detail and give their respective applicability and limitations. Below are descriptions and examples of the three major technology categories: containment, extraction, and treatment.

Containment technologies are used to stop the further spread or migration of contaminants. Some examples of common containment techniques for constituents in land-based units include waste stabilization, solidification, and capping. Capping and other surface-water diversion techniques, for instance, can control infiltration of rainwater to the contaminated medium. Typical ways to contain contaminated ground-water plumes include ground-water pumping, subsurface drains, and barrier or slurry walls. These ground-water containment technologies control the migration of contaminants in the ground-water plume and prevent further dissolution of contaminants by water entering the unit.

- **Ground-water pumping.** Ground-water pumping can be used to manipulate and manage ground water for the purpose of removing, diverting, and containing a contaminated plume or for adjusting ground-water levels to prevent plume movement. For example, pumping systems consisting of a series of extraction wells located directly downgradient from a contaminated source can be used to collect the contaminated plume. The success of any contaminant capture system based upon pumping wells is dependent upon the rate of ground-water flow and the rate at which the well is pumped. Thus, the zone of capture for the pumping system must be established.

- **Subsurface drains.** Subsurface drains are essentially permeable barriers designed to intercept the ground-water flow. The water is collected at a low point and pumped or drained by gravity to the treatment system. Subsurface drains can also be used to isolate a waste disposal area by intercepting the flow of uncontaminated ground water before it enters into a contaminated site. Subsurface drains are most useful in preliminary containment applications for controlling pollutant migration, while a final treatment design is developed and implemented. They also provide a measure of long-term protection against residual contaminants following conclusion of treatment and site closure.

- **Barrier walls.** Low permeability barriers are used to direct the uncontaminated ground-water flow around a particular site or to prevent the contaminated material from migrating from the site. Barrier walls can be made of a wide variety of materials, as long as they have a lower permeability than the aquifer. Typical materials include mixtures of soil and bentonite, mixtures of cement and bentonite, or barriers of engineered materials (sheet piling). A chemical analysis of wall/contaminant compatibility is necessary for the final selection of materials. The installation of a low permeability barrier usually entails a great deal of earth moving, requires a significant amount of land area, and is expensive. Once in place, however, it represents a long-term, low maintenance system.

Extraction or removal technologies physically remove constituents from a site. Extraction techniques might remove the constituent of concern only, or the contaminated media itself. For example, vapor extraction might just remove the constituent vapors from the soil, while excavation could remove all of the contaminated soil. Extraction technologies

include excavation, pumping, product recovery, vapor extraction or recovery, and soil washing.

Treatment or destruction technologies render constituents less harmful through physical, biological, chemical, and thermal processes including ground-water treatment, pH adjustment, oxidation and reduction, bioremediation, and incineration.

- **Ground-water pump-and-treat** is one of the most widely used ground-water treatment technologies. Conventional methods involve pumping contaminated water to the surface for treatment. Pump-and-treat systems are used primarily for hydraulic containment and treatment to reduce the dissolved contaminant concentrations in ground water so that the aquifer complies with clean-up standards or the treated water withdrawn from the aquifer can be put to beneficial use. A thorough, three-dimensional characterization of subsurface soils and hydrogeology, including particle-size distribution, sorption characteristics, and hydraulic conductivity, provides a firm basis for appropriate placement of pump-and-treat wells. The following techniques can be useful in effectively designing and operating the pump-and-treat system:

- Using capture zone analysis, optimization modeling, and data obtained from monitoring the effects of initial extraction wells to identify the best locations for wells.
- Phasing the construction of extraction and monitoring wells so that information obtained from the operation of the initial wells informs decisions about siting subsequent wells.
- Phasing pumping rates and the operation of individual wells to enhance containment, avoid stagnation zones, and ensure removal of the most contaminated ground water first.

• **Chemical treatment** is a class of processes in which specific chemicals are added to wastes or to contaminated media in order to achieve detoxification. Depending on the nature of the contaminants, the chemical processes required might include pH adjustment, lysis, oxidation, reduction, or a combination of these. In addition, chemical treatment is often used to prepare for or facilitate the treatment of wastes by other technologies.

- The function of pH adjustment is to neutralize acids and bases and to promote the formation of precipitates, which can subsequently be removed by conventional settling techniques. Typically, pH adjustment is effective in treating inorganic or corrosive wastes.
- Oxidation and reduction reactions are utilized to change the chemical form of a hazardous material, in order to render it less toxic or to change its solubility, stability, separability, or otherwise change it for handling or disposal purposes. In any oxidation reaction, the oxidation state of one compound is raised (i.e., oxidized) while the oxidation state of another compound is lowered (i.e., reduced). In the reaction, the compound supplying the oxygen (or chlorine or other negative ion) is called the oxidizer or oxidizing agent, while the compound accepting the oxygen (i.e., supplying the positive ion) is called the reducing agent. The reaction can be enhanced by catalysis, electrolysis, or photolysis.
- The basic function of lysis processes is to split molecules to permit further treatment. Hydrolysis is a chemical reaction in which water reacts with another substance. In the reaction, the water molecule is ionized while the other compound

is split into ionic groups. Photolysis, another lysis process, breaks chemical bonds by irradiating a chemical with ultraviolet light. Catalysis uses a catalyst to achieve bond cleavage.

- **Biological treatment** is a destruction process relying primarily on oxidative or reductive mechanisms. The two types of biological treatment processes are aerobic and anaerobic. Aerobic processes are oxidative processes and are the most widely used. These processes require a supply of molecular oxygen and include suspended growth systems, fixed-film systems, hybrid reactors, and in situ application. Anaerobic processes achieve the reduction of organic matter to methane and carbon dioxide in an oxygen-free environment. The use of biological treatment processes is directed toward accomplishing destruction of organic contaminants, oxidation of organic chemicals whereby the organic chemicals are broken down into smaller constituents, and dehalogenation of organic chemicals by cleaving a chlorine atom(s) or other halogens from a compound.

  Biological processes can be used on a broad class of biodegradable organic contaminants. It should be noted, however, that very high concentrations as well as very low concentrations of organic contaminants are difficult to treat via biological processes. Since microorganisms need appropriate conditions in which to function, you must provide an optimum environment, whether aboveground in a reactor or belowground for an in situ application. The primary conditions which can affect the growth of the microbial community, in addition to providing them sufficient food (organic material), are pH, temperature, oxygen concentration, nutrients, and toxicity.

  - Typically, a biological treatment system operates best when a waste stream is at a pH near 7. However, waste treatment systems can operate (with some exceptions) between pH values of 4 and 10. The exceptions are aerobic systems in which ammonia is oxidized to NO_x as well as anaerobic methane fermenting systems. For these, the pH should be between 6 and 8; outside this range, efficiency will suffer.

  - Waste treatment systems can function over a temperature range of 5° to 60°C. Most waste treatment systems operate between 15° to 45°C and use mesophilic organisms.

  - Microorganisms need a certain amount of oxygen not only to survive but also to control their reactions. Therefore, the residual dissolved oxygen concentrations should be maintained at approximately 2 mg/l or greater within a typical liquid biotreatment system.

  - The quantity of nutrients needed depends on the biochemical oxygen demand (BOD) of the waste. The higher the BOD, the higher the number of cells produced and the greater the quantity of nutrients required.

  - The presence of toxic substances will obviously produce adverse conditions in a biological system. Unfortunately, it is difficult to cite specific toxic materials because toxicity depends on concentration. Nutrients can be toxic in higher concentrations and all types of organic compounds which can be used as food by bacteria can be toxic if their concentrations are high enough. Frequently, toxicity concerns can be avoided by waste dilution and microbe acclimation.

- **Thermal treatment**, or incineration, is a treatment technology applicable to the treatment of wastes containing a wide range of organic concentrations and low concentrations of water, metals, and other inorganics. Incineration is the thermal decomposition of organic constituents via cracking and oxidation reactions at high temperatures that can be used for detoxification, sterilization, volume reduction, energy recovery, and by-product chemical recovery. A well-designed and properly operated incinerator will destroy all but a tiny fraction of the organic compounds contained in the waste. Incinerator emission gases are composed primarily of carbon dioxide and water. The type and quantity of other compounds emitted depends on the composition of the wastes, the completeness of the combustion process, and the air pollution control equipment with which the incinerator is equipped. Incinerators are designed to accept wastes of varying physical forms, including gasses, liquids, sludges, and solids.
- **Stabilization/solidification** processes immobilize toxic or hazardous constituents in a waste by changing the constituent into immobile forms, binding them in an immobile matrix, or binding them in a matrix which minimizes the waste material surface exposed to solvent. Often, the immobilized product has a structural strength sufficient to prevent fracturing over time. Solidification accomplishes the intended objective by changing a non-solid waste material into a solid, monolithic structure that ideally will not permit liquids to percolate into or leach materials out of the mass. Stabilization, on the other hand, binds the hazardous constituents into an insoluble matrix or changes the hazardous constituent to an insoluble form. Other objectives of solidification/stabilization processes are to improve handling of the waste and produce a stable solid (no free liquid) for subsequent use as a construction material or for landfilling. Major categories of industrial waste solidification/stabilization systems are cement-based processes. Waste characteristics such as organic content, inorganic content, viscosity, and particle size distribution can affect the quality of the final solidified product. These characteristics inhibit the solidification process by affecting the compatibility of the binder and the waste, the completeness of encapsulation, and the development of preferential paths for leaching due to spurious debris in the waste matrix.

In selecting a treatment technology or set of technologies, it is important to consider the information obtained from the waste and site characterizations, see Chapter 2–Characterizing Waste and Chapter 4–Considering the Site. For example, the waste characterization should tell the location of the waste and in what phase(s) the waste should be expected to be found, (e.g., sorbed to soil particles). Waste characterization information also allows for the assessment of the leaching characteristics of the waste, its ability

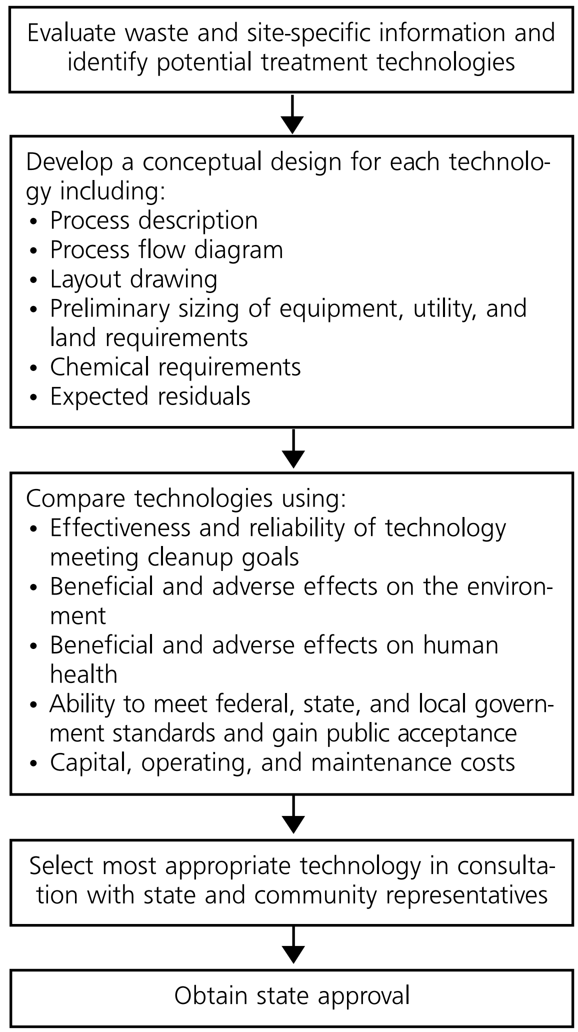
1 U.S. EPA, 1991. *Site Characterization for Subsurface Remediations.*

to be degraded, and its tendency to react with chemicals. The site characterization information should reveal important information about subsurface flow conditions and other physical characteristics, such as organic carbon content. You should use the information from the waste and site characterizations to select the appropriate treatment technology.

A screening process for selecting an appropriate technology is presented in Figure 2. In some cases, a treatment train, a series of technologies combined together, might be appropriate.[1] This step-by-step approach helps ensure that technologies that might be applicable at a site are not overlooked. In addition, the rationale for the elimination of specific technologies will be available to justify decisions to interested parties.

Figure 2

Recommended Screening Process for Selecting Appropriate Treatment Technologies



Additional information regarding the use and development of innovative treatment technologies is available from EPA's Hazardous Waste Clean-up Information (CLU-IN) Web site **<clu-in.org>**. This Web site describes programs, organizations, publications, and other tools for all waste remediation stakeholders. Of particular interest is the Remediation Technologies Screening Matrix which is a user-friendly tool to screen for technologies for a remediation project. The matrix allows you to screen through 64 in situ and ex situ technologies for either soil or ground-water remediation. Variables used in screening include contaminants, development status, overall cost, and cleanup time. The matrix can be accessed through CLU-IN or directly from the Federal Remediation Technologies Roundtable's Web site **<www.frtr.gov/matrix2/top_page.html>**.

Another source of information is the Field Analytic Technologies Encyclopedia (FATE) developed by EPA's Technology Innovation Office (TIO), in collaboration with the U.S. Army Corps of Engineers. FATE is an online encyclopedia of information about technologies that can be used in the field to characterize contaminated soil and ground water, monitor the progress of remedial efforts, and in some cases, confirm sampling and analysis for site closure. To access FATE visit: **<www.epa.gov/tio/chartext_tech.htm>**.

3. *Evaluating the Long- and Short-Term Effectiveness of the Remedy*

Evaluating the long- and short-term effectiveness of the remedy, involves analyzing the risks associated with potential exposure pathways, estimates of potential exposure levels, and the duration of potential exposure associated with the construction and implementation of the corrective measure. Because waste characteristics vary from site to site, the effect of a treatment technology with a particular waste might be unknown. It is important, therefore, to consider performing a treatability study to evaluate the effectiveness of one or more potential remedies. Spending the time and money up-front to better assess the effectiveness of a technology on a waste can save significant time and money later in the process. To judge the technical certainty that the remedy will attain the corrective action goal, also consider reviewing case studies where similar technologies have been applied.

It is also important to analyze the time to complete the corrective measure, because it directly impacts the cost of the remedy. It is therefore important to carefully evaluate the long-term costs of the remedial alternatives and the long-term financial condition of the facility. Consider including quality control measures in the implementation schedule to assess the progress of the corrective measure. It is also important to determine the degree to which the remedy complies with all applicable state laws.

The Federal Remediation Technologies Roundtable **<www.frtr.gov>** is at the forefront of the federal government's efforts to promote interagency cooperation to advance the use of innovative remediation technologies. Roundtable member agencies include EPA, the U.S. Department of Defense, the U.S. Department of Energy, and the U.S. Department of Interior. This group has prepared over 209 cost and performance reports that can be accessed through CLU-IN **<clu-in.org/remed1.cfm>**. These reports contained in the "Federal Remediation Technologies Roundtable Case Studies" document results from completed full-scale hazardous waste site remediation projects and several large-scale demonstration projects.

Treatability Studies

The four general types of treatability studies are laboratory-scale, bench-scale, pilot-scale, and field-scale.

- **Laboratory-scale** studies are small scale screening studies that generate qualitative information concerning the general validity of a treatment approach.
- **Bench-scale** studies are intermediate studies conducted in the laboratory. Bench scale studies are intended to answer specific design, operation, and cost questions, and are more detailed than laboratory studies.
- **Pilot-scale** studies are large scale experiments intended to provide quantitative cost and design data. They simulate anticipated full-scale operational configurations as closely as possible.
- **Field-scale** studies are large scale studies intended to monitor the performance of treatment systems under real world conditions at close to full scale operations.

More information on treatability studies can be found in *A Guide for Conducting Treatability Studies Under CERCLA* (U.S. EPA, 1992a).

They are meant to serve as primary reference sources, and they contain information on site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application.

EPA has also prepared an overview of ground-water cleanup at 28 sites entitled *Groundwater Cleanup: Overview of Operating Experience at 28 Sites* (U.S. EPA, 1999a) that is also available from CLU-IN. This overview presents a range of the types of cleanups typically performed at sites with contaminated ground water and summarizes information about the remediation systems at the 28 sites. Summarized information includes design, operation, and performance of the systems; capital, operating, and unit costs of the systems; and factors that potentially affect the cost and performance of the systems.

EPA's TIO Web site **<www.epa.gov/tio>** provides additional information about site characterization and treatment technologies for remediation. This Web site offers technology selection tools and describes programs, organizations, and available publications. Some of the available publications include *Abstracts of Remediation Case Studies, Volumes 1-4* (U.S. EPA, 2000a) which summarize 218 case studies of site remediation prepared by federal agencies. Many of these publications and links are also available through CLU-IN.

4. Evaluating the Effectiveness of Reducing or Eliminating the Source of Contamination

There are two major components of source control that should be evaluated. First, if source control consists of the removal, redisposal, or treatment of wastes, the volume of wastes and residual materials should be quantified and the potential to cause further contamination evaluated. Second, engineering controls intended to upgrade or repair deficient conditions at a waste management unit should be quantified in terms of anticipated effectiveness according to current and future conditions. This evaluation should determine what is technically and financially practicable. Health considerations and the potential for unacceptable exposure(s) to both workers and the public can affect an evaluation.

5. Evaluating the Ease of Implementation

The ease of implementing the proposed corrective measure will affect its schedule. To evaluate the ease of implementation of a specific corrective measure, it is important to

Selecting a Corrective Action Specialist

Once it has been determined that corrective measures are necessary, you should determine if in-house expertise is adequate or if an outside consultant is necessary.

If a consultant is needed, determine if the prospective consultant has the technical competence to do the work needed. A poor design for a recovery system, unacceptable field procedures, lack of familiarity with state requirements, or an inadequate investigation might unnecessarily cost thousands of dollars and still not complete the cleanup.

Some of the most important information to consider in selecting a consultant is whether the consultant has experience performing site investigations and remediations at similar sites, is familiar with state regulations, has staff trained in the use of field screening instruments, has experience in monitoring well design and installations, has established quality assurance and quality control procedures, and can provide references.

consider the availability of technical expertise and equipment, the ability to properly manage, dispose, or treat wastes generated by the corrective measure, and the likelihood of obtaining local permits and public acceptance for the remedy. Consider also the potential for contamination to transfer from one media to another as part of the overall feasibility of the remedy. Cross-media impacts should be addressed as part of the implementation phase. Develop a corrective-measure schedule identifying the beginning and end periods of the permitting, construction, treatment, and source control measures.

