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HAZARDOUS LANDFILL MANAGEMENT, CONTROL OPTIONS*

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Summary

The land disposal of hazardous wastes has been a common practice over the last half century. The industrial and environmental communities, as well as the public, have an immediate challenge to control the contaminants that may be released from waste land disposal facilities. At the same time, land disposal continues to be, in many cases, the only available disposal technique that can be utilized in the next five years. Thus, it is extremely important that environmentally sound landfill management and control techniques be utilized, both for inactive and active sites.

There are a number of key steps in developing a sound management and control plan. These include problem definition, personnel safety, characterization, evaluation of control options, cost-effectiveness analysis and development of an integrated control plan. A number of control options, including diversion, regrading, sealing, and leachate treatment are available and more cost effective in most cases than waste removal. These and other options, as well as the methodology to develop an integrated control plan, are discussed, together with examples.

Introduction

An immediate challenge facing the environmental community is the control of contaminants released from hazardous waste land disposal facilities. The Love Canal Episode, the "Valley of Drums", and the PCB release in the Hudson River Valley, as well as other similar cases, serve as examples of the extent of the challenge and the difficulty of reversing the environmental damage.

These situations are caused at not only abandoned or inactive landfills, but also at active landfills. In many instances, active landfills that have been in operation for many years have, unfortunately, not maintained adequate control over the type of wastes accepted. When hazardous contamination is observed from these landfills, the specific cause of the contamination may not be known. Hazardous wastes may be deposited in a landfill in drums, solid form, liquid or slurry from a tanker truck, sludge form, or as dusts.

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Potential environmental and/or health and safety impacts that may be caused by the release of hazardous pollutants include:

- Human consumption of contaminated surface or subsurface water.
- Inhalation of contaminated air in the vicinity of a landfill site.
- Degradation of ground water quality through migration of hazardous substances from a landfill site. Infiltration and contaminant migration can be intensified by improper grading, cracking of final grades, or insufficient soil and vegetation coverage.
- Degradation of surface water quality through washing and surface transport of contaminants from a landfill site. Exposed waste and lack of run-off control devices can result in the washing of hazardous substances from disposal areas into surface waters.
- Degradation of air quality through the release of toxic and noxious gases from a landfill site. Improper covering, venting, and control of such emissions can result in release of toxic, flammable, or irritating gases and fumes from a facility into the ambient atmosphere.
- Fires or explosions at active sites, or during uncontrolled construction activities at closed sites.
- Endangering the health and safety of people who are redeveloping an abandoned site for other uses, or attempting to recover (or scavenge) waste materials from a site.

Basic control approach

The development and implementation of a control program for hazardous waste landfills is based on several key steps, as shown in Fig. 1. The initial step — problem definition — must fully identify the effect of existing or potential contamination. Characterization of the mechanisms which "drive" contaminants from the landfill site is an essential step to designing a control action plan and projecting its effectiveness, as summarized in Fig. 1. Based on the results of site investigations and an analysis of the data, a control program can be developed to consider control measures at the source and contaminant retrieval.

- **Problem Definition and Site Investigations**
- **Personnel Safety**
- **Characterize Driving Function - Migration Pathways and Potential Impacts**
- **Evaluate Control Options At the Source**
- **Evaluate Contaminant Retrieval Options**
- **Analyze Cost Effectiveness of Alternate Control Scenarios**
- **Develop An Integrated Control Program**

Fig. 1. Hazardous waste landfill control approach.

Problem definition — the key

The initial step in developing a control plan for a polluting hazardous waste landfill is to define the impact and extent of the contamination problem. In addition, the characteristics of the disposal site and landfilled waste material must be investigated. The following steps should be considered and investigated as appropriate to the site situation.

Review past records

Disposal records relating to past activities at most sites are limited or nonexistent. However, an attempt should be made to obtain whatever information is available. Information which is of most value deals with the type of waste which has been buried, location of the waste which could cause a contamination problem, and site conditions prior to, and during, landfilling. Typical questions may include:

- Was waste placed in the water table?
- Was waste dumped in liquid form?
- Were drums crushed or broken?
- During what years and in what locations were certain wastes dumped?
- What quantities of waste were dumped?
- What key contaminants may be leached from these wastes?

In pursuing this information, the following sources should be considered: interviews with past and present operating personnel, waste haulers, and eye witnesses; regulatory agency and local health department records; and plant production and shipping records.

Test pits

Generally test pits are a low cost effective method for determining the area where waste has been buried and investigating natural soil conditions at the site. They may be constructed using a backhoe or auger drill, when safety considerations permit, and depending on site topography and equipment availability. The authors have successfully used a gasoline powered auger drill to construct test pits in wooded areas which are not accessible to a backhoe.

The number of pits which should be constructed is site specific and will vary widely. Several test pits should be placed so that natural background conditions can be determined. Soil samples can be collected from these pits and tested for parameters which characterize natural migration-related mechanisms of the site, such as:

- Permeability.
- Cation exchange capacity.
- pH.
- Soil type (sieve analysis).

Precaution should be employed when constructing test pits in areas of potentially heavy contamination and where waste may be buried in drums. Sudden release of contaminants and vapors may occur during digging, and strict safety measures must be followed.

Sensor detection

Technology is developing rapidly in the field of sensor detection of buried waste material and leachate contamination. Magnetometers and Surface Interference Radar (SIR) may be used for subsurface metallic detection to locate concentrations of buried drums. A grid system should be set up over the site and the detector passed along the grid network. Relative signal strength readings can be used to plot buried drum densities. However, this technique for defining the extent of landfilled material is applicable only for waste buried in metallic drums.

Other sensor techniques have been used (with varying degrees of success) for the subsurface detection of leachate contamination, such as:

- Infrared aerial photography.
- Thermal scanning.
- Resistivity survey.

These techniques must be applied selectively to meet specific site conditions.

Subsurface borings and monitor wells

Well drilling equipment can generally be used to construct subsurface borings and install ground water monitoring points. The use of this subsurface information for the development of a control strategy can be summarized as shown in Table 1.

