CHAPTER 3

CONTROL AND CONTAINMENT TECHNOLOGIES

3-1. Definition. Control and containment technologies are those remedial systems that are used primarily for management of contaminants onsite and to prevent excursions to the air or ground water.

3-2. Applicability. Control and containment remedial techniques are usually undertaken where the volume of waste or hazard associated with the waste makes it impractical or impossible to dispose of the contamination offsite to a secure landfill site or to treat the waste or contaminated material onsite. In some cases, portions of waste materials have been removed, but the residual contamination in soil and ground water must be contained onsite. Remedial techniques generally are used for onsite containment with processes such as flushing of an aquifer or natural biological degradation accounting for the actual destruction of contaminants. Site control and containment remedial techniques are often implemented along with treatment systems to minimize the volume of material requiring treatment. For example. if leachate seeps from the site it must be treated, and control of run-on and percolation through the site can reduce the volume of water that must be collected and treated.

3-3. Techniques.

a. Waste Collection and Removal. The first step in remediation is usually the collection and removal of waste materials, including wastes, soils, sediments, liquids, and sludges.

b. Contaminated Ground Water Plume Management. Often it is necessary to control contaminant movement in the subsurface by intercepting or controlling leachate and ground water around and under a site.

c. Surface Water Controls. Control and containment technologies usually involve managing the movement of contaminants in and out of the controlled area. Many common construction processes used in managing ground water and surface water are often employed. Leachate control involves containment and collection of water contaminated by contact with hazardous wastes. Control of leachate will involve the use of subsurface drains and liners.

d. Gas Control. Gases and volatile compounds must be controlled at many hazardous waste sites both to allow access to the area and to prevent wider dispersion of contaminants.

Section I. Waste Collection and Removal

3-4. Drum Handling.

a. Background.

(1) The disposal of drums containing wastes in landfills and at abandoned storage facilities has been common practice in the United States.

Many of the problems with uncontrolled disposal sites can, in part, be linked to improper drum disposal. In addition to contributing to ground-water, soil, air, and surface-water contamination, several explosions and fires, resulting from incompatible wastes can be attributed to leaking drums.

(2) Since each disposal site is different, selection and implementation of equipment, and methods for handling drum-related problems, must be independently determined. The primary factors that influence the selection of equipment or methods include worker safety, site-specific variables affecting performance, environmental protection, and costs. All sites should include the construction of earthen dikes and installation of synthetic liners in the drum-handling area to minimize seepage and run-off of spilled materials, and the use of real-time, air-monitoring equipment during all phases of site activity.

(3) The organization of a typical drum cleanup site is shown in Figure 3-1.

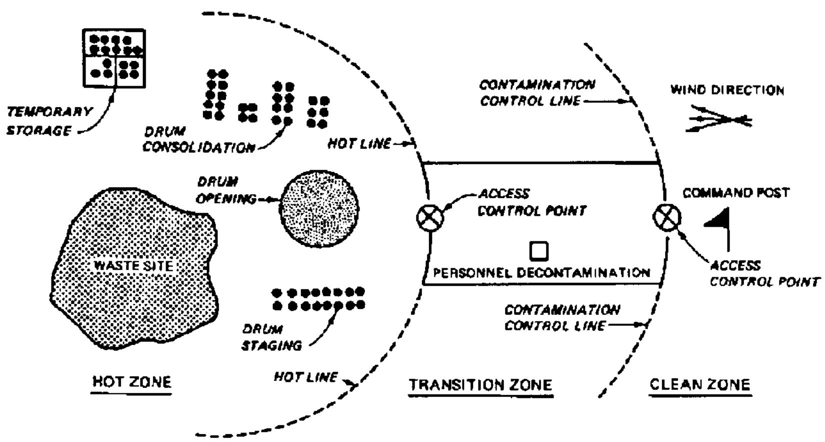


Figure 3-1. Organization of the Waste Site Cleanup Area

b. Drum-Handling Activities.

(1) Site-specific variables. The safety of drum handling is greatly affected by site-specific conditions, including accessibility of the site, drum integrity, surface topography and drainage, number of drums, depth of burial, and the type of wastes present.

(2) Detecting and locating drums. Typically, drums at an abandoned site will be detected through the use of historic and background data on the site, aerial photography, geophysical surveying, and sampling. Background data and aerial photography records which will show changes in the site over time, such as filling in of trenches and mounding of earth, should be available onsite during the construction phase of the remedial action to

determine if the drum location is as predicted. Geophysical survey methods are highly dependent upon site-specific characteristics. Magnetometry is usually the most useful survey method for locating buried drums. Metal detectors, ground penetrating radar, and electromagnetics are also used to detect buried drums with varying success. Regardless of the geophysical method used to determine the location of buried drums, the results must be verified by sampling.

(3) Environmental protection. Four basic techniques for environmental protection which should be practiced at all sites are: (a) measures to prevent contaminant releases, such as overpacking or pumping the contents of leaking drums; (b) actions which mitigate or contain releases once they have occurred, such as perimeter dikes, (c) avoidance of uncontrolled mixing of incompatible wastes by handling only one drum at a time during excavation, and (d) isolating drum-opening operation from staging and working areas. Some of the preventive measures and mitigating actions for minimizing contaminant releases during drum-handling activities are summarized in Table 3-1.

(4) Determining drum integrity. The excavation and handling of damaged drums can result in spills and reactions which may jeopardize worker safety and public health. Generally a drum is inspected visually to check the drum surface for corrosion, leaks, swelling, and missing bungs. Worker safety should be stressed during this inspection since it requires close contact with the drum. Any drum that is critically swollen should not be approached. Swollen drums should be isolated behind a barrier and the pressure released remotely. Nondestructive testing methods to determine drum integrity have been found to have serious drawbacks and limitations. Most of these methods such as ultrasonics or eddy currents require that the drum surface be relatively clean and free from chipped paint and floating debris. Buried drums are usually not in condition to be safely and easily cleaned.

(5) Container opening, sampling, and compatibility. Each container on a site may have to be opened, sampled, and analyzed prior to disposal.

(a) Container opening and sampling should be conducted in an isolated area to minimize the potential of explosions and fires should the drum rupture or the contents spill. Drum-opening tools include hand tools (nonsparking hand tools, bung wrenches, and deheaders) and remotely operated plungers, debungers, and backhoe-attached spikes. EPA*s National Enforcement Investigations Center (NEIC) has developed two remotely controlled drumopening devices. Procedures for drum opening and sampling are outlined in Appendix XIV of the Chemical Manufacturers Association, Inc. (CMA), report “A Hazardous Waste Site Management Plan.

(b) Compatibility testing is required prior to bulking, storing, or shipping many of the containers. Compatibility testing should be rapid, using onsite procedures for assessing waste reactivity, solubility, presence of oxidizer, water content, acidity, etc. A compatibility testing procedure is also outlined in Appendix XV of the CMA report.

(6) Drum consolidation and recontainerization.

Table 3-1. Measures for Minimizing Contaminant Releases during Drum Handling

Potential environmental problem	Preventive measures
Ground-water contamination	Improve site drainage around the drum-handling area and minimize run-on and run-off by constructing a system of dikes and trenches.
	Where ground water is an important drinking water source; it may be necessary to hydrologically isolate the work area using well-point dewatering.
	Use liners to prevent leaching of spilled material into ground water during drum handling, drum opening, recontainerization, and decontamination.
	Use sorbents or vacuum equipment to clean up spills promptly.
	Locate a temporary storage area on highest ground area available; install an impervious liner in the storage area and a dike around the perimeter of the area; utilize a sump pump to promptly remove spills and rainwater from storage area for proper handling.
Surface-water contamination	Construct dikes around the drum-handling and storage areas.
	Construct a holding pond downslope of the site to contain contaminated run-off.
	Use sorbents or vacuum equipment to promptly clean up spills.
	Design the dikes for temporary storage area to contain a minimum of 10 percent of total waste volume; ensure that holding capacity of storage area is not exceeded by utilizing a sump pump to promptly remove spills and rainwater.
Air pollution	Avoid uncontrolled mixing of incompatible wastes by (1) handling only one drum at a time during excavation, (2) isolating drum-opening operation from staging and working areas, (3) pumping or overpacking leaking drums, and (4) conducting compatibility tests on all drums.

(Continued)

Table 3-1. (Concluded)

Potential environmental problem	Preventive measures
Air pollution (Cont.)	Promptly reseal drums following sampling.
	Any drum which is leaking or prone to rupture or leaking, promptly overpack or transfer the contents to a new drum.
	Utilize vacuum units which are equipped with vapor scrubbers.
	Where incompatible wastes are intentionally mixed (i.e., acids and bases for neutralization) in a "compatibility chamber" or tank, releases of vapors can be minimized by covering the tank with plastic liner.
Fire protection	Use nonsparking hand tools, drum-opening tools, and explosion-proof pumps when handling flammable, explosive, or unknown waste.
	Avoid uncontrolled mixing of incompatible waste by (1) handling only one drum at a time, (2) pumping or overpacking drums with poor integrity, (3) isolating drum opening, and (4) conducting compatibility testing of all drums.
	Use sand or foams to suppress small fires before they spread.
	Avoid storage of explosives or reactive wastes in the vicinity of buildings.
	In a confined area, reduce concentration of explosives by venting to the atmosphere.
	Cover drums which are known to be water-reactive.

(a) A proposed drum consolidation protocol that can be used as a guide in assessing drum consolidation requirements was also prepared by the CMA. The protocol is based on grouping the waste into categories that are compatible based on limited testing rather than doing individual analyses of the contents of each drum prior to disposal. This approach would be best suited to a manufacturing facility where the products or wastes types are limited and the objective is to consolidate many samples into a relatively small number of waste streams for bulk disposal. In the case where a disposal method is based on concentrations of a particular waste constituent (e.g., concentration of PCBs), care must be taken not to consolidate containers into bulk streams that would substantially alter the method for disposal, subsequently increasing the costs for the remedial action.

(b) In the case where consolidation is not feasible, based on incompatibility of wastes or costs, drums can be overpacked, contents transferred to new drums, or contents solidified to facilitate handling.

(7) Storage and shipping. Temporary onsite storage of drums may be part of the remedial action prior to ultimate disposal. Requirements for storage of hazardous wastes over 90 days are regulated under the RCRA. RCRA-permitted facilities for drum storage for over 90 days require:

(a) Use of dikes or berms to enclose the storage area and to segregate incompatible waste types.

(b) Installation of a base or liner that is impermeable to spills.

(c) Sizing of each storage area (containing compatible wastes) so that it is adequate to contain at least 10 percent of the total waste volume in event of a spill.

(d) Design of the storage area so that drums are not in contact with rainwater or spills for more than one hour.

(e) Weekly inspections.

(8) Technical standards. The technical standards for these requirements are found in 40 CFR Parts 264-265. Manifesting and shipping of the hazardous wastes are covered by DOT regulations found in 49 CFR 171-177, 40 CFR 263, and other applicable Federal, state, and local laws and regulations. A RCRA storage permit will be required for onsite storage of hazardous waste held over 90 days.

3-5. <u>Storage</u>. Storage is the holding of a waste for a temporary period of time, at the end of which the waste is treated, disposed of, or stored elsewhere.

a. <u>Applicability</u>.

(1) Storage systems have general applicability to all types of waste streams as a mechanism for accumulating and holding waste on a temporary basis. Storage should be considered viable only in cases where the

accumulation of waste prior to treatment or disposal results in a cost reduction or makes some treatment process or disposal method more feasible. Examples include accumulation of waste until a sufficient volume is obtained for bulk shipment or bulk treatment, thus decreasing costs. Under the RCRA regulations, a generator may accumulate hazardous waste onsite without a permit for a period of up to 90 days as long as certain conditions are met as specified in CFR Title 40, Part 262, Subpart C, Section 262.34.