6. Measuring the Degree to Which Community Concerns are Met

Prior to selecting the corrective measure(s), you should hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Consider notifying adjacent property owners via mail of any identified contamination and proposed remedies. You also should identify any public concerns that have been expressed, via written public comments or from public meetings, about the facility's contamination and should address these concerns by the corrective measures being evaluated. The best remedy selected and implemented will be the one that is agreed upon by the state or local regulatory agency, the public, and the facility owner. Review Chapter 1–Understanding Risk and Building Partnerships before selecting any final remedies.

Citizen Guides to Treatment Technologies

EPA's Technology Innovation Office has developed a series of fact sheets that explain, in basic terms, the operation and application of innovative treatment technologies for remediating sites. The fact sheets address issues associated with innovative treatment technologies as a whole, bioremediation, chemical dehalogenation, in situ soil flushing, natural attenuation, phytoremediation, soil vapor extraction and air sparging, soil washing, solvent extraction, thermal desorption, and the use of treatment walls. English and Spanish versions of these fact sheets can be downloaded from CLU-IN **<clu-in.org/remed1.cfm>**.

E. Implementing Corrective Measures

The implementation of corrective measures encompasses all activities necessary to initiate and continue remediation. During the evaluation and assessment of the nature and extent of the contamination, you should decide whether no further assessment is necessary, whether institutional controls are necessary to protect human health and the environment, whether monitoring and site maintenance are necessary, and whether no further action and closure are appropriate for the unit.

1. Institutional Controls

Institutional controls are those controls that can be utilized by responsible parties and regulatory agencies in remedial programs where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Institutional controls can also be considered in situations where there is an immediate threat to human health. Institutional controls can vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement one or more of the controls. A state could adopt a statutory mandate, for example, requiring the use of deed restrictions as a way of enforcing use restrictions and posting signs. Commonly used institutional controls include deed restrictions, use restrictions, access controls, notices, registry act requirements, transfer act requirements, and contractual obligations. Additional information on institutional controls is available at EPA's Office of Solid Waste and Emergency Response Web site at <**www.epa.gov/oerrpage/superfund/action/postconstruction/ic.htm**>.

- **Deed restrictions.** These restrictions, also called restrictive covenants, place limits on the use and conveyance of land. They inform prospective owners/tenants of the environmental status of the property and ensure long-term compliance with the institutional controls. Typically, there are four requirements for a promise in a deed restriction: the conveyance of land must be documented in writing; it should precisely reflect the parties' intentions with respect to the scope and duration of the restrictions; there should be "privity of estate" so that it can be enforced by states; and the promise "touches and concerns the land."
- **Use restrictions.** Use restrictions are usually the heart of what is in a deed restriction. Use restrictions describe appropriate and inappropriate uses of the property, in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applicable cleanup standard. Such techniques also prohibit any person from making use of the site in a manner that creates an unacceptable risk of human or environmental exposure to the residual contamination. Use restrictions address uses that might disturb a containment cap or any unremediated soils under the surface or below a building. A prohibition on drinking onsite or offsite ground water might also be appropriate. Well restriction areas can be a form of institutional control by providing notice of the existence of contaminants in ground water and by prohibiting or conditioning the placement and use of any or all wells within an area.
- **Access controls.** Access to any particular site can be controlled by either fencing and gates, security, or posting or warnings. A state might use the following criteria to determine the appropriate level and means of access control: whether the site is located in a residential or mixed-use neighborhood; proximity to sensitive land-use areas including day care centers, playgrounds, and schools; and whether the site is frequently traversed by neighbors.
- **Notices.** Controls of this type generally provide notice of specific location of contamination on site and disclose any restrictions on access, use, and development of part or all of the contaminated site to preserve the integrity of the remedial action. Types of notices include record notice (notices on land records), actual notice (direct notice of environmental information to other parties to a land transaction), and notice to government authorities.
- **Registry act requirements.** Some states have registry act programs that provide for the maintenance of a registry of hazardous waste disposal sites and the restriction of the use and transfer of listed sites. When a site appears on the registry, the owner

must comply with regulatory requirements in regard to use and transfer of the site. The use of a site listed on the registry can not be changed without permission from the state agency.

- **Transfer act requirements.** Some states have transfer act programs that require full evaluation of all environmental issues before or after the transfer occurs. It might be that, within such a program, institutional controls can be established by way of consent order, administrative order, or some other technique that establishes implementation and continued responsibility for institutional controls. A typical transfer act imposes obligations and confers rights on parties to a land transaction arising out of the environmental status of the property to be conveyed. Transfer acts impose information obligations on the seller or lessor of a property. That party must disclose general information about strict liability for clean-up costs as well as property-specific information, such as the presence of hazardous substances, permitting requirements and status, releases, and enforcement actions and variances.
- **Contractual obligations.** One system for ensuring future restrictions on the use of a site, or the obligation to remediate a site, is to require private parties to restrict use by contract. While this method is often negotiated among private parties, it is difficult, if not impossible, to institutionalize control over the process without interfering with the abilities and rights of private parties to freely negotiate these liabilities. Another avenue is for the landowner or responsible party to obligate itself to the state by contract. The state might require a contractual commitment from the party to provide long-term monitoring of the site, use restrictions, and the means of continued funding for remediation.

2. *Monitoring and Site Maintenance*

In many cases, monitoring might need to be conducted to demonstrate the effectiveness of the implemented corrective measures. Consult with your state to determine the amount of time that monitoring should be conducted. Some corrective measures, such as capping, hydraulic control, and other physical barriers, can require long-term maintenance to ensure integrity and continued performance. Upon completion and verification of cleanup goals, reinstitute your original or modified ground-water monitoring program if the unit is still in active use.

3. *No Further Action and Site Closure*

When the corrective action goals have been achieved, and monitoring and site maintenance are no longer necessary to ensure that this condition persists, reinstitute your original or modified ground-water monitoring program if the unit is still in active use. It might be necessary, however, to ensure that any selected institutional controls remain in place. Refer to Chapter 11–Performing Closure and Post-Closure Care for additional information on site closures.

Taking Corrective Action Activity List

Consider the following when developing a corrective action program for industrial waste management units:

- ❑ Locate the source(s) of the release(s) of contaminants and determine the extent of the contamination.
- ❑ Consult with the state, community representatives, and qualified remedial experts when developing a corrective action program.
- ❑ Identify and evaluate all potential corrective measures including interim measures.
- ❑ Select and implement corrective measures based on the effectiveness and protectiveness of the remedy, the ease of implementing the remedy, and the degree that the remedy meets local community concerns and all applicable state laws.
- ❑ Design a program to monitor the maintenance and performance of corrective measures to ensure that human health and the environment are being protected.

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Part V
Ensuring Long-Term Protection

Chapter 11
Performing Closure and Post-Closure Care

Contents

Contents (cont.)

Performing Closure and Post-Closure Care

This chapter will help you:

- *Provide closure and post-closure care as an integral part of a unit's overall design and operation.*
- *Provide long-term environmental protection by reducing or eliminating potential threats and the need for potential corrective action at the site.*
- *Plan and accomplish the goals of closure and post-closure care by requiring that adequate funding be set aside to cover the planned costs of closure and post-closure care.*

The overall goal of closure is to minimize or eliminate potential threats to human health and the environment and the need for future corrective action at the site. If removing the wastes, containment devices, and any contaminated subsoils from a unit, the unit should be returned to an acceptable risk level so that it is not a current or future threat. If wastes will be left in place at closure, the unit should be closed in a manner that also reduces and controls current or future threats. Steps should also be taken to avoid future disruptions to final cover systems and monitoring devices.

This chapter will help address the following questions.

- How do I develop a closure plan?
- What factors should I consider when choosing a closure method?
- What are the components of a final cover?
- What costs are associated with post-closure care?

For post-closure care, the overall goal is to minimize the infiltration of water into a unit by providing maintenance of the final cover. Maintenance should be continued until such time as it is determined that care is no longer necessary. Also, during post-closure care, closed units should be monitored to verify and document that no unacceptable releases are occurring.

I. Closure Plans

A well-conceived closure plan is the primary resource document for the final stage in the life of a waste management unit. The purpose of a closure plan is to consider all aspects of the closure scenario. It should be comprehensive so that staff who will implement it years after its writing will clearly understand the activities it specifies. It also needs to provide enough detail to allow calculation of closure and post-closure care costs for determining how much funding needs to be set aside for those activities.

What should be considered when developing a closure plan?

You should tailor a closure plan to account for the unique characteristics of the unit, the waste managed in the unit, and anticipated future land use. Each unit will have different closure activities. Closing a surface impoundment, for example, involves removal of remaining liquids and solidifying sludges prior to placing a final cover on the unit.

The following information is important to consider when developing a closure plan:

- Overall goals and objectives of closure.
- Future land use.
- Type of waste management unit.
- Types, amount, and physical state of waste in the unit.
- Constituents associated with the wastes.
- Whether wastes will be removed or left in place at closure.
- Schedule (overall and interim).
- Costs to implement closure.
- Steps to monitor progress of closure actions, including inspections, maintenance, and monitoring (e.g., groundwater and leachate monitoring).
- Health and safety plans, as necessary.
- Contingency plans.
- Description of waste treatment or stabilization (if applicable).
- Final cover information (if applicable).
- Vegetation management.
- Run-on and runoff controls.
- Closure operations and maintenance.
- Erosion prevention and repair.
- Waste removal information (if applicable).
- Parameters to assess performance of the unit throughout the post-closure period.

The plan should address the types of waste that have been or are expected to be deposited in the management unit and the constituents that can reasonably be associated with those wastes. The types of expected wastes will affect both the design of the final cover and the types of activities that should be undertaken during the post-closure care period. Biodegradable waste, for example, can cause a final cover to subside due to decomposition and can also require gas management.

The closure plan should provide other information that will address the closure strategy. If, for instance, a final cover is planned, then the closure plan should consider seasonal precipitation that could influence the performance of both the cover and the monitoring system. Information concerning freeze cycles and the depth of frost permeation will provide supporting information with which to assess the adequacy of the cover design. Similarly, arid conditions should be addressed to support a decision to use a particular cover material, such as cobbles.

The closure plan should address the closure schedule, stating when closure is expected to begin, and when closure is expected to be completed. You should consider starting closure when the unit has reached capacity or has received the last expected waste for disposal. For units containing inorganic wastes, you should complete closure as soon as possible after the last expected waste has been received. A period of 180 days is a good general guide for completing closure, but the actual time frame will be dictated by site-specific conditions. For units receiving organic wastes, more time might be needed for the wastes to stabilize prior to completing closure. Similarly, other site-specific conditions, such as precipitation or winter weather, can also cause delay in completing closure. For these situations, you should complete closure as soon as feasible. You should also consult with the state agency to determine if any requirements exist for closure schedules.

Even within a waste management unit, some areas will be closed on different schedules, with certain areas in partial closure, while other areas continue to operate. The schedules and partial closure activities (such as intermediate cover) should be considered in the closure plan. Although the processes for closing such areas might not be different than those for closing the unit as a whole, it is still more efficient to integrate partial closure activities into the closure plan.

If the closure plan calls for the stabilization, solidification, or other treatment of wastes in the unit before the installation of a final cover, the plan should describe those activities in detail. Waste stabilization, solidification, or other treatment has four goals:

- Removing liquids, which are ill-suited to supporting the final cover.
- Decreasing the surface area over which the transfer or escape of contaminants can occur.
- Limiting the solubility of leachable constituents in the waste.
- Reducing toxicity of the waste.

For closure strategies that will use engineering controls, such as final covers, the plan should provide detailed specifications. This includes descriptions of the cover materials in each layer and their permeability as well as any drainage and/or gas migration control measures included in the operation of the final cover. Also the plan should identify measures to verify the continued integrity of the final cover and the proper operation of the gas migration and/or drainage control strategies.

If wastes will be removed at closure, the closure plan should estimate volumes of waste and contaminated subsoil and the extent of contaminated devices to be removed during closure. It should further state waste removal procedures, establish performance goals, and address any state or local requirements for closure by waste removal. The plan should identify numeric clean-up standards and existing background concentrations of constituents. It also should discuss the sampling plan for determining the effectiveness of closure activities. Finally, it should describe the provisions made for the disposal of removed wastes and other materials.

The closure plan should also provide a detailed description of the monitoring that will be conducted to assess the unit's performance throughout the post-closure period. These measurements include monitoring leachate volume and characteristics to ensure that a cover is minimizing infiltration. It is important to include appropriate ground-water quality standards with which to compare ground-water monitoring reports. You should develop the performance measures section of the plan prior to completing closure. This section establishes the parameters that will describe successful closure of the unit. If limits on these parameters are exceeded, it will provide an early warning that the final cover system is not functioning as designed and that measures should be undertaken to identify and correct problems.

II. Selecting a Closure Method

Factors to consider in deciding whether to perform closure by means of waste removal or through the use of a final cover include the following:

- **Feasibility.** Is closure by waste removal feasible? For example, if the waste volumes are large and underlying soil and ground water are contaminated, closure by total waste removal might not be possible. If the unit is contaminated, consult Chapter 10–Taking Corrective Action to identify activities to address the contamination. In some cases partial removal of the waste might be useful to remove the source of ground-water contamination.
- **Cost-effectiveness.** Compare the cost of removing waste, containment devices, and contaminated soils, plus subsequent disposal costs at another facility, to the cost of installing a final cover and providing post-closure care.
- **Long-term protection.** Will the final cover control, minimize, or eliminate post-closure escape of waste constituents or contaminated runoff to ground or surface waters to the extent necessary to protect human health and the environment?
- **Availability of alternate site.** Is an alternate site available for final disposal or treatment of removed waste? You should consult with the state agency to determine whether alternate disposal sites are appropriate.

Sections III and V address closure by use of final cover systems and associated post-closure care considerations. Alternatively, Section IV addresses closure by waste removal.

III. Closure by Use of Final Cover Systems

You might elect to close a waste management unit by means of a final cover system. This approach is common for landfill units and some surface impoundment units where some waste is left in place. The choice of final cover materials and design should be the result of a careful review and consideration of all site-specific conditions that will affect the performance of the cover system. If you are not knowledgeable about the engineering properties of cover materials, you should seek the advice of professionals or representatives of state and local environmental protection agencies.

This section addresses the more important technical issues that should be considered when selecting cover materials and designing a cover system. It discusses the various potential components of final cover systems, including the types of materials that can be used in their design and some of the advantages and disadvantages of each. This section also examines the interaction between the various components as they function within the system.

A. Purpose and Goal of Final Cover Systems

The principal goals of final cover systems are to:

- Provide long-term environmental protection of human health and the environment by reducing or eliminating potential risk of contaminant release.
- Minimize infiltration of precipitation into the waste management unit to minimize generation of leachates within the unit by promoting surface drainage and maximizing runoff.
- Minimize risk by controlling gas migration (as applicable), and by providing physical separation between waste and humans, plants, and animals.
- Minimize long-term maintenance needs.

The final cover should be designed to provide long-term protection and minimization of leachate formation. Final cover systems can be inspected, managed, and repaired to maintain long-term protection. For optimal performance, the final cover system should be designed to minimize infiltration, surface ponding, and the erosion of cover material. To avoid the accumulation of leachate within a unit, the cover system should be no more permeable than the liner system. For example, if a unit's bottom liner system is composed of a low-permeability material, such as compacted clay or a geomembrane, then the cover should also be composed of a low-permeability material unless an evaluation of site-specific conditions shows an equivalent reduction in infiltration. If the cover system is more permeable than the liner, leachate will accumulate in the unit. This buildup of liquids within a unit is often referred to as the "bathtub effect." In addition, since many units can potentially generate gas, cover systems should be designed to control gas migration. Proper quality assurance and quality control during construction and installation of the final cover are essential in order to ensure that the final cover performs in accordance with its design. For general information on quality assurance during construction of the final cover, refer back to the construction quality assurance section of Chapter 7, Section B–Designing and Installing Liners. Recommendations for the type of final cover system to use will depend on the type of liner and the gas and liquids management strategy employed in a unit.

B. Technical Considerations for Selecting Cover Materials

Several environmental and engineering concerns can affect cover materials and should be considered in the choice of those materials.

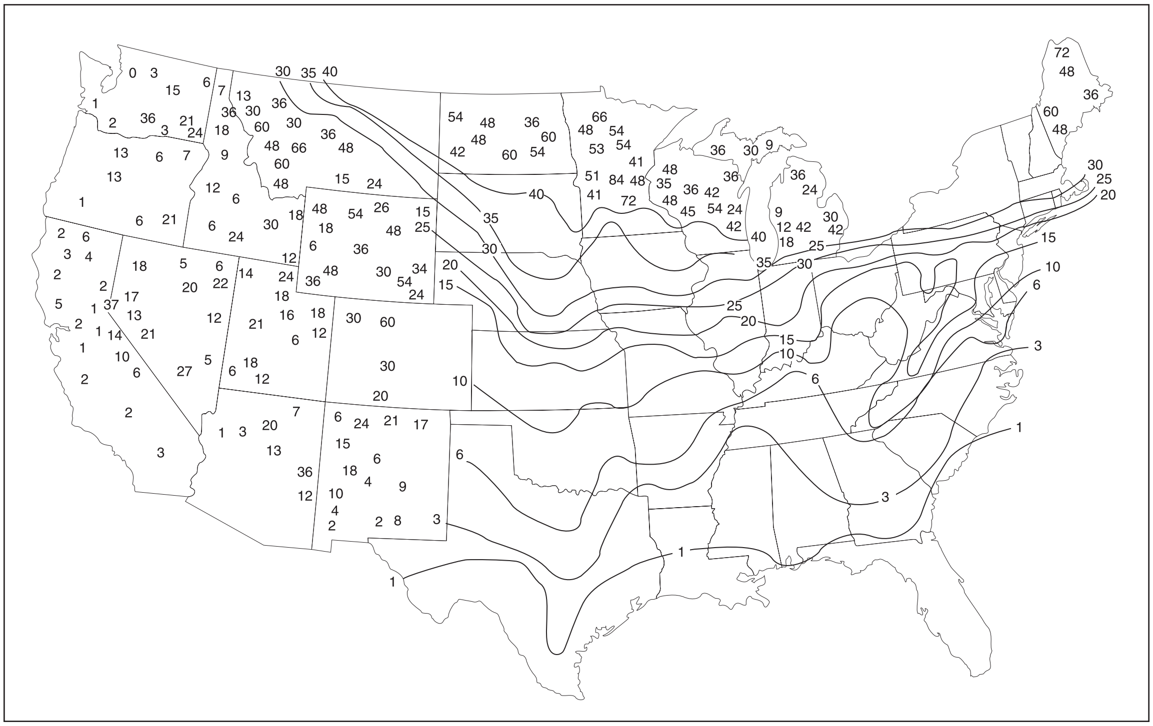
How can climate affect a final cover?