TABLE 1

Raw data	Interpretation of data
Soil samples	— Degree of attenuation and attenuation capability. — Rate of contaminant migration. — Location of confining layers.
Geologic formations (cuttings or core boring)	— Contaminant migration pathways. — Hydraulic connection between water bearing zones. — Rate of contaminant migration.
Static ground water elevations	— Direction of possible contaminant migration. — Ground water contours. — Head differential between water bearing zones. — Possible input to mathematical plume models.
Ground water samples	— Background water quality. — Degree and extent of contamination in ground water. — Possible input to mathematical plume models.

Prior to initiating the subsurface investigation, locations for the borings must be identified and well construction details defined. Well construction and water sample analysis are costly; as a result, each well must be used effectively. Mathematical plume models often are useful in placing wells to minimize the number of bore holes. A 50% reduction in the number of wells can be achieved when using models on a 100 acre site.

A review of published literature can be used to obtain preliminary site data. Field inspections of the landfill will provide initial data on the most probable pathways for contaminant travel in the ground water and possible locations for collecting soil samples and constructing borings. Borings can then be constructed to confirm this data. When locating the borings and designing the well points, particular attention should be paid to the following considerations:

- Locate the wells a proper distance from the landfill to detect the expected leachate plume. The rate of ground water movement should be estimated based on soil characteristics and gradient.
- Locate background wells that will not be affected by contamination from the landfill.
- Construct the borings deep enough to intercept all water bearing zones that may be effected.
- Seal the well casing to prevent possible vertical leakage.
- Construct the well point to be compatible with the sampling device and other testing that may be performed (e.g., transmissivity).

Laboratory analysis of water samples should establish key water quality parameters along with specific contaminants that may be characteristic of the waste material. Ground water contaminant readings can then be used to establish the boundaries and characteristics of the leachate plume. Figure 2 depicts a typical T.O.C. contaminant contour map that may be prepared from a ground water quality investigation.

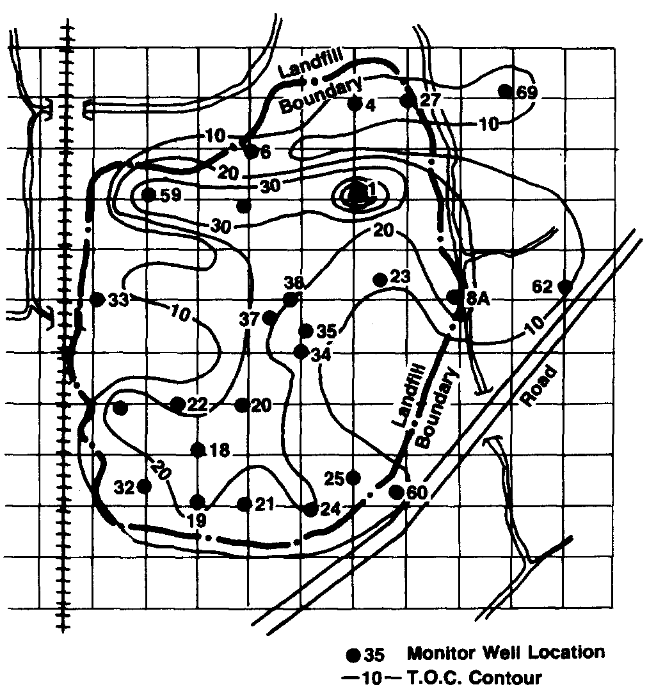

Fig. 2. Leachate contamination contours at a landfill site.

Surface water

Analysis of any surface water affected by the landfill should define the level and extent of any contaminant migration. Sampling stations should be set up to measure both upstream (background) and downstream conditions. These stations should be permanently identified to allow for repeat sampling. Flow measurements and water quality data may be used to compute contaminant loadings. This is often important when more than one source of potential contamination is present or more than one surface water stream is involved.

A biological survey conducted along a stream may also be useful. It can be used to determine the net effect of a landfill on the biological community in the stream. The level of stress observed in the biological community will generally be proportional to the level of contamination present in the stream. Contaminant uptake in plant material may also be analytically measured to gauge the presence of contaminants and their potential impact on vegetation. This is particularly important for food chain vegetation.

As the field investigation program and problem definition phase are being completed, data must be thoroughly analyzed so that effective control measures can be identified and evaluated.

Personnel safety

Prior to beginning any site work on a hazardous waste landfill, the safety of the personnel working at the site must be considered. This is of paramount importance.

In developing a personnel safety program for the investigating team, prior knowledge of the types of material deposited on the site is helpful. Unfortunately, this is not often available. When no data is available, caution is of the utmost importance.

In the preliminary investigation, the team should be equipped with:

- Personal safety equipment (e.g., protective splash suits, boots, face shields, hard hats, etc.).
- Gloves.
- Respirators.
- Escape oxygen packs.

In addition, the field investigation team should be equipped with a Hazardous Materials Protection Kit and either a portable Infrared (IR) or Gas Chromatograph (GC) Unit, as well as an explosion meter and a geiger counter.

On entering the field site, a rapid survey should be made of the atmospheric conditions to determine whether or not entry by additional people is safe. This should be done with the explosion meter, the hazardous detection kit and the more sophisticated instrumentation. If the atmosphere is found to be safe, entry of additional personnel for detailed investigation can take place.

Personnel should be trained in looking for potential hazards such as liquid pockets, leaking drums, closed or bulging drums, and piles of solid materials. Sampling of open containers and piles of solid material should be done with extreme care. Personnel should wear appropriate protective clothing. The degree of protection must be determined based on potential hazards anticipated or previously established. Particular care must be taken when sampling closed drums. In this case, full protective clothing and respiration equipment should be used, as drums may contain highly volatile and highly toxic materials.

