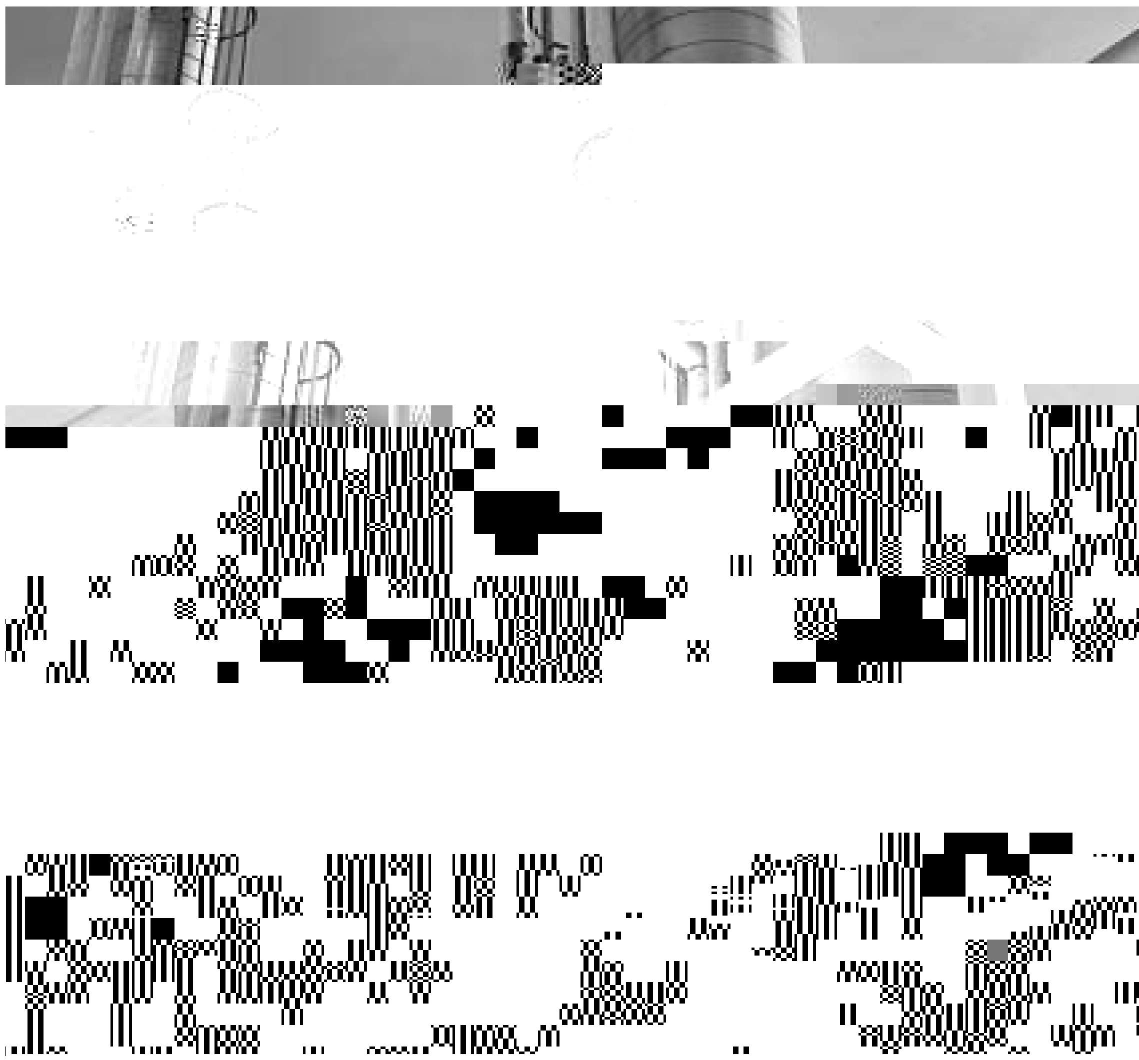
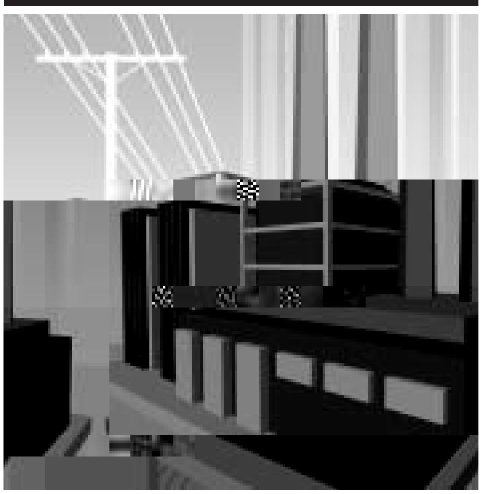
Guide for Industrial Waste Management

Protecting
Land
Ground Water
Surface Water
Air





Building
Partnerships

I G , W :

- 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

A P c G ?

When using the *G ide fo Ind t ial Wa te Management*, please keep in mind that it reflects four underlying principles:

- 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.
- 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.
- 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.
- 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.

C I E c F G ?

The *G ide fo Ind t ial Wa te 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 < >, 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

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.

R B G R P ?

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

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) < >. 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 <

guidance for making management decisions by
providing one of the inputs to the decision

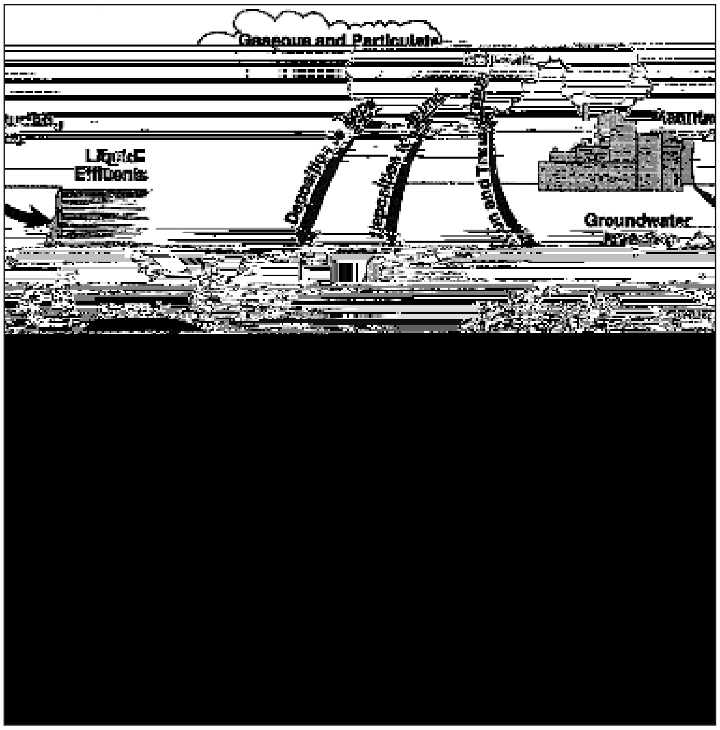


Figure 1. Multiple Exposure Pathways/Routes *(National Research Council, "Frontiers in Assesssing Human Exposure," 1991)*

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.

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

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

K C mc P c

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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 fac-

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 E po e Facto 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

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. I m E m R

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 < [illegible] >.

III. B P

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. D P P

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.
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ronmental 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. I
P m c A N w
F c c
C F c
O P

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.

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.
[illegible]	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.)

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	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.
[illegible]	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.
[illegible]	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. M K R P A I m

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. P I m A F c O

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.

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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

A m c C C m C c ’ R

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’ F I

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

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.

Resources

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Part I
Getting Started

Chapter 2
Characterizing Waste

Contents

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

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. P m A

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

[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 <

- 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 *Te t Method fo E al ating Solid Wa te, Ph ical/Chemical Method SW-846* (U.S. EPA, 1996e), *G idance fo the Data Q alit Objecti e P oce* (U.S. EPA, 1996b), *G idance on Q alit A ance P oject Plan* (U.S. EPA, 1998a), and *G idance fo the Data Q alit A e ment: P actical Method fo Data Anal i* (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 *Ind t ial Wa te Management E al ation Model Technical Backg o nd Doc ment* (U.S. EPA 2002). The LCTV tables also are included in the *IWEM Technical Backg o nd Doc ment* 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:

- [illegible] 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.
- [illegible] 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 <[illegible]>.

- [illegible] 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.
- [illegible] 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

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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: <[illegible]>. 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 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

[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.

[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

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 leachin[(taastsescusonyeriod ogement unit emns eme imong in)9.6(e v
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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 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 <[illegible]>.

III. C c O c E m

To determine whether volatile organic emissions are of concern at a waste management unit, determine the concentration of the 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

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.

Resources

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[illegible]

[illegible]						
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
[illegible]						
Sequential Extraction Tests	0.04 m acetic acid	50:1	9.5 mm	15	24 hours per extraction	
[illegible]						
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
[illegible]						
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	

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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
[illegible]						
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	
[illegible]						
ASTM D4874-95 Column Test	Type IV reagent water	One void volume	10 mm	1	24 hours	
[illegible]						
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*

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.

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

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 dedicaMed greaMer 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 highlighMed 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 mighM pose. For example:

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 maMerial 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.

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

I. B P P

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.