Freeze and thaw effects can lead to the development of microfractures in low permeability soil layers. These effects also can cause the realignment of interstitial fines (silts and clays), thereby increasing the hydraulic conductivity of the final cover. As a result, you should determine the maximum depth of frost penetration at a site and design covers accordingly. In other words, barrier layers should be below the maximum frost penetration depth. Information regarding the maximum frost penetration depth for a particular area can be obtained from the Natural Resource Conservation Service with the U.S. Department of Agriculture, local utilities, construction companies, local universities, or state agencies. Figure 1 illustrates the regional depth of frost penetration. You should ensure that vegetation layers are thick enough that low permeability soil layers in the final cover are placed below the maximum frost penetration depth.

How can settlement and subsidence affect a final cover?

When waste decomposes and consolidates, settlement and subsidence can result. Excessive settlement and subsidence can significantly impair the integrity of the final cover system by causing ponding of water on the surface, fracturing of low permeability infiltration layers, and failure of geomembranes. The degree and rate of waste settlement are difficult to estimate, but they should be considered during design and development of closure plans. Waste settlement should also be considered when determining the timing of closure. Steps should be taken to minimize the degree of settlement that will occur after the final cover system has been installed.

Figure 1. Regional Depth of Frost Penetration in Inches



Source: U.S. EPA, 1989a.

How can erosion affect the performance of a final cover?

Erosion can adversely affect the performance of the final cover of a unit by causing rills that require maintenance and repair. Extreme erosion can lead to the exposure of the infiltration layer, initiate or contribute to sliding failures, or expose the waste. Anticipated erosion due to surface-water runoff for a given design criteria can be approximated using the USDA Universal Soil Loss Equation[1] (U.S. EPA, 1989a). By evaluating erosion loss, you might be able to optimize the final cover design to reduce maintenance through selection of the best available soil materials. A vegetative cover not only improves the appearance of a unit, but it also controls erosion of the final cover.

The vegetation components of the erosion layer should have the following characteristics:

- Locally adapted perennial plants that are resistant to various climatic changes reasonably expected to occur at the site.
- Roots that will not disrupt the low-permeability layer.
- The ability to thrive in low-nutrient soil with minimum nutrient addition.
- The ability to survive and function with little or no maintenance.

Why are interfacial and internal friction properties for cover components important?

Adequate friction between cover components, such as geomembrane barrier layers and soil drainage layers, as well as between any geosynthetic components, is needed to prevent extensive slippage or interfacial shear. Water and ice can affect the potential for

[1] USDA Universal Soil Loss Equation: X = RKLSCP where: X = Soil loss (tons/acre/year); R = Rainfall erosion index; K = Soil erodibility index; L = Slope length factor; S = Slope gradient factor; C = Crop management factor; P = Erosion control practice. For minimal long-term care X < 2.0 tons/acre/year.

cover components to slip. Sudden sliding can tear geomembranes or cause sloughing of earthen materials. Internal shear can also be a concern for composite or geosynthetic clay liner materials. Measures to improve stability include using flatter slopes or textured geosynthetic membranes, geogrids designed to resist slipping forces, otherwise reinforcing the cover soil, and providing drainage.

Can dry soil materials affect a final cover?

Desiccation, the natural drying of soil materials, can have an adverse affect on the soil layers compromising the final cover. Although this process is most commonly associated with layers of low permeability soil, such as clay, it can cause problems with other soil types as well. Desiccation causes cracks in the soil surface extending downward. Cover layers are not very thick, and therefore these cracks can extend through an entire layer, radically changing its hydraulic conductivity or permeability. Care should be taken to detect desiccation at an early stage in time to mitigate its damage. Also, the tendency for final covers to become dry makes root penetration even more of a problem in that plants respond to drought by extending their root systems downward.

Can plants and animals have an effect on a final cover?

When selecting the plant species to include in the vegetative cover of a waste management unit, you should consider the potential for root systems to grow through surface cover layers and penetrate underlying drainage and barrier layers. Such penetration will form preferential pathways for water infiltration and compromise the integrity of the final cover system. Similarly, the presence of burrowing animals should be foreseen when designing the final cover system. Such animals can burrow in the surface layers and can potentially breach the underlying barrier layer. Strategies for mitigating the effects described here are discussed below in the context of protection layers composed of gravel or cobbles.

Is it necessary to stabilize wastes?

Before installing a final cover, liquid or semi-liquid wastes might need to be stabilized or solidified. Stabilization or solidification might be necessary to allow equipment on the unit to install the final cover or to ensure adequate support, or bearing capacity, for the final cover. With proper bulk cover technique, it might be feasible to place the cover over a homogeneous, gel-like, semi-liquid waste. When selecting a stabilization or solidification process, it is important to consider the effectiveness of the process and its compatibility with the wastes. Performance specifications for stabilization or solidification processes include leachability, free-liquid content, physical stability, bearing capacity, reactivity, ignitability, biodegradability, strength, permeability, and durability of the stabilized and solidified waste. You should consider seeking professional assistance to properly stabilize or solidify waste prior to closure.

Where solidification is not practical, you should consider reinforcement and construction of a specialized lighter weight cover system over unstable wastes. This involves using combinations of geogrids, geotextiles, geonets, geosynthetic clay liners, and geomembranes. For more detail on this practice, consult references such as the paper by Robert P. Grefe, *Closure of Papermill Sludge Lagoons Using Geosynthetics and Subsequent Performance*, and the Geosynthetic Research Institute proceedings, *Landfill Closures: Geosynthetics Interface Friction and New Developments*, cited in the Resources section.

How can wastes be stabilized?

Many stabilization and solidification processes require the mixing of waste with other materials, such as clay, lime, and ash. These processes include either sorbents or encapsulating agents. Sorbents are nonreactive and nonbiodegradable materials that soak up free liquids to form a solid or near-solid mass. Encapsulating agents enclose wastes to form an impermeable mass. The following are examples of some commonly used types of waste stabilization and solidification methods.

- **Cement-based techniques.** Portland cement can use moisture from the waste (sludge) for cement hydration. The end product has high strength, good durability, and retains waste effectively.
- **Fly ash or lime techniques.** A combination of pozzolanic fly ash, lime, and moisture can form compounds that have cement-like properties.
- **Thermoplastic techniques.** Asphalt, tar, polyolefins, and epoxies can be mixed with waste, forming a semirigid solid after cooling.
- **Organic polymer processes.** This technique involves adding and mixing monomer with a sludge, followed by adding a polymerizing catalyst. This technique entraps the solid particles.

After evaluating and selecting a stabilization or solidification process, you should conduct pilot-scale tests to address issues such as safety, mix ratios, mix times, and pumping problems. Testing will help assess the potential for an increase in waste volume. It will also help to plan the production phase, train operators, and devise construction specifications.

When conducting full-scale treatment operations, options exist for adding and mixing materials. These options might include in situ mixing and mobile plant mixing. In situ mixing is the simplest technique, using common construction equipment, such as backhoes, excavators, and dump trucks. In situ mixing is most suitable where large amounts of materials are added to stabilize or solidify the waste. The existing waste management area, such as a surface impoundment, can be used as the mixing area. The in situ mixing process is open to the atmosphere, so environmental and safety issues, such as odor, dust, and vapor generation, should be taken into consideration. For mobile plant mixing, wastes are removed from the unit, mechanically mixed with treatment materials in a portable processing vessel, and deposited back into the unit. Mobile plant mixing is generally used for treating sludges and other wastes with a high liquid content.

C. Components of a Final Cover

Cover systems can be designed in a variety of ways to accomplish closure goals. This flexibility allows a final cover design system to integrate site-specific technical considerations that can affect performance. This section discusses the potential components or layers of a final cover system, their functions, and appropriate materials for each layer. Since the materials used in cover systems are the same as those used in liner systems, refer to Chapter 7, Section B–Designing and Installing Liners for a more detailed discussion of the engineering properties of the various materials.

Table 1 presents the types of layers and typical materials that might exist in a final cover. The minimum appropriate thicknesses of each of the five types of layers depends upon many factors including site drainage, erosion potential, slopes, types of vegetative cover, type of soil, and climate.

Table 1
Types of Layers in Final Cover Systems

Layer	Type of Layer	Typical Materials
1	Surface (Erosion, Vegetative Cover) Layer	Topsoil, Geosynthetic Erosion Control Layer, Cobbles
2	Protection Layer	Soil, Recycled or Reused Waste Materials, Cobbles
3	Drainage Layer	Sand and/or Gravel, Geonet or Geocomposite, Chipped or Shredded Tires
4	Barrier (Infiltration) Layer	Compacted Clay, Geomembrane, Geosynthetic Clay Liner
5	Foundation/Gas Collection Layer	Sand or Gravel, Soil, Geonet or Geotextile, Recycled or Reused Waste Material

Source: Jesionek *et al.*, 1995

What function does the surface layer serve?

The role of the surface layer in the final cover system is to promote the growth of native, non-woody plant species, minimize erosion, restore the aesthetics of the site, and protect the barrier layer. The surface layer should be thick enough so that the root systems of the plants do not penetrate the underlying barrier layer. The vegetation on the surface layer should be resistant to drought and temperature extremes, able to survive and function with little maintenance, and also be able to maximize evapotranspiration, which will limit water infiltration to the barrier layer. It is recommended that you consult with agriculture or soil conservation experts concerning appropriate cover vegetation. Finally, the surface layer should be thick enough to withstand long-term erosion and to prevent desiccation and freeze/thaw effects of the barrier layer. The recommended minimum thickness for the surface layer is at least 12 inches. The state agency can help to determine the appropriate minimum thickness in cold climates to protect against freeze-thaw effects.

What types of materials can be used in the surface layer?

Topsoil has been by far the most commonly used material for surface layers. The principal advantages of using topsoil in the surface layer include its general availability and its suitability for sustaining vegetation. When topsoil is used as a surface layer, the roots of plants will reinforce the soil, reduce the rate of erosion, decrease runoff, and remove water from the soil through evapotranspiration. To achieve these benefits, however, the soil should have sufficient water-holding capacity to sustain plant growth. There are some concerns with regard to using topsoil. For example, topsoil requires ongoing maintenance, especially during periods of drought or heavy rainfall. Prolonged drought can lead to cracking in the soil, creating preferential pathways for water infiltration. Heavy rainfall can lead to erosion causing rills or gullies, especially on newly-seeded or steeply sloping covers. If the topsoil does not have sufficient water holding capacity, it can not adequately support surface plant growth, and evapotranspiration can excessively dry the soils. In this case, irrigation will be required to restore the water balance within the soil structure. Topsoil is also vulnerable to penetration by burrowing animals.

Geosynthetic erosion control material can be used as a cover above the topsoil to limit erosion prior to the establishment of a mature vegetative cover. The geosynthetic material can include embedded seeds to promote plant growth, and can be anchored or reinforced to add stability on steeply sloped areas. Geosynthetic material, however, does not enhance the water-holding capacity of the soil. In arid or semi-arid areas, therefore, the soil might still be prone to wind and water erosion if its water-holding capacity is insufficient.

Cobbles can be a suitable material for the surface layer in arid areas or on steep slopes which might hinder the establishment of vegetation. If they are large enough they will provide protection from wind and water erosion without washout. Cobbles can also protect the underlying barrier layer from intrusion by burrowing animals, but cobbles might not be available locally, and their use does not protect the underlying barrier layer from water infiltration. Because cobbles create a porous surface through which water can percolate, they do not ordinarily support vegetation. Wind-blown soil material can fill voids between cobbles, and plants can establish themselves in these materials. This plant material should be removed, as its roots are likely to extend into the underlying barrier layer in search of water.

What function does the protection or biotic barrier layer serve?

A protection or biotic barrier layer can be added below the surface layer, but above the drainage layer, to protect the latter from intrusion by plant roots or burrowing animals. This layer adds depth to the surface layer, increasing its water storage capacity and protecting underlying layers from freezing and erosion. In many cases, the protection layer and the surface layer are combined to form a single cover layer.

What types of materials can be used in the protection layer?

Soil will generally be the most suitable material for this layer, except in cases where special design requirements exist for the protection layer. The advantages and disadvantages of using soil in the protection layer are the same as those stated above in the discussion of the surface layer topsoil. Factors impacting the thickness and type of soil to use as a protection layer include freeze and thaw properties and the interaction between the soil and drainage layers. Other types of materials that can be used in the protection layer include cobbles with a geotextile filter, gravel and rock, and recycled or reused waste.

Cobbles with a geotextile filter can form a good barrier against penetration by plant roots and burrowing animals in arid sites. The primary disadvantage is that cobbles have no water storage capacity and allow water percolation into underlying layers.

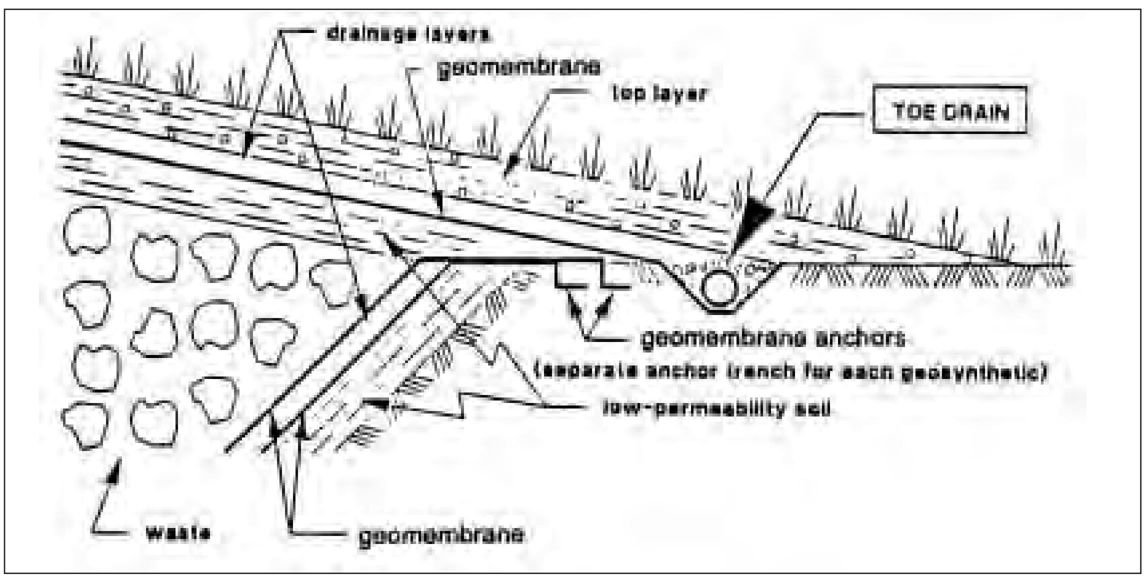
Gravel and rock are similar to cobbles since they can form a good barrier against penetration by plant roots and burrowing animals. Again, this use is usually only considered for arid sites, because gravel and rocks have no water storage capacity and allow water percolation into underlying layers.

Recycled or reused waste materials such as fly ash and bottom ash can be used in the protection layer, when available. Check with the state agency to verify that use of these materials is allowable. The advantages of using these materials in the protection layer are that they store water that has infiltrated past the surface layer, which can then be returned to the surface through evapotranspiration, and that they offer protection against burrowing animals and penetration by roots. If planning to use waste material in the protection layer, consider its impact on surface runoff at the unit's perimeter. Design controls to ensure runoff does not contribute to surface-water contamination. Consult Chapter 6–Protecting Surface Water for more details on designing runoff controls.

What function does the drainage layer serve?

A drainage layer can be placed below the surface layer, but above the barrier layer, to direct infiltrating water to drainage systems at the toe of the cover (see Figure 2) or to intermittent benches on long steep slopes. For drainage layers, the thickness will depend on the level of performance being designed and the properties of available materials. For example, some geonet composites, with a thickness of less than 1 inch, have a transmissivity equal to a much thicker layer of aggregate or sand. The recommended thickness of the high permeability soil drainage layer is 12 inches with at least a 3 percent slope at the bottom of the layer. Based on standard practice, the drainage layer should have a hydraulic conductivity in the range of 10^{-2} to 10^{-3} cm/sec. Water infiltration control through a drainage layer improves slope stability by reducing the duration of surface and protection layer saturation. In this role, the drainage layer works with vegetation to remove infiltrating water from the cover and protect the underlying barrier layer. If this layer drains the overlying soils too well, it could lead to the need for irrigation of the surface layer to avoid desiccation.

Figure 2. Drainage Layer Configuration



Source: U.S. EPA, 1991.

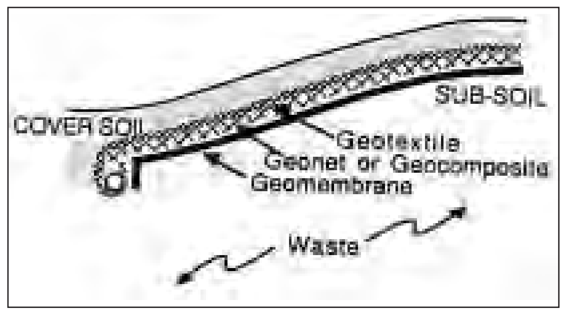
Another consideration for design of drainage layers is that the water should discharge freely from the toe of the cover or intermittent benches. If outlets become plugged or are not of adequate capacity, the toe of the slope can become saturated and potentially unstable. In addition, when designing the drainage layer, you should consider using flexible corrugated piping in conjunction with either the sand and gravel or the gravel with geotextile filter material to facilitate the movement of water to the unit perimeter.

What materials can be used in the drainage layer?

Sand and gravel are a common set of materials used in the drainage layer. The principal consideration in their use is the hydraulic conductivity required by the overall design. There can be cases in which the design requires the drainage of a large amount of water from the surface layer, and the hydraulic properties of the sand and gravel layer might be insufficient to meet these requirements. The advantages of using sand and gravel in the drainage layer include the ability to protect the underlying barrier layer from intrusion, puncture, and temperature extremes. The principal disadvantage to these materials is that they are subject to intrusions from the overlying protective layer that can alter their hydraulic conductivity. Similarly, fines in the sand and gravel can migrate downslope, undermining the stability of the cover slope. A graded filter or a geotextile filter can be used to separate and protect the sand and gravel from intrusions by the overlying protection layer.