Particular care must be taken prior to the use of mechanical equipment in any hazardous waste landfill area. The potential for a spark-generated explosion or fire should be evaluated when selecting equipment and preparing a subsurface investigation program. Excavation of buried drums or material may result in the sudden release of toxic contaminants, and precautionary safety measures should be followed. Depending on site specific conditions, an industrial hygienist or toxicologist and a safety engineer should review the safety plans prior to a team entering any hazardous waste landfill.

Data analysis — identification of driving function and potential impacts

Analysis of the field data should focus on developing information which will lead to development of effective control measures. The analysis should include the following:

Determine driving function

Determination of the driving function entails learning how contaminants are released or carried from the landfill. Figure 3 depicts the leachate generation and migration mechanisms. Characterizing these driving and transport

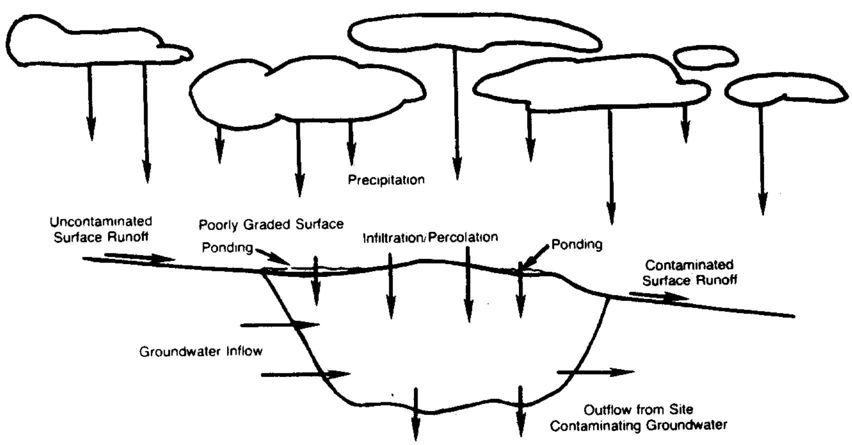

Fig. 3. Leachate generation/migration.

mechanisms is the basis for engineering appropriate control scenarios. In many cases, the release of contaminants will be caused by a combination of several mechanisms; however, the relative load contributed by each can usually be estimated. In this fashion, a control priority listing can be established based on cost-benefit analysis.

The following driving functions may be observed at a hazardous waste landfill:

(1) Excessive surface infiltration. The effect of excessive surface infiltration is to accelerate the release of soluble contaminants from the buried waste. Generally, these contaminants are dissolved and are carried with infiltration as it migrates into the ground water. Generally, this is the major mechanism to evaluate.

(2) Ground water. In the event that the ground water table is located within the landfill, waste is in a saturated condition and soluble contaminants will dissolve in the ground water. As ground water migrates through the fill, these contaminants will be transported from the site. The rate of ground water movement provides a good estimate of how far contaminants may have moved from the site. This is important only in coastal and high water table zones.

(3) Erosion. Erosion represents a mechanism for surface transport of contaminants. Many hazardous waste landfills are poorly maintained and, as a result, erosion problems are common. Erosion can serve to carry not only waste material but also contaminated soils from the landfill into nearby surface water In addition, erosion may serve to expose buried waste to possible human contact.

(4) Gravity. Gravity is a primary driving force for movement of liquid wastes released into the fill either when they are dumped from a truck or when a drum (or other container) is broken.

(5) Diffusion. Diffusion of contaminants will occur in the absence of any bulk movement of ground water and will cease only when concentration gradients become non-existent. The mass flow rate of a diffusing contaminant passing through a given cross-section will be proportional to the concentration gradient. In a soil medium, diffusion coefficients are greatly reduced and, as a result, this transport mechanism is generally negligible.

Identify migration pathways

The analysis should focus on characterizing the migration pathways for contaminants and, when possible, gauge the rate of migration. Typical migration pathways include the following:

(1) Surface water. Release of contamination into surface water represents a pathway for rapid migration of these contaminants from the site. Contaminants may be released directly into surface water, as shown in Fig. 4, or indirectly through ground water discharge into surface water or by erosion transport into surface water.

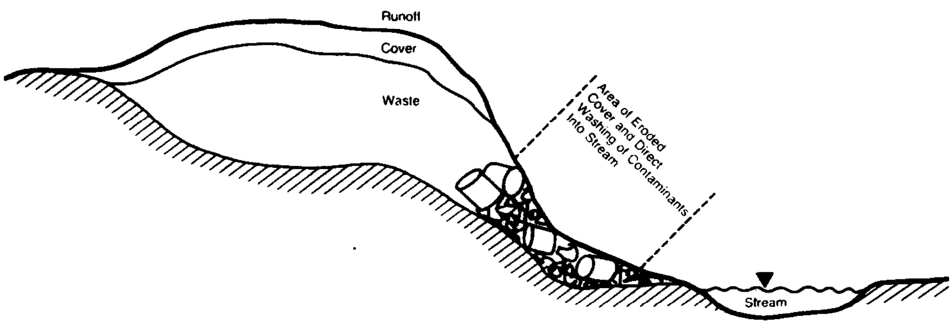

Fig. 4. Contamination of surface water quality.

(2) Ground water. Ground water may carry contamination as it moves through and away from a landfill. The rate of ground water movement will generally be determined by the most permeable geologic strata and soil layer which would have been identified from the site investigations. Generally, ground water movement will be relatively slow except in the case of porous soils, highly fractured geologic strata, or possible Karst terrain. Figure 5 depicts the movement of a leachate plume which may result in future impact on a nearby stream. Ground water contours and monitoring wells are also shown in this figure.