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prevention activitiey proteng human health ang
the environme. Deincreucing th[(v-b3 i or)]TJT*tox(filitis n pr)19.6(oc

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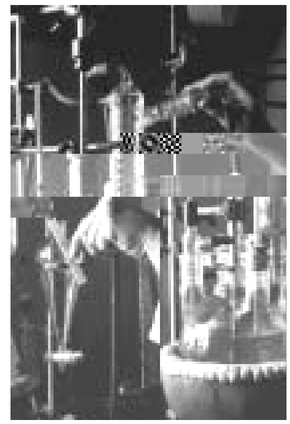
II. I P m m P

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. c R c

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.



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.

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.

[illegible] 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.

[illegible] 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.

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[1] Freeman, Harry. 1995. *Ind t ial Poll tion P e ention Handbook*. McGraw-Hill, Inc. p. 13.

Segregating waste streams is another good housekeeping procedure that enables a facili-

- 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

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

- $ $, 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. < >
- ( ) promotes the development, implementation, and evaluation of pollution prevention. NPPR's Web site provides an abridged online version of *The Poll tion P e ention Yello Page* < >, 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. < > Phone: 202 466-P2P2
- 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. < >
- ( ) PPIC maintains a collection of EPA non-regulatory documents related to waste reduction. < > Phone: 202 260-1023 e-mail: ppic@epamail.epa.gov
- ( ) ( ) 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. < >

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:

- 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 <[illegible]> has a locator that can help you find the nearest center.

- **[illegible]** Trade associations provide industry-specific assistance through publications, workshops, field research, and consulting services. EPA's WasteWise program <[illegible]> provides an online resources directory which can help you locate specific trade associations. The National Trade and Professional Associations of the Unites States' *Di ecto of T ade A ociation* (Washington, DC: Columbia Books, Inc., 2000) is another useful resource.

- **[illegible]** 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 <[illegible]> provides such assessments for small and medium-sized manufacturers.

- **[illegible]** 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) <[illegible]> is one example.

- **[illegible]** 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.

- **[illegible]** 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.

- **[illegible]** 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.

- **[illegible]** 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.

Integrating Pollution

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 ened 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 < > 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 < >. 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 < >.

I. G C

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 < >. Also, the University of Missouri-Rolla maintains a current list of state geological survey offices on its library's Web site at < >.

A. F

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?

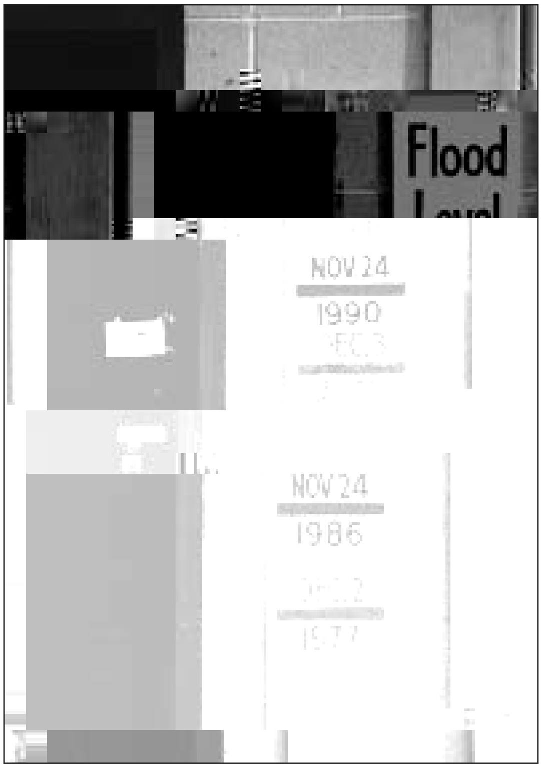
The first step in determining whether a prospective site is located in a 100-year floodplain is to consult with the Federal Emergency Management Agency (FEMA). FEMA has prepared flood hazard boundary maps for most regions. If a prospective site does not appear to be located in a floodplain, further exploration 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 < >.

Additional information can be found on flood insurance rate maps in FEMA's publication *Ho to Read a Flood In ance Rate Map* (visit: < >). FEMA also publishes *The National Flood In ance P og am Comm nit Stat 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 < >.

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.



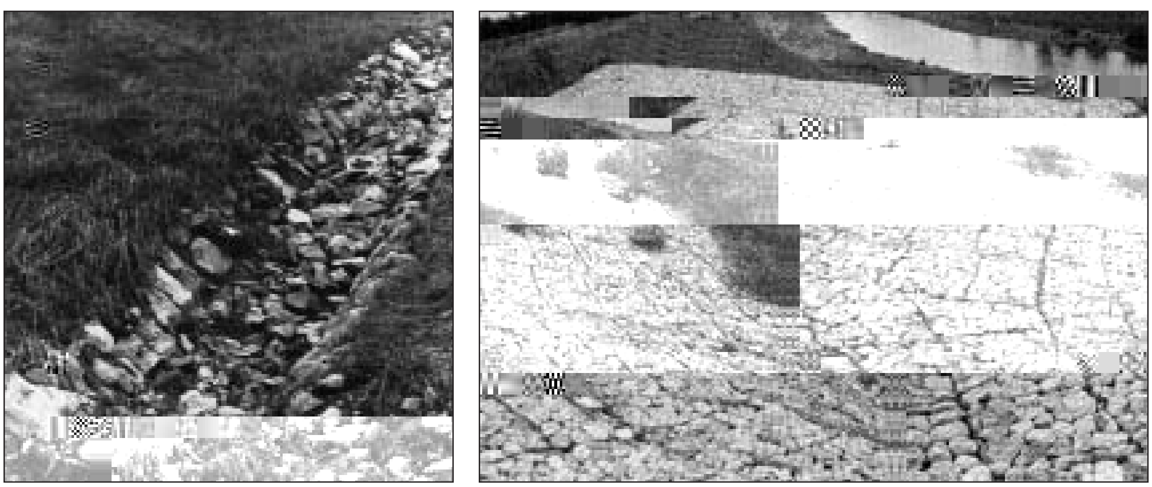
Knowing the behavior of waters at their peak flood level is important for determining whether waste will wash out.

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, 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, < >.

[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 <[illegible]>, under Title 33, Chapter 26.

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:

[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 <[illegible]>. Local aerial photography firms and surveyors are also good sources of information.

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.

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, *P obabili tic Ea thq ake Accele ation and Velocit Map fo the United State and P e to 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 <[illegible]>. 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 <[illegible]>, or a latitude-longitude coordinate pair <[illegible]>. 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 Accele ation (%g) ith 2 % P obabilit of E ceedance in 50 Yea* maps available at <[illegible]>. 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: <[illegible]>).

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

[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 <[illegible]>.

[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: <[illegible]>.

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 rain, 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 nature are water-bearing, are also subject to subsidence when water is (>.)Tj11c mW n0 792.06o10 0 0 ph62.818 9005den7055.

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 <[illegible]>.

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.

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. P c
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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 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. R c mm B

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.

[illegible] Waste management units can present noise, odor, and dust problems for residents or businesses located on

[18] For the full text of the Endangered Species Act, visit the U.S. House of Representatives Internet Law Library Web site at <[illegible]>, under Title 16, Chapter 35.

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

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.

Resources (cont.)

U.S. Army Corps of Engineers. 1991. 1987 U.S. Army Corps of Engineers Wetlands Delineation Manual. HQUSACE.

U.S. Army Corps of Engineers. 1984. Engineering and Design: Use of Geotextiles Under Riprap. ETL 1110-2-286.

U.S. EPA. 2000a. Social Aspects of Siting RCRA Hazardous Waste Facilities. EPA530-K-00-005.

U.S. EPA. 2000b. Siting of Hazardous Waste Management Facilities and Public Opposition. EPAOSW-0-00-809.

U.S. EPA. 1997. Sensitive Environments and the Siting of Hazardous Waste Management Facilities. EPA530-K-97-003.

U.S. EPA. 1995a. OSWER Environmental Justice Action Agenda. EPA540-R-95-023.

U.S. EPA. 1995b. Decision-Maker's Guide to Solid Waste Management, 2nd Ed. EPA530-R-95-023.

U.S. EPA. 1995c. RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities. EPA600-R-95-051.

U.S. EPA. 1995d. Why Do Wellhead Protection? Issues and Answers in Protecting Public Drinking Water Supply Systems. EPA813-K-95-001.

U. S. EPA. 1994. Handbook: Ground Water and Wellhead Protection. EPA625-R-94-001.

U. S. EPA. 1993a. Guidelines for Delineation of Wellhead Protection Areas. EPA440-5-93-001.

U.S. EPA. 1993b. Solid Waste Disposal Facility Criteria: Technical Manual. EPA530-R-93-017.

U. S. EPA. 1992. Final Comprehensive State Ground-Water Protection Program Guidance. EPA100-R-93-001.

U. S. EPA. 1991. Protecting Local Ground-Water Supplies Through Wellhead Protection. EPA570-09-91-007.

U. S. EPA. 1988. Developing a State Wellhead Protection Program: A User's Guide to Assist State Agencies Under the Safe Drinking Water Act. EPA440-6-88-003.

U.S. Geological Survey. Preliminary Young Fault Maps, Miscellaneous Field Investigation 916.

U.S. Geological Survey. Probabilistic Acceleration and Velocity Maps for the United States and Puerto Rico. Map Series MF-2120.

- 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

[illegible]

- 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

[illegible]	[illegible]		[illegible]	
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

[illegible]	[illegible]		[illegible]	
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

[illegible]		[illegible]	
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

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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.

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.

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 quali-

[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. N E m H A P

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 <[illegible]>. 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 2

HAPs Defined in Section 112 of the CAA Amendments of 1990

#	
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)

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

Table 3
Source Categories With MACT Standards

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

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. P O m

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 < >.