Gravel with a geotextile filter is also a widely-used design, whose applicability can be limited by the local availability of materials. The gravel promotes drainage of water from the overlying layers, while the geotextile filter prevents the clogging of granular drainage layers. Again, be aware of the possibility that a gravel drainage layer might drain overlying soils so well that irrigation of the surface layer might become necessary. The principal advantage to a gravel/geotextile drainage layer is the engineering community's considerable body of knowledge regarding their use as drainage materials. Other advantages include their ability to protect underlying layers from intrusion, puncture, temperature extremes, and their common availability. The geotextile filter provides a cushion layer between the gravel and the overlying protection layer.

Figure 3.
Geonet with Geotextile Filter Design for Drainage Layer



Source: U.S. EPA, 1991.

Geonet and geotextile filter materials can be used to form an effective drainage layer directly above a compacted clay or geomembrane liner (see Figure 3). They are a suitable alternative especially in cases where other materials, such as sand and gravel, are not locally available. The principal advantage is that lightweight equipment can be used during installation, reducing the risk of damaging the underlying barrier layer.

The disadvantages associated with geonet and geotextile materials are that they provide little protection for the barrier layer against extreme temperature changes, and there can be slippage between the interfaces between the geomembrane, geotextile, and low permeability soil barrier materials. The use of textured materials can be considered to address slippage. Furthermore, problems can arise in the horizontal seaming of the geotextile drainage layer on long slopes.

Chipped or shredded tires are an additional option for drainage layer materials. Chipped or shredded tires have been used for bottom drainage layers in the past and might be suitable for cover drainage layers as well. One caution concerning the use of chipped or shredded tires is possible metal contaminants, or pieces of metal that could damage a geomembrane liner. You should consult with the state agency to determine whether this option is an acceptable practice.

What function does the barrier layer serve?

The barrier layer is the most critical component of the cover system because it prevents water infiltration into the waste. It also indirectly promotes the storage and drainage of water from the overlying protection and surface layers, and it prevents the upward movement of gases. This layer will be the least permeable component of the final cover system. Typically, the hydraulic conductivity of a barrier layer is between 10^{-9} to 10^{-7} cm/sec.

What types of materials can be used in the barrier layer?

Single compacted clay liners (CCLs) are the most common material used as barrier layers in final cover systems. CCL popularity arises largely because of the local availability of materials and the engineering community's extensive experience with their use. Drying and subsidence are the primary difficulties posed by CCLs. When the clay dries, cracks appear and provide preferential pathways along which water can enter the waste, promoting leachate formation, waste decomposition, and gas formation (when methane producing waste is present). Dry waste material and gas formation within the unit contribute to drying from below, while a range of climatological conditions, including drought, can affect CCLs from above. Even with extremely thick surface and protection layers, CCLs can still undergo some desiccation.

Clay liners are also vulnerable to subsidence within the waste unit. This problem can first manifest itself during liner construction. As the clay is compacted with machinery, the waste might not provide a stable, even foundation for the compaction process. This will make it difficult to create the evenly measured lifts comprising the liner. As waste settles over time, depressions can form along the top of the CCL. These depressions put differential stresses on the liner, causing cracks which compromise its integrity. For instance, a depression of only 5 to 11 inches across a 6-foot area can be sufficient to crack the liner materials.

Single geomembrane liners are sheets of a plastic polymer combined with other ingredients to form an effective barrier to water infiltration. Such liners are simple and straightforward to install, but they are relatively fragile and can be easily punctured during installation or by movement in surface layer materials. The principal advantage of a geomembrane is that it provides a relatively impermeable barrier with materials that are generally available. It is not damaged by temperature extremes and therefore does not require a thick surface layer. The geomembrane is more flexible than clay and not as vulnerable to cracking as a result of subsidence within the unit. The principal disadvantage is that it provides a point of potential slippage at the interface with the cover soils. Such slippage can tear the geomembrane, even if it is anchored.

Single geosynthetic clay liners (GCLs) are composed of bentonite clay supported by geotextiles or geomembranes held together with stitching or adhesives. These liners are relatively easy to install and have some self-healing capacity for minor punctures. They are easily repaired by patching. The main disadvantages include low shear strength, low bearing capacity, vulnerability to puncture due to relative thinness, and potential for slippage at interfaces with under- and overlying soil materials. When dry, their permeability to gas makes GCLs unsuitable as a barrier layer for wastes that produce gas, unless the clay will be maintained in a wet state for the entire post-closure period.

Geomembrane with compacted clay liners (CCLs) can be used to mitigate the shortcomings of each material when used alone. In this composite liner, the geomembrane acts to protect the clay from desiccation, while providing increased tolerance to differential settlement within the waste. The clay acts to protect the geomembrane from punctures and tearing. Both components act as an effective barrier to water infiltration. The principal disadvantage is slippage between the geomembrane and surface layer materials.

Geomembrane with geosynthetic clay liners (GCLs) can also be used as a barrier layer. As with geomembrane and CCL combinations, each component serves to mitigate the weakness of the other. The geosynthetic material is less vulnerable than its clay counterpart to cracking and has a moderate capacity to self-heal. The geomembrane combined with the GCL is a more flexible cover and is less vulnerable to differential stresses from waste settlement. Neither component is readily affected by extreme temperature changes, and both work together to form an effective barrier layer. For more information on the properties of geosynthetic clay liners, including their hydration after installation, refer to Chapter 7, Section B–Designing and Installing Liners. The potential disadvantage is slippage between the upper and lower surfaces of the geomembrane and some types of GCL and other surface layer materials. The geomembrane is still vulnerable to puncture, so placement of cover soils is important to minimize such damage.

Textured geomembranes can be used to increase the stability of cap side slopes. Textured geomembranes are nearly identical to standard "smooth" geomembranes differing only in the rough or textured surface that has been added. This textured surface increases the friction between the liner and soils and other geosynthetics used in the cap, and can help prevent sliding failures. In general, textured geomembranes are more expensive than comparable "smooth" geomembranes.

Using textured geomembranes allows cap designers to employ steeper slopes which can increase the available airspace in a waste management unit, and therefore increase its capacity. Textured geomembranes also help keep cover soil in place improving overall liner stability on steep slopes. The degree to which textured geomembranes will improve frictional resistance (friction coefficients/friction angles) will vary from site-to-site depending upon the type of soil at the site and its condition (e.g., moisture content).

Textured geomembranes are manufactured by two primary methods. Some textured geomembranes have a friction coating layer added to standard "smooth" geomembranes through a secondary process. Others are textured during the initial production process, meaning textured layers are coextruded as part of the liner itself. Textured geomembranes can be textured on one or both sides.

Textured geomembranes are seam-welded by the same technologies as standard geomembranes. Due to their textured surface, however, seam welds can be less uniform with textured liners than with normal liners. Some textured geomembranes have smooth edges on the top and bottom of the sheet to allow for more uniform seam welding.

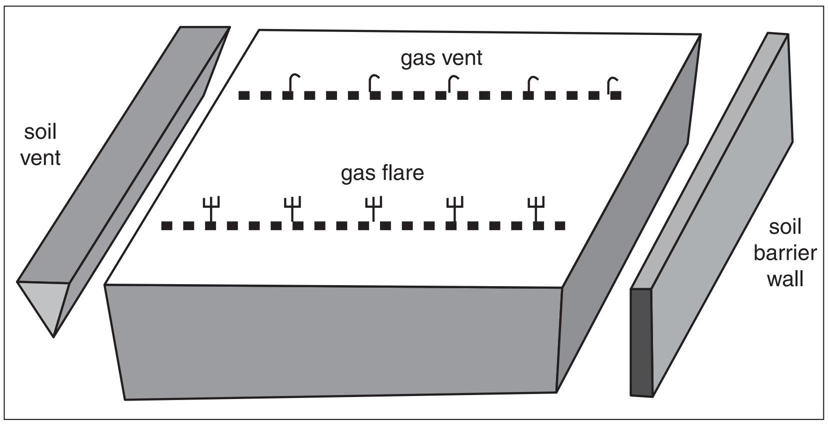
What function does the gas collection layer serve?

The role of the gas collection layer is to control the migration of gases to collection vents. This collection layer is a permeable layer that is placed above the foundation layer. It is often used in cases where the foundation layer itself is not the gas collection layer. For more information on Clean Air Act requirements for managing gas from landfills and other waste management units, refer to Chapter 5–Protecting Air Quality.

Gas control systems generally include mechanisms designed to control gas migration and to help vent gas emissions into the atmosphere. Systems using natural pressure and convection mechanisms are referred to as passive gas control systems (see Figure 4). Examples of passive gas control system elements include ditches, trenches, vent walls, perforated pipes surrounded by coarse soil, synthetic membranes, and high moisture, fine-grained soil. Systems using mechanical means to remove gas from the unit are referred to as active gas control systems. Figure 5 illustrates an active gas system. Gas control systems can also be used as part of corrective action measures should the concentration of methane rise to dangerous levels. As with all aspects of a waste containment system, construction quality assurance plays a critical role in the success of a gas management system.

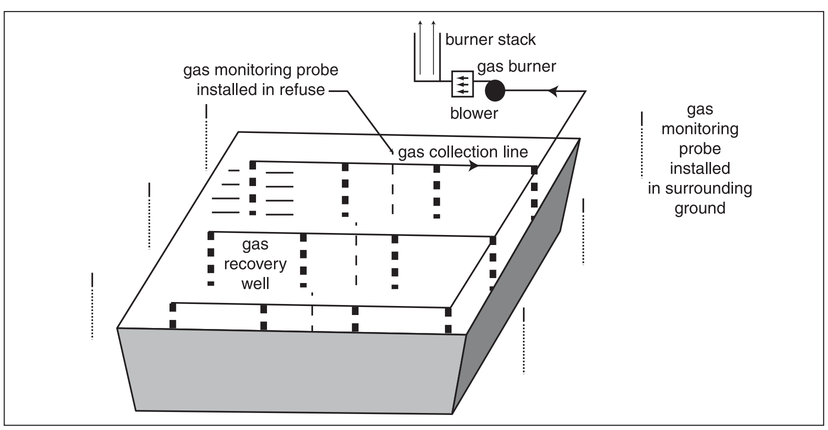
Gas extraction wells are an example of active gas control systems. For deep wells, the number, location, and extent of the pipe perforations are important. Also, the depth of the well must be kept safely above the liner system beneath the waste. For continuous gas

Figure 4. Passive Gas Venting System



Source: Robinson, W., ed. 1986. *The Solid Waste Handbook: A Practical Guide*. Reprinted by permission of John Wiley & Sons, Inc.

Figure 5. Active Gas Venting System



Source: Robinson, W., ed. 1986. *The Solid Waste Handbook: A Practical Guide*. Reprinted by permission of John Wiley & Sons, Inc.

collection layers beneath the barrier layer, continuity is important for both soils and geosynthetics.

Knowing the rate of gas generation is essential to determining the quantity of gas that can be extracted from the site. Pumping an individual well at a greater vacuum will give it a wider zone of influence, which is acceptable, but obviously there are points of diminishing marginal returns. Larger suction pressures influence a larger region but involve more energy expended in the pumping. Pumping at greater vacuum also increases the potential for drawing in atmospheric air if the pumping rate is set too high. Significant air intrusion into the unit can result in elevated temperatures and even underground fires. You should perform routine checks of gas generation rates to better ensure that optimal pumping rates are used.

The performance of gas extraction systems is affected by the following parameters, which should be considered when designing and operating gas systems:

- Daily cover, which inhibits free movement of gas.
- Sludge or liquid wastes, which affect the ease at which gas will move.
- Shallow depth of unit, which makes it difficult to extract the gas, because atmospheric air will be drawn in during the pumping.
- Permeability of the final cover, which affects the ability of atmospheric air to permeate the wastes in the unit.

What types of materials can be used in the gas collection layer?

Sand and gravel are the most common materials used for gas collection layers. With these materials, a filter might be needed to prevent infiltration of materials from the barrier layer. Geotextile and geosynthetic drainage composites also can make suitable gas collection layers. In many cases, these can be the most cost-effective alternatives. The same disadvantages exist with these materials in the gas collection layer as in other layers, such as slippage and continuity of flow.

With a geomembrane in the final cover barrier system, uplift pressures will be exerted unless the gas is quickly and efficiently conveyed to the wells, vents, or collection trenches. If this is not properly managed, uplift pressure will either cause bubbles to occur, displacing the cover soil and appearing at the surface, or decrease the normal stress between the geomembrane and its underlying material. This problem has led to slippage of the geomembrane and all overlying materials creating high tensile stresses evidenced by folding at the toe of the slope and tension cracks near the top.

D. Capillary-Break Final Covers

The capillary-break (CB) approach is an alternative design for a final cover system (see Figure 6). This system relies on the fact that for adjacent layers of fine- and coarse-textured material to be in water-potential equilibrium, the coarse-grained material (such as crushed stone) will tend to have a much lower water content than the fine-grained material (such as sand). Because the conductivity of water through a soil decreases exponentially with its water content, as a soil becomes more dry, its tendency to stay dry increases. Therefore, as long as the strata in a capillary break remain unsaturated (remain above the water table), the overlying fine-textured soil will retain nearly all the water and the coarse soil will behave as a barrier to water percolation due to its dryness. Since this phenomenon breaks down if the coarse layer becomes saturated, this alternative cover system is most appropriate for semiarid and desert environments.

What types of materials are used in capillary-break covers?

The CB cover system typically consists of five layers: surface, storage, capillary-break, barrier, and foundation. The surface, barrier, and foundation layers play the same role in the cover system as described above. The storage layer consists of fine material, such as silty sand. The capillary-break, or coarse, layer consists of granular materials, such as gravel and coarse sand. A fabric filter is often placed between the coarse and fine layers.

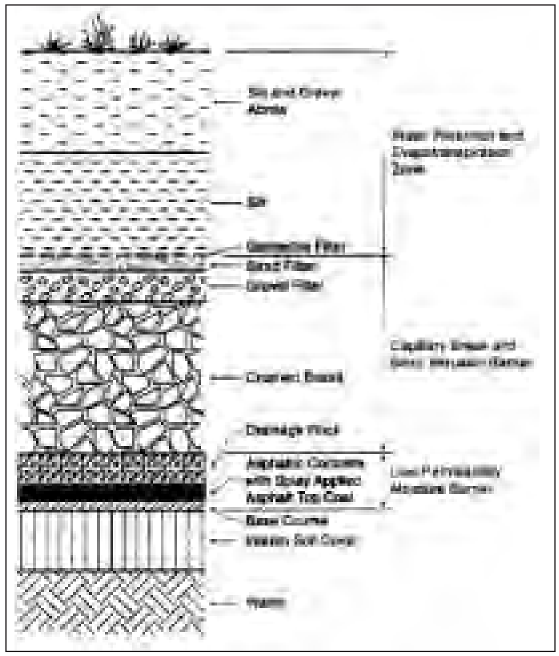
E. The Hydrologic Evaluation of Landfill Performance (HELP) Model

The relative performance of various cover designs can be evaluated with the Hydrologic Evaluation of Landfill Performance (HELP) model, developed by the U.S. Army Corps of Engineers Waterway Experiment Station for EPA. The HELP model was designed specifically to support permit writers and engineers in evaluating alternative landfill designs, but it can also be used to evaluate various final cover designs.

The HELP model integrates runoff, percolation, and subsurface-water flow actions into one model. The model can be used to estimate the flow of water across and through a final cover. To achieve this, the HELP model uses precipitation and other climatological information to partition rainfall and snow melt into surface runoff, evaporation, and downward infiltration through the barrier layer to the waste.

The HELP model essentially divides a waste management unit into layers, each defined in terms of soil type, which is related to the hydraulic conductivity of each. Users fill in data collection sheets that request specific information on the layers and climate, and this information is input to the model. In performing its calculations, the model will take into account the reported engineering properties of each layer, such as slope, hydraulic conductivity, and rates of evapotranspiration, to estimate the amount of precipitation that can enter the waste unit through the final cover. To use the HELP model properly, refer to the HELP Model *User's Guide* and documentation (U.S. EPA, 1994b; U.S. EPA, 1994c). The model itself, the *User's Guide*, and supporting documentation can be obtained from the U.S. Army Corps of Engineers Web site at **<www.wes.army.mil/el/elmodels>**.

Figure 6. Example of a Capillary-Break Final Cover System



Adapted from **<www.hanford.gov/eis/hraeis/eisdoc/graphics/fige-1.gif>**

F. Recommended Cover Systems

The recommended final cover systems correspond to a waste management unit's bottom liner system. A unit with a single geomembrane bottom liner system, for example, should include, at a minimum, a single geomembrane in its final cover system unless an evaluation of site-specific conditions can show an equivalent reduction in infiltration. Table 2 summarizes the minium recommend-

Table 2: Minimum Recommended Final Cover Systems*

Type of Bottom Liner	Recommended Cover System Layers (From top layer down)[a]	Thickness (In inches)	Hydraulic Conductivity (In cm/sec)
Double Liner	Surface Layer	12	not applicable
	Drainage Layer	12[b]	1×10^{-2} to 1×10^{-3}
	Geomembrane	30mil(PVC) 60mil (HDPE)	—
	Clay Layer	18	less than 1×10^{-5}
Composite Liner	Surface Layer	12	not applicable
	Drainage Layer	12[b]	1×10^{-2} to 1×10^{-3}
	Geomembrane	30 mil (PVC) 60 mil (HDPE)	—
	Clay Layer	18	less than 1×10^{-5}
Single Clay Liner	Surface Layer	12	not applicable
	Drainage Layer	12[b]	1×10^{-2} to 1×10^{-3}
	Clay Layer	18	less than 1×10^{-7}
Single Clay Liner in an Arid Area	Cobble Layer	2-4	not applicable
	Drainage Layer	12[b]	1×10^{-2} to 1×10^{-3}
	Clay Layer	18	less than 1×10^{-7}
Single Synthetic Liner	Surface Layer	12	not applicable
	Drainage Layer	12[b]	1×10^{-2} to 1×10^{-3}
	Geomembrane	30 mil (PVC) 60 mil (HDPE)	—
	Clay Layer	18	less than 1×10^{-5}
Natural Soil Liner	Earthen Material	24[c]	No more permeable than base soil

* Please consult with your state regulatory agency prior to constructing a final cover.