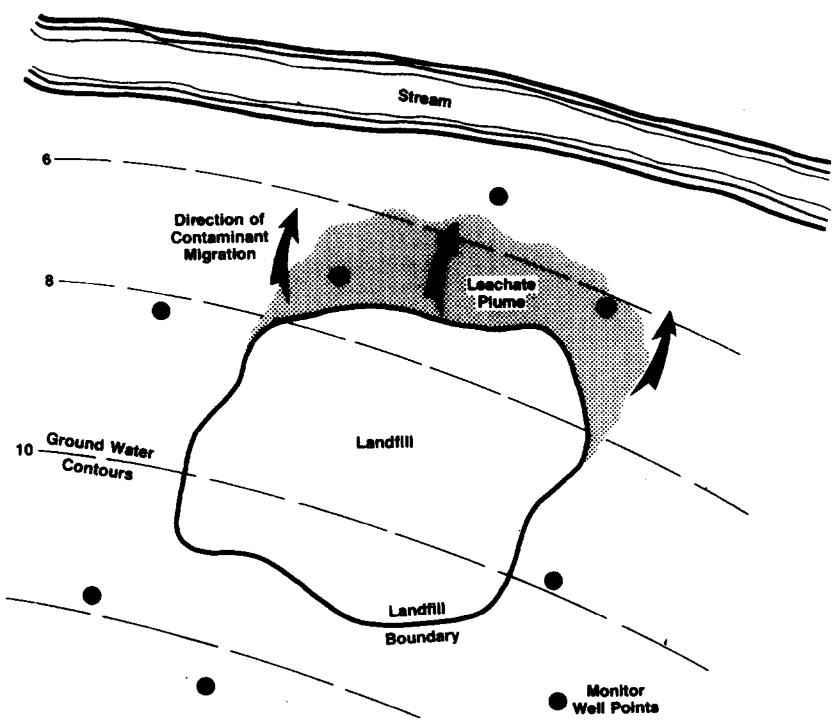

Fig. 5. Migration of leachate plume.

(3) Volatilization. Release of contaminants may occur through volatilization. This mechanism is most common when volatile organic or solvent waste has been deposited in the top layers of soil at a site.

(4) Sediment transport. Sediment transport acting with erosion may carry contaminants off site. Generally, this mechanism is observed as sedimentation on adjoining property. This transport mechanism usually acts slowly and may involve migration of waste material or contaminated soils.

Determine impacts or potential impacts

In conjunction with the analysis of migration pathways, the engineer should determine actual environmental and health impacts or potential impacts of this contamination migration. This determination will assist in developing priorities and should evaluate such factors as:

- Downstream surface and ground water use.
- Future potential water use.
- Adjacent land use.
- Potential for contaminant uptake in the food chain.
- Human activity in the vicinity of the landfill.
- Toxicity and degree of hazard of contamination.
- Comparison of contaminant levels with background conditions.
- Direction of possible air movement of contaminants.

From the analysis of the driving function and migration pathways coupled with the evaluation of potential impacts, an identification of control measure priorities can be prepared.

Identify control alternatives

The analysis of site investigation data will lead to identification of viable effective control alternatives. Many control options exist for hazardous waste landfills; however, they must be tailored to meet site and waste specific conditions.

Control at the source

Site rehabilitation

The site rehabilitation control techniques are basic corrective measures that may be applied to a hazardous waste landfill. These controls can be used to reduce infiltration, improve surface water management, prevent direct contact between humans and the waste, prevent direct flow or washing of the wastes out of the landfill, and control the release of toxic vapors. Rehabilitation controls shown in Fig. 6 which should be evaluated based on the specific landfill conditions include:

(1) Placement of additional cover. In many cases, a hazardous waste landfill does not, or did not, use sufficient soil cover. In cases where cover was

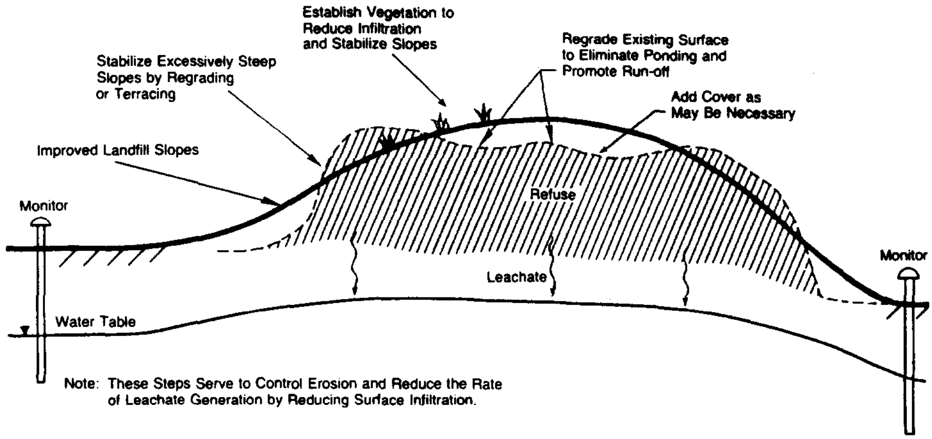

Fig. 6. Basic steps for upgrading closed and active landfills.

used, erosion has, and will, continue to severely reduce the in-place depth and quantity of the original soil cover. In these cases, the use of additional cover should be strongly considered as a means for reducing surface infiltration, preventing the direct exposure of waste to human contact, physically preventing the exposure of wastes to direct washing with surface water, and controlling the possible release of vapors.

(2) Improved grading. In conjunction with soil cover, an improved site grading plan should be used to encourage run-off, reduce infiltration, minimize erosion, direct surface water around the landfill, and eliminate ponding. During regrading, caution must be exercised to prevent the possible puncture of drums and personnel contact with toxic waste or vapors. It should be remembered that the puncture of drums and movement of wastes may create violent reactions between incompatible chemical wastes.

(3) Revegetation. Following regrading and placement of cover, revegetation should be undertaken to control erosion and to reduce infiltration through evapotranspiration.

(4) Control of off-site run-off. Diversions of off-site run-off requires interception and routing of surface water that would otherwise flow onto the landfill site. This may be accomplished by using stone-lined or asphalt-lined ditches. Figure 7 depicts this concept.

(5) Vapor and gas control. In the event that the release of toxic or explosive gases is a possibility, positive gas control will be needed. Several control concepts are illustrated in Fig. 8.