(2) Different storage techniques are capable of handling wastes in solid, semisolid, and liquid forms. Problems associated with the applicability of storage techniques to various wastes generally occur with regard to storage of hazardous waste. The RCRA regulations pertaining to storage facilities under Part 264 address two particular problem wastes, ignitable or reactive wastes and incompatible wastes. Special requirements for each storage technique are detailed in the regulations for these wastes.

(3) Wastes that emit or produce toxic fumes should not be stored in a manner which allows for the emission of fumes except possibly in emergency situations.

b. Methods. Storage methods include waste piles, surface impoundments, containers, and tanks.

(1) Waste piles. Waste piles are small noncontainerized accumulations of a single solid dry nonflowing waste. They may be maintained in buildings or outside on concrete or other pads. Waste pile storage is suitable for semisolid and solid hazardous wastes such as mine tailings or unexploded ordnance wastes. The siting criteria for waste piles are less stringent than those for landfills or surface impoundments. Waste piles should be located in a hydrogeologic setting that offers both sufficient vertical separation of wastes from uppermost ground water and low permeability soils providing the hydraulic separation. The design elements required by the regulations for waste piles include liner, leachate collection and removal, run-on and run-off control, and wind dispersal control.

(a) Liners selected for a waste pile must be compatible with the waste material and be able to contain the waste until closure. Considerable flexibility is permitted in the choice of liners for short-term storage of wastes. A liner may be constructed of clay, synthetic materials, or admixes. Table 3-2 summarizes liner types, characteristics, and compatibilities. If a waste pile is going to be used for an extended period of time, a double liner with a leachate collection system may be required. Figure 3-2 illustrates waste pile details and a double liner system. If the waste pile contains particulate matter, wind dispersal controls are required by the regulations.

(b) The principal closure requirement for a waste pile is removal or decontamination of all waste and waste residue and all system components (liners), subsoils, structures, and equipment which have been contaminated by contact with the waste. However, if contamination of the subsoils is so extensive as to preclude complete removal or decontamination, the closure and postclosure requirements applying to landfills must be observed. Ensuring

Table 3-2. Summary of Liner Types

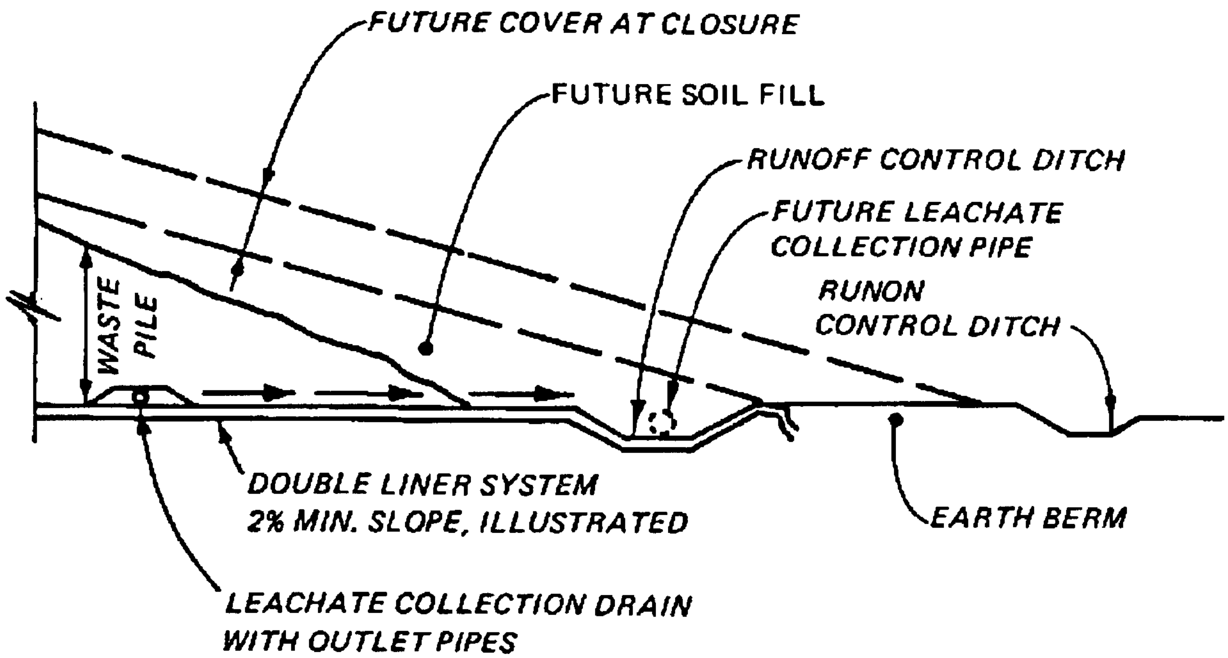
Liner material	Characteristics	Range of costs[1]	Advantages	Disadvantages
Soils				
Compacted clay soils	Compacted mixture of onsite soils to a permeability of 10^{-7} cm/sec	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Soil bentonite	Compacted mixture of onsite soil, water, and bentonite	L	High cation exchange capacity; resistant to many types of leachate	Organic or inorganic acids or bases may solubilize portions of clay structure
Admixes				
Asphalt concrete	Mixtures of asphalt cement and high-quality mineral aggregate	M	Resistant to water and effects of weather extremes; stable on side slopes; resistant to acids, bases, and inorganic salts	Not resistant to organic solvents; partially or wholly soluble in hydrocarbons; does not have good resistance to inorganic chemicals; high gas permeability
Asphalt membrane	Core layer of blown asphalt blended with mineral fillers and reinforcing fibers	M	Flexible enough to conform to irregularities in subgrade; resistant to acids, bases, and inorganic salts	Ages rapidly in hot climates; not resistant to organic solvents, particularly hydrocarbons
Soil asphalt	Compacted mixture of asphalt, water, and selected in-place soils	L	Resistant to acids, bases, and salts	Not resistant to organic solvents, particularly hydrocarbons
Soil cement	Compacted mixture of portland cement, water, and selected in-place soils	L	Good weathering in wet-dry/freeze-thaw cycles; can resist moderate amount of alkali, organics, and inorganic salts	Degraded by highly acidic environments
Polymeric membranes				
Butyl rubber	Copolymer of isobutylene with small amounts of isoprene	M	Low gas and water vapor permeability; thermal stability; only slightly affected by oxygenated solvents and other polar liquids	Highly swollen by hydrocarbon solvents and petroleum oils difficult to seam and repair
Chlorinated polyethylene	Produced by chemical reaction between chlorine and high-density polyethylene	M	Good tensile strength and elongation strength; resistant to many inorganics	Will swell in presence of aromatic hydrocarbons and oils

(Continued)

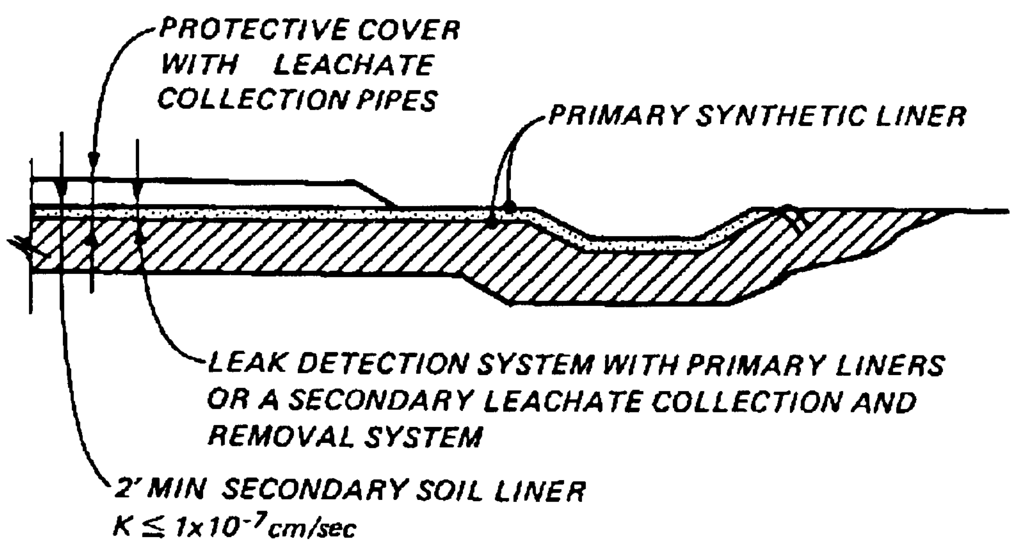
[1] L - \$1.12 to \$4.78 per square meter (\$1 to \$4 installed costs per square yard) in 1981 dollars; M - \$4.78 to \$9.57 /m^2 (\$4 to \$8 per square yard); H - \$9.57 to \$14.35 /m^2 (\$8 to \$12 per square yard). (Source: "Comparative Evaluation of Incinerators and Landfills," prepared for the Chemical Manufacturers Association, by Engineering Science, McLean, VA, May 1982).

Table 3-2. (Concluded)

Liner material	Characteristics	Range of costs[1]	Advantages	Disadvantages
Polymeric membranes (Cont.)				
Chlorosulfonate polyethylene	Family of polymers prepared by reacting polyethylene with chlorine and sulfur dioxide	H	Good resistance to ozone, heat, acids, and alkalis	Tends to harden on aging; low tensile strength; tendency to shrink from exposure to sunlight; poor resistance to oil
Elasticized polyolefins	Blend of rubbery and crystalline polyolefins	L	Low density; highly resistant to weathering, alkalis, and acids	Difficulties with low temperatures and oils
Epichlorohydrin rubbers	Saturated high molecular weight, aliphatic polyethers with chloromethyl side chains	M	Good tensile and tear strength; thermal stability; low rate of gas and vapor permeability; resistant to ozone and weathering; resistant to hydrocarbons, solvents, fuels, and oils	None reported
Ethylene propylene rubber	Family of terpolymers of ethylene, propylene, and nonconjugated hydrocarbon	M	Resistant to dilute concentrations of acids, alkalis, silicates, phosphates, and brine; tolerates extreme temperatures; flexible at low temperatures; excellent resistance to weather and ultraviolet exposure	Not recommended for petroleum solvents of halogenated solvents
Neoprene	Synthetic rubber based on chloroprene	H	Resistant to oils, weathering, ozone, and ultraviolet radiation; resistant to puncture, abrasion, and mechanical damage	None reported
Polyethylene	Thermoplastic polymer based on ethylene	L	Superior resistance to oils, solvents, and permeation by water vapor and gases	Not recommended for exposure to weathering and ultraviolet light conditions
Polyvinyl chloride	Produced in roll form in various widths and thicknesses; polymerization of vinyl chloride monomer	L	Good resistance to inorganics; good tensile, elongation, puncture, and abrasion resistant properties; wide ranges of physical properties	Attacked by many organics, including hydrocarbons, solvents, and oils; not recommended for exposure to weathering and ultraviolet light conditions
Thermoplastic elastomers	Relatively new class of polymeric materials ranging from highly polar to nonpolar	M	Excellent oil, fuel, and water resistance with high tensile strength and excellent resistance to weathering and ozone	None reported



TYPICAL WASTE PILE DETAILS



DOUBLE LINER SYSTEM

Figure 3-2. Base Liner Details for Waste Piles adequate containment of waste should be an important consideration in initial design of a waste pile.