E. F A E m R M m Ac

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

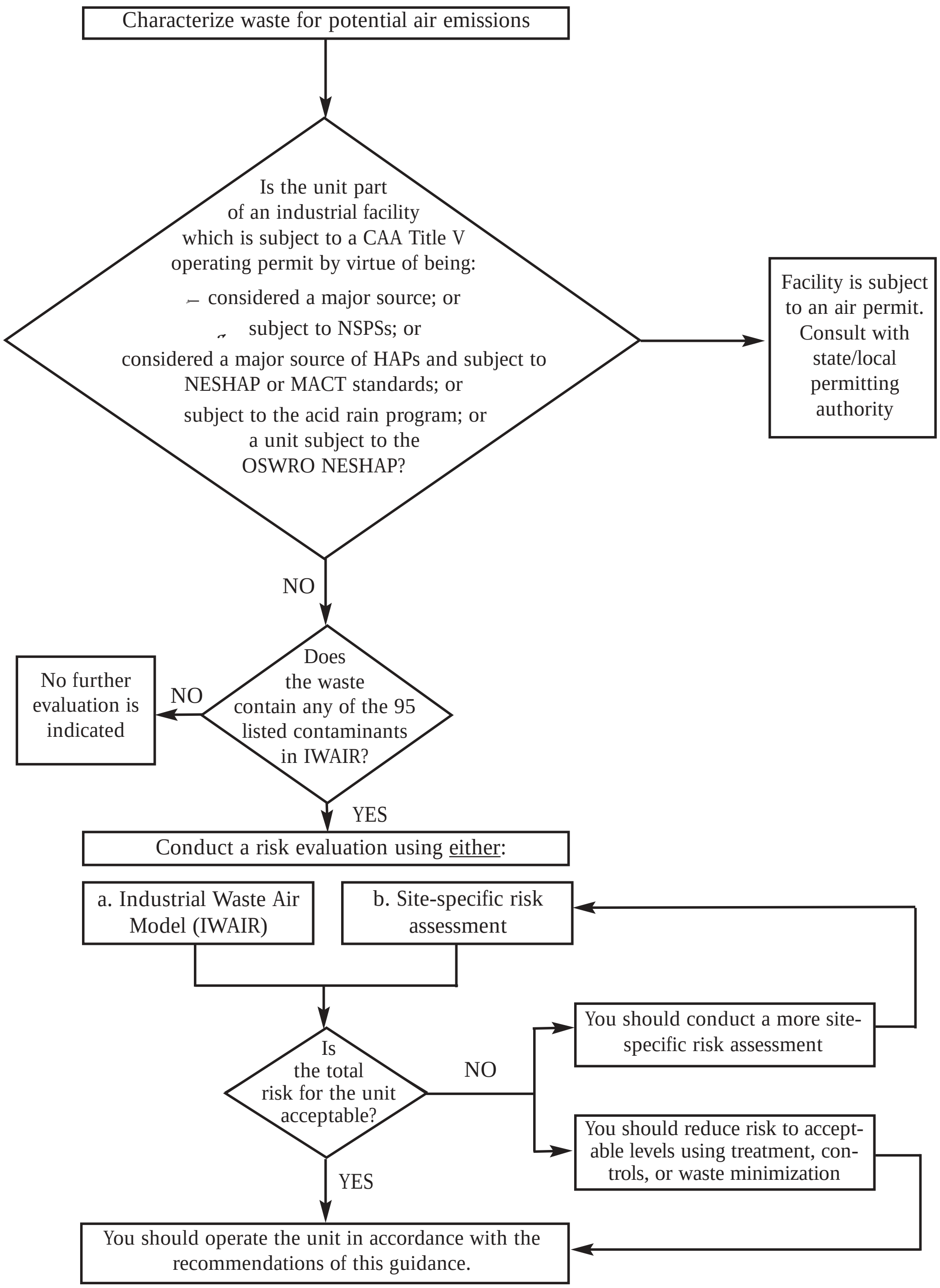
Under Section 3004(n) of RCRA, EPA

(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 D c G A c CAA R m

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 (equir)9.6(ir)9.6(ements addr)9.75<Rust emit or ive9nt


Characterize waste for potential air emissions
Is the unit part of an industrial facility which is subject to a CAA Title V operating permit by virtue of being:
considered a major source; or
subject to NSPSs; or
considered a major source of HAPs and subject to NESHAP or MACT standards; or
subject to the acid rain program; or
a unit subject to the OSWRO NESHAP?
Facility is subject to an air permit. Consult with state/local permitting authority
NO
Does the waste contain any of the 95 listed contaminants in IWAIR?
NO
No further evaluation is indicated
YES
Conduct a risk evaluation using either:
a. Industrial Waste Air Model (IWAIR)
b. Site-specific risk assessment
Is the total risk for the unit acceptable?
NO
You should conduct a more site-specific risk assessment
You should reduce risk to acceptable levels using treatment, controls, or waste minimization
YES
You should operate the unit in accordance with the recommendations of this guidance.

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

[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

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. A R

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. A R A c l A m A

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 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 identifyty 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

F 4. F c A c C m P m .

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. I AIR M

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

Table 5. Constituents Included in IWAIR

[illegible]	[illegible]
75-07-0	
67-64-1	
75-05-8	
107-02-8	
79-06-1	
79-10-7	
107-13-1	
107-05-1	
62-53-3	
71-43-2	
92-87-5	
50-32-8	
75-27-4	
106-99-0	
75-15-0	
56-23-5	
108-90-7	
124-48-1	
67-66-3	
95-57-8	
126-99-8	
1006-10-15	
1319-77-3	
98-82-8	
108-93-0	
96-12-8	
75-71-8	
107-06-2	
75-35-4	
78-87-5	
57-97-6	
95-65-8	
121-14-2	
123-91-1	
122-66-7	
106-89-8	
106-88-7	
11-11-59	
110-80-5	
100-41-4	
106-93-4	
107-21-1	
75-21-8	
50-00-0	
98-01-1	
87-68-3	
118-74-1	

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

F 6. c 1, M , M , M .


A. Selec
calc la ion
me hod
B. Selec
C. Selec me
a ion search
op ion
En er ip code
and search for
me a ion
En er la i de
and longi de
and search for
me a ion
D. Vie
selec ed me
a ion

b. 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. 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. 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. The user can provide site-specific unitized dispersion factors (µg/m³ per µg/m²-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. For each receptor, the model combines emission rates and dispersion data to estimate ambient air concentrations for all waste constituents of concern.

g. 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:

Fo a d calc lation: 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.

Back a d calc lation: 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 particulate emissions are not accounted for in the model.

- 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.
- 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 *G ideline on Ai Q alit Model* (U.S. EPA, 1993) can assist users in determining whether a facility is in an area of simple, intermediate, or complex terrain.
- 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. - c c R A

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

[illegible]	[illegible]
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 <[illegible]>.
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 <[illegible]>.
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 <[illegible]>.

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

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

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

B. OC E m C c

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 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.

[illegible] 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

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 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?

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.

I. D Q H m c

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.

> **W ?**
>
> 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. Q C

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. Q

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	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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. [illegible] M[illegible] L[illegible] (MDL) P[illegible]

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.

II. c - P c P A c m M m

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. N P D c E m (NPDE m) P m P m

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, non-process 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 agencyitor 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 < [illegible] >. 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.

1. Storm-Water DischargesA an

[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.

ment 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 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 correallowed 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.

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

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,

stream will be deposited on the bottom of the streambed as the particles fall out of the

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.

[illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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 Ecoto icolog* , Volume One. Blackwell Scientific Publications.

[illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] is the decomposition of a substance into more elementary compounds by action of microorganisms such as bacteria. Sullivan. 1993. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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, Vado e Zone, and G o nd-Wate Contamination: A e ment, P e ention, and Remediation.*

[illegible] ([illegible]) [illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] is the chemical changes brought about by the radiant energy of the sun acting upon various polluting substances. Sullivan. 1993. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