Encapsulation

Encapsulation may be considered as a more sophisticated means for control

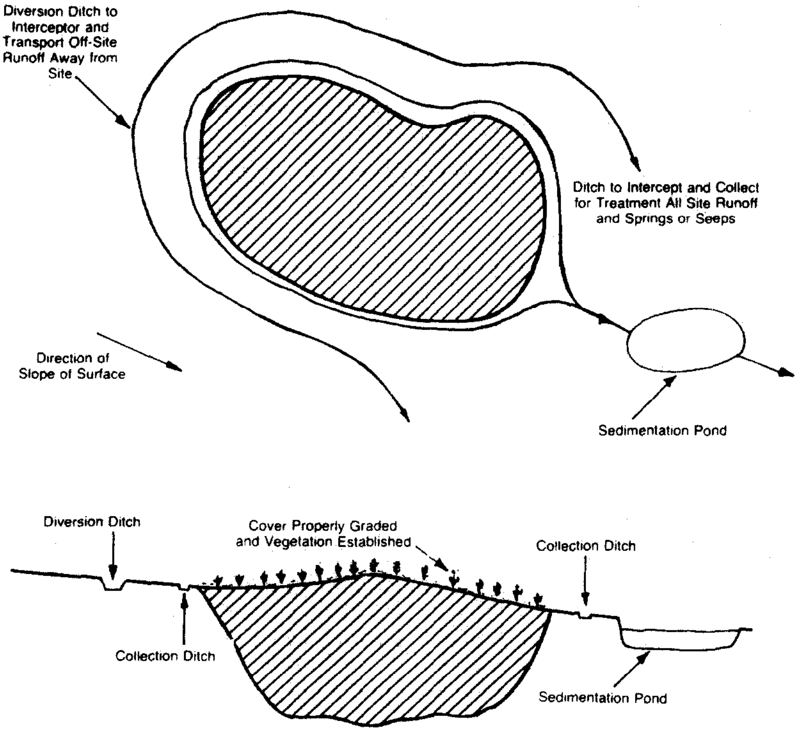

Fig. 7. Diversion of off-site run-off.

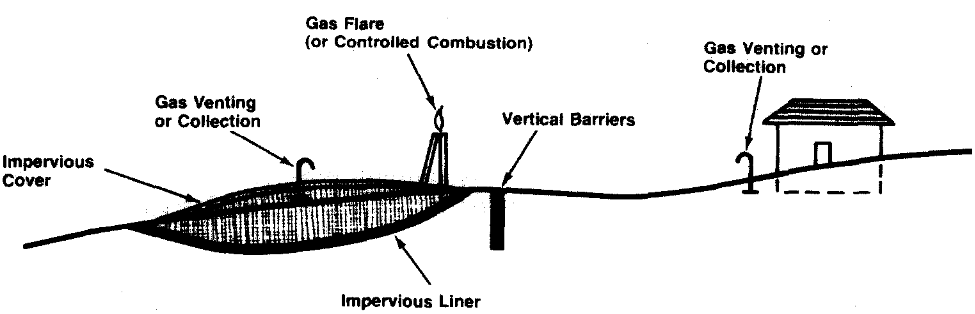

Fig. 8. Means of controlling gaseous emissions in hazardous waste disposal sites.

at the source. Encapsulation may be utilized at the time waste is placed in the landfill or as an in situ means for control of pollutant release from an inactive or abandoned hazardous waste landfill.

One method for encapsulating hazardous waste is through the use of a liner system that is designed to provide positive collection of leachates, and prevent or minimize surface water infiltration. Liners may be constructed from natural materials such as low permeability soils or soil admixtures, and synthetic material such as asphalt, PVC, polyethylene, hypalon, and other special-formulation synthetic membranes.

(1) Impermeable cover. Placement of an impermeable cover over the landfill site, as shown in Fig. 9, will greatly reduce precipitation infiltration into the site and will physically isolate contaminated material from surface run-off and from the atmosphere. This control attains several goals:

- Decreases the quantity of water entering the site from rainfall and eliminates the downward infiltration vector which results in mounding of ground water in the landfill and which drives contaminated leachate into the ground water.
- Reduces the potential for contamination of surface water run-off, through physical separation.
- Eliminates the potential for volatilization of contaminants (such as PCB's) through physical separation from the atmosphere.
- Eliminates the potential for human or animal contact with the contaminated waste by means of physical separation.

It should be noted that the use of an impermeable cover is most effective when contaminant transport is the primary result of surface infiltration.

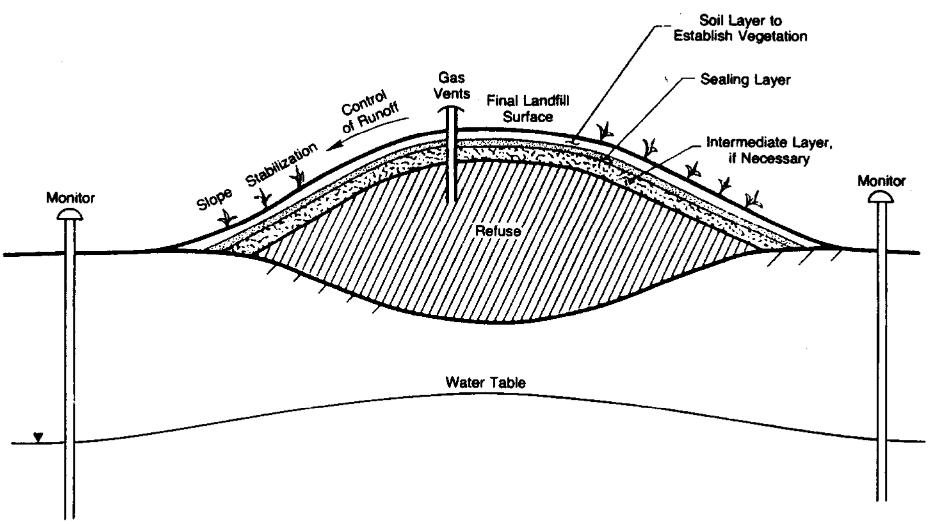

Fig. 9. Concept for sealing the final landfill surface.