[a] The final selection of geomembrane type, thickness, and drainage layer requirements for a final cover should be design-based and consultation with your state agency is recommended.

[b] This recommended thickness is for high permeability soil material with at least a 3 percent slope at the bottom of the layer. Some geonet composites, with a minimal thickness of less than 1 inch, have a transmissivity equal to a much thicker layer of aggregate or sand.

[c] Thickness might need to be increased to address freeze/thaw conditions.

ed final cover systems based on the unit's bottom liner system. While the recommended minimum final cover systems include closure layer component thicknesses and hydraulic conductivity, the cover systems can be modified to address site-specific conditions. In addition, you should consider whether to include a protection layer or a gas collection layer. Figures 7 through 11 display recommended minimum final cover systems.

Figure 7. Recommended Final Cover System for a Unit With a Double or Composite Liner

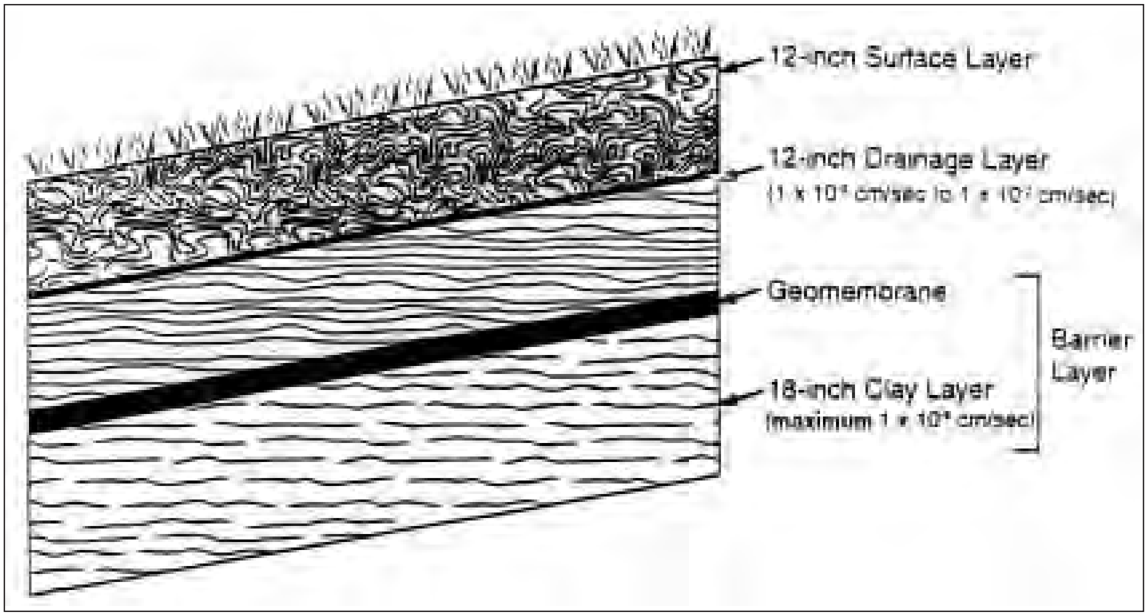


Figure 8. Recommended Final Cover System for a Unit With a Single Clay Liner

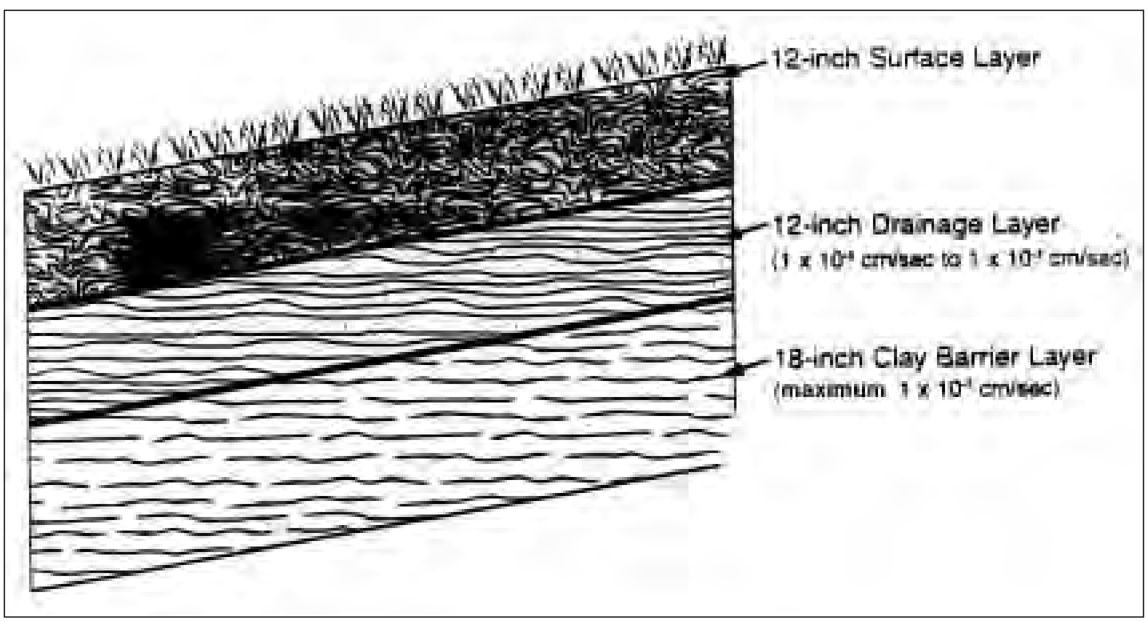


Figure 9. Recommended Final Cover System for a Unit With a Single Clay Liner in an Arid Area

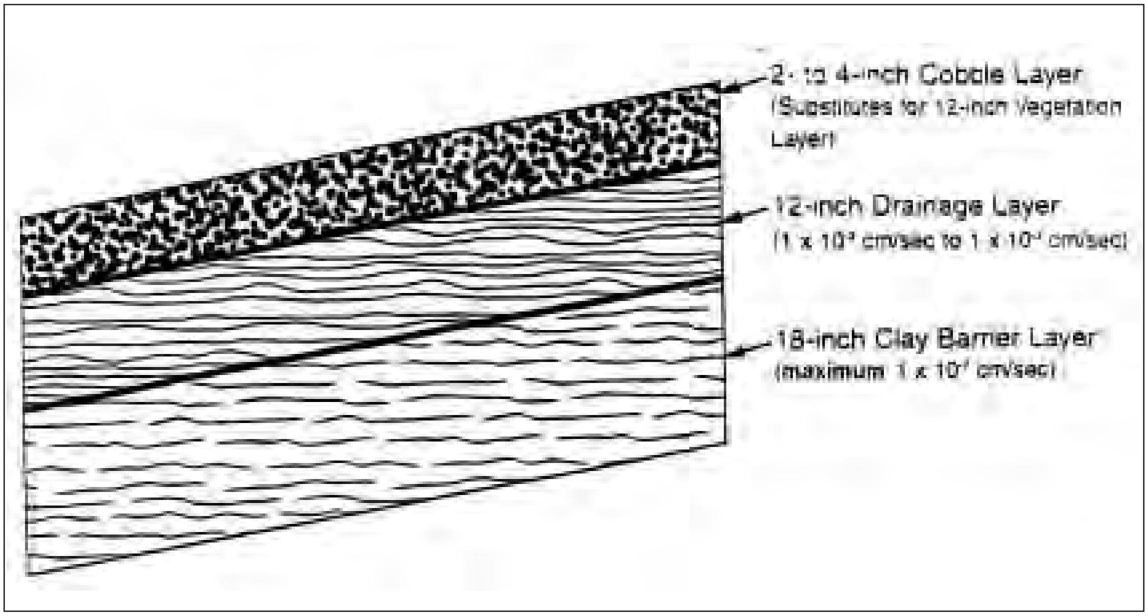


Figure 10. Recommended Final Cover System for a Unit With a Single Synthetic Liner

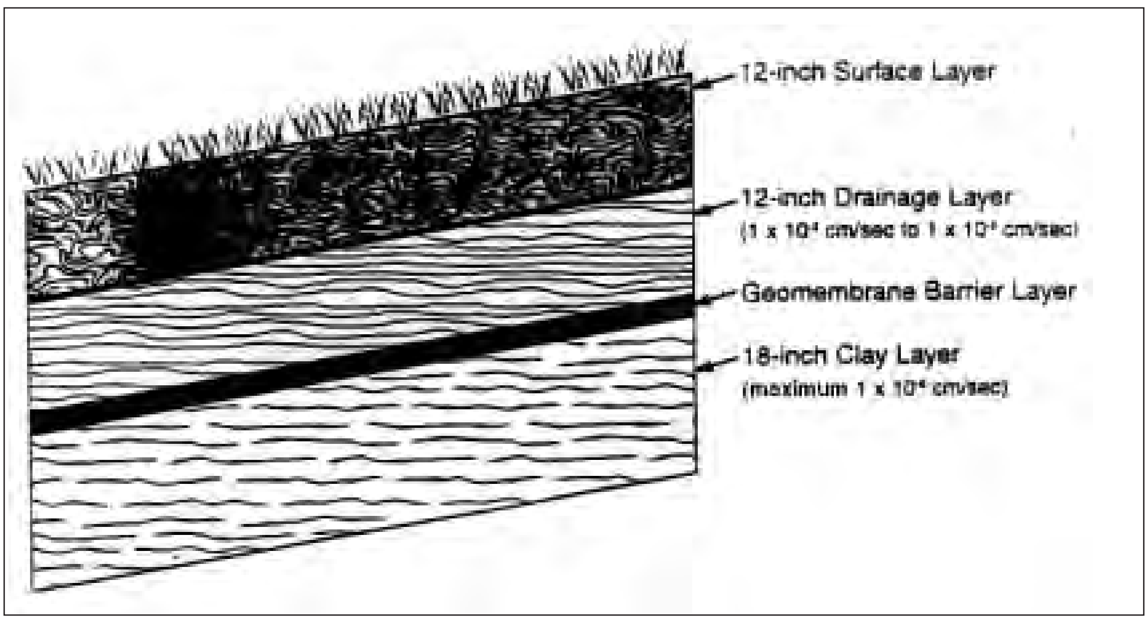
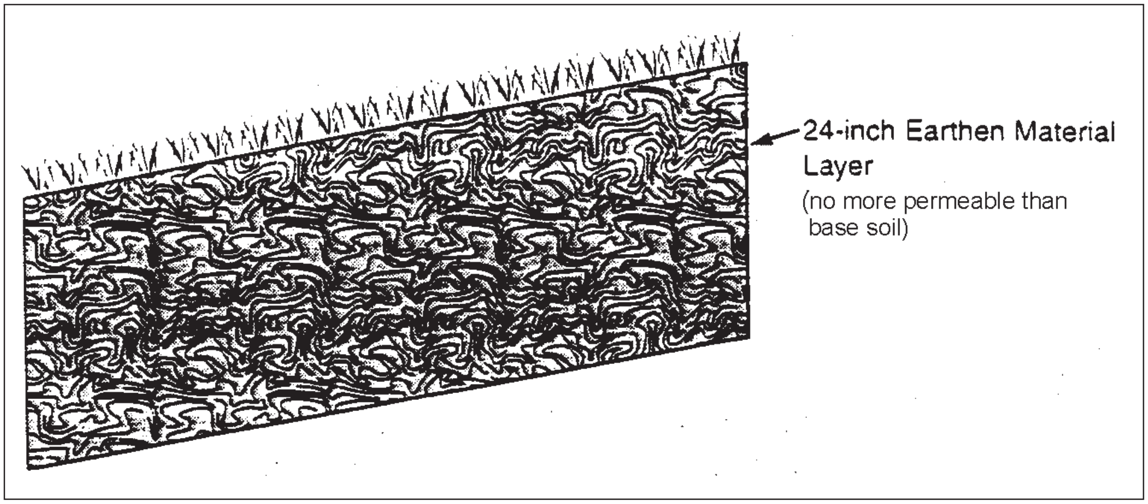


Figure 11. Recommended Final Cover System for a Unit With a Natural Soil Liner



While these recommendations include the use of compacted clay, a facility manager might want to consider the use of a geomembrane barrier layer in addition to, or in place of, a compacted clay barrier layer. Subsidence of a final cover constructed with a compacted clay barrier layer can allow precipitation to enter the closed unit and increase leachate production. The use of a geomembrane in place of compacted clay might be more cost effective. Due to cracking or channeling or continued subsidence, post-closure care of a compacted clay barrier layer can be more expensive to maintain than a geomembrane barrier layer. A geomembrane barrier layer can also accommodate more subsidence without losing its effectiveness.

IV. Closure by Waste Removal

Closure by waste removal is a term that describes the removal and decontamination of all waste, waste residues, contaminated ground water, soils, and containment devices. This approach is common for waste piles and some surface impoundments. Removal and decontamination are complete when the constituent concentrations throughout the unit and any areas affected by releases from the unit do not exceed numeric cleanup levels. You should check with the state agency to see if it has established any numeric cleanup levels or methods for establishing site-specific levels. In the absence of state cleanup levels, metals and organics should be removed to either statistically equivalent background levels or to maximum contaminant levels (MCLs) or health-based numbers (HBNs)[2]. Metals and organics might have different cleanup levels, but they both should be based on either local background levels or on health-based guidelines.

Future land use considerations can also be important in determining the appropriate level of cleanup. One tool that can be used to help evaluate whether waste removal is appropriate at the site is the risk-based corrective action (RBCA) process described in Chapter 10–Taking Corrective Action. The RBCA process provides guidance on integrating ecological and human health risk-based decision-making into the traditional corrective action process.

[2] To learn about the regulatory and technical basis for MCLs, access the Integrated Risk Information System (IRIS), a database of human health effects that can result from exposure to environmental contaminants, at **<www.epa.gov/iris>**. Call the EPA Risk Information Hotline at 513 569-7254 for more information.

A. Establishing Baseline Conditions

A good management practice is to establish the baseline conditions for a waste management unit. Baseline conditions include the background constituent concentrations at a site prior to waste placement operations. Identifying the types of contaminants that might be present can provide an indication of the potential contamination resulting from the operation of a unit and the level of effort and resources that can be required to reach closure. Naturally-occurring elevated background levels that are higher than targeted closure levels might be encountered. In such cases, consult with the state agency to determine whether these elevated background levels are a more appropriate targeted cleanup level. The identification of potential contaminants will also provide a guideline for selecting sampling parameters. If constituents other than those initially identified are discovered through subsequent soil and water sampling, this might indicate that contaminants are migrating from another source.

In some cases, waste contaminants might have been present at a site before a waste management unit was constructed, or they might have migrated to the site from another unrelated source. In these situations, closure by waste removal can still proceed, provided that any contamination originating from the closing unit is removed to appropriate cleanup levels. You should determine whether additional remediation is required under other federal or state laws, such as the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or state cleanup laws.

How are baseline conditions established?

Initial soil and ground-water sampling around, within, and below a unit will serve to identify baseline conditions. Sampling can detect contaminant levels that exceed background levels or federal, state, or local health-based benchmarks. Contact local environmental protection officials for guidance on the number and type of samples that should be taken. If the initial round of sampling does not reveal any contaminant levels that exceed benchmarks, you should proceed with the removal of waste and the restoration of the unit. If the sampling does reveal contamination that exceeds the benchmarks, you should consider ways to remediate the site in compliance with federal, state, or local requirements.

B. Removal Procedures

Proper removal procedures are vital to the long-term, post-closure care of a unit and surrounding land. Properly removing waste can minimize the need for further maintenance, thereby saving time and money and facilitating reuse of the land. You should perform closure by waste removal in a manner that prevents the escape of waste constituents to the soil, surface water, ground water, and atmosphere. After removing the waste, you should remove all equipment, liners, soils, and any other materials containing waste or waste residues. Removal verification should include specifics as to how it will be determined that residues, equipment, liners, and soils have been removed to baseline conditions. Finally, the land should be returned to the appearance and condition of surrounding land areas to the extent possible consistent with the closure and post-closure plans.

Should a plan for waste removal procedures be prepared?

The waste removal process should be fully described in a closure plan. The removal process description should address estimates of the volumes and types of waste and contaminated equipment or structures to be removed during closure. It should also include the types of equipment to be used, the removal pattern, and the management of loading areas. The closure plan should also detail steps to be taken to minimize and prevent emissions of waste during closure activities. For example, if activities during closure include loading and transporting waste in trucks, the closure plan should describe the steps that will be taken to minimize air emissions from windblown dust. Proper quality assurance and quality control during the waste removal process will help ensure that the removal proceeds in accordance with the waste removal plan. A key component of the waste removal procedure is the consideration of proper disposal or treatment methods for any wastes or contaminated materials.

C. Disposal of Removed Wastes

When a unit is closed by removing waste, waste residues, contaminated ground water, soils, and containment devices, you should ensure that disposal of these materials is in compliance with state law. If the composition of the waste can not be determined using process knowledge, you should test it using procedures such as those described in Chapter 2–Characterizing Waste. Then consult with the state agency to determine which requirements might apply to the waste.

D. Final Sampling and Analysis

The purpose of final sampling and analysis is to ensure that target cleanup levels have been achieved. While initial sampling is intended to establish baseline levels of contaminants, final sampling is used more as a safeguard to make sure levels have not changed. It is important to conduct a final sampling, in addition to the initial sampling, because removal actions can increase the contaminant levels at the site, and sometimes contamination is overlooked in the initial baseline sampling event. Refer to Chapter 9–Monitoring Performance for a detailed discussion of sampling and analysis procedures.

How should the sampling data be used?

The results of this sampling event should be compared to the results of the baseline event, and any discrepancies should be noted. The results can be compared to performance measures established at the beginning of the closure process with state or local regulators. Closure plans incorporating waste removal should include a sampling and analysis plan for the initial and final sampling and analysis efforts. The plan should specify procedures to ensure that sample collection, handling, and analysis will result in data of sufficient quality to plan and evaluate closure activities. The sampling and analysis plan should be designed to define the nature and extent of contamination at, or released from, the closing unit. The level of detail in the sampling and analysis plan should be commensurate with the complexity of conditions at the closing unit.