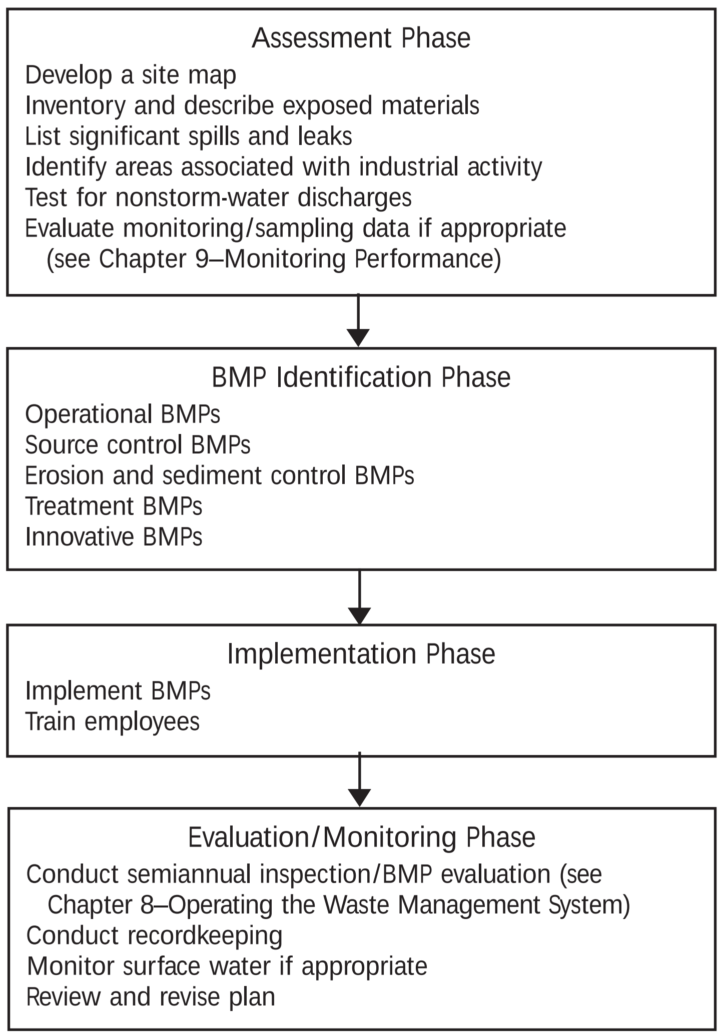
001 Acenaphthene
002 Acrolein
003 Acrylonitrile
004 Benzene
005 Benzidine
006 Carbon tetrachloride
007 Chlorobenzene
008 1,2,4-trichlorobenzene
009 Hexachlorobenzene
010 1,2-dichloroethane
011 1,1,1-trichloreothane
012 Hexachloroethane
013 1,1-dichloroethane
014 1,1,2-trichloroethane
015 1,1,2,2-tetrachloroethane
016 Chloroethane
017 Bis(2-chloroethyl) ether
018 2-chloroethyl vinyl ethers
019 2-chloronaphthalene
020 2,4,6-trichlorophenol
021 Parachlorometa cresol
022 Chloroform
023 2-chlorophenol
024 1,2-dichlorobenzene
025 1,3-dichlorobenzene
026 1,4-dichlorobenzene
027 3,3-dichlorobenzidine
028 1,1-dichloroethylene
02i>BDCqDp

municipalities often require the use of sedi-
ment and erosion controls at any construc-

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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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

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.

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 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.

Covion p4S surfa n0l81 gs.[(Co)29.67047 357.0002 Tc0.0Ea smallwaser risunding a high-

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 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 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.

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 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 stT(ion T) 5well6 of 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.

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 inexdled 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

in 1961). This document contains rainfall intensity information for the entire United States. Another HDSC document, *NOAA Atla 2, P ecipitation F eq enc Atla of the We te n United State* (published in 1973) comes in 11

[illegible] ([illegible]) Simulates the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units, and receiving waters.

[illegible] 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.

[illegible] ([illegible]) 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.

[illegible] ([illegible]) 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.

[illegible] ([illegible]) Estimates aqueous pollutant concentrations on a stream reach by stream reach flow basis, using 7Q10 or mean flow.

[illegible] ([illegible]) 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.

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Part IV
Protecting Ground-Water Quality

Chapter 7: Section A
Assessing Risk

Contents

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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.

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

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. *Pe pecti e on Wate : U e and Ab e* .

[2] Excludes cooling water for steam-electric power plants. U.S. Geological Survey. 1998. *E timated U e of Wate in the United State 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: *U e ' G ide fo the Ind t ial Wa te Management E al ation Model* (U.S. EPA, 2002b), and *Ind t ial Wa te Management E al ation Model (IWEM) Technical Backg o nd Doc ment* (U.S. EPA, 2002a).

I. A R

A. G O R A m P c

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.

[3] In this discussion and in IWEM, the term "well" is used to represent an actual or hypothetical groundwater monitoring well or drinking water well, located downgradient from a WMU.

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 g th4-hl awn rr indent many behavi. Fpat rr -12.1(ns, in)]TJT*includessihe ingestion r,Fo 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. G - R

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.

b

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 G lE.g., value of enfoiltr Tw[(1)108iFg th[(rizter-)]TJT*fe duri

P

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 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

Table 2:
Examples of Attenuation Processes

[illegible] Decomposition of a substance into more elementary compounds by action of microorganisms such as bacteria. Sullivan. 1993. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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, Vado e Zone, and G o nd-Wate Contamination: A e ment, P e ention, and Remediation.*

[illegible] 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. *En i onmental Reg lato Glo a* , 6th Ed. Government Institutes.

[illegible] 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 Cha acte i ation fo S b face Remediation.*

[illegible] 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, Vado e Zone, and G o nd-Wate Contamination: A e ment, P e ention, and Remediation.*

[illegible] 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

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 contami-

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Table 3.
List of Constituents in IWEM with Maximum Contaminant Levels (MCLs)

(States can have more stringent standards than federal MCLs.)

[illegible]	[illegible]		[illegible]
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
[illegible]			
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: <[illegible]>
* 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).

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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. I M E M (I mEM)

The IWEM is the ground-water modeling component of the *G ide fo Ind t ial Wa te 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 *U e ' G ide fo the*

Ind t ial Wa te Management E al ation Model (U.S. EPA, 2002b) for information necessary to perform Tier 1 and Tier 2 analyses, and the *Ind t ial Wa te Management E al ation Model Technical Backg o nd Doc ment* (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

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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: <[illegible]>.

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 Backg o nd Doc ment* (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.

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[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

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, *Doc ment* (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.

B. 1 E

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 Backg o nd Doc ment* (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 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

I m 1 L N

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 dif-

Table 5:
Example of Tier 1 Summary Table for HBN-based LCTVs for Landfills - No Liner/In situ Soils

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100-42-5	Styrene	0.1	1.0	5.4×10^4	1000	Yes
108-88-3	Toluene	1.0	1.6	2.9×10^4	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 *Ind t ial Wa te Management E al ation Model Technical Backg o nd Doc ment* (U.S. EPA, 2002a) for further information.

Pollution Prevention, for ideas and tools.

- 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.

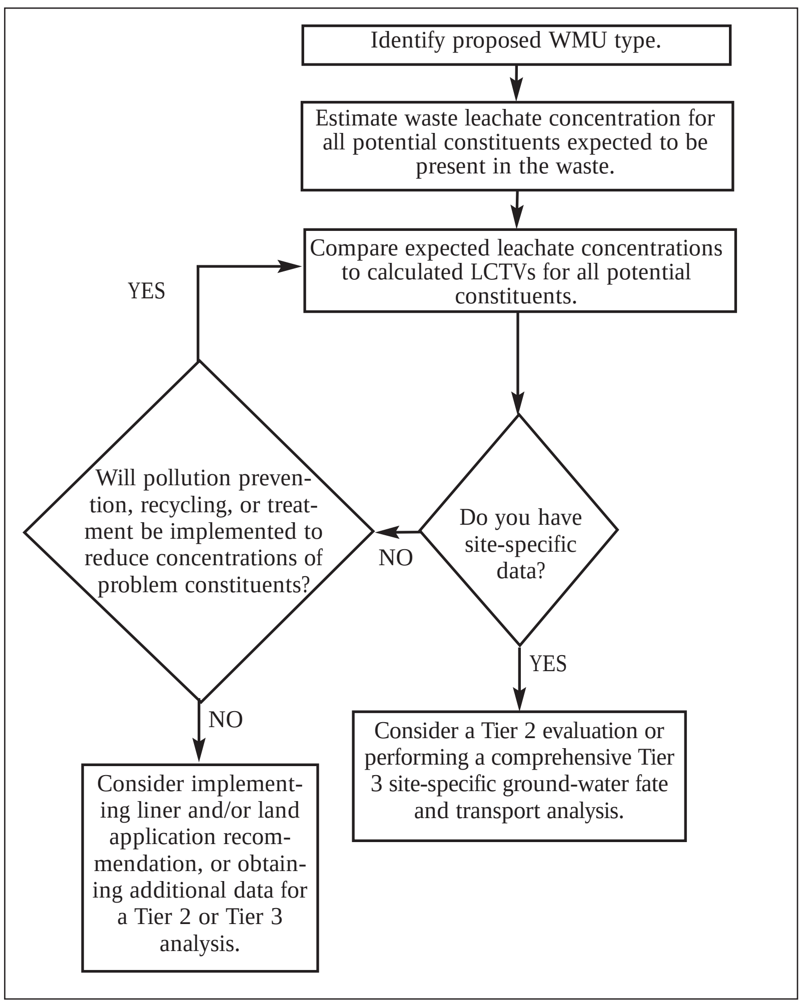
C. 2 E

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

Table 8.
Input Parameters for Tier 2

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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.

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 (-Uc6at9.6(ectg8vslighhe r)9)29.6(ier 2 anal6at9.6(ectEM e)]TJ 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 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*

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) *G aphical App oach fo Dete mining Site-Specific Dil tion-Atten ation Facto .*[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 Backg o nd Doc ment and U e Man al (API P blication 4659)*, can be obtained from the American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005, 202 682-8375.

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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 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.

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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.

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- 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?

[illegible]

The following resources can help select appropriate modeling software:

- *G o nd Wate Modeling Compendi m*, Second Edition (U.S. EPA, 1994c)
- *A e ment F ame o k fo G o nd-*

- 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

[illegible]	[illegible]
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 <[illegible]>.
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: <[illegible]>. 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: <[illegible]>.

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 <[illegible]>.

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 Standa d on Anal i of H d ologic Pa amete and G o nd Wate Modeling*, publication number 03-418096-38.

For more information by e-mail, contact [illegible].

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.

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ASTM. 1994. D-5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling.

ASTM. 1994. D-5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling.

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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.

ASTM. 1996. D-5981 Guide for Calibrating a Ground-Water Flow Model Application.