(2) Leachate control. A liner system may be used to provide a positive control and collection of leachates. The basic approach is to install a liner along the bottom and sides of a landfill to physically restrict the possible flow of leachate out of the landfill and into surface water or ground water. The liner system must be designed so that leachate can be retrieved once it is collected. In cases where extremely toxic wastes are being handled or the

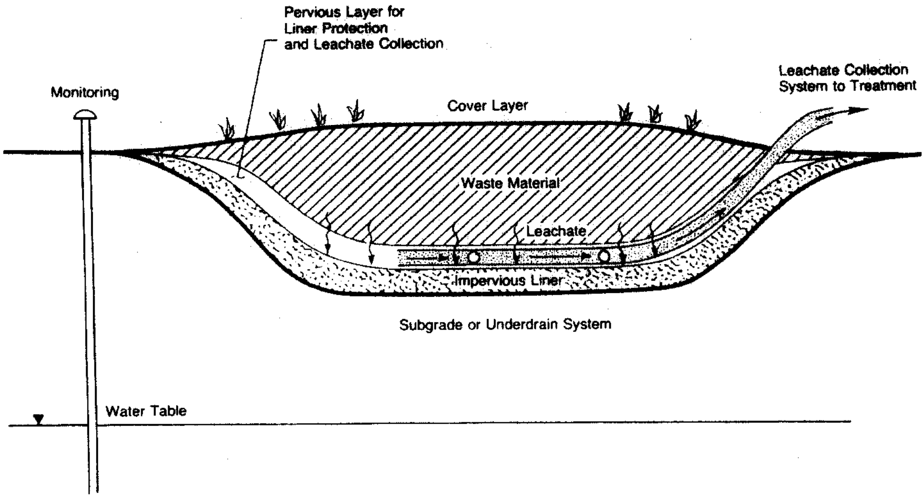

Fig. 10. Landfill concept for secure leachate management.

potential impact is severe, a dual liner system may be necessary. The concept for leachate control by means of a liner system is shown in Fig. 10.

(3) Waste fixation (microencapsulation). The two encapsulation concepts just discussed may be viewed as macroencapsulation techniques. An alternative to these techniques is microencapsulation, which involves the chemical conditioning of the waste prior to landfilling to achieve fixation or stabilization. In this manner, leachable contaminants are bound in the waste mass. A simplified waste fixation process flow diagram is shown in Fig. 11.

When microencapsulated waste is suitably compacted into a landfill site in accordance with good engineering principles such that a low permeability

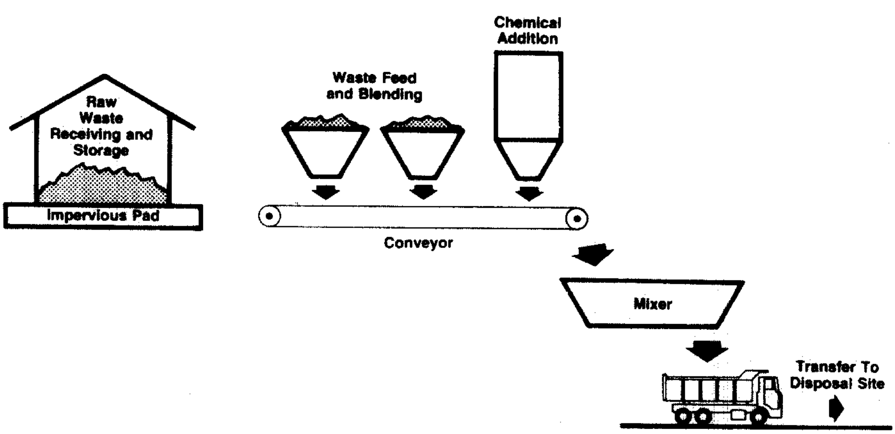

Fig. 11. Waste fixation process flow diagram.

monolithic material is produced, a further benefit results. In addition to the controlled-release properties resulting from microencapsulation, the landfilled waste has less surface area exposed to water contact. Thus, the total amount of leachable waste is greatly reduced, even from the level made possible by just the stabilization or microencapsulation process.

Typically, fly ash and lime-bearing additives are used to generate the cementitious reactions required for waste fixation. The alumina and silica in the fly ash, the lime compounds, and sometimes components from the waste itself participate in several sets of simultaneous reactions. Primary reaction products include several species of calcium silicates, calcium aluminates, and calcium sulfoaluminates. These compounds become hydrated in the source of a reaction with as many as 32 waters of hydration attached to each molecule of unhydrated compound. Thus, the process takes advantage of some of the free water typically present in waste materials, particularly sludges. In fact, it is important that prior to placement the final material contains sufficient water to allow these reactions to proceed at their maximum rate.

Cementitious reaction products typically are a mixture of gel and semi-crystalline structures, with gels predominating. The net effect is that the waste particles are microencapsulated within a largely gel matrix. The process is in essence a microscopic version of embedding small objects within resin, except that, in the case of microencapsulation, some residual porosity remains, although it tends to decrease with time.

The result of the stabilization process is a cementitious material with good structural integrity and low permeability. Depending on the final characteristics of the fixed waste, this process may be used to convert a hazardous waste into a non-hazardous waste. It should be noted that waste fixation has been used most successfully with inorganic wastes.

Hydrogeologic controls.

The use of hydrogeologic measures to control the release of pollutants is generally directed toward the hydrologic isolation of the landfill. The diversion of ground water flowing into a landfill site may eliminate a major source for driving hazardous contaminants from a landfill. The flow of ground water into a landfill can be a significant source of water in which contaminants may be solubilized or materials containing contaminants may be suspended. Also, this inflow provides a force to drive and carry contaminants from the site.