(2) Surface impoundments. Surface impoundments include any facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area. They may be formed primarily of earthen materials or man-made materials, and designed to hold an accumulation of liquid wastes or wastes containing free liquids. Examples of surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. Surface impoundments are used for the storage, evaporation, and treatment of bulk aqueous wastes.

(a) Mixing of wastes is inherent in a surface impoundment. Incompatible wastes should not be placed in the same impoundment. The potential dangers from the mixing of incompatible wastes include extreme heat, fire, explosion, violent reaction, production of toxic mists, fumes, dusts, or gases. Some examples of potentially incompatible wastes are presented in Table 3-3.

(b) Surface impoundments should be located in a hydrogeologic setting that limits vertical and horizontal hydraulic continuity with ground water. The hydraulic head formed in the impoundment provides for a high potential for liquid seepage and subsurface migration. As with waste piles, surface impoundments may require the use of liners, leachate collection and removal, and runon and runoff controls. An example detailing base liners for surface impoundments is shown in Figure 3-3.

(c) Surface impoundments must be inspected during their operating life. These inspections should include monitoring to ensure that liquids do not rise into the freeboard (prevention of overtopping), inspecting containment berms for signs of leakage or erosion, and periodic sampling of the impounded wastes for selected chemical parameters.

(3) Removal methods.

(a) Removal methods for settled residues and contaminated soil include removal of the sediment as a slurry by hydraulic dredging, excavation of the sediments with a jet of high-pressure water or air, vacuum transport of powdery sediments, excavation of hard solidified sediments by either dragline, front-end loader, or bulldozer.

(b) The major operation at an impoundment involves the “removal” of the liquid waste. Table 3-4 summarizes liquid waste removal methodologies.

(c) In addition to the requirement of a single liner with ground-water monitoring wells or a double liner with a leak detection system, other design elements include prevention of overtopping the sides of the impoundment and construction specifications that ensure the structural integrity of the dikes.

(d) Closure options include the removal or decontamination of all wastes, waste residues, system components, subsoils, structures, and equipment or the removal of the liquid waste and solidification of the remaining waste.

Table 3-3. Examples of Potentially Incompatible Wastes

Group A chemicals	Mixed with	Group B chemicals	May have	Potential consequence
1-A Acetylene sludge Alkaline caustic liquids Alkaline cleaner Alkaline corrosive liquids Alkaline corrosive battery fluid Caustic wastewater Lime sludge and other corrosive alkalies Lime wastewater Lime and water Spent caustic		**1-B** Acid sludge Acid and water Battery acid Chemical cleaners Electrolyte, acid Etching acid liquid or solvent Pickling liquor and other corrosive acids Spent acid Spent mixed acid Spent sulfuric acid		Heat generation; violent reaction
2-A Aluminum Beryllium Calcium Lithium Magnesium Potassium Sodium Zinc powder Other reactive metals and metal hydrides		**2-B** Any waste in Group 1-A or 1-B		Fire or explosion; generation of flammable hydrogen gas
3-A Alcohols Water		**3-B** Any concentrated waste in Group 1-A or 1-B Calcium Lithium Metal hydrides Potassium SO_2, Cl_2, $SOCl_2$, PCl_3, CH_3, $SiCl_3$ Other water-reactive waste		Fire, explosion, or heat generation; generation of flammable or toxic gases
4-A Alcohols Aldehydes Halogenated hydrocarbons Nitrated hydrocarbons Unsaturated hydrocarbons Other reactive organic compounds and solvents		**4-B** Concentrated Group 1-A or 1-B wastes Group 2-A wastes		Fire, explosion, or violent reaction
5-A Spent cyanide and sulfide solutions		**5-B** Group 1-B wastes		Generation of toxic hydrogen cyanide or hydrogen sulfide gas

(Continued)

Table 3-3. (Concluded)

Group A chemicals	Mixed with	Group B chemicals	May have	Potential consequence
6-A		6-B		
Chlorates Chlorine Chlorites Chromatic acid Hypochlorites Nitrates Nitric acid, fuming Perchlorates Permanganates Peroxides Other strong oxidizers		Acetic acid and other organic acids Concentrated mineral acids Group 2-A wastes Group 4-A wastes Other flammable and combustible wastes		Fire, explosion, or violent reaction

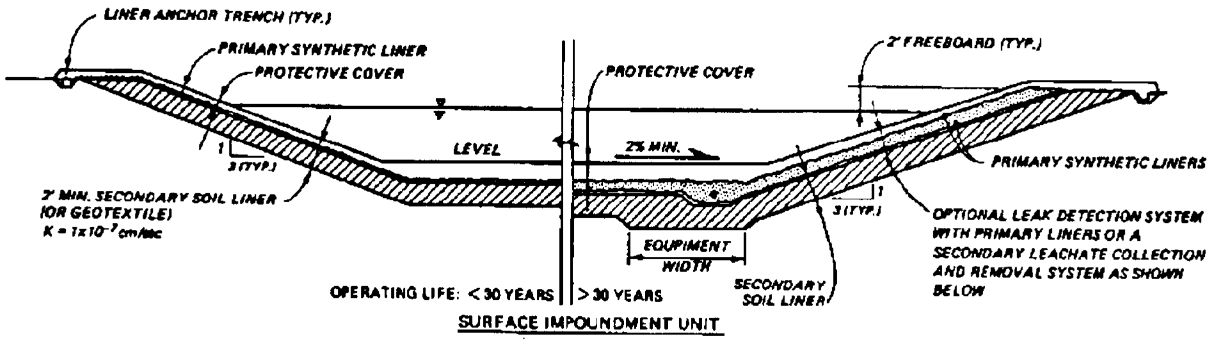


Figure 3-3. Base Liner Details for Surface Impoundments

Solidification also requires the placement of a final cover and ground-water monitoring to ensure that stabilization and capping operations were successful.

(4) Tanks. Tanks are stationary devices designed to contain an accumulation of hazardous waste and are constructed primarily of nonearthen materials (e.g. , wood, concrete, steel, plastic) which provide structural support. Tanks should be designed to be strong enough to ensure against collapse or rupture. Closed tanks should be vented or have some means to control the pressure. Tanks should be compatible or have a liner that is compatible with the stored waste. Incompatible wastes should not be stored in the same tank.

c. Summary of Current Regulations. References to EPA advisories and regulations for hazardous waste storage, treatment, or disposal are listed below.

Containment Method	Regulations
Landfills, surface impoundments, waste piles, and land treatment units	Federal Register, Vol 47, No. 143
Containers and tanks	Federal Register, Vol 46, Page 2867
Standards for waste containers	40 CFR Part 264, Subpart I, Sections 264.170-264.178; and Subpart J, Sections 264.190-264.199
Standards for surface impoundments	40 CFR Part 264, Subpart K
Standards for waste piles	40 CFR Part 264, Subpart L and Subpart F

Table 3-4. Liquid Waste Removal Methods for Surface Impoundments

Method	Description
Decanting	Liquids within or ponded on the surface of the impoundment can be removed by gravity flow or pumping to a treatment facility if there is not a large percentage of settleable solids.
Pumping and settling	Liquids or slurries composed of suspended or partially suspended solids can be removed by pumping into a lined settling pond and then decanting. Sludges are disposed in a dry state, and either returned to the impoundment or disposed in another contained site.
Solar drying	Liquids are removed by evaporation; sludges remaining after evaporation are left in the impoundment or disposed in another contained site. Note that volatile organics should not be handled in this manner.
Chemical neutralization	Aqueous waste with low levels of hazardous constituents frequently lends itself to chemical neutralization and subsequent normal discharge under NPDES permit requirements
Infiltration	Certain aqueous waste can be handled by infiltration through soil, provided that the hazardous substances are removed by either soil attenuation or underdrain collection of the solute. Collected solutes are usually treated.
Process reuse	Some aqueous waste can be recycled in the manufacturing process a number of times until the contaminants are at a level requiring disposal by one of the methods previously mentioned. Reuse does not dispose of the waste but can significantly reduce the quantities to be disposed.
Absorbent addition	Materials can be added to aqueous impounded wastes to absorb free liquids. Absorbents include sawdust; wood shavings; agricultural wastes such as straw, rice, and peanut hulls; and commercially available sorbents.

3-6. Tank Cleaning and Demolition. Tank cleaning and demolition procedures are site specific and depend largely on the nature of tank contents. A major consideration is whether the contents are ignitable or explosive. If possible, the contents of the tank should be removed by pumping or draining, then the tank can be decontaminated and demolished. Provisions must be made for treatment and disposal of contaminated washwaters.

a. Tanks Containing Sludges. If the sludge cannot be removed, water should be pumped into the tank to completely cover the sludge and the contents of the tank should be blanketed with nitrogen. The tank head space should then be checked with an explosion meter to ensure a safe working environment before proceeding. Then the top area of the tank should be cut using an oxyacetylene torch. Explosion meter checks should be made after each cut to ensure that no explosive gases are collecting during cutting operations. Successive “slices” of the tank should be removed until there is sufficient working room to remove the contents of the tank. Adequate fire protection should be available onsite along with a paramedic unit during tank demolition activities if there is a risk of fire or explosion.

b. Tanks Containing Liquids. Once the tank contents have been removed by pumping or draining, the tank can be decontaminated. Depending upon the contents, water and/or organic solvents may be used. The final decontamination process should be water flushing if the tank contained ignitable or explosive waste material. Chemical emulsifiers may be used to remove hydrophobic organics. Before proceeding with tank demolition, explosion meter checks should be taken. If an explosive hazard exists, the tank should be blanketed with water and nitrogen before being cut. Again, explosive checks should be made after each cut while the tank is cut away in “slices.” Fire protection personnel and paramedics should be present any time there is the danger of fire or explosion.

3-7. Lagoon Management. Existing lagoons, ponds, and disposal pits have the potential to contaminate surface water, ground water, soil, and the surrounding air. Precipitation (rainwater and surface runoff) may increase the volume of the contaminated waste, increasing the potential for ground- and surface-water contamination, and increasing total cleanup costs. Background information on geology, hydrology, soils, and the character of the waste itself is most important in determining the potential for leachate generation and its vertical and horizontal migration through the ground-water system.

a. Management Plans. The contents of a lagoon may be contained, treated, or disposed of onsite or may be removed from the lagoons to an offsite treatment or disposal facility.

(1) Onsite remedial actions.

(a) Onsite management plans may include a no-action alternative with no treatment for the waste and establishment of a monitoring program to detect any surface or subsurface migration of contaminants. This option may be appropriate if it has been determined that the underlying aquifer is unusable and there is no imminent danger of contaminating nearby surface waters or residential wells. Long-term monitoring can be very expensive and the potential liability of the impounded waste may not decrease over time.

(b) The wastes may be pumped to an onsite treatment facility. Liquids may be pumped with one or more of many available pumps. However, the compatibility of the liquid waste with the pump*s materials that come in contact with the liquid should be considered to avoid equipment failures. Sludges and contaminated sediments at the bottom of the lagoon may or may not require dredging to remove them from the lagoon depending on viscosity. Onsite treatment of the liquid waste may be accomplished through physical, chemical, and/or biological methods. Treatment systems are further discussed in Chapter 4.

(c) The wastes may also be treated in situ using one of many options. These options include solidification, stabilization, or encapsulation. When preparing the contract for a project with in-situ treatment, a pilot-scale demonstration using the actual construction equipment proposed for the job should be required. Obtaining a sufficient mixing action with sludges using heavy construction equipment can be a difficult task with low quality control at hazardous waste impoundments.