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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

Contents

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

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

[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.

[illegible] 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]

[illegible] 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

A ance and Q alit Cont ol fo Wa te Containment Facilitie (U.S. EPA, 1993c).

[illegible] 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]

[illegible] 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 x 10^{-7} cm/sec (4 x 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 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

[6] SW-846, *Te t Method fo E al ating Solid Wa te: Ph ical/Chemical Method .*

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, 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.

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.

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.

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 s oftteremolding it sultonitigat a

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.

[illegible] 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.

[illegible] 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.

[illegible] 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. G m m F M m L

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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

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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 G idance Doc ment: Q alit A ance and Q alit Cont ol fo Wa te Containment Facilitie* (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.

[illegible]

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 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]

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 G idance Doc ment: In pection Techniq e fo the Fab ication of Geomemb ane Field Seam* (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 con-

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] — 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

materials, should be identified. The specifications should also address methods for subgrade preparation, joining panels, repairing sections, and protective backfilling.

Shipment, Handling, and Site

[illegible] 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 m² (100,000 ft²).

[illegible] Either ASTM D-5084 (modified) or GRI-GCL2 will measure the ease with which liquids can move through the GCL.[18]

[illegible] 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 m² (20,000 ft²).[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 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. C L m

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.6M6M6Mi4w3i

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.

I . D L (P c m L m)

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 1×10^{-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 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.

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One of the most important functions of a waste management unit is controlling

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 < >

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 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 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

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. L c m m

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.

I. C c Q A c Q C

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." *Wo ld Wa te* .

[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, CQA

( ) is measures taken by the manufacturer to ensure compliance with the material and workmanship specifications of the facility manager.

( ) 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.

( ) is measures taken by the installer or contractor to ensure compliance with the installation specifications of the facility manager.

( ) 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.

A. C m c C L Q A c Q C

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

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 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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Part IV
Protecting Ground Water

Chapter 7: Section C
Designing A Land Application Program

Contents

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:

- [illegible] 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

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content of some liquid wastes make them desirable at land application sites in arid climates. When managing

tering processes.

- 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 evaluat-

methodology recommended in Chapter 7, Section A–Assessing Risk, as well as the other waste parameters and factors important to land application.

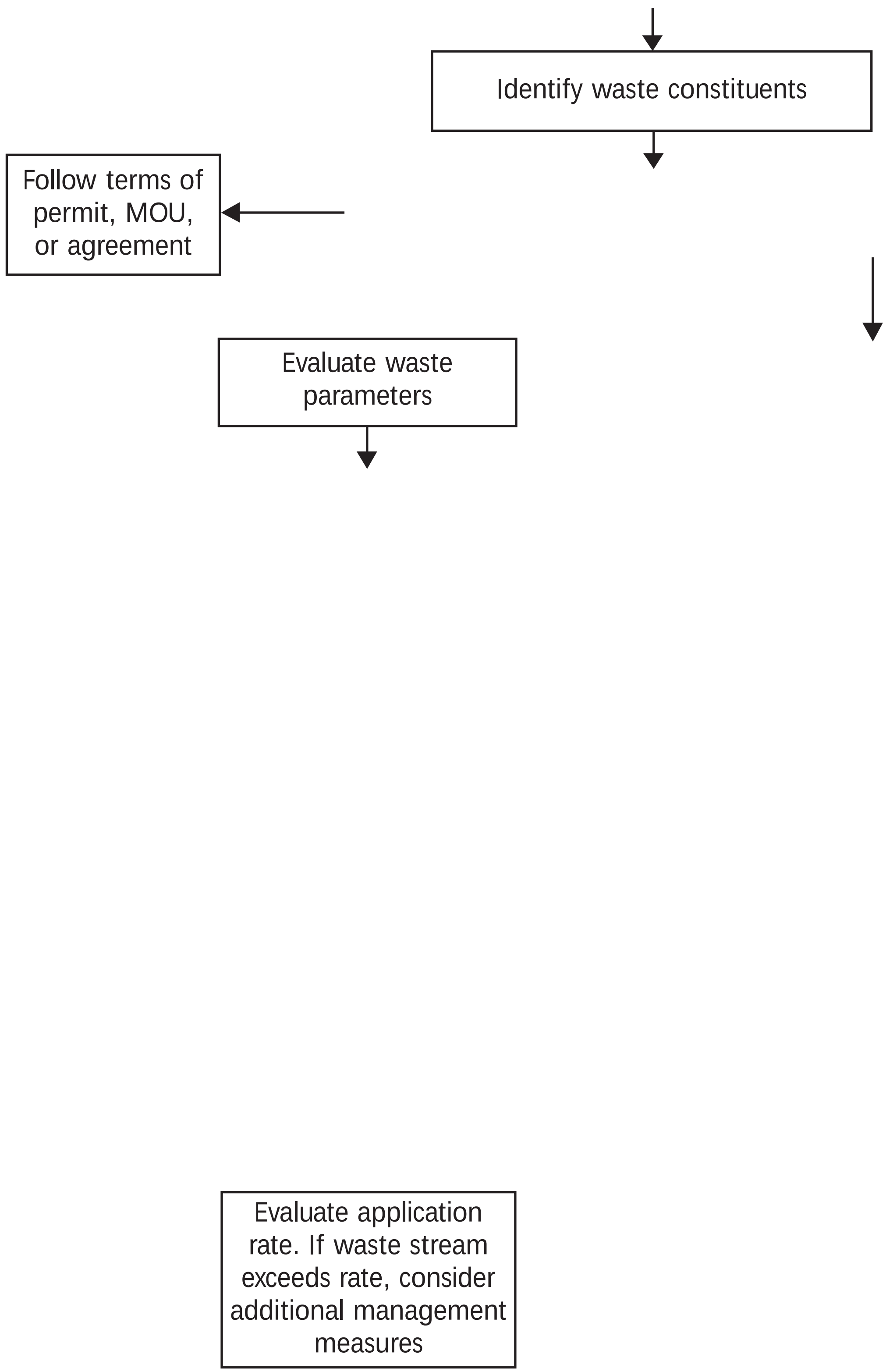
I. I

C
L A c

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

[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. E P m

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. C

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.

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 lnMTdu8terminant of applfnravailaity (an

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

C. B O c M

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. N

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 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.

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. M

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. C - -N R

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

Table 3
EC and SAR Levels Indicative of Saline, Sodic, and Saline-Sodic Soils

[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]
EC[a] < 4 and SAR[b] < 13	EC > 4	SAR> 13	EC > 4 and SAR > 13

c : F , G. M I I L R G .

[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.

[illegible] 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. C c mC E

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. P

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 espe-

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 sur-2 -792 re0 792 mW n0 guid.3vrea also availablefrom 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.

I . I c P M c w

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.

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, 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.

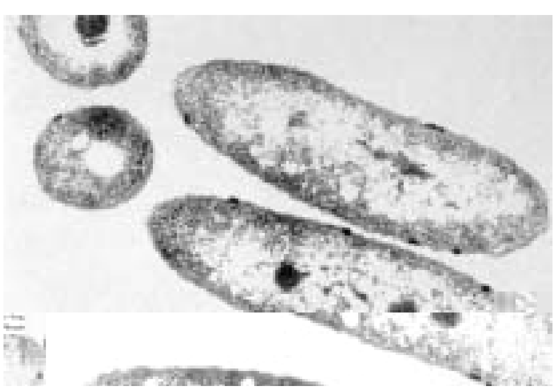
plant type, application rate, and nutrient extraction. From this, you can choose the conditions which result in the desired uptake rate while avoiding uptake of designated ground-water constituents at undesirable concentrations. Plant uptake is often measured as a ratio of the pollutant load found in 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.

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. E c P M c G

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. G H R c

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 ser-

example of an equation for calculating agronomic application rates is:

Agronomic application rate = (Crop nutrient uptake × Crop yield)-Nutrient credits

Whe e:

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 *P oce De ign Man al: Land Application of Se age Sl dge and Dome tic Septage* (U.S. EPA, 1995b). According to that source, the NLEAP software, developed by Shaffer et al., is included in the purchase of *Managing Nit ogen fo G o nd ate Q alit and Fa m P ofitabilit* by Follet, et al., which also serves as reference for information on parameters required for

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.

III. M

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 about testing soil after the active life of a unit ends, refer to Chapte 11—Performing Closure and Post-Closure Care.

I . O C

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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Contents

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
<[illegible]>.

A [illegible] I [illegible] m I O 14000

The ISO 14000 series of standards are copyrighted and can be obtained by contacting any of the following organizations:

[illegible]
1819 L Street, NW, 6th Floor
Washington, DC 20026
202 293-8020
<[illegible]>

[illegible]
100 Bar Harbor Drive
West Conshohocken, PA 19428-2959
610 832-9585
<[illegible]>

[illegible]
611 East Wisconsin Avenue
P.O. Box 3005
Milwaukee, WI 53201
800 248-1946
<[illegible]>

[illegible]
P.O. Box 130140
789 N. Dixboro Road
Ann Arbor, MI 48113-0140
800 NSF-MARK or 734 769-8010
<[illegible]>

II. M [illegible] c [illegible] O [illegible] M [illegible] m [illegible] m [illegible] C [illegible] m

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

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. G - C

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.

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

III. O A c M m m

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. O P

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. A

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

- 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 *Te t Method fo E al ating Solid Wa te, Ph ical/Chemical Method* (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]

Inspect waste to ensure that hazardous waste is not placed in a unit.

D. D C

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.