V. Post-Closure Care Considerations When Final Cover Is Used

For units that will close with a final cover, the following factors should be considered:

- Routine maintenance of the unit's systems, including the final cover, leachate collection and removal systems, run-on and runoff controls, gas and ground-water monitoring systems, and surface-water and gas quality monitoring where appropriate.
- The names and telephone numbers of facility personnel for emergencies.
- Mechanisms to ensure the integrity of the final cover system, such as posted signs or notifications on deeds.
- The anticipated uses of the property during the post-closure period.
- The length of the post-closure care period.
- Costs to implement and conduct post-closure care.
- Conditions that will cause post-closure care to be extended or shortened.

A. Maintenance

After the final cover is installed, some maintenance and repair likely will be necessary to keep the cover in good working condition. Maintenance can include mowing the vegetative cover periodically and reseeding, if necessary. Repair the cover when erosion or subsidence occurs. Maintaining healthy vegetation will ensure the stability of slopes, reduce surface erosion, and reduce leachate production by increasing evapotranspiration.

A regular schedule for site inspections of maintenance activities during the post-closure period, as well as prompt repair of any problems found at inspection, can help ensure the proper performance of the cover system. Maintenance of the proper thickness of surface and drainage layers can ensure long-term minimization of leachate production and protection of geomembranes, if present.

What maintenance and repair activities should be conducted after the final cover has been installed?

In the case of damage to the final cover, you should determine the cause of damage so that proper repair measures can be taken to prevent recurrence. For example, if the damage is due to erosion, potential causes might include the length and steepness of slopes, insufficient vegetation growth due to poor planting, or uneven settlement of the waste. Sedimentation basins and drainage swales should be inspected after major storms and repaired or cleaned, as necessary.

Components of the leachate collection and removal system, such as leachate collection pipes, manholes, tanks, and pumps should also receive regular inspection and maintenance. If possible, flush and pressure-clean the collection systems on a regular basis to reduce sediment accumulation and to prevent clogging caused by biological growth. The manholes, tanks, and pumps should be visually inspected at least annually, and valves and manual controls should be exercised even more frequently, because leachate can corrode metallic parts. Repairs will help prevent future problems, such as leachate overflow from a tank due to pump failure.

You should inspect and repair gas and ground-water monitoring wells during the post-closure period. Proper operation of monitoring wells is essential to determine whether releases from a closed waste management unit are occurring. For example, ground-water monitoring wells should be inspected to ensure that they have not been damaged by vehicular traffic or vandalism. Physical scraping or swabbing might be necessary to remove biological clogging or encrustation from calcium carbonate deposits on well screens.

B. Monitoring During Post-Closure Care

Post-closure care monitoring should include the leachate collection system, surface-water controls, the ground-water monitoring system where appropriate, and gas controls where appropriate. Post-closure monitoring will serve as your main source of information about the integrity of the final cover and liners. A reduction in the intensity (i.e., frequency) and scope of monitoring might be warranted after some period of time during post-closure care. Conversely, an increase in intensity and scope might become necessary due to unanticipated problems.

What should be considered when monitoring post-closure leachate, ground water, and gas?

The quantity of leachate generated should be monitored, as this is a good indicator of the performance of the closure system. If the closure system is effective, the amount of leachate generated should decrease over time. In addition, the concentration of contaminants in leachate should, in time, reach an equilibrium. An abrupt decline in the contaminant concentration could mean that the cover has failed, and surface water has entered the waste and diluted the leachate.

To ensure leachate has not contaminated ground-water supplies, you should sample ground water regularly. Regular ground-water monitoring detects changes, or the lack thereof, in the quality of ground water. For a more detailed discussion, consult Chapter 9–Monitoring Performance.

As no cover system is impermeable to gas migration, and if gas production is a concern at the unit, you should install gas monitoring wells around the perimeter of the unit to detect laterally moving gas. If geomembranes are used in a cover, more gas can escape laterally than vertically. Gas collection systems can also become clogged and stop performing properly. Therefore, you should periodically check gas vents and flush and pressure-clean those vents not working properly.

C. Recommended Length of the Post-Closure Care Period

The overall goal of post-closure care is to provide care until wastes no longer present a threat to the environment. Threats to the environment during the post-closure care period can be evaluated using leachate and ground-water monitoring data to determine whether there is a potential for migration of waste constituents at levels that might threaten human health and the environment. Ground-water monitoring data can be compared to drinking water standards or health-based criteria to determine whether a threat exists.

Leachate volumes and constituent concentrations can also be used to show that the unit does not pose a threat to human health and the environment. The threats posed by waste constituents in leachate should be evaluated based on the potential release of leachate to ground and surface waters. Consequently, you should consider doing post-closure care maintenance for as long as that potential exists. Individual post-closure care periods can be long or short depending on the type of waste being managed, the waste management unit, and a variety of site-specific characteristics. You should contact the appropriate state agency to determine what post-closure period it recommends. In the absence of any state guidance on the appropriate length of the post-closure period, consider a minimum of 30 years.

D. Closure and Post-Closure Cost Considerations

The facility manager of a closed industrial unit is responsible for that unit. To ensure long-term protection of the environment, you should account for the costs of closure and post-closure care when making initial plans. There are guidance documents available to help plan for the costs associated with closing a unit. For example, guides produced by the R.S. Means Co. provide up-to-date cost estimates for most construction-related work, such as moving soil, and material and labor for installing piping. Table 3 also presents an example of a closure/post-closure cost estimate form. Table 4 presents a sample summary cost estimating worksheet to assist in determining the cost of closure. Also you should consider obtaining financial assurance mechanisms so that the necessary funds will be available to complete closure and post-closure care activities if necessary. Financial assurance planning encourages internalization of the future costs associated with waste management units and promotes proper design and operating practices, because the costs for closure and post-closure care are often less for units operated in an environmentally protective manner. You should check with the state agency to determine whether financial assurance is required and what types of financial assurance mechanisms might be acceptable.

The amount of financial assurance that might be necessary is based on site-specific estimates of the costs of closure and post-closure care. The estimates should reflect the costs that a third party would incur in conducting closure and post-closure activities. This recommendation ensures adequate funds will be available to hire a third party to carry out necessary activities. You should consider updating the cost estimates annually to account for inflation and whenever changes are made to the closure and post-closure plans. For financial assurance purposes, if a state does not have a regulation or guidance regarding the length of the post-closure care period, 30 years could be used as a planning tool for developing closure and post-closure cost estimates.

Financial assurance mechanisms do not force anyone to immediately provide full funding for closure and post-closure care. Rather, they help to ensure the future availability of such funds. For example, trust funds can be built up gradually during the operating life of a waste management unit. By having an extended "pay-in" period for trust funds, the burden of funding closure and post-closure care will be spread out over the economic life of the unit. Alternatively, consider the use of a corporate financial test or third-party alternative, such as surety bonds, letters of credit, insurance, or guarantees.

What costs can be expected to be associated with the closure of a unit?

The cost of constructing a final cover or achieving closure by waste removal will depend on site-specific activities. You should consider developing written cost estimates before closure procedures begin. For closure by means of a final cover, the cost of constructing the final cover will depend on the complexity of the cover profile, final slope

Table 3: Example Closure/Post-Closure Cost Estimate Form* (All Costs Shown in ($000)

Provisions	Total Closure Costs Yrs. (-)	Total Post-Closure Costs Yrs. (-)	Total Closure/ Post-Closure Costs Yrs. (-)
i Soil Erosion and Sediment Control Plan		NA	
ii Final Cover		NA	
iii Final Cover Vegetation		NA	
iv Maintenance Program for Final Cover and Final Cover Vegetation	NA		
v Maintenance Program for Side Slopes	NA		
vi Run-On and Runoff Control Program		NA	
vii Maintenance Program for Run-On and Runoff Control System	NA		
viii Ground-water Monitoring Wells		NA	
ix Maintenance Program for Ground-water Monitoring Wells	NA		
x Ground-water Monitoring	NA		
xi Methane Gas Venting or Evacuation System		NA	
xii Maintenance Program for Methane Gas Venting or Evacuation System	NA		
xiii Leachate Collection and/or Control System		NA	
xiv Maintenance Program for Leachate Collection and/or Control System	NA		
xv Facility Access Control System		NA	
xvi Maintenance Program for Facility Access Control System	NA		
xvii Measures to Conform the Site to Surrounding Area		NA	
xviii Maintenance Program for Site Conformance Measures	NA		
xix Construction Quality Assurance and Quality Control		NA	
TOTAL COSTS			

* Developed from New Jersey Department of Environmental Protection, Bureau of Landfill Engineering Landfill Permits.

Table 3: Example Closure/Post-Closure Cost Estimate Form (Cont'd)

Provisions		Total Post-Closure Costs	Year #1	Year #2	Year #3	Year #4	Year #5	Year #6	Year #7
i	Soil Erosion and Sediment Control Plan	NA							
ii	Final Cover	NA							
iii	Final Cover Vegetation	NA							
iv	Maintenance Program for Final Cover and Final Cover Vegetation								
v	Maintenance Program for Side Slopes								
vi	Run-On and Runoff Control Program	NA							
vii	Maintenance Program for Run-On and Runoff Control System								
viii	Ground-water Monitoring Wells	NA							
ix	Maintenance Program for Ground-water Monitoring Wells								
x	Ground-water Monitoring								
xi	Methane Gas Venting or Evacuation System	NA							
xii	Maintenance Program for Methane Gas Venting or Evacuation System								
xiii	Leachate Collection and/or Control System	NA							
xiv	Maintenance Program for Leachate Collection and/or Control System								
xv	Facility Access Control System	NA							
xvi	Maintenance Program for Facility Access Control System								
xvii	Measures to Conform the Site to Surrounding Area	NA							
xviii	Maintenance Program for Site Conformance Measures								
xix	Construction Quality Assurance and Quality Control	NA							
TOTAL COSTS									

Table 4: Sample Summary Cost Estimating Worksheet

Summary Worksheet for Landfills			
Activity Some of the activities listed below are routine. The owner or operator might elect or be required to conduct additional activities. Italic type denotes worksheets for estimating the costs of those additional activities		Worksheet Number	Cost
1	Installation of Clay Layer	LF-3	$
2	Installation of Geomembrane	LF-4	$
3	Installation of Drainage Layer	LF-5	$
4	Installation of Topsoil	LF-6	$
5	Establishment of Vegetative Cover	LF-7	$
6	*Installation of Colloid Clay Liner*	LF-8	$
7	*Installation of Asphalt Cover*	LF-9	$
8	*Decontamination*	DC-1	$
9	*Sampling and Analysis*	SA-2	$
10	*Monitoring Well Installation*	MW-1	$
11	*Transportation*	TR-1	$
12	*Treatment and Disposal*	TD-1	$
13	**Subtotal of Closure Costs (Add lines 1 through 12)**		
14	Engineering Expenses (Engineering expenses are typically 10% of closure costs, excluding survey plat, certification of closure, and post-closure care.)		$
15	Survey Plat	LF-10	$
16	Certification of Closure	LF-11	$
17	**Subtotal (Add engineering expenses and cost of the survey plat, certification of closure, and post-closure care to closure costs [Add lines 12 through 16])**		$
18	Contingency Allowance (Contingency allowances are typically 20% of closure costs, engineering expenses, cost of survey plat, cost of certification of closure, and post- closure care.)		$
19	Post-Closure Care	PC-1	$
	TOTAL COST OF CLOSURE (Add lines 17, 18, and 19)		**$**

Worksheet generated from CostPro©: Closure and Post-Closure Cost Estimating Software. Available from Steve Jeffords of Tetra Tech EM Inc., 404 225-5514, or 285 Peach Tree Center Avenue, Suite 900, Atlanta, GA, 30303.

contours of the cover, whether the entire unit will be closed (or partial closures), and other site-specific factors. For example, the components of the final cover system, such as a gas-vent layer or a biotic layer, will affect costs. In addition, closure-cost estimates would also include final-cover vegetation, run-on and runoff control systems, leachate collection and removal systems, ground-water monitoring wells, gas-monitoring systems and controls, and access controls, such as fences or signs. Closure costs might also include construction quality assurance costs, engineering fees, accounting and banking fees, insurance, permit fees, legal fees, and, where appropriate, contingencies for cost overruns, reworks, emergencies, and unforeseen expenses.

For closure by means of waste removal, closure costs would include the costs of removal procedures, decontamination procedures, and sampling and analysis. Closure cost estimates should also consider the costs for equipment to remove all waste, transport it to another waste management unit, and properly treat or dispose of it. In addition, fugitive dust emission controls, such as dust suppression practices, might need to be included as a closure cost. Table 5 presents example estimates of average closure costs for typical closure activities. It also presents estimates of typical post-closure care costs discussed in more detail below.

What costs can be expected to be associated with post-closure care?

After a waste management unit is closed, you should conduct monitoring and maintenance to ensure that the closed unit remains secure and stable. Consider the costs to conduct post-closure care and monitoring for some period of time, such as 30 years (in the absence of a state regulation or guidance). If a unit is successfully closed by means of waste removal, no post-closure care costs would be expected. Post-closure care costs should include both annual costs, such as monitoring, and periodic costs, such as cap or monitoring well replacement.

For units closed by means of a final cover, you should consider the costs for a maintenance program for the final cover and associated vegetation. The more frequent the timing of the maintenance activities, the greater your post-closure care costs will be. This program might include repair of damaged or stressed vegetation, and maintenance of side slopes. Costs to maintain the run-on and runoff control systems, leachate collection and removal systems, and ground-water and gas monitoring wells should also be expected. In addition, sampling, analysis, and reporting costs should be factored into the post-closure cost estimates. See Table 5 above for estimates of post-closure care costs.

Post-closure costs should be updated annually as a record of actual unit costs is developed. Some costs, such as erosion control and ground-water sampling, might be reduced over time as the vegetation on the cover matures and a meaningful amount of monitoring data is accumulated. Due to site-specific conditions, a shorter or longer post-closure period might be determined to be appropriate.

How can long-term financial assurance for a unit be obtained?

Different examples of financial assurance mechanisms include trust funds, surety bond, insurance, guarantee, corporate guarantees, and financial tests. Trust funds are a method whereby cash, liquid assets, certificates of deposit, or government securities are deposited into a fund controlled by a trustee, or state agency. The trust fund amount should be such that the principal plus accumulated earnings over the projected life of the waste management unit would be sufficient to pay closure

Table 5. Example Estimated Closure and Post-Closure Care Costs

Closure Activity	Cost Estimate
Estimated average total landfill closure cost	$4,000,000 [1]
Complete site grading	$1,222/acre [2]
Landfill capping	
Total (all capping materials & activities)	$80,000 – $100,000/ acre [3]
Compacted clay cap	$5.17/cubic yard of clay [2]
Geosynthetic clay liner cap	$16,553/acre [2]
Leachate collection and treatment	$0.05 – $0.15/gallon [3] $0.25/gallon [2]
Reclamation of area (applying 2.5 feet of top soil and seeding)	$10,200/acre [3]
Install ground-water monitoring wells	$2,400/well [4]
Install methane monitoring wells (if applicable)	$1,300/well [4]
Install perimeter fence	$13/linear foot [4]
Repair/replace perimeter fence	$2.20/linear foot [2]
Construct surface-water structures	$1/linear foot [4]

Post-Closure Activity (based on 30 year post-closure care period)	Cost Estimate
Estimated average total landfill post-closure care cost	$1,000,000 [1]
Conduct annual inspections	$22,000/facility/year [4] $15,000/facility/year [2]
Maintain leachate collection systems	$60,000 [2]
Conduct Post-closure ground-water monitoring (sampling and analysis)	$15,000 – $25,000/year [3] $12,000/well [4]
Conduct methane monitoring	$7,200/well [4]
Maintain perimeter fence	$12/linear foot [4]
Maintain surface-water structures	$1/linear foot [4]
Remove perimeter fence (at end of post-closure care period)	$2/linear foot [4]

[1] ICF Incorporated. Memo to Dale Ruhter, September 11, 1996

ICF's data show that total closure and post-closure care costs are dependent upon the size of the landfill. The size ranges and corresponding cost estimates were used to calculate the estimated average total costs.

Notes for Table 5

Subtitle D Landfill Closure Costs

Size Range (tons per day)	Cost (in 2000 dollars)
50 – 125	$2,700,000
126 – 275	$5,100,000
276 – 563	$8,300,000
564 – 1125	$11,800,000

Subtitle D Landfill Post-Closure Care Costs

Size Range (tons per day)	Cost (in 2000 dollars)
50 – 125	$820,000
126 – 275	$980,000
276 – 563	$1,400,000
564 – 1125	$1,700,000

[2] Oklahoma Department of Environmental Quality. Table 5.2 Closure Cost Estimate and Table 5.3 Post Closure Estimate from Chapter 5 of Solid Waste Financial Assurance Program Report. December 2000.

[3] Jeffrey H. Heath "Landfill Closures: Balancing Environmental Protection with Cost," MSW Management. January/February 1996. pp. 66-70.

[4] Wyoming Department of Environmental Quality, Solid and Hazardous Waste Division. Solid Waste Guideline #12: Participation in the State Trust Account. May 1994.

and post-closure care costs. Surety bond, insurance, and guarantee are methods to arrange for a third party to guarantee payment for closure and post-closure activities if necessary. A financial test is a standard, such as an accounting ratio, net worth, bond rating, or a combination of these standards, that measures the financial strength of a firm. By passing a financial test, it is determined that one has the financial strength to pay for closure and post-closure costs.

A more detailed explanation of these examples and other potential financial assurance mechanisms is provided below. These mechanisms can be used individually or in combination. This Guide, however, does not recommend specific, acceptable, financial assurance mechanisms.

- **Trust funds.** A trust fund is an arrangement in which one party, the grantor, transfers cash, liquid assets, certificates of deposit, or government securities into a fund controlled by a special "custodian," the trustee, who manages the money for the benefit of one or more beneficiaries. The trust fund should be dedicated to closure and post-closure care activities. Payments are made annually into the fund so that the full amount for closure and post-closure care accumulates before closure and post-closure care activities start. A copy of the trust agreement, which describes how the funds will be used to pay for closure and post-closure care activities, should be placed in the waste management unit's operating record.
- **Surety bond.** A surety bond guarantees performance of an obligation, such as closure and post-closure care. A surety company is an entity that agrees to answer for the debt or default of another. Payment or performance surety bonds are acceptable in the event an owner or operator fails to conduct closure and post-closure care activities. If you use a surety bond or letter of credit, you should establish a standby trust fund (essentially the same as a trust fund).

In most cases, a standby trust fund is established with an initial nominal fee agreed to by the owner or the operator and the trustee. Further payments into this fund are not required until the standby trust is funded by a surety company. The surety company should be listed as an acceptable surety in Circular 570 of the U.S. Department of Treasury.