(d) If the waste is left in place after being treated, it should be isolated from surface and ground water. Capping and surface water diversion can prevent most leachate generation. Ground water can be controlled with the use of subsurface barriers or by ground-water pumping.

(2) Offsite remedial actions. The contents of a lagoon may also be removed and transported to an offsite facility for treatment or disposal. Treatment processes may be applied to the waste during the removal operation depending on the treatment/disposal option being used. The additional handling and transportation problems should be considered. Also, once the liquid contents of the lagoon have been removed, the remaining sludge and underlying contaminated soil may have to be removed and treated at the same offsite facility.

3-8. <u>Excavation of Landfills and Contaminated Soils</u>. Excavation is a common technique used to move solid and thickened sludge materials. Where offsite treatment methods are to be used, excavation and transportation of the waste material will be required.

a. <u>Design and Construction Considerations</u>. Important factors that should be considered before excavation of a refuse site can begin are listed below.

(1) Density of solid waste in a landfill. Density is dependent on the composition of the waste and the degree of compaction achieved. Average densities of landfilled wastes generally range from 474 to 593 kg/m^3 (800 to 1,000 lb/yd^3) with moderate compaction.

(2) Settlement of the fill. As a result of decomposition of the waste and the addition of new waste material, settling of fine particles into voids between solid matter can occur.

(3) Bearing capacity of the fill. Bearing capacity is the ability to support foundations (and heavy equipment). Average values ranging from 23.9 KPa to 38.3 KPa (500 to 800 lb/ft^2) have been reported.

(4) Decomposition rate of waste. Most of the materials present in a refuse site will decompose. Decomposition of organic waste under anaerobic conditions predominantly occurs at the base of the site and can generate highly corrosive organic acids and toxic gases such as methane or hydrogen sulfide.

(5) Packaging of waste. Packaging of waste in barrels and tanks may present additional removal problems.

b. Mechanical Methods. Excavation of a landfill may be achieved by mechanical means. Typical excavation equipment includes draglines, backhoes, and clamshells.

(1) The dragline.

(a) A dragline excavator is a crane unit with a drag bucket connected by cable to the boom. The bucket is filled by scraping it along the top layer of soil toward the machine by a drag cable. The dragline can operate below and beyond the end of the boom.

(b) Maximum digging depth of a dragline is approximately equal to half the length of the boom, while digging reach is slightly greater than the length of the boom. Draglines are very suitable for excavating large land areas with loosely compacted soil.

(2) The backhoe.

(a) The backhoe unit is a boom or dipper stick with a hoe dipper attached to the outer end. The unit may be mounted on either crane-type or tractor equipment.

(b) The largest backhoe will dig to a maximum depth of about 13.7 m (45 feet). Deeper digging depth can be achieved by attaching long arms to one-piece booms or by adjusting the boom angle on two-piece booms.

(c) Some hydraulic backhoes having booms that can be extended up to 30.5 m (100 feet) or retracted for close work can be used to excavate, backfill, and grade.

(3) The clamshell. To achieve deeper digging depth, clamshell equipment must be used. A clamshell bucket is attached to a crane by cables. A clamshell excavator can reach digging depths greater than 30.5 m (100 feet).

c. Advantages and Disadvantages. Advantages and disadvantages of the excavation technique using dragline and backhoe are listed below.

Advantages	Disadvantages
Dragline	
Readily available	Difficult to spot bucket for scraping and dumping
Applicable for excavation of large area	Cannot backfill or compact

(Continued)

Advantages	Disadvantages
Easy to operate	Not applicable for digging depth more than 9.1 m (30 ft)
Backhoe	
Readily available	Not applicable for digging depth over 9.1 m (30 ft)
Easy to control the bucket and thus control width and depth of excavation	Cannot be extended beyond 30.5 m (100 ft)
Can excavate hard and compacted material	
More powerful digging action than dragline	
Can be used to backfill and compact	

3-9. Removal of Contaminated Sediments.

a. Background.

(1) Uncontrolled waste disposal sites may directly or indirectly contaminate bottom sediments deposited in streams, creeks, rivers, ponds, lakes, estuaries, and other bodies of water. Sediment contamination by waste disposal sites may occur along several different pathways. Contaminated soil may be eroded from the surface of hazardous waste disposal sites by natural run-off and subsequently deposited in nearby watercourses or sediment basins constructed downslope of the site. Also, existing sediments along stream and river bottoms may adsorb chemical pollutants that have been washed into the watercourse from disposal areas within the drainage basin. Similarly, contaminated ground water may drain to surface watercourses and the transported pollutants may settle into, or chemically bind with, bottom sediments. Another possible source of sediment contamination is direct leakage or spills of hazardous liquids from damaged or mishandled waste containers; spilled chemicals that are heavier and denser than water will sink to the bottom of natural waters, coating and mixing with sediments.

(2) Dredging serves the same basic function as mechanical excavation: removal of hazardous waste materials from improperly constructed or sited disposal sites for offsite treatment or disposal. Several types of dredges are commonly used, including hydraulic, pneumatic, and mechanical dredges. Dredged material management includes techniques for drying, physical processing, chemical treatment, and disposal. Plans to remove and treat contaminated sediments must be designed and implemented on a site-specific basis. An evaluation of the need for placing fill or dredged materials in waters of the United States or by alternate routes must be made in accordance with the 404 (b)(l) Guidelines (40 CFR Part 230). Discharge of fill or dredged materials will not be permitted if a practicable alternative having less adverse environmental impact exists.

(3) A knowledge of the physical properties and distribution of contaminated sediments is essential in selecting a dredging technique and in planning the dredging operation. Information on grain size, bed thickness, and source and rate of sediment deposition is particularly useful. Such information can be obtained through a program of bottom sampling or core sampling of the affected sediment.

b. Description and Application of Dredging Techniques.

(1) Hydraulic dredging.

(a) Available techniques for hydraulic dredging of surface impoundments include centrifugal pumping systems and portable hydraulic pipeline dredges. Centrifugal pumping systems utilize specially designed centrifugal pumps that chop and cut heavy, viscous materials as pump suction occurs. The special chopper impeller devices within these pumps allow high-volume handling of heavy sludges and other solids mixtures without the use of separate augers or cutters.

(b) Cutterhead pipeline dredges are widely used in the United States; they are the basic tool of the private dredging industry. Cutterhead dredges loosen and pick up bottom material and water, and discharge the mixture through a float-supported pipeline to offsite treatment or disposal areas. They are generally from 7.6 to 18.3 m (25 to 60 feet) in length, with pump discharge diameters from 152 to 508 mm (6 to 20 inches). There are two basic types of portable cutterhead dredges: the standard basket cutters (Figure 3-4) and the smaller specialty dredges that use a horizontal auger assembly and move only by cable and winch.

(c) For dredging surface impoundments deeper than 6.1 m (20 feet), the standard cutterhead dredge (Figure 3-5) is required. This type of dredge moves forward by pivoting about on two rear-mounted spuds (heavy vertical posts), which are alternately anchored and raised. The swing is controlled by winches pulling on cables anchored forward of the dredge (Figure 3-6). The rotating cutter on the end of the dredge ladder physically excavates material ranging from light silts to consolidated sediments or sludge, cutting a channel of variable width (depending on ladder length) as the dredge advances. For deep surface impoundments containing only soft, unconsolidated bottom materials, a variation of the standard cutterhead dredge--the suction pipeline dredge--can be used to dredge the impoundment. Suction dredges are not equipped with cutterheads, or they simply operate without cutterhead rotation; they merely suck the material off the bottom and, like most dredges, discharge the mixture through a stern-mounted pipeline leading to a disposal area.

(2) Low-turbidity hydraulic dredging.

(a) Low-turbidity dredging is any hydraulic dredging operation that uses special equipment (dredge vessels, pumps) or techniques to minimize the

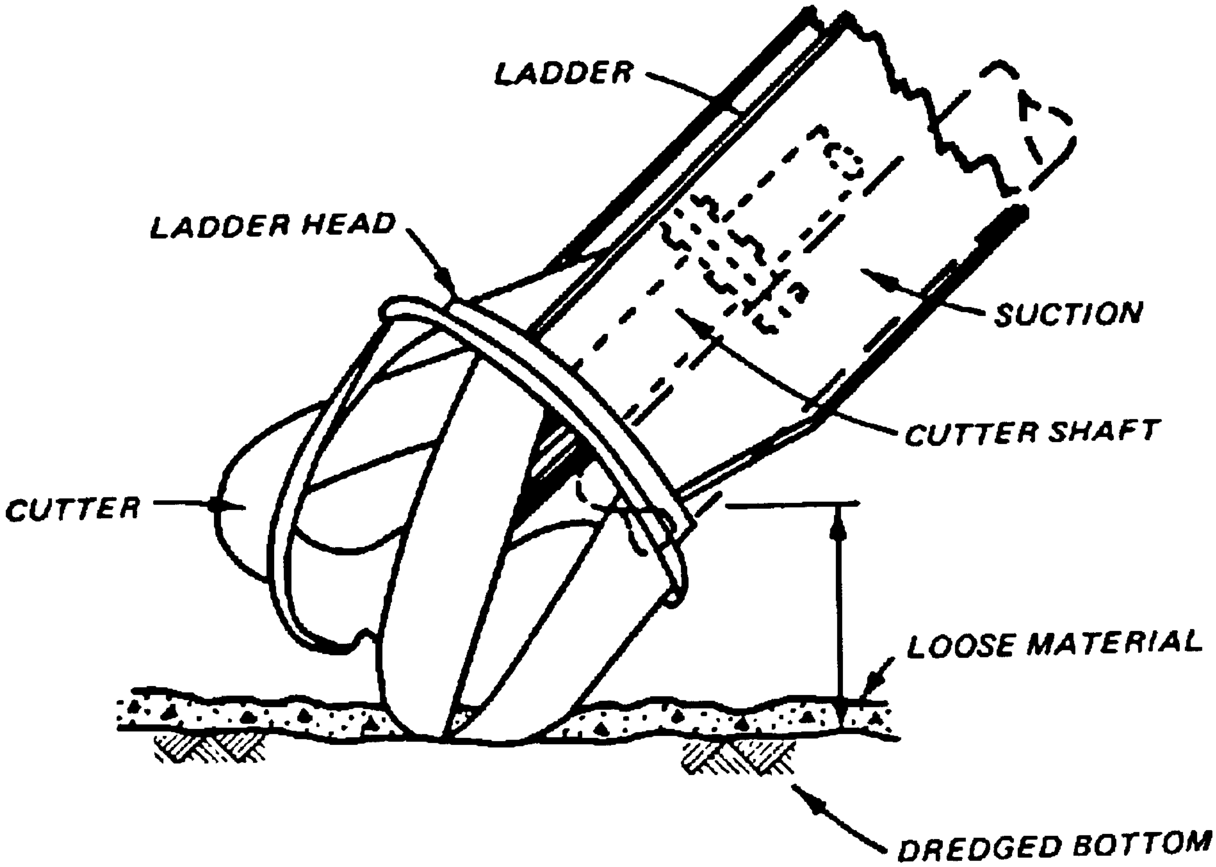


Figure 3-4. Standard Cutter Assembly, Spiral Basket Cutter

resuspension of bottom materials and subsequent turbidity that may occur during the operation. Conventional hydraulic dredging may cause excessive agitation and resuspension of contaminated bottom materials, which decreases sediment removal efficiency and which may lead to downstream transport of contaminated materials, thereby exacerbating the original pollution. Low-turbidity hydraulic dredging systems include small specialty dredge vessels, suction dredging systems, and conventional cutterhead dredges that are modified using special equipment or techniques for turbidity control.