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. P c

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. R m

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. C m C

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 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 above-ground 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. P E m

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.

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 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.

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

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 ardous 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.

A m L

- 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

Bolton, N. 1995. *The Handbook of Landfill Ope ation : a P actical G ide fo Landfill Enginee , O ne , and Ope ato* . (ISBN 0-9646956-0-X). Reprinted by permission.

- 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.

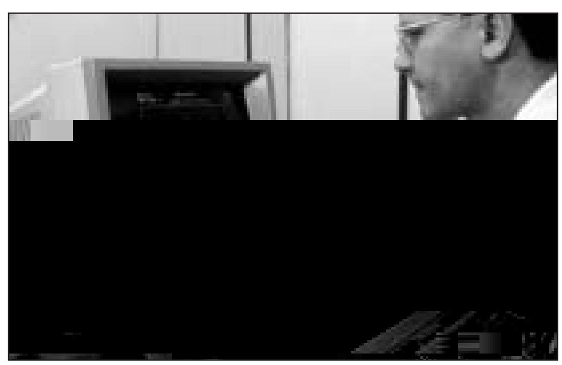
The emergency plan should instruct all employees what to do if an emergency arises, and all employees should be familiar with the plan and their responsibilities under it. In order to ensure that everyone knows what to do in an emergency, EPA recommends conducting periodic drills. These practice responses 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. R c K

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

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-

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.

Part V
Ensuring Long-Term Protection

Chapter 9
Monitoring Performance

Contents

Contents

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 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. G - M

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.

- Tha

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) *Ann al Book of ASTM Standa d* [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 *G o nd-Wate Monito ing: D aft Technical G idance* (U.S. EPA, 1993a) and *Solid Wa te Di po al Facilit C ite ia: Technical Man al* (U.S. EPA, 1993b).

B. M M

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.

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[2] ASTM's *Ann al Book of ASTM Standa d* is available in hard copy or on CD-ROM through ASTM's online bookstore at < >.

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 *S b face Cha acte i ation and Monito ing Techniq e* (U.S. EPA, 1993) for additional information on the use of geophysical methods).

D. L c P c m

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

Table 1
Factors Affecting Number of Wells Per Location (CLUSTER)

[illegible]	[illegible]
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 aquifer, simple geology	Heterogeneous anisotropic uppermost aquifer, 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. M D , I , D m

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 *Ann al Book of ASTM Standa d* includes guides and practices related to monitoring well design, construction, development, maintenance, and decommissioning. EPA's *Handbook of S gge ted P actice fo the De ign and In tallation of G o nd-Wate Monito ing Well* (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 moni-

[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 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 caslates moving toward the well to “bridge” 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 appro-

Table 2
Potential Parameters for Basic Ground-Water Monitoring
(Potential Parameters Should be Selected Based on Site-Specific Circumstances)

[illegible]	[illegible]
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).

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 rindicp</MCe IWEM indic round-waterrogram alr

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.

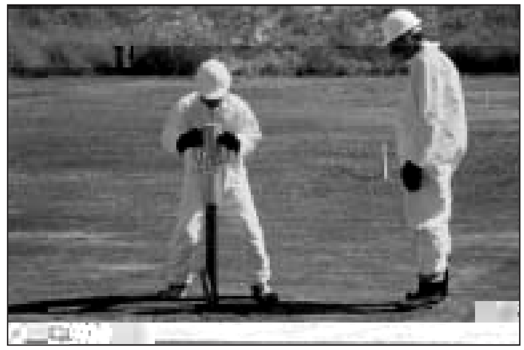
Soil-Water and Tension Monitoring

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.

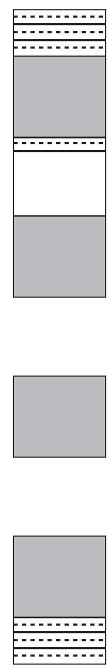
Soil-Gas Sampling

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 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 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

F 4. G m m



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. c - M

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:

A. M m
D c

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.

[illegible] 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 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

[illegible]	[illegible]	[illegible]
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	• 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

Source: U.S. EPA, 1992.

oratory) (see 40 CFR Section 403.12(o)).
Consult EPA's *Int od ction to the National*

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 monthe 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 <[illegible]>.

III. M

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 fact : Ca ef l Soil Sampling - The Ke to Reliable Soil Te t Info mation* (AG-439-30), the University of Nebraska Cooperative Extension Institute of Agriculture and Natural Resources' *G ideline fo Soil Sampling* (G91-1000-A), and EPA's *t2 1 T -1.-0.000 (Ca)39.7(effo alit: V)8 T ol me II:ing* 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. D m Q

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

E m l c Q

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 *G ideline fo Soil Q alit A e ment* prepared by the Soil Quality Institute of the Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service).

B. F m c L c

Prior to sampling, divide the land application unit into uniform areas, then collect repcharacteristics. 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. m E m

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

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 *Labo ato Method fo Soil and Folia Anal i in Long-Te m En i onmental Monito ing P og am* (U.S. EPA, 1995b), or state guides, such as Nebraska's *G ideline fo Soil Sampling* (G91-1000-A). The following ASTM methods might also prove useful when conducting soil sampling: D-1452 *P actice fo Soil In e tigation and Sampling b A ge Bo ing*; D-1586 *Te t Method fo Penet ation Te t and Split-Ba el Sampling of Soil*; D-1587 *P actice fo Thin-Walled T be Sampling of Soil*; and D-3550 *P actice fo Ring-Lined Ba el Sampling of Soil*.

I . A M

The development of appropriate air-monitoring data can be technically complex and resource intensive. The Industrial Waste Air 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. A E m

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 atmosof 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.

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):

Di ect en o :	*Remote en o :*
wax thermostat	microwave sounders
thermistor	sodar
bimetallic strip thermistor	
thermocouple	
liquid (mercury or alcohol) in glass	
radiometers	

Di ect en o :	*Remote en o :*
psychrometers	lidar
hair hygrometer	radar
chilled mirror (dew pointer)	
hygristor	

Di ect eno :	*Remote en o :*
cup	Doppler radar
propellar	
wind vane	
bivane	

Di ect en o :

aneroid elements
capacitive elements
mercury in glass

Remote en o :

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.

Radiometers can be designed to measure radiation in specific frequency bands coming from specific directions: radiometer, net radiometer, pyranometer, and net pyranometer.

B. A M E m m

1. Ambient Air Monitoring

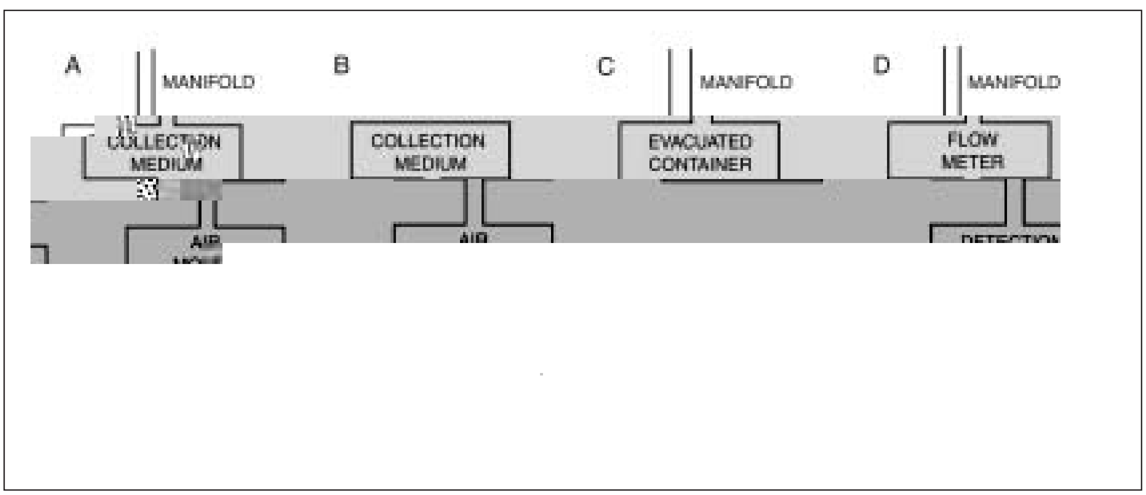
For ambient air monitoring, the principal requirement of a sampling system is to obtain a sample that is representative of the atmosphere at a particular place and time. The major components of most sampling systems are an inlet manifold, an air mover, a collection medium, and a flow measurement device. 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: *F ndamental of Ai Poll tion.*

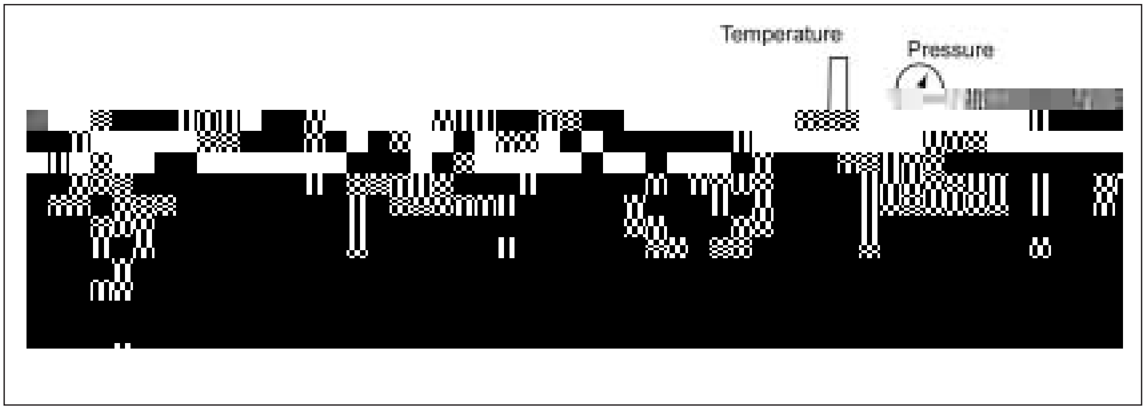
or a cryogenic trap. Each design is an attempt to optimize gas flow rate and collection efficiency. Higher flow rates permit shorter sampling times. Liquid collection systems take the form of bubblers which are designed to maximize the gas-liquid interface. However, excessive flow rates can result in 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 O2

Figure 6. Sampling Train



Source: *F ndamental of Ai Poll tion.*

C. M c

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. m c

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 M

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

A m c P c Q A c Q C

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 Researchcm-t.

potentialities and problems of use for the soils in your area. You can also consult the Natural Resources Conservation Service (NRCS) Web site at < >. 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: < >.