The technology for diversion of groundwater is readily available and well proven, and has been used for many years in the construction industry. Specific techniques must be selected based on site conditions, including well points, trenches, grouting, and sheet piling. Several of these control concepts are depicted in Fig. 12.

Site management

The final measure which applies to all of the aforementioned concepts is that of site management. This does not directly reduce the release of pollu-

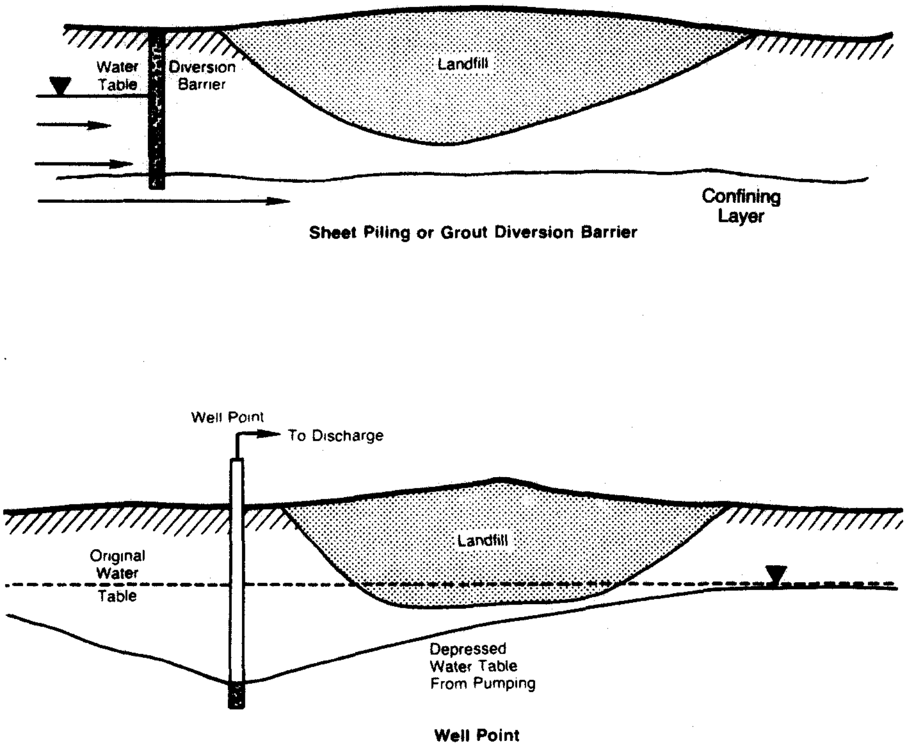

Fig. 12. Ground water diversion.

tants to the environment; nevertheless, it is important to the overall control program. The basic aspects to consider are:

- Delineation of disposal areas.
- Posting of warning signs and markers.
- Restricting human access to the site.
- Inspection and maintenance of control measures.
- Long-term monitoring.

Contaminant recovery

Retrieval and interception of pollutants

In cases where the previous strategies will not offer satisfactory results if implemented, it may be necessary to consider the collection of hazardous leachates after they leave the landfill. This approach is site specific and requires a thorough understanding of hydrogeologic conditions and ground water flow patterns at the site. The following steps should be considered, since they may be effectively combined to form a complete program:

- Thorough investigation of site and subsurface conditions.
- Collection of contaminated surface run-off.

- Collection of contaminated springs and seeps.
- Interception and collection of contaminated ground water.
- Treatment of collected leachate.

The collection of surface run-off, springs, and seeps may be accomplished through a system of lined ditches, swales, or trenches encircling the landfill. The distance between the ditches and the landfill depends on the potential for seeps to occur and on the probable location of these out-flows since it is essential that these be inside the ditch perimeter. The ditch system should be sloped in such a manner that it will transport the collected waters to a central basin or sump.

The collection of ground water may utilize such techniques as well points, interception trenches, or infiltration galleries. These measures should be designed and located to effectively intercept and collect the leachate plume while minimizing the quantity of uncontaminated water that is collected. The use of these concepts is shown in Fig. 13.

Waste removal

An alternative for contaminant retrieval may be excavation and removal

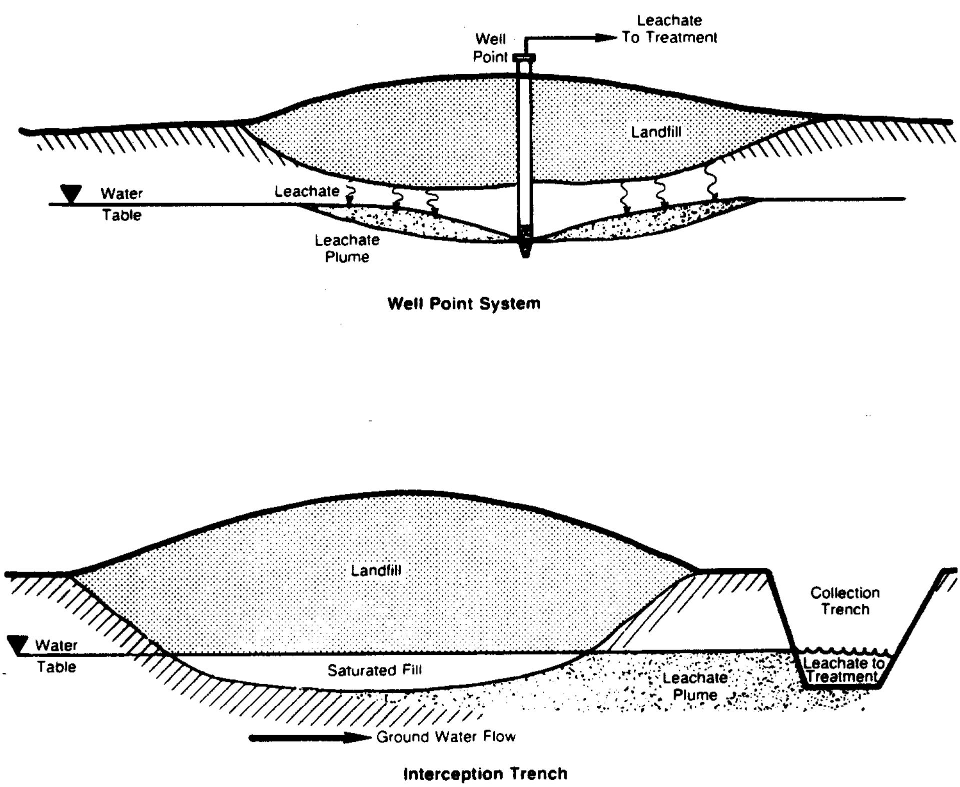

Fig. 13. Collection of contaminated ground water.