(b) The Mud Cat dredge utilizes a submerged pump mounted directly behind a horizontal auger to handle highly viscous chemical sludges or thick, muddy sediments. The Mud Cat MC-915 (Figure 3-7) can remove sediment in a 2.7 m (9-foot-wide) swath, 457 mm (18 inches) deep, at depths as great as 4.6 m (15 feet) and as shallow as 508 mm (21 inches). The horizontal auger can be tilted left and right to a 45-degree angle to accommodate sloping sides of impoundments. With an auger wheel attachment, the Mud Cat can dredge in lined impoundments without damaging the liner. Two people are required to operate the 9.1 m (30-foot-long) machine, which moves by winching itself in either direction along a taut, fixed cable at average operating speeds of

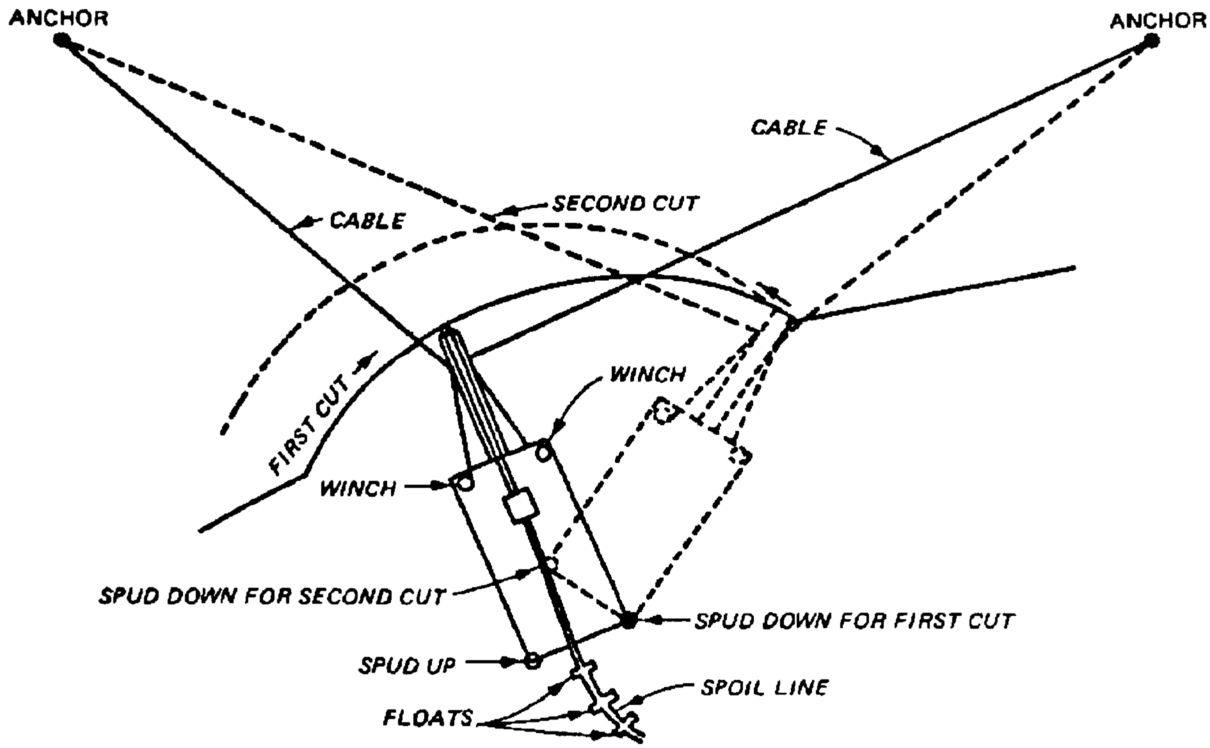


Figure 3-5. Standard Cutterhead Dredge Operation

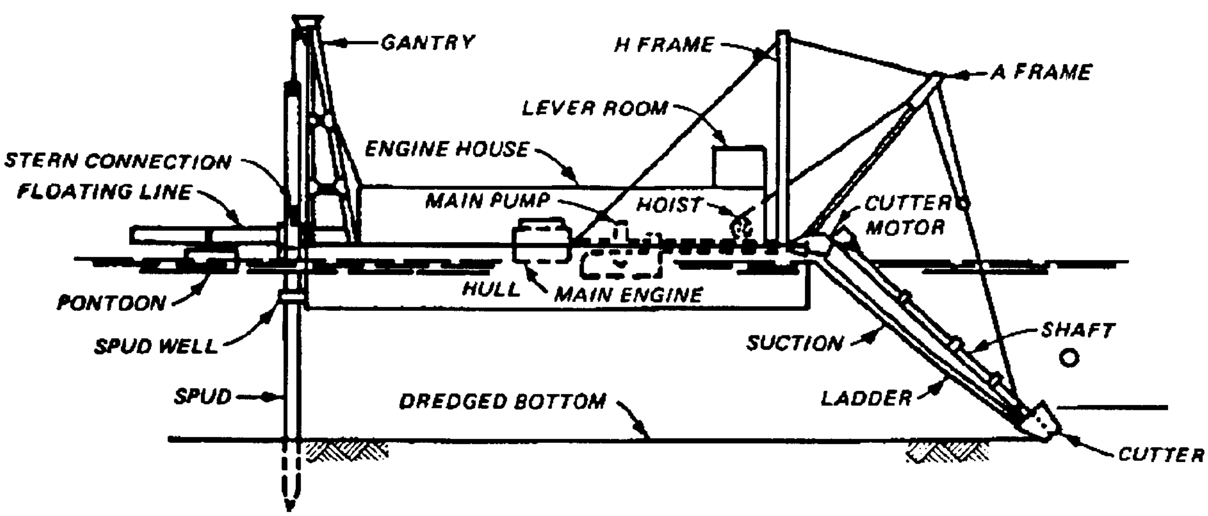


Figure 3-6. Standard Cutterhead Dredge Vessel

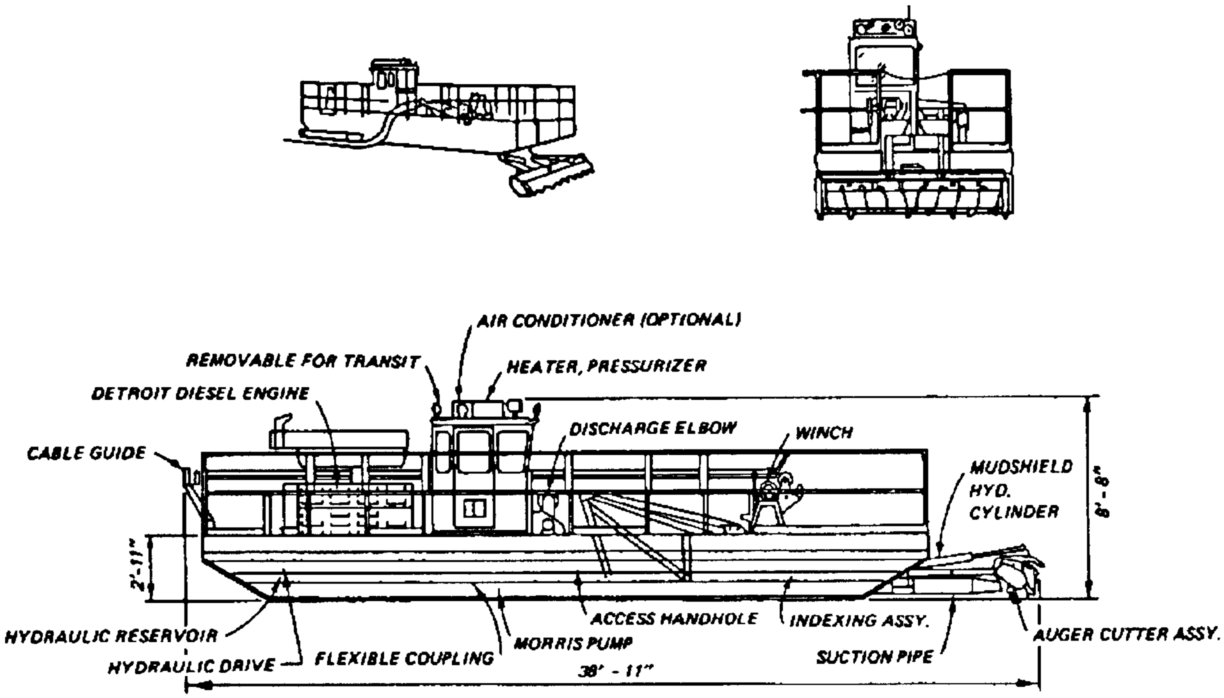


Figure 3-7. Views of the Mud Cat MC-915 Dredge

41 to 61 mm/s (8 to 12 feet per minute). The Mud Cat has a retractable mudshield, which surrounds the cutter head, entrapping suspended material, increasing suction efficiency, and minimizing turbidity. The Mud Cat can discharge approximately 95 ℓ/s or 5.7 m^3/min (1,500 gallons per minute) of slurry with 10 to 30 percent solids through an 203 mm (8-inch) pipeline and, depending on site-specific conditions, can remove up to 92 m^3/hr (120 cubic yards per hour) of solids. The Mud Cat dredge was 95 to 99 percent efficient in removing sediments and simulated hazardous materials from impoundment bottoms in field tests conducted for the EPA.

(c) A Japanese suction dredge, the “Clean Up” (Figure 3-8), uses a hydraulically driven, ladder-mounted submerged centrifugal pump to “vacuum” muddy bottom sediments (fine grained; high water content) from depths as great as 22.9 m (75 feet), with very low turbidity. This system can pump very dense mixtures 40 to 50 percent solids by volume at constant flow rates as great as 526 ℓ/s or 1895 m^3/hr (500,000 gallons per hour), removing up to 688.5 m^3 (900 cubic yards) of sediment per hour. A dredge vessel equipped with this pumping system may be used to remove contaminated sediments from large rivers or harbors in depths as shallow as 4.9 m (16 feet), with minimal pollution of the surrounding environment from dredgegenerated turbidity.