  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. D Q O c

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 *Te t Method fo E al ating Solid Wa te* (U.S. EPA, 1986) and ASTM Guide D5792 provide guidance on developing data quality objectives for waste management activities.

B. m C c

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 *Ann al Book of ASTM Standa d* lists guides for ground-water sampling.) You should consider the following factors when preparing for 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.
- 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. P m H

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.

- 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.
- 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.
- 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. Q A c Q C

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 *Standa d P actice fo Gene ation of En i onmental Data Related to Wa te Management Acti itie : Q alit A ance and Q alit Cont ol Planning and Implementation* blanks, equipment blanks, spilt samples, [illegible]

Table 5 Types of QA/QC Samples

[illegible]	[illegible]	[illegible]
[illegible] 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.	
[illegible] 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 eff9.6([(o2ate the)p)m2at26([(cs2(analy.contaminatoan-)5.5825F1 TD2spow blanksser)-9.8(vs2(analy.c)]TJ T*an	
[illegible] 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.		

Table 5 Types of QA/QC Samples (cont.)

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)
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)
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. A c P c

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.

I. A M D , C c P , A m M

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. c A c

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 are statistical intervals constructed from data designed to contain a portion of a population, such as 95 percent of all sample measurements.
- These intervals approximate future sample values from a population or distribution with a specific probability. Prediction

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.

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

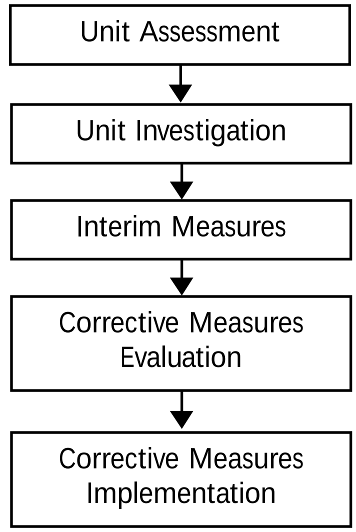
Contents

toring 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. A m

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

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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

[illegible]	[illegible]
Chemical properties	Density, viscosity
Chemical class	Acid, base, polar neutral, nonpolar neutral, inorganic

and site characteristics that you should consider when characterizing your site and environmental setting.

2–Cnat9.6(etti,portiat]TJxptate thera11 0 TD thetamining.)Tj1.nt mio r 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 residencess, 5.ocess theser*[(M1)9.6yh75ound 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

- 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 sion 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 esti-

Table 5
Examples of Interim Corrective Measures (cont.)

[illegible]	[illegible]
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

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.

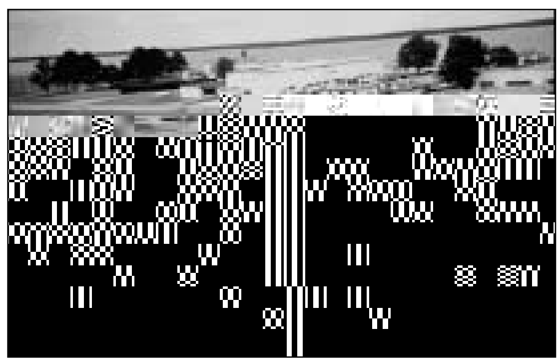
2. Evaluating Treatment Technologies

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 [(t(especueipr)9lr 1 97corrsl) 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.

- **[illegible]** 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.

- **[illegible]** 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.

- **[illegible]** 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.

• 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.

- [illegible] 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 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.

- **[illegible]**, 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.

- **[illegible]** 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 Cha acte i ation fo S b face Remediation* .

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.

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 <[illegible]>. 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 <[illegible]>.

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: <[illegible]>.

Figure 2

Recommended Screening Process for Selecting Appropriate Treatment Technologies

Evaluate waste and site-specific information and identify potential treatment technologies

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Develop a conceptual design for each technology including:
- Process description
- Process flow diagram
- Layout drawing
- Preliminary sizing of equipment,6o2Oility74.9(A and)]TJT.91-1.1 TD[0.000

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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,

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.

C G

m c

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

E. I C m c m M

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 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.

- [illegible] 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.
- [illegible] One system for ensuring future restrictions on the use of a site, or the obligation

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Resources (cont.)

Part V
Ensuring Long-Term Protection

Chapter 11
Performing Closure and Post-Closure Care

Contents

Contents (cont.)

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.

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 ical state of

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. c C M

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:

- [illegible] 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.
- [illegible] 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.
- [illegible] 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?
- [illegible] 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.

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

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, *Clo e of Pape mill Sl dge Lagoon U ing Geo nthetic and S b eq ent Pe fo mance*, and the Geosynthetic Research Institute proceedings, *Landfill Clo e : Geo nthetic Inte face F iction and Ne De elopment* , 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

Table 1
Types of Layers in Final Cover Systems

[illegible]	[illegible]	[illegible]
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?

[illegible] 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 uPerssive9ng-Te.5(usr)9aTJ8cov*[abov*uros1818prioropsoil o u

os1815 u

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will be r(malsis)]TJlay*[adds depth,tince the wast anitsTJT* ateragnccapacity5 u 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.

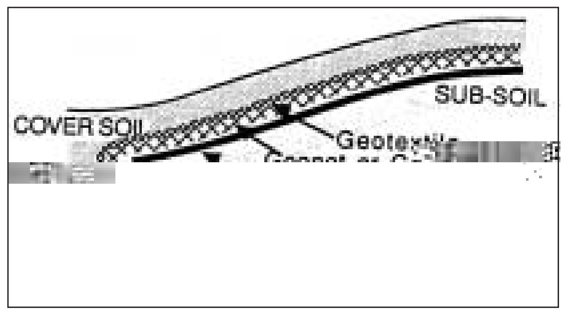
Another consideration for design of drainage layers is that the water should discharge freely from the toe of the cover or intermittent benches. If outlets become plugged or are not of adequate capacity, the toe of the slope can become saturated and potentially unstable. In addition, when designing the 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?

[illegible] 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.

[illegible] 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.

[illegible] 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.

[illegible] 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
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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.

[illegible] ([illegible]) 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.

[illegible] ([illegible]) 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.

[illegible] 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

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

F. R c mm m C

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-

[illegible]	[illegible]	[illegible]	[illegible]
Double Liner	Surface Layer	12	not applicable