- **Letters of credit.** A letter of credit is a formalized line of credit from a bank or another institution on behalf of an owner or operator. This agreement states that it will make available to a beneficiary, such as a state, a specific sum of money during a specific time period. The letter of credit should be irrevocable and issued for 1 year. The letter of credit should also establish a standby trust fund.
- **Insurance.** An insurance policy is basically a contract through which one party guarantees another party monies, usually a prescribed amount, to perform the closure or post-closure care in return for premiums paid. The policy should be issued for a face amount at least equal to the current cost estimate for closure and post-closure care. The face amount refers to the total amount the insurer is obligated to pay; actual payments do not change the face amount.
- **Corporate financial test.** Corporate financial tests are a method for an owner and operator to self-guarantee that they have the financial resources to pay for closure and post-closure costs. These tests might require that a company meet a specified net worth, a specified ratio of total liabilities to net worth, and a specified net working capital in the United States. Implicit in using a financial test is a reliance on Generally Accepted Accounting Principles (GAAP) to provide fairly represented accounting data. Your financial statements should be audited by an independent certified public accountant. If the accountant gives an adverse opinion or a disclaimer of opinion of the financial statements, you should use a different financial assurance mechanism.
- **Corporate guarantee.** Under a corporate guarantee, a parent company guarantees to pay for closure and post-closure care, if necessary. The parent company should pass a financial test to show that it has adequate financial strength to provide the guarantee. A financial test is a way for guarantors to use financial data to show that their resources are adequate to meet closure and post-closure care costs. The guarantee should only be used by firms with adequate financial strength.
- **Other financial assurance mechanisms.** If you consider other financial assurance mechanisms, you should talk to your state to see if the mechanism is acceptable.

Performing Closure and Post-Closure Care Activity List

You should consider the following while developing closure and post-closure care activities for industrial waste management units.

- ❑ Develop a closure and post-closure plan, specifying the activities, unit type, waste type, and schedule of the closure.
- ❑ If using a final cover to accomplish closure:
  - — Include the specifications for the final cover in the closure plan.
  - — Determine whether the waste will need stabilization or solidification prior to constructing the final cover.
  - — Address site-specific factors that can affect cover performance.
  - — Select the appropriate materials to use for each layer of the final cover.
  - — Evaluate the effectiveness of the final cover design using an appropriate methodology or modeling program.
  - — Establish a maintenance plan for the cover system.
  - — Establish a program for monitoring the leachate collection system, ground-water quality, and gas generation during the post-closure period.
  - — Ensure proper quality assurance and quality control during final cover installation and post-closure monitoring.
- ❑ If accomplishing closure by waste removal:
  - — Include estimates of the waste volume, contaminated soils and containment structures to be removed during closure.
  - — Establish baseline conditions and check to see if the state requires numeric cleanup levels.
  - — Develop removal procedures.
  - — Develop a sampling and analysis plan.
  - — Ensure proper quality assurance and quality control during sampling.
- ❑ Determine what post-closure activities will be appropriate at the site.
- ❑ Estimate the costs of closure and post-closure care activities and consider financial assurance mechanisms to help plan for these future costs.

Resources

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Glossary

24-hour, 25-year storm event a rainfall event of 24 hours duration and of such a magnitude that it has a 4 percent statistical likelihood of occurring in any given year.

acceptance and conformance testing methods used to evaluate the performance of geomembranes. While the specific ASTM test methods vary depending on geomembrane type, recommended acceptance and conformance testing for geomembranes includes evaluation of thickness, tensile strength and elongation, and puncture and tear resistance testing, as appropriate.

access controls measures, such as fences or security guards, used to restrict entry to a site.

active gas control systems mechanical means, such as a vacuum or pump, to forcibly remove gas from a waste management unit.

adsorption the process by which molecules of gas, liquid, or dissolved solids adhere to the surface of other particles, such as activated carbon or clay.

aerobic processes a biochemical process or condition occurring in the presence of oxygen.

agronomic rate in land application, a waste application rate designed to provide the amount of nitrogen needed by a crop or vegetation to attain a desired yield, while minimizing the amount of nitrogen that will pass below the root zone of the crop or vegetation to ground water.

anaerobic processes a biological process that reduces organic matter to compounds such as methane and carbon dioxide in an oxygen-free environment.

anchor trench a long, narrow ditch along the perimeter of a unit cell in which the edges of a geomembrane are buried or secured.

annular seal impermeable material used to prevent infiltration of surface water and contaminants into the space between the borehole wall and the ground-water well casing.

attenuation the process by which a compound is reduced in concentration over time through chemical, physical, and biological processes such as adsorption, degradation, dilution, and transformation.

Atterberg limits a soil's plastic limit (percent moisture at which soil transitions from solid to plastic) and its liquid limit (percent moisture at which soil transitions from plastic to liquid); useful in characterizing soil plasticity when designing liners with clay soils.

Glossary (cont.)

barrier (infiltration)	in a final cover system, a layer preventing water infiltration into the waste, indirectly promoting the storage and drainage of water from the overlying protection and surface layers, and preventing the upward movement of gases.
barrier walls	low permeability partitions used to direct uncontaminated ground-water flow around a disposal site or to prevent contaminated material from migrating from a site.
bathtub effect	the buildup of leachate within a unit that occurs when the cover system is more permeable than the liner. Leachate accumulates due to the infiltration rate through the cover system exceeding the exfiltration rate through the liner system.
bench-scale treatability study	a study used to evaluate the effectiveness of one or more potential treatment remedies. It establishes the validity of a technology and generates data indicating the remedy's potential to meet performance goals.
berm	a raised flow diversion structure made from compacted earth or rock fill and used to buttress a slope and prevent run-on from entering a waste management unit.
best management practices (BMPs)	measures used to reduce or eliminate contaminant releases to the environment. BMPs can take the form of a process, activity, or physical structure.
bioaccumulation	the uptake and concentration of substances, such as waste constituents, by exposed organisms. This phenomenon has the potential to cause high concentrations especially in the tissues of higher predators.
biochemical oxygen demand (BOD)	the amount of oxygen consumed in the biological processes that break down organic matter (typically measured in mg oxygen per L waste or leachate).
biodegradable organic matter	significant component of waste used in land application. Carbon-based material derived from biological organisms; eventually decomposed by microbes into nontoxic products often useful as plant nutrients. (Compare to synthetic organic compounds.)
biological treatment	a process relying primarily on oxidative or reductive mechanisms initiated by microorganisms to stabilize or de-toxify a waste or leachate. Biological treatment can rely either on aerobic or anaerobic processes.

Glossary (cont.)

blanks samples of ground water, air, or other media, collected to determine background contaminants in the field; used for comparison purposes when analyzing monitoring data.

borrow pit a location where soils are excavated for use as fill or for compaction into liners.

buffer zone an area between waste management units and other nearby properties, such as schools. Buffer zones provide time and space to shield surrounding properties from ongoing activities and disruptions associated with waste management activities.

calcium carbonate equivalent (CCE) a measure of a waste's ability to neutralize soil acidity—its buffering capacity—compared to pure calcium carbonate.

capillary-break (CB) approach an alternative design for a final cover system that exploits the relative differences in porosity between soil types to inhibit water infiltration.

carbon to nitrogen ratio in land application, the ratio of the relative quantities of these two elements in a waste. Carbon is associated with the biodegradable organic matter in a waste, and the carbon to nitrogen ratio reflects the level of inorganic nitrogen available in the soil for plant growth.

cation exchange capacity the ability of a soil to take up and give off positively charged ions—a process which affects the movement of metals in soil.

chain-of-custody record a document tracking possession of samples from the time of collection through laboratory analysis. A chain-of-custody record generally includes the date and time of collection, signatures of those involved in the chain of possession, time and dates of possession, and other notations to allow tracking of samples.

chemical oxygen demand (COD) a measure of the oxygen equivalent of the organic matter in a waste or leachate that is susceptible to oxidation by a strong chemical oxidant such as chromate. COD is used to determine the degree of contamination of a waste or leachate that is not readily biodegradable (see biochemical oxygen demand.)

chemical seaming the use of solvents, cement, or an adhesive to join panels or rolls of a liner. Chemical seaming processes include chemical fusion and adhesive seaming.

chemical treatment a class of processes in which chemicals are added to wastes or to contaminated media to reduce toxicity, mobility, or volume.

Glossary (cont.)

closure termination of the active life of a waste management accompanied by one of the following measures: 1) use of engineered controls, such as a final cover, and post-closure care activities to maintain and monitor the controls, or 2) removal of waste and contaminated containment devices and soils.

closure plan a document describing the procedure envisioned for the termination of a waste management unit's active life. Topics addressed often include future land use, whether wastes will be removed or left in place at closure, closure schedule, steps to monitor progress of closure actions, contingency plans, and final cover information.

collection and sedimentation basin an area that retains runoff long enough to allow solids/particles that are suspended in and being transported by surface water to settle out by gravity.

compacted clay liner (CCL) a hydraulic barrier layer composed of natural mineral materials (natural soils), bentonite-soil blends, and other materials placed and compressed in layers called lifts.

construction quality assurance (CQA) a planned series of observations and tests of unit components, such as liners, as they are being built. CQA is designed to ensure that the components meet specifications. CQA testing, often referred to as acceptance inspection, provides a measure of final product quality and its conformance with project plans and specifications.

construction quality control (CQC) an ongoing process of measuring and controlling the characteristics of unit components, such as liners, in order to meet manufacturer's or project specifications. CQC inspections are typically performed by the contractor to provide an in-process measure of construction quality and conformance with the project plans and specifications, thereby allowing the contractor to correct the construction process if the quality of the product is not meeting the specifications and plans.

control charts a statistical method of evaluating ground-water monitoring data using historical data for comparison purposes. Appropriate only for initially uncontaminated wells.

corrective action the process of taking appropriate steps to remediate any contamination.

critical habitat areas which are occupied by endangered or threatened species and which contain physical or biological features essential to the proliferation of the species.

Glossary (cont.)

daily cover	a level of soil and/or other materials applied at the end of a day after waste has been placed, spread, and compacted. Covering the waste helps control nuisance factors, such as the escape of odors, dust, and airborne emissions, and can limit disease vectors.
deed restriction	a notation on a property's deed or title placing limits and conditions on the use and conveyance of the property.
design storm event	a storm of an intensity, volume, and duration predicted to recur once in a given number of years, whose effects you are designing a system or structure to withstand. (See 24-hour, 25-year storm event.)
destructive testing	the removal of a sample from a liner seam or sheet to perform tests to assess quality.
dilution/attenuation factor (DAF)	DAFs are used to measure the difference in the concentration of waste constituents found in the leachate released from a waste management unit at the source and the same leachate subsequently arriving at a receptor well. DAF is defined as the ratio of the leachate concentration at the source to the receptor well concentration.
direct-push sampling	a method of sampling ground water by hydraulically pressing and/or vibrating a probe to the desired depth and retrieving a ground-water sample through the probe. The probe is removed for reuse after the desired volume of ground water is extracted.
diversion dike	a raised land feature built to channel or control the flow of run-on and runoff water around and within a waste management unit.
downgradient well	a ground-water monitoring installation built to detect contaminant plumes from a waste management unit. In the absence of specific state requirements, monitoring points should be no more than 150 meters downgradient from your waste management unit boundary and placed in potential contamination migration pathways.
drainage layer	in a final cover system, a stratum that directs infiltrating water to drainage systems at the toe of the cover. The drainage layer can be placed below the surface or protection layer, but above the barrier layer.
electrical conductivity (EC)	the ability of a sample to carry an electrical charge. Used in land application to estimate the total dissolved solids content of a soil or waste.
emergency response plan	procedures to address major types of waste management unit emergencies: accidents, spills, and fires/explosions.

Glossary (cont.)

environmental justice the practice of identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of waste manage ment programs, policies, and activities on minority and low-income populations.

environmental stress cracks imperfections or failures in a liner caused by environmental factors before the liner is stressed to its stated maximum strength.

EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) EPACMTP is a ground-water fate and transport model. It simulates subsurface fate and transport of contaminants leaching from the bottom of a waste management unit and predicts concentrations of those contaminants in a downstream receptor as well.

erosion layer (see surface layer.)

expansive soils soils that lose their ability to support a foundation when subjected to certain natural events, such as heavy rain, or human-caused events, such as explosions.

fate and transport modeling a methodology which examines numerous waste and site characteristics to determine how waste constituents move through the environment, how they are degraded or changed, and where they end up.

fault a failure that occurs in a geologic material, such as rock, when tectonic, volcanic, or other stresses exceed the material's ability to withstand them.

field study in land application, a scientific investigation of waste, soil, and plant interaction conducted under natural environmental conditions. (Compare to greenhouse study.)

filter pack in a ground-water monitoring well, a quantity of chemically inert material such as quartz sand, that prevents material from surrounding geological formations from entering the well intake and helps stabilize the adjacent formation. Might be necessary in boreholes that are oversized with regard to the casing and well intake diameter.

final cover a system of multiple layers of soil; engineered controls, such as liners; and/or other materials placed atop a closed waste management unit. Typically improves aesthetics, prevents erosion, blocks roots and burrowing animals, collects and drains incoming water, provides a barrier between waste and the environment, and collects gas generated within the unit.

financial assurance mechanism a funding instrument, such as a bond or trust, that provides or guarantees sufficient financial resources for the closure and post-closure care of a unit in the event the owner or operator is unable to pay.

Glossary (cont.)

fines silt and clay-sized particles.

100-year floodplain a relatively flat, lowland area adjoining inland and coastal waters that is susceptible to inundation during a 100-year flood. A 100-year flood is a large magnitude occurrence with a 1 percent chance of recurring in any given year.

foundation/gas collection layer in a final cover system, a stratum of permeable material such as sand or gravel that controls the migration of gases to collection vents and supports overlying strata.

freeboard depth (capacity) intended to remain unused above the expected highest liquid level in a liquid storage facility, such as a surface impoundment.

freeze-thaw cycles climatic changes in which water enters a small crack in a material, expands upon freezing, and thereby expands the crack; the process then repeats itself and the crack progressively grows. It can increase the hydraulic conductivity of low permeability soil layers or damage geomembranes in final covers.

fugitive dust solid particulate matter, excluding particulate matter emitted from exhaust stacks, that become airborne directly or indirectly as a result of human activity.

fugitive emission control dust suppression at a waste management unit through measures such as watering or chemical dust suppression.

gabion a structure formed from crushed rock encased in wire mesh and used to check erosion and sediment transport.

gas migration the lateral and/or vertical movement of gas through a waste management unit or its cover systems; can convey methane or other dangerous gases to other sites or buildings if gas monitoring is not implemented.

geogrid plastic material manufactured into an open, lattice-like sheet configuration and typically used as reinforcement; designed with apertures or openings sized to allow strike through of surrounding rock and soil.

geomembrane a synthetic sheet composed of one or more plastic polymers with ingredients such as carbon black, pigments, fillers, plasticizers, processing aids, cross- linking chemicals, anti-degradants, and biocides. Geomembranes are used as hydraulic barriers in liner and cover systems.

geophysical monitoring measurement of changes in the geophysical characteristics of subsurface soils, and in some cases, in the ground water itself, to determine potential changes in ground-water quality.

Glossary (cont.)

geosynthetic clay liner (GCLs) a factory-manufactured, hydraulic barrier typically consisting of bentonite clay (or other very low permeability materials), supported by geotextiles and/or geomembranes held together by needling, stitching, or chemical adhesives.

geotextile a woven, nonwoven, or knitted synthetic fabric used as a filter to prevent the passing of fine-grained material such as silt or clay. A geotextile can be placed on top of a drainage layer to prevent the layer from becoming clogged with fine material.

gravel soil particles unable to pass through the openings of a U.S. Number 4 sieve, which has 4.76 mm (0.2 in.) openings.

greenhouse study in land application, a scientific investigation of waste, soil, and plant interaction conducted under controlled indoor conditions. (Compare to field study.)

ground-water monitoring well a borehole in soil outfitted with components typically including a casing, an intake, a filter pack, and annular and surface seals; used to collect ground water from one or more soil layers for sampling and analysis.

ground-water monitoring program The objectives of a ground-water monitoring program are to measure the effectiveness of a waste management unit's design; to detect changes, or the lack thereof, in the quality of ground water caused by the presence of a waste management unit; and to provide data to accurately determine the nature and extent of any contamination that might occur.

ground-water pump-and-treat a ground-water remediation technology in which contaminated water is pumped to the surface for treatment.

ground-water specialist a scientist or engineer who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgements regarding ground-water monitoring, contaminant fate and transport, and corrective action.

health-based number (HBN) a concentration limit for a waste constituent. The HBN is derived from reference doses or reference concentrations that estimate the maximum daily exposure to a waste constituent through a specific pathway (i.e., ingestion) that would be without appreciable risk of deleterious effects during a lifetime.

hydraulic conductivity the velocity at which a fluid, such as leachate, flows through a material, such as a compacted clay liner.

Glossary (cont.)

hydraulic loading capacity in land application, the quantity of liquid or aqueous waste that can be assimilated per unit area by the soil system.

hydraulic overloading in land application, the application of waste in excess of the liquid or water handling capacity of a soil; can result in ponding, anaerobic waste degradation, and odors.

hydrogeologic characterization study and quantification of a site's subsurface features to determine ground-water flow rate and direction; necessary for an effective ground-water monitoring program.

Hydrologic Evaluation of Landfill Performance (HELP) an EPA model that evaluates the relative performance of various final cover designs, estimates the flow of water across and through a final cover, and determines leachate generation rates.

infiltration the entry of precipitation, ground water, waste, or other liquid into a soil layer or other stratum.

in-situ soil geological material already present at a site; known as an in-situ liner when used as a barrier layer in place of imported soil or synthetic materials.

institutional control a measure that can be used by responsible parties and regulatory agencies to prevent use of or access to a site in a remedial program where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Can also be considered in situations where there is an immediate threat to human health; can include deed restrictions, restrictive covenants, use restrictions, access controls, notices, registry act requirements, transfer act requirements, and contractual obligations.

interfacial shear the friction or stress between components, such as a compacted clay liner and a geomembrane, that occurs on side slopes of waste management units. When the interfacial shear is inadequate, a weak plane can form on which sliding can occur. The shift in components can compromise liner and cover performance, negatively affecting unit stability.

interim measure in corrective action, a step taken to control or abate ongoing risks before final remedy selection.

internal shear a stress that can lead to tearing of liner or cover components when overlying or underlying pressure upon a liner or cover exceeds its ability to withstand this stress.

ISO 14000 procedures voluntary set of standards for good environmental practices developed by the International Standards Organization (ISO), also known as Environmental Management Standards (EMS).

Glossary (cont.)

karst terrain	areas containing soluble bedrock, such as limestone or dolomite, that have been dissolved and eroded by water, leaving characteristic physiographic features including sinkholes, sinking streams, caves, large springs, and blind valleys.
land application	(see land application unit.)
land application unit	a waste management unit in which waste (such as sludge or wastewater) is spread onto or incorporated into the land to amend the soil and/or treat or dispose of the waste.
landfills	a waste management unit in which waste is compacted in engineered cells for permanent disposal, usually covered daily.
leachate	liquid (usually water) that has percolated through waste and taken some of the waste or its constituents into solution.
leachate concentration	the concentration (usually in mg/L) of a particular waste constituent in the leachate.
leachate collection and removal system	a system of porous media, pipes, and pumps that collect and convey leachate out of a unit and/or control the depth of leachate above a liner.
leachate testing	used to characterize waste constituents and their concentrations, and to estimate the potential amount and/or rate of the release of waste constituents under worst case environmental conditions.
leak detection system (LDS)	also known as a secondary leachate collection and removal system; a redundant leachate collection and removal system to detect and capture leachate that escapes or bypasses the primary system. Sudden increases in leachate captured by an LDS can indicate failure of a primary leachate collection and removal system.
lifts	layers of compacted natural mineral materials (natural soils), bentonite-soil blends, and other materials that compose a liner or other compacted stratum.
liner	a hydraulic barrier, such as compacted clay or a geomembrane, used to restrict the downward or lateral escape of waste, waste constituents, and leachate. Liners accomplish this by physically impeding the flow of leachate and/or by adsorbing or attenuating pollutants.
in-situ soil	geological material already present at a site; known as an in-situ liner when used as a barrier layer in place of imported soil or synthetic materials.

Glossary (cont.)

single liner	a hydraulic barrier consisting of one soil layer, one geomembrane, or any other individual barrier without a second barrier to impede contaminants that might breach it.
composite liner	a liner consisting of both a geomembrane and a compacted clay layer (or a geosynthetic clay liner).
double liner	a hydraulic barrier between a waste management unit and the natural environment, consisting of primary (top) and secondary (bottom) levels. Each level can consist of compacted clay, a geomembrane, or a composite (consisting of a geomembrane and a compacted clay layer or GCL).
liquefaction	occurs when vibrating motions caused by an earthquake turn saturated sand grains in the soil into a viscous fluid, diminishing the bearing capacity of the soil and possibly leading to foundation and slope failures.
lithology	the description of geological materials on the basis of their physical and chemical characteristics.
lower explosive limit (LEL)	the minimum percentage of a gas by volume in the air that is necessary for an explosion. This level is 5 percent for methane.
lysimeter	a device used to measure the quantity or rate of water movement through or from a block of soil or other material. It collects soil-pore liquids by applying a vacuum that exceeds the soil moisture tension; usually a buried chamber made from wide perforated pipe.
material balances	used to calculate all input and output streams, such as the annual quantities of chemicals transported to a facility and stored, used, or produced at a facility, and released or transported from a facility as a commercial product or by-product or a waste. Material balances can assist in determining concentrations of waste constituents where analytical test data are limited.
Maximum Achievable Control Technology (MACT) standards	national standards that regulate major sources of hazardous air pollutants. Each MACT standard specifies particular operations, processes, and/or wastes that are covered. If a facility is covered by a MACT standard, it must be permitted under Title V.
maximum contaminant level (MCL)	the maximum permissible level of a contaminant in water delivered to any user of a public water system.

Glossary (cont.)

molding water content for natural soils, the degree of saturation of the soil liner at the time of compaction; influences the engineering properties, such as hydraulic conductivity, of the compacted material.

Monte Carlo analysis an iterative process involving the random selection of model parameter values from specified frequency distributions, followed by simulation of the system and output of predicted values. The distribution of the output values can be used to determine the probability of occurrence of any particular value given the uncertainty in the parameters. In this guidance, used to predict a statistical distribution of exposures and risks for a given site.

National Ambient Air Quality Standards (NAAQS) airborne emission limits set by EPA as authorized by the Clean Air Act. EPA has designated NAAQS for the following criteria pollutants: ozone, sulfur dioxide, nitrogen dioxide, lead, particulate matter, and carbon monoxide.

National Emission Standards for Hazardous Air Pollutants (NESHAP) national standards regulating 188 hazardous air pollutants listed in Section 112(b) of the Clean Air Act Amendments of 1990.

numeric clean-up standard a state corrective action requirement mandating that a site be cleaned up such that concentrations of a waste constituent do not exceed a set level.

operating plan a document that specifies methods of running a waste management unit, such as standard waste-handling practices, management and maintenance activities, employee training, and emergency plans; based on comprehensive knowledge of the chemical and physical composition of the waste managed, unit type, operational schedules, and monitoring performed at the unit.

overland flow ("flood") application land application of liquid waste by irrigation methods; can lead to increased surface runoff of waste if not properly managed and, therefore, is regulated by some states and localities.

parametric analysis of variance (ANOVA) a method of statistical analysis that attempts to determine whether different monitoring wells have significantly different average constituent concentrations.

particulate matter (PM) a mixture of solid particles and liquid droplets suspended in the atmosphere that can cause a variety of respiratory problems, carry adsorbed pollutants far from their source, impair visibility, and stain or damage surfaces, such as buildings or clothes, on which it settles.

Glossary (cont.)

passive gas control system	a gas control system using natural pressure and convection mechanisms to control gas migration and to help vent gas emissions into the atmosphere; can include ditches; trenches; vent walls; perforated pipes surrounded by coarse soil; synthetic membranes; and high moisture, fine-grained soil.
pathogens	potentially disease-causing microorganisms, such as bacteria, viruses, protozoa, and the eggs of parasitic worms.
peak flow period	the phase of a storm event when flood waters are at their highest level.
pH	A measure of acidity or alkalinity equal to the logarithm of the reciprocal of hydrogen ion (H+) concentration in a medium. pH is represented on a scale of 0 to 14; 7 represents a neutral state, 0 represents the most acid, and 14 the most alkaline.
pH adjustment	the neutralization of acids and bases (alkaline substances) and promotion of the formation of precipitates, which can subsequently be removed by conventional settling techniques.
piezometer	a well installed to monitor hydraulic head of ground water or to monitor ground-water quality.
pilot-scale treatability study	a small study to evaluate the effectiveness of and determine the potential for continued development of one or more potential remedies; typically conducted to generate information on quantitative performance, cost, and design issues.
plasticity characteristics	parameters describing a material's ability to behave as a moldable material.
plume	an elongated and mobile column or band of a contaminant moving through the subsurface.
point of monitoring	the location(s) where ground-water is sampled; should be appropriate for site conditions and located at waste management boundary or out to 150 meters downgradient of the waste management unit area.
post-closure care	monitoring of a closed waste management unit to verify and document that unacceptable releases from the unit are not occurring. The overall goal is to ensure that waste constituents are contained until such time as containment is no longer necessary.

Glossary (cont.)

prediction intervals a statistical method of approximating future sample values from a population or distribution with a specific probability; used with ground-water monitoring data, both for comparison of downgradient wells to upgradient wells (interwell comparison) and for comparison of current well data to previous data for the same well (intrawell comparison).

process knowledge an understanding of industrial processes used to predict the types of waste generated and to determine the mechanism by which they are generated.

protection layer a stratum in a final cover system that protects the drainage layer from intrusion by plant roots or burrowing animals; located below the surface layer and above the drainage layer.

public involvement dialogue between facility owners and operators and public to share information, identify and address issues and concerns, and provide input into the decision-making process.

public notice a document, announcement, or information release that publicizes a meeting, decision, operational change, or other information of interest to the public; usually provides the name and address of the facility owner and operator and information about the issue being publicized.

puncture resistance the degree to which a material, such a liner, will resist rupture by jagged or angular materials which might be placed above or below it.

quality assurance and quality control (QA/QC) procedures in ground-water sampling, steps for collection and handling of ground-water samples to ensure accurate results. In liner construction, steps to ensure that liners are installed according to design and will perform specifications.

rational method a method for calculating the volume of storm water runoff. The rational method approximates the surface water discharge from a watershed using a runoff coefficient, the rainfall intensity, and the drainage area.

receptor a person or other organism that might be exposed to waste constituents, especially an organism whose exposure is addressed by a fate and transport analysis; or, a downgradient ground-water monitoring well that receives ground water which has passed near a waste management unit.

recycling the process of collecting, processing, and reusing waste materials.

redox (oxidation-reduction) potential the capacity of a medium to raise the valence state of molecules (such as metals), add oxygen, or remove hydrogen (oxidation); or to lower the valence state of molecules, remove oxygen, or add hydrogen (reduction).

Glossary (cont.)

riprap	rock cover used to protect soil in dikes or channels from erosion.
risk-based corrective action (RBCA)	an approach to corrective action that integrates the components of traditional corrective action with alternative risk and exposure assessment practices. States and ASTM have developed RBCA as a three stage process.
runoff	storm water that flows from a waste management unit to surface waters.
run-on	storm water that falls directly on a waste management unit or flows toward the unit from adjoining areas.
saline soil	soil with excessive salt concentrations.
sampling parameters	for monitoring, those items for which ground water samples will be tested, such as waste constituents reasonably expected to migrate to the ground water and other geochemical indicators of contaminant migration.
seaming process	the joining of panels or rolls of a liner using thermal, chemical, or other methods compatible with the properties of the liner material.
seismic impact zone	an area having a 10 percent or greater probability that the maximum horizontal acceleration caused by an earthquake at the site will exceed 0.1g in 250 years. g is a unit of force equal to the force exerted by gravity on a body at rest and used to indicate the force to which a body is subjected when accelerated.
setback	the placing of a waste management unit or one of its components some distance from an adjoining property, a geologic feature, or other feature that could affect the unit or be affected by the unit. (Compare to buffer zone.)
shear strength	for soils, the internal resistance per unit area that a soil mass can offer to resist failure and sliding along any plane inside it; in liner design, indicates the degree to which stability problems and desiccation cracks are likely to occur in liner material (such as clay).
silt fence	a barrier consisting of geotextile fabric supported by wooden posts; slows the flow of water and retains sediment as water filters through the geotextile.
slip	for soils, to slide downhill in mass movements such as avalanches, land slides, and rock slides; can be caused by inherent properties of the soil or by cutting or filling of slopes during construction.

Glossary (cont.)

slippage movement of a geomembrane liner due to a lack of adequate friction between the liner and the soil subgrade or between any geosynthetic components.

sodic soil soil with excessive levels of sodium ions (Na+) relative to divalent ions, such as calcium (Ca2+) and magnesium (Mg2+).

soil gas sampling collection of gas from soil pores to detect the presence or movement of volatile contaminants and gases, such as carbon dioxide and methane, that are associated with waste degradation.

soil-pore liquids fluids present in spaces between soil particles in the vadose zone; can be collected to determine the type and concentration of contaminants that might be moving within the vadose zone.

soil water content the ratio of the weight of water to the weight of solids in a given volume of soil; usually stated as a percentage and can be greater than 100 percent for very soft clays.

soil water tension a measure of the strength of capillary effects holding water between soil particles; decreases as soil water content increases, so decreases in soil water tension beneath a lined waste management unit might indicate the presence of leachate due to a leaking liner.

solidification processes the conversion of a non-solid waste into a solid, monolithic structure that ideally will not permit liquids to percolate into or leach materials out of the mass; used to immobilize waste constituents.

soluble salts materials that could dissolve in or are already in solution in your waste. Major soluble salts include calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, and nitrate.

Source Loading and Management Model (SLAMM) an urban nonpoint source water quality model developed by the University of Alabama at Birmingham; useful for designing run-on and runoff controls.

source reduction the prevention or reduction of waste at the point of generation.

spill prevention and response procedures for avoiding accidental releases of waste or other contaminants and promptly addressing any releases that occur.

stabilization process a means of immobilizing waste constituents by binding them into an insoluble matrix or by changing them to insoluble forms.

Glossary (cont.)

standard operating procedures	established, defined practices for the operation of a waste management unit; useful in maintaining unit safety and protection of human health and the environment; should be recorded in an operating plan to facilitate employees' familiarity.
storm water conveyances	pipes, ditches, swales, and other structures or landforms that carry, divert, or direct run-on and/or runoff.
Storm Water Management Model (SWMM)	EPA computer model capable of simulating the movement of precipitation and pollutants from the surface through pipe and channel networks, storage treatment units, and finally to surface water; used in the design of run-on and runoff controls.
stratigraphy	characterization of the origin, distribution, and succession of geologic strata, such as soil and rock layers.
subsidence	lowering of the land surface due to factors such as excessive soil loading, compaction of soil owing to high moisture content, or reduction in waste volume due to degradation; can significantly impair the integrity of the final cover system by causing ponding of water on the surface, fracturing of low permeability infiltration layers, and failure of geomembranes.
sump	a low point in a liner system constructed to gravitationally collect leachate from either the primary or secondary leachate collection system.
surface completion	the part of a ground-water monitoring well constructed at or just above ground level, often consisting of a protective outer casing around the inner well casing, fitted with a locking cap; discourages vandalism and unauthorized entry into the well, prevents damage by contact with vehicles, reduces degradation caused by direct exposure to sunlight, and prevents surface runoff from entering and infiltrating the well.
surface impoundment	a natural or manmade topographic depression, excavation, or diked area designed to hold liquid waste.
surface layer	in a final cover system, a stratum that promotes the growth of native, nonwoody plant species, minimizes erosion, restores the aesthetics of the site, and protects the barrier layer.
surface seal	neat cement or concrete surrounding a ground-water monitoring well casing and filling the space between the casing and the borehole at the surface; protects against infiltration of surface water and potential contaminants from the ground surface.

Glossary (cont.)

synthetic organic molecules man-made carbon compounds used in a variety of industrial and agricultural processes, sometimes hazardous, and unlike biodegradable organic matter, not necessarily biodegradable, or if biodegradable, not necessarily broken down into nonhazardous byproducts.

Synthetic Precipitation Leaching Procedure (SPLP) The SPLP is currently used by several state agencies to evaluate the leaching of TC hazardous constituents from wastes and can be used to assess the risks posed by wastes placed in a landfill and subject to acid rain. The SPLP is designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes.

tear resistance the ability of a material, such as a geomembrane, to resist being split due to stresses at installation, high winds, or handling.

tensile behavior the tendency of a material to elongate under strain.

tensiometer an instrument that measures soil water tension.

terraces and benches earthen embankments with flat tops or ridges and channels; used to hold moisture and minimize sediment loadings in runoff.

test pad in liner design, a small-scale replica of a liner system used to verify that the materials and methods tested will yield a liner that provides the desired hydraulic conductivity.

thermal seaming the use of heat to join panels or rolls of a liner.

Title V operating permits established by the Clean Air Act, these permits are required for any facility emitting or having the potential to emit more than 100 tons per year of any air pollutants, as defined by Section 302(g) of the Clean Air Act. Permits are also required for all sources subject to MACT or NSPS standards.

toe the lower endpoint of a slope.

tolerance interval a statistical interval constructed from data designed to contain a portion of a population, such as 95 percent of all sample measurements; used to compare data from a downgradient well to data from an upgradient well.

topography the physical features (configuration) of a surface area including relative elevations and the position of natural and constructed features.

total dissolved solids (TDS) the sum of all ions in solution.

Glossary (cont.)

total solids content the sum of suspended and dissolved solids in a liquid waste, usually expressed as a percentage.

Toxicity Characteristic Leaching Procedure (TCLP) The TCLP is most commonly used by EPA and state agencies to evaluate the leaching potential of wastes, and to determine toxicity. The TCLP quantifies the extractability of certain hazardous constituents from solid waste under a defined set of laboratory conditions. It evaluates the leaching of metals, volatile and semi-volatile organic compounds, and pesticides from wastes.

ultraviolet resistance the degree to which a material, such as a geomembrane, can resist degradation and cracking from prolonged exposure to ultraviolet radiation.

unstable area a location susceptible to human-caused or natural events or forces, such as earthquakes, capable of impairing the integrity of a waste management unit.

upgradient well a ground-water monitoring installation built to measure background levels of contamination in ground water at an elevation before it encounters a waste management unit.

upper explosive limit the maximum percentage of a gas by volume in the air that will permit an explosion. This level is 15 percent for methane; at higher percentages, non- explosive burning is still possible.

use restrictions stipulations describing appropriate and inappropriate future uses of a closed site, in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applied clean-up standard.

vadose zone the soil (or other strata) between the ground surface and the saturated zone; depending on climate, soils, and geology, can be very shallow or as deep as several hundred feet.

vegetative cover layer (see surface layer.)

volatile organic compounds (VOCs) carbon compounds which tend to evaporate at low to moderate temperatures due to their low vapor pressure.

waste pile a noncontainerized accumulation of solid, nonflowing waste that is used for treatment or storage.

Glossary (cont.)

waste reduction waste reduction practices include source reduction, recycling and reuse, and treatment of waste constituents. Waste reduction minimizes the amount of waste that needs to be disposed of in the first place, and limits the environmental impact of those wastes that actually are disposed.

water content (see soil water content.)

well casing in a ground-water monitoring well, the pipe or tube lowered into the borehole as the outer wall of the well; supports the sides of the hole and prevents water from entering or leaving the well other than by normal ground-water flow.

well intake (well screen) a perforated segment of a ground-water monitoring well designed to allow ground water to flow freely into the well from an adjacent geological formation while minimizing or eliminating the entrance of fine-grained materials such as clay or sand.

well purging methods procedures for removing stagnant water from a ground-water monitoring well and its filter pack before collecting a sample; employed to ensure collection of samples that accurately represent current ground-water quality.

wellhead protection area (WHPA) the most easily contaminated zone surrounding a wellhead; officially designated for protection in many jurisdictions to prevent public drinking water sources from becoming contaminated.

wetlands areas, such as tidal zones, marshes, and bottomland forests, that are inundated or saturated by surface or ground water at a frequency or duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

working face the area of a waste management unit, especially a landfill, where waste is currently being placed and compacted.

zoning local government classification of land into areas designated for different use categories, such as residential, commercial, industrial, or agricultural; used to protect public health and safety, maintain property values, and manage development.