(d) Another Japanese dredging system for removal of high-density sludges is called the “oozer pump” which may have applications in very deep bodies of water such as large rivers or harbors. This system utilizes vacuum

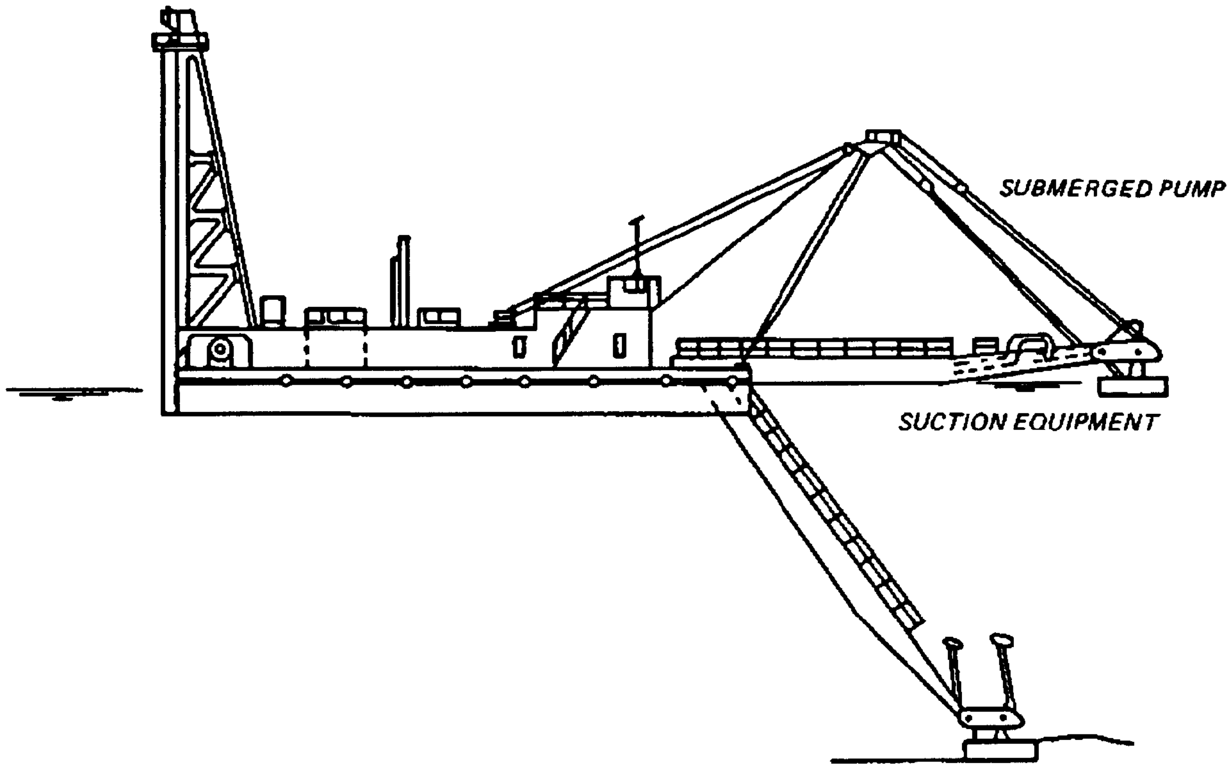


Figure 3-8. The Japanese Suction Dredge "Clean Up"

suction and air compression to efficiently remove muddy sediments (silt and clay) and sludges with low turbidity.

(e) A typical centrifugal pumps system (Figure 3-9) is 2.4 m (8 feet) wide, 4.3 m (14 feet) long, approximately 2.1 m (7 feet) high, and weighs about 2730 kg (3 tons); its 75 kw (100-horsepower) motor can pump up to 76 L/S or 4.5 m^3/min (1,200 gallons per minute) of 15 to 20 percent solids from depths up to 4.6 m (15 feet).

(f) Other specialty low turbidity dredges include the bucket-wheel-type dredge, recently developed by Ellicott Machine Corporation, that is capable of digging highly consolidated material and has the ability to control the solids content in the slurry stream. The Delta Dredge and Pump Corporation has also developed a small portable unit that has high solids capabilities. The system uses a submerged 305 mm (12-inch) pump coupled with two counter-rotating, low-speed, reversible cutters.

(3) Mechanical dredging.

(a) Mechanical dredging of contaminated sediments should be considered under conditions of low, shallow flow. Dredging should be used in conjunction with stream diversion techniques to hydraulically isolate the area of sediment

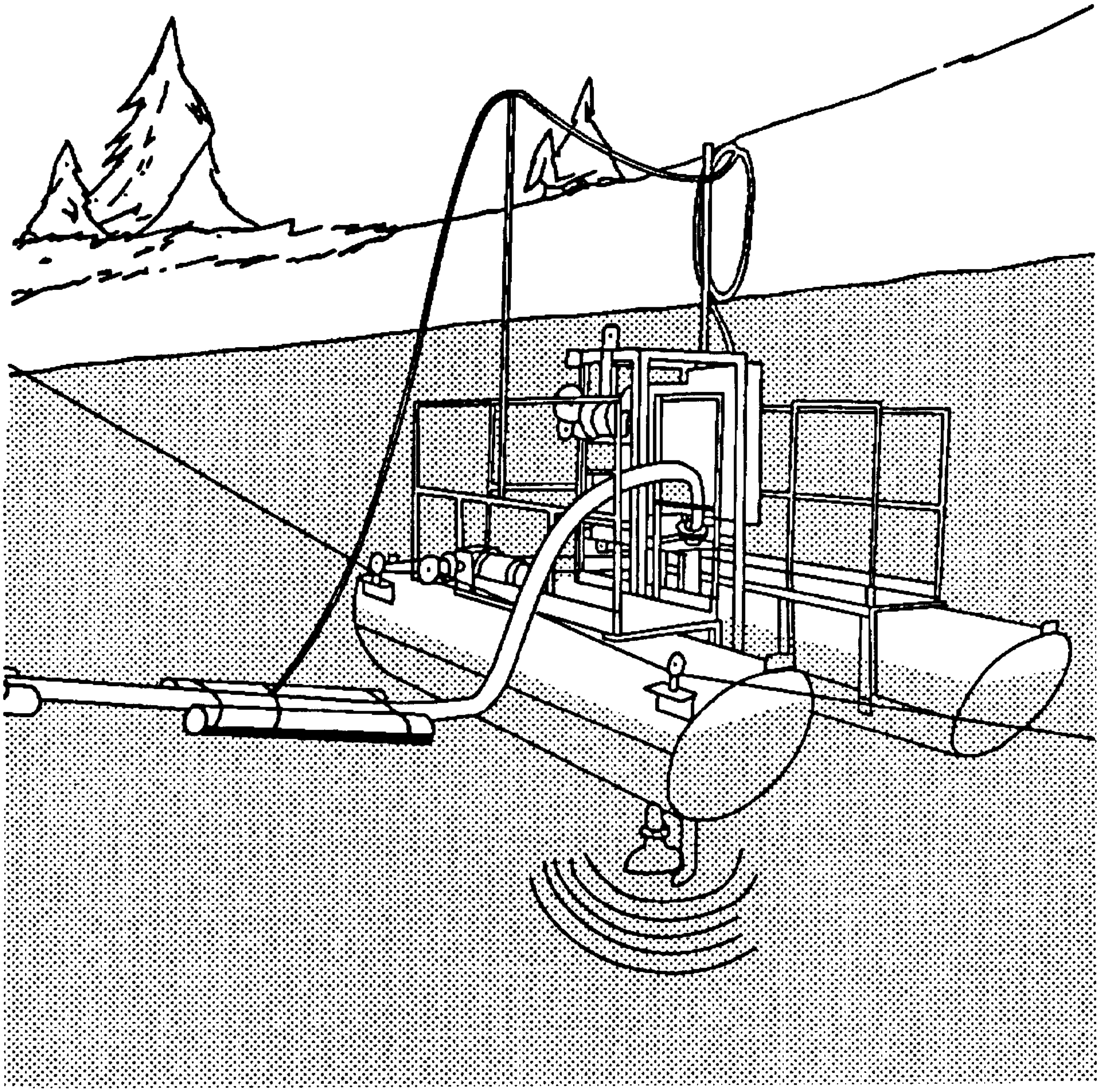


Figure 3-9. Portable Centrifugal Pump System for Lagoon Dredging

removal. Under any other conditions mechanical excavation with draglines, clamshells, or backhoes may create excessive turbidity and cause uncontrolled transport of contaminated sediments further downstream. Stream diversions with temporary cofferdams can be followed by dewatering and mechanical dredging operation for streams, creeks, or small rivers. Mechanical excavation can also be used to remove contaminated sediments that have been eroded from disposal sites during major storms and deposited in floodplains or along riverbanks above the level of base flow.

(b) For streams and rivers that are relatively shallow and whose flow velocity is relatively low, backhoes, draglines or clamshells can be used to excavate areas of the streambed where sediments are contaminated. The excavated sediments can be loaded directly onto haul vehicles for transport to a predesignated disposal area; however, the excavated material must be sufficiently drained and dried before transport. Backhoe and dragline operation requires a stable base from which to work. For these reasons, direct mechanical dredging of contaminated sediments in streams is not recommended except for small streams with stable banks, slow and shallow flow, and underwater structures, and where contaminated sediments are relatively consolidated and easily drained.

(c) A more efficient mechanical dredging operation with broader application involves stream or river diversion with cofferdams, followed by dewatering and excavation of contaminated sediments. Such an operation may prove quite costly; however, there is little chance of stirring up sediments and creating downstream contamination. Efficiency of sediment removal is much greater by this method than by instream mechanical dredging without diversion of flow.

(d) Sheet-pile cofferdams may be installed in pairs across streams to temporarily isolate areas of contaminated sediment deposition and allow access for dewatering and excavation (Figure 3-10). Alternatively, a single curved or rectangular cofferdam may be constructed to isolate an area along one bank of the stream or river (Figure 3-11); this method only partially restricts natural flow and does not necessitate construction of a temporary diversion (bypass) channel to convey entire flow around the area of excavation, as the first method does.

c. <u>Design and Construction Considerations of Dredging Techniques</u>.

(1) The selection of dredging equipment or pumping systems for the removal of contaminated materials will depend largely on manufacturer specifications for a given dredge vessel or pump system. Important selection criteria that will vary from site to site are:

(a) Surface area and maximum depth of the impoundment.

(b) Total volume of material to be dredged.

(c) Physical and chemical nature of sediments.

(d) Pumping distance and terminal elevation (total head).

(e) Presence of bottom liner in impoundment.

(f) Type and amount of aquatic vegetation.

(g) Power source for dredge.

(h) Ease of access and size and weight limits of roads.

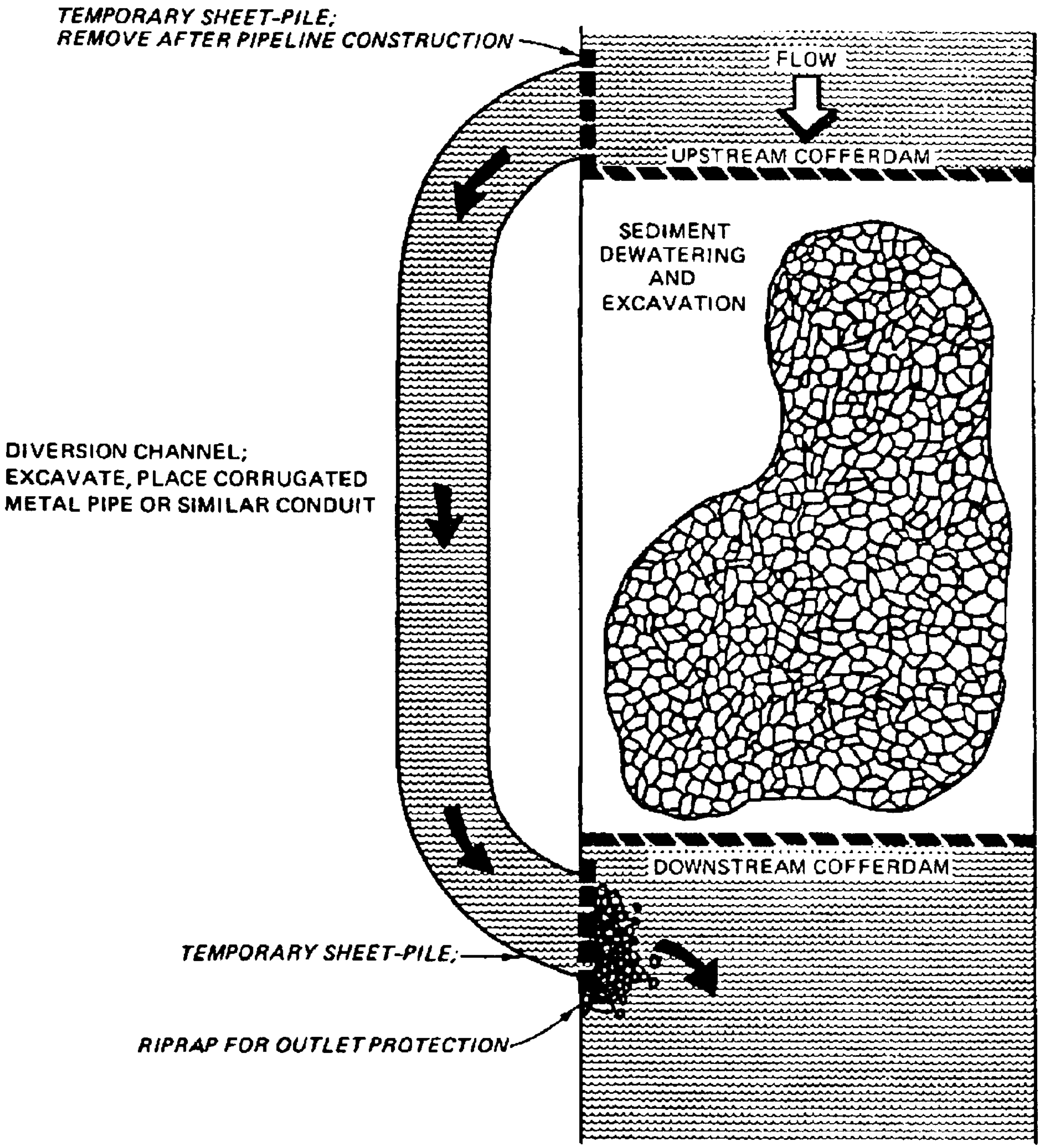


Figure 3-10. Streamflow Diversion for Sediment Excavation Using Two Cofferdams and Diversion Channel

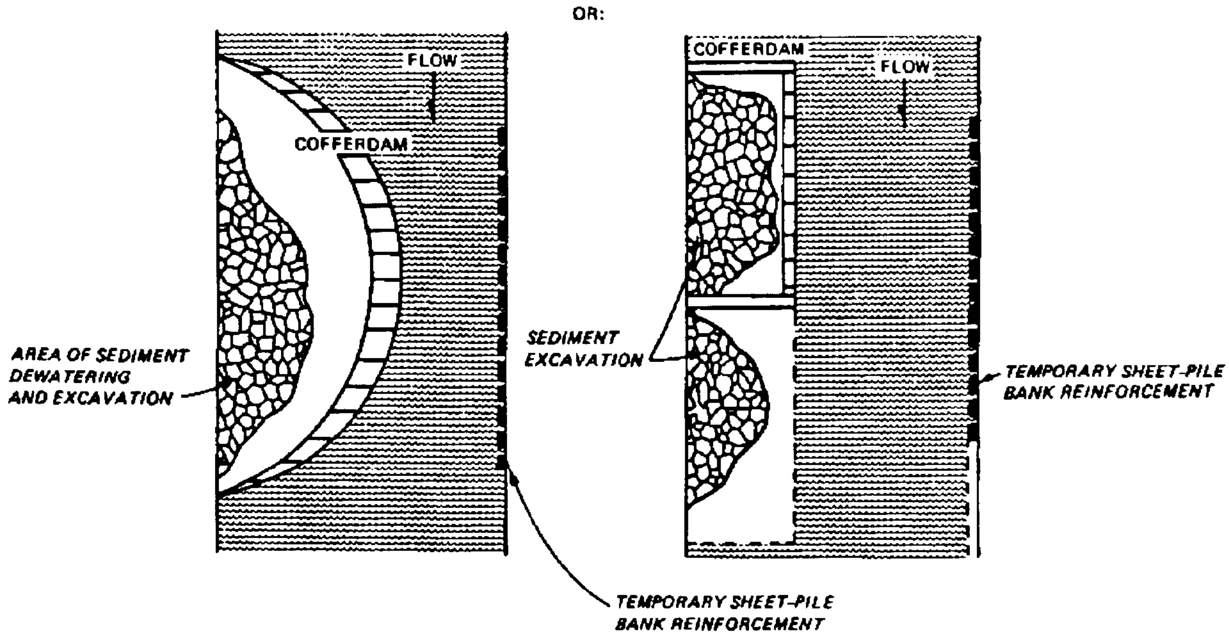


Figure 3-11. Streamflow Diversion for Sediment Excavation Using Single Cofferdam (Source: EPA 1982)

(2) All criteria must be considered before selection of a pumping system or dredge vessel of the appropriate size, efficiency, and overall capabilities can be made. The centrifugal pumps used in pumping systems or dredge vessels have a rated discharge capacity based on maximum pump speed (in revolutions per minute, rpm) and a given head against which they are pumping. The total head against which pumps must work is affected by the depth of dredging, the distance over which the material is pumped, and the terminal elevation of the discharge pipeline in relation to the water level within the impoundment.

(3) When preparing dredging contracts for contaminated sediment removal where turbidity control is essential, contract provisions should specify the use of special low-turbidity dredge vessels or auxiliary equipment and techniques designed to minimize turbidity generation. The bidder should be made to specify minimum sediment removal volumes and maximum allowable turbidity levels in the downstream environment to ensure an effective dredging operation.

(4) During dredging of stream or river sediments, agitation of the bed deposits during excavation may generate a floating scum of contaminated debris on the water surface, particularly if the chemical contaminant is oily or greasy in nature. The installation of a silt curtain downstream of the dredging site will function to trap any contaminated debris so generated; the debris can then be collected through skimming. Similarly, silt curtains can be employed to minimize downstream transport of contaminated sediments. A schematic of a silt curtain is shown in Figure 3-12. It is constructed of

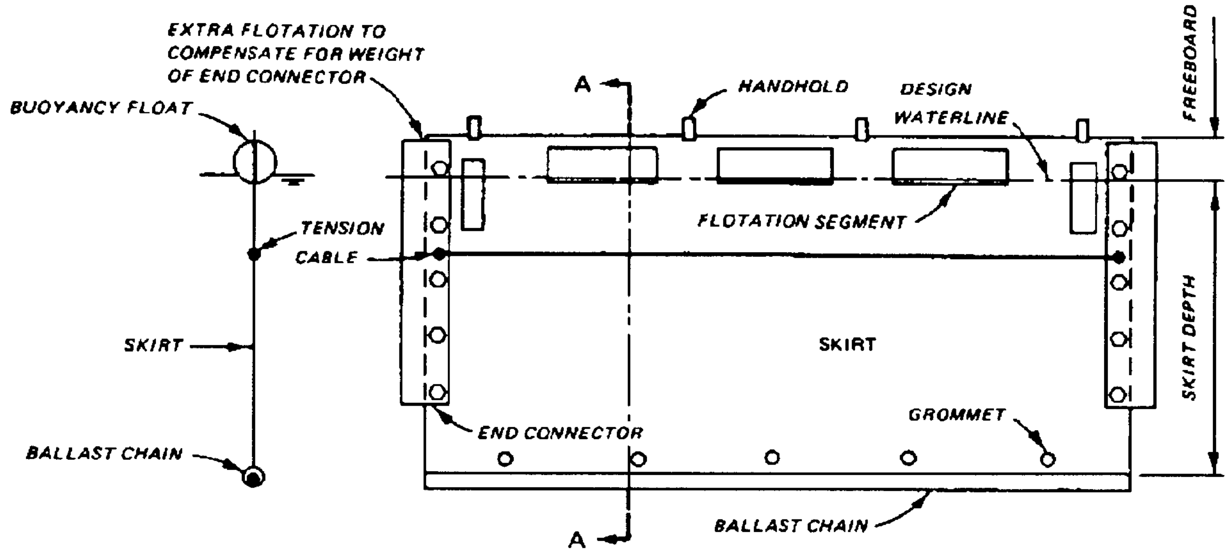


Figure 3-12. Construction of a Typical Center Tension Silt Curtain Section

nylon-reinforced polyvinyl chloride and manufactured in 27.4 m (90-foot) sections that can be joined together in the field to provide the specified length. Silt curtains are usually employed in U-shaped or circular configurations, as shown in Figure 3-13. Silt curtains are not recommended for flow velocities greater than 0.46 m/s (1.5 feet per second).

(5) Sheet-pile cofferdams are generally constructed of black steel sheeting, in thickness from 5.6 to 2.7 mm (5 to 12 gage) and in lengths from 1.2 to 12.2 m (4 to 40 feet). For additional corrosion protection, galvanized or aluminized coatings are available. Cofferdams may be either single walled or cellular, and can be earth-filled in sections. Single-wall cofferdams may be strengthened by an earth fill on both sides. Cellular cofferdams consist of circular sheet-pile cells filled with earth, generally a mixture of sand and clay. Single-wall sheet-pile cofferdams are most applicable for shallow water flows. For depths greater than 1.5 m (5 feet), cellular cofferdams are recommended.

(6) Mechanical excavation of dewatered, contaminated sediments can be accomplished with backhoes, draglines, or clamshells. Mechanical dredging output rates will vary depending on the size and mobility of the equipment, and on site-specific conditions such as available working area. Excavated sediments can be loaded directly into haul trucks onsite for transport to special disposal areas. Haul truck loading beds should be bottom sealed and covered with a tarpaulin or similar flexible cover to ensure that no sediments are lost during transport.

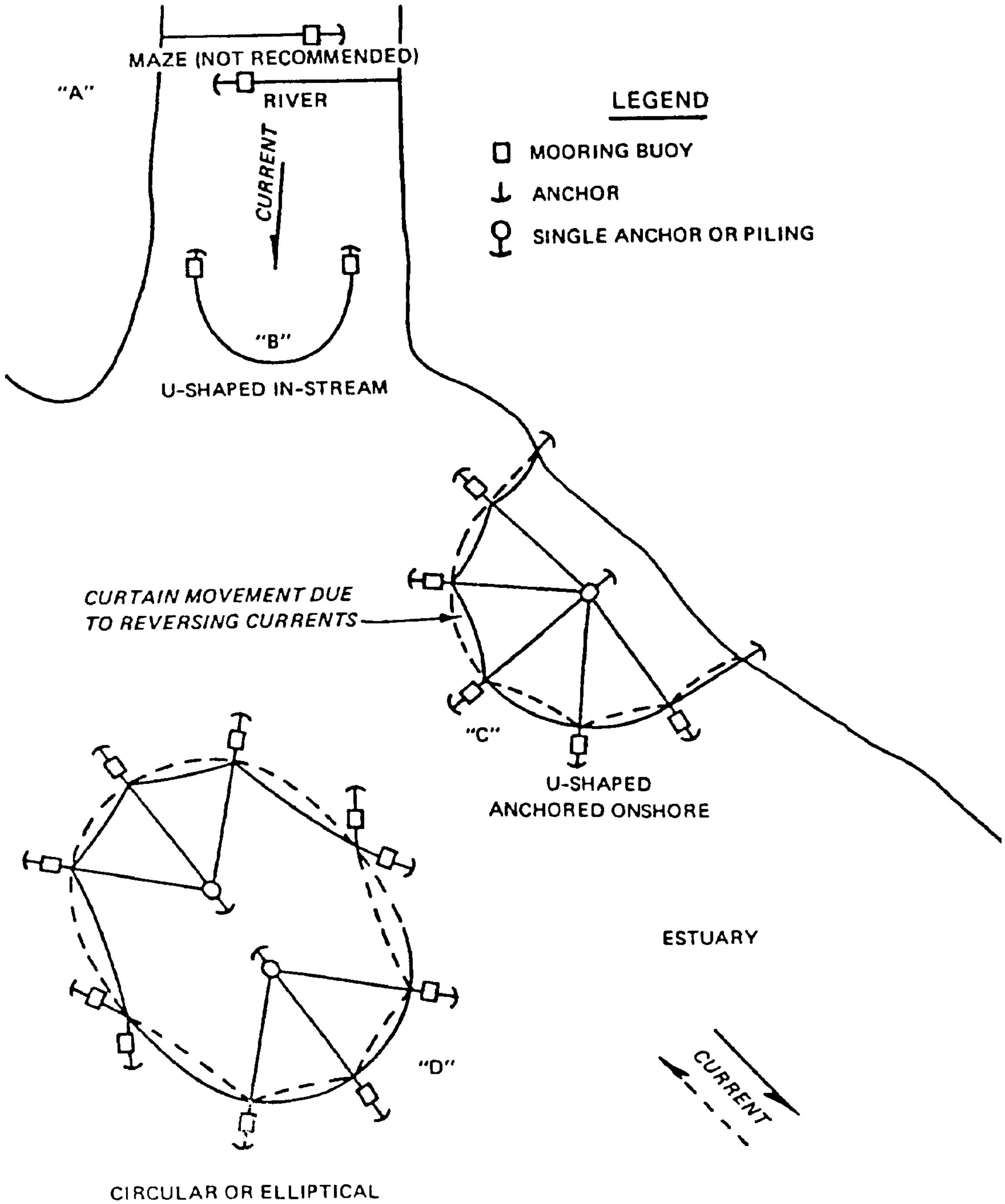


Figure 3-13. Typical Silt Curtain Deployment Configurations

d. Advantages and Disadvantages.

(1) The main disadvantage associated with hydraulic removal of materials from surface impoundments is the necessity of locating and/or constructing dewatering/disposal areas (or treatment facilities) within economical distances of the dredging site. Containment facilities must be able to handle large volumes of dredged material in a liquid slurry form, unless dewatering is performed prior to transport. Advantages and disadvantages of hydraulic dredging of surface impoundments are as follows:

Advantages	Disadvantages
Efficient removal of solids/water mixtures from impoundments	Necessitates locating dredge material management facilities (dewatering, disposal, treatment) nearby
Removes hazardous materials in readily processed form (slurry)	Necessitates high volume handling of solids/water mixtures
Suitable for removal of materials from surface impoundments in wide range of consistencies- -from free-flowing liquids to consolidated/ solidified sludges	May require booster pumps for long-distance transport of dredged slurries
Utilizes well-established, widely available technology	Mobilization and demobilization may be time-consuming and costly
	Cannot remove large items (such as drums)

(2) The advantages and disadvantages of direct instream mechanical dredging are listed below:

Advantages	Disadvantages
May be cost-effective for slow, shallow streams or sediments in dry streambeds or flood-plains	Generates excessive turbidity; may cause downstream transport of sediments
Also effective for small, isolated pools or ponds containing contain-mated sediments	Only feasible for low, shallow flows with stable streambanks and consolidated sediments
Barge-mounted operations may be used for large rivers	May require special dewatering methods (clamshell) lift and drain over haul (trucks)
	Efficiency of removal generally poor
	Generally not recommended for handling contaminated sediments instream

(3) Cofferdam diversion streamflow, with subsequent dewatering and mechanical excavation of contaminated sediments, is addressed below.

Advantages	Disadvantages
High efficiency of removal; low turbidity	May be quite costly for deep, wide flows and sites requiring diversion pipeline
Involves well-established construction techniques	Not feasible for fast stream flows (greater than 0.61 in/s (2 feet per second))
Structures easily removed and transported	Not recommended for flows deeper than 3 m (10 feet)
Cost-effective for slow-flowing streams and rivers with favorable access (stable banks; open areas)	Sediment dewatering may be required
	Access for mechanical excavation equipment may be difficult
	May require large excavation and loading area
	Transportation costs may be excessive (remote areas)
	Geologic substrate may prevent sheet-pile drive

3-10. Decontamination of Structures. Decontamination of structures is a common requirement at sites where the uncontrolled release of hazardous substances has occurred. A variety of techniques are available for decontamination surfaces and structures.

a. Decontamination of Surfaces.

(1) Absorption is widely used in industrial settings to clean up chemical and other liquid spills and is most applicable immediately following liquid contaminant spills. Contaminants rapidly penetrate most surfaces, and absorbents act to contain them. Depending on the surface and time elapsed since the spill, further decontamination procedures may have to be employed.

(2) Acid etching of a contaminated surface is used to promote corrosion and removal of the surface layer. Muriatic acid (hydrochloric acid) is used to remove dirt and grime from brick building surfaces in urban areas and to clean metal parts (e.g., pickle liquors from metal finishing operations). The resulting contaminated debris is then neutralized. Thermal or chemical treatment of the removed material may be required to destroy the contaminant before disposal. Although this technique is not known to have been applied to chemically contaminated building surfaces, it is believed to have good potential.

(3) Bleaching formulations (usually strong oxidants) are applied to a contaminated surface, allowed to react with contaminants, and removed. Application usually occurs in conjunction with other decontamination efforts, such as the use of absorbents and/or water-washing. Bleach has been used as a decontaminant against mustard, G and V chemical agents, and (experimentally) organophosphorus pesticides.

(4) Drilling and spalling can remove up to 5 centimeters of contaminated surface material from concrete or similar materials by drilling holes 2.5 to 4 centimeters in diameter approximately 7.5 centimeters deep. The spalling tool bit is inserted into the hole and hydraulically spreads to spall off the contaminated concrete. The technique can achieve deeper penetration (removal) of surfaces than other surface-removal techniques, and it is good for large-scale applications. The treated surface is very rough and coarse, however, and may require resurfacing (i.e., capping with concrete). The drilling and spalling method has been used in the decommissioning of nuclear facilities.

(5) Dusting/vacuuming/wiping is simply the physical removal of hazardous dust and particles from building and equipment surfaces by common cleaning techniques. Variations include vacuuming with a commercial or industrial-type vacuum; dusting off surfaces such as ledges, sills, pipes, etc., with a moist cloth or wipe; and brushing or sweeping up hazardous debris. Dusting and vacuuming are applicable to all types of particulate contaminants, including dioxin, lead, PCB*s, and asbestos fibers, and to all types of surfaces. Dusting/vacuuming/wiping is the state-of-the-art method for removing dioxin-contaminated dust from the interior of homes and buildings.

(6) Flaming refers to the application of controlled high temperature flames to contaminated noncombustible surfaces, providing complete and rapid destruction of all residues contacted. The flaming process has been used by the Army to destroy explosive and low-level radioactive contaminants on building surfaces. Its applicability to other contaminants is not well known. This surface decontamination technique is applicable to painted and unpainted concrete, cement, brick, and metals. Subsurface decontamination of building materials may be possible, but extensive damage to the material would probably result. This technique can involve high fuel costs.

(7) Fluorocarbon extraction of contaminants from building materials involves the pressure-spraying of a fluorocarbon solvent onto the contaminated surface followed by collection and purification of the solvent. RadKleen is an example of a commercial process that uses Freon 113 (l,l,2-trichloro-1,2,2-trifluoroethane or $C_2C1_3F_3$) as the solvent. The RadKleen process is currently used for cleaning radioactive material from various surfaces. It has been applied to chemical agents on small objects, and thus field capability has been demonstrated. Studies have been conducted for agent-contaminated clothing materials, such as polyester-cotton, Nomex, butyl rubber gloves, and charcoal-impregnated cloth. Although this method has not been demonstrated for removing contaminants from building surfaces, it looks very promising.

(8) Gritblasting is a removal technique in which abrasive materials (such as sand, alumina, steel pellets, or glass beads) are used for uniform removal of contaminated surfaces from a structure. Gritblasting has been used since 1870 to remove surface layers from metallic and ceramic objects and is currently used extensively. For example, sandblasting is commonly used to clean the surfaces of old brick and stone buildings. Gritblasting is applicable to all surface contaminants except some highly sensitive explosives such as lead azide and lead styphnate. This method is applicable to all surface materials except glass, transite, and Plexiglas.

(9) Hydroblasting/waterwashing refers to the use of a high-pressure (3500 to 350,000 kPa) water jet to remove contaminated debris from surfaces. The debris and water are then collected and thermally, physically, or chemically decontaminated. Hydroblasting has been used to remove explosives from projectiles, to decontaminate military vehicles, and to decontaminate nuclear facilities. Hydroblasting also has been employed commercially to clean bridges, buildings, heavy machinery, highways, ships, metal coatings, railroad cars, heat exchanger tubes, reactors, piping, etc. Off-the-shelf equipment is available from many manufacturers and distributors.

(10) Microbial degradation is a developing process whereby contaminants are biologically decomposed by microbes capable of utilizing the contaminant as a nutrient source. Conceptually, microbes are applied to the contaminated area in an aqueous medium and allowed to digest the contaminant over time; the microbes are then destroyed chemically or thermally and washed away. Microbial degradation as a building decontamination technique has not been demonstrated.

(11) Painting/coating/stripping includes the removal of old layers of paint containing high levels of toxic metals such as lead, the use of fixative/stabilizer paint coatings, and the use of adhesive-backed strippable coatings.

(a) In the first technique, paint containing lead in excess of 0.06 percent is removed from building surfaces by commercially available paint removers and/or physical means (scraping, scrubbing, waterwashing). Resurfacing or further decontamination efforts may be necessary.

(b) The second technique involves the use of various agents as coatings on contaminated surfaces to fix or stabilize the contaminant in place, thereby decreasing or eliminating exposure hazards. Potentially useful stabilizing agents include molten and solid waxes, carbo-waxes (polyoxyethylene glycol), saligenin (",2-dihydroxytoluene), organic dyes, epoxy paint films, and polyester resins. The stabilized contaminants can be left in place or removed later by a secondary treatment. In some cases, the stabilizer/fixative coating is applied in situ to desensitize a contaminant such as an explosive residue and prevent its reaction or ignition during some other phase of the decontamination process.

(c) In the third technique, the contaminated surface is coated with a polymeric mixture. As the coating polymerizes, the contaminant becomes entrained in the lattice of or attached to the polymer molecules. As the polymer layer is stripped or peeled off, the residue is removed with it. It may be possible, in some cases, to add chemicals to the mixture to inactivate the contaminants.

(12) Sealing is the application of a material such as paint that penetrates a porous surface and immobilizes contaminants in place. One example is K-20, a newly developed commercial product. The effectiveness of this product is not fully known. Although it acts more as a barrier than a detoxifier, K-20 may facilitate chemical degradation as well as physical separation of some contaminants.

(13) Photochemical degradation refers to the process of applying intense ultraviolet light to a contaminated surface for some period of time. Photodegradation of the contaminant follows. In recent years, attention has been focused on this method because of its usefulness in degrading chlorinated dioxins (TCDD in particular). Three conditions have been found to be essential for the process to proceed: the ability of the compound to absorb light energy, the availability of light at appropriate wavelengths and intensity, and the presence of a hydrogen donor.

(14) Scarification is a method that can be used to remove up to an inch of surface material from contaminated concrete or similar materials. The scarifier tool consists of pneumatically operated piston heads that strike the surface, causing concrete to chip off. This technique has been used in the decommissioning of nuclear facilities and in the cleanup of military arsenals.

(15) Solvent washing refers to the application of an organic solvent (e.g., acetone) to the surface of a building to solubilize contaminants. This technique has not yet achieved widespread use in building decontamination although it is beginning to be used in the decommissioning of nuclear facilities. The method needs further development in application, recovery, collection, and efficiency. The hot solvent soaking process has been shown to be effective in decontamination of PCB-contaminated transformers.