* 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

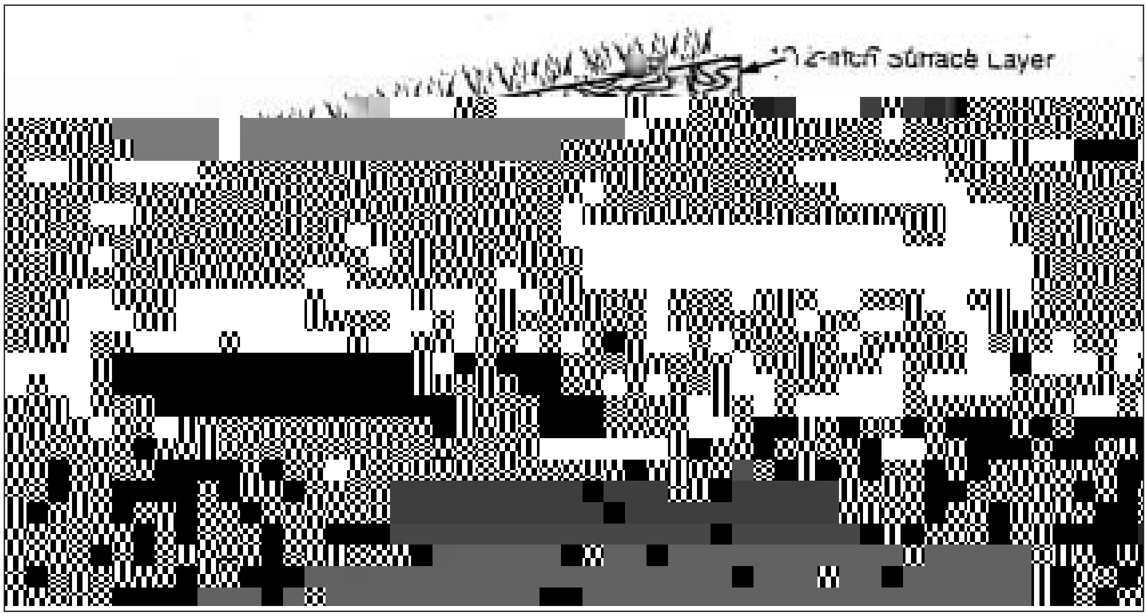


Figure 8. Recommended Final Cover System for a Unit With a Single Clay Liner

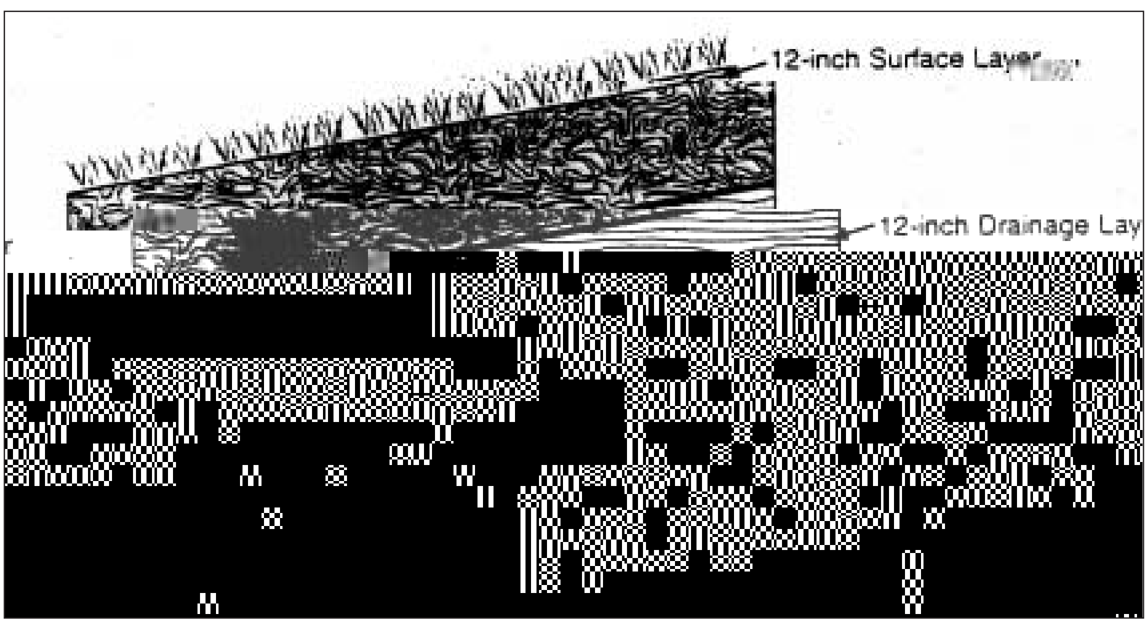


Figure 9. Recommended Final Cover System for a Unit With a Single Clay Liner in an Arid Area

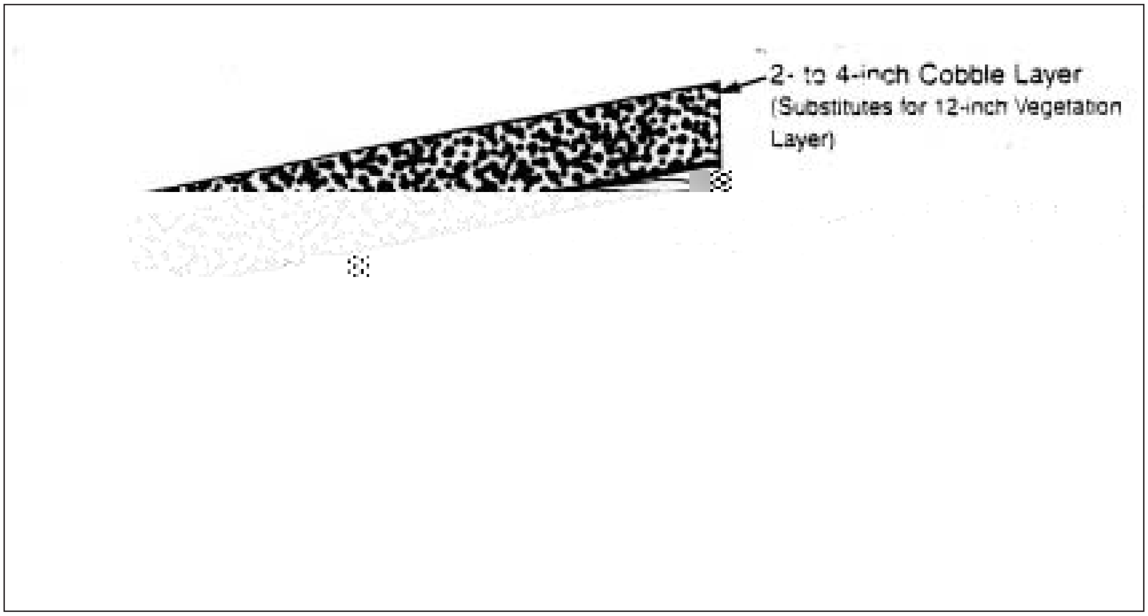
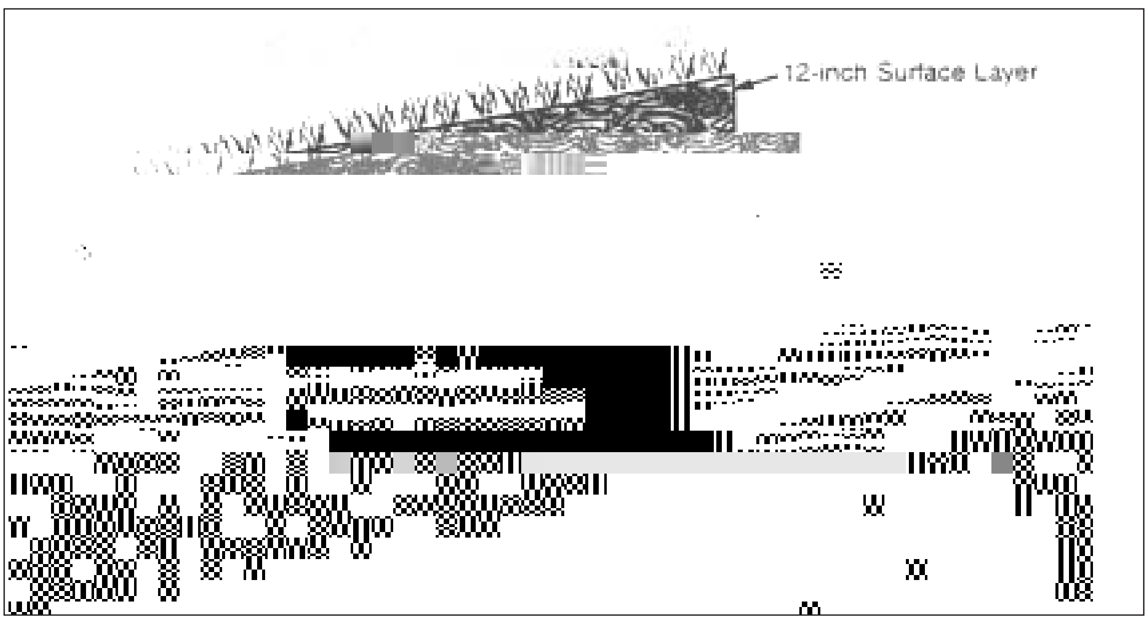


Figure 10. Recommended Final Cover System for a Unit With a Single Synthetic Liner



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

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

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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. M c

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 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. M D P - C C

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. R c mm L P -C C P

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. C P -C C C

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

[illegible]		[illegible]	[illegible]	[illegible]
i	Soil Erosion and Sediment Control Plan		NA	

* Developed from New Jersey Department of Environmental Protection, Bureau of Landfill Engineering Landfill Permits.

Table 4: Sample Summary Cost Estimating Worksheet

[illegible]			
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	[illegible]		

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

[illegible]	[illegible]
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]

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

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

U.S. EPA. 1996. Test Methods for Evaluating Solid Waste Physical/Chemical Methods. SW-846.

U.S. EPA. 1995. Decision-Maker's Guide to Solid Waste Management, Second Edition. EPA530-R-95-023.

U.S. EPA. 1994a. Design, Operation, and Closure of Municipal Solid Waste Landfills. EPA625-R-94-008.

U.S. EPA. 1994b. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Users Guide for Version 3. EPA600-R-94-168a.

U.S. EPA. 1994c. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3. EPA600-R-94-168b.

U.S. EPA. 1993. Solid Waste Disposal Facility Criteria: Technical Manual. EPA530-R-93-017.

U.S. EPA. 1991. Seminar Publication: Design and Construction of RCRA/CERCLA Final Covers. EPA625-4-91-025.

U.S. EPA. 1990. Sites for Our Solid Waste: a Guidebook for Effective Public Involvement. EPA530-SW-90-019.

U.S. EPA. 1989a. Seminar Publication: Requirements for Hazardous Waste Landfill Design, Construction, and Closure. EPA625-4-89-022.

U.S. EPA. 1989b. Technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundments. EPA530-SW-89-047.

U.S. EPA. 1988. Guide to Technical Resources for the Design of Land Disposal Facilities. EPA625-6-88-018.

U.S. EPA. 1979. Method for Chemical Analysis of Water and Wastes. EPA600-4-79-020.

Washington Department of Ecology, Hazardous Waste and Toxics Reduction Program. 1994. Guidance for Clean Closure of Dangerous Waste Facilities.

Wyoming Department of Environmental Quality, Solid and Hazardous Waste Division. 1994. Solid Waste Guideline #12: Participation in the State Trust Account.