of the waste material and contaminated soil. This approach entails removal of the source of contamination, and an effective program should include the following:

- Identify the location and extent of the waste to be removed.
- Determine the extent of contaminated soils which must also be removed.
- Establish a strict safety program for the work; do not overlook the potential for toxic and ignitable fumes.
- Utilize protective clothing and equipment.
- Determine if there is a potential for mixing of incompatible wastes, and take precautionary measures.
- Locate an approved secure site to accept the material once it is excavated.
- Utilize secure transportation.

The strategy of waste removal is more applicable for smaller waste quantities, where wastes have been buried/deposited in one location and can be easily excavated.

Cost effectiveness

Application of control measures should consider not only the environmental effect of these measures but also the economics. Prescreening of the cost effectiveness of control measures should first consider the status of the hazardous waste landfill and which measures will be most applicable. The following review summarizes this prescreening step.

Inactive/abandoned landfills

An inactive or abandoned landfill offers many unique challenges with respect to developing a corrective program. Often, it is impossible to determine who is responsible for performing the corrective work and how the costs for the work should be borne. Frequently, public funds must be used for the improvement work. In many cases, landfill records are either non-existent or sketchy, and financial resources are limited to undertake corrective action.

When a particular landfill has been operated to accept a wide range of wastes, it can become difficult to determine:

- The specific composition and characteristics of the hazardous wastes which have been landfilled.
- The quantity of these hazardous wastes.
- The location of the wastes.
- The extent of the leachate plume and migration of pollutants.

In general, most of the source oriented and contaminant control concepts can be applied to abandoned landfills. One concept that is generally not economically feasible is that of installing a liner system along the bottom and sides of the landfill to collect leachate. This would require the following steps:

- Site investigation.
- Waste excavation.
- Site preparation.

- Liner construction and installation.
- Re-landfilling of the waste.
- Site closure.

Control concepts that are generally applied to abandoned landfills are site rehabilitation and use of an impermeable cover. Measures such as leachate collection, hydrologic controls, and waste removal may exceed available financial resources and should be considered only when the other actions are unacceptable.

Active landfills

Control strategies for active landfills are similar to those employed for abandoned sites. Several important differences should be considered:

- Landfill operating records may be more complete and operators may have knowledge of past filling activities; this information should reduce the amount of site investigation and detective work.
- Landfill equipment and personnel are available to carry out site rehabilitation work.
- Control measures can be instituted to restrict the type of wastes being landfilled.
- Secure site controls can be incorporated for future landfill areas.
- It may be possible to finance site improvements by collecting tipping fees from on-going landfill operations.
- A landfill operator can assume responsibility for completing the corrective actions.

The use of a liner system constructed along the bottom and sides of the landfill is also more feasible for future areas of an active landfill site. The lined area could be used to handle on-going hazardous wastes, or hazardous wastes that can be excavated or removed from the landfilled area.

When leachate collection is implemented an existing industrial or domestic wastewater treatment facility may be available to treat the leachate. Otherwise, a new facility must be constructed to handle the leachate. Costs for treatment can then be amortized over the total landfill life.

New landfills

In the case of new landfills, the opportunity exists to make maximum use of the natural site conditions, along with sound engineering design to prevent the uncontrolled release of toxic pollutants. By selecting a site with relatively secure and favorable hydrogeologic conditions, engineering controls generally need to be less sophisticated and less costly. In addition, the operators of a new site must establish requirements concerning physical and chemical characteristics of the wastes that will be accepted for landfill.

The cost effectiveness of an overall control program will be based on the effectiveness of each successive engineered control component as compared to the added cost of each control measure. To make this comparison, it must be possible to estimate the relative quantity of contaminants or contaminant loading that will be controlled by each specific control measure.

Figure 14 reflects an analysis that was made by the authors to evaluate the capital cost and control effectiveness of distinct engineering improvements that could be applied to control contaminant release from a hazardous waste disposal site. From the analysis shown in this figure, application of all control components will approach an overall control effectiveness of 100%. The cost for a lesser degree of control can be projected by adding the cost of each component selected.

Control Alternative	Total Program Cost	Contaminant Removed or Contained (pounds)	% Contaminant Removed or Contained
1. Pumping Well Recovery System & Contaminant Disposal	$425,000	45	50
2. Groundwater Treatment			
a) Carbon Adsorption or	$400,000	9	10
b) Recharge System or	$ 50,000	0	0
c) Discharge to Sanitary Sewer	$100,000	9	10
3. Surface Water Inflow Reduction			
a) Regarding or	$175,000	1	1
b) Asphalt Paving or	$250,000	9	10
c) Clay Cover	$200,000	9	10
4. Groundwater Control by Sheet Piling	$500,000	27	30

Fig. 14. Cost effectiveness analysis of control scenario.

When implementing a program of controls for a polluting landfill, several items should be enacted during the corrective action and after it has been completed. These items include:

- Monitoring of ground and surface water before (to establish a baseline) and after the corrective action is implemented.
- Air monitoring, if necessary, during and following the work.
- Provision for employee and worker safety.
- A plan for handling emergency situations.

Data gathered during the monitoring program is the feedback needed to determine the net effectiveness of the upgrading and control work, and to identify what other action may be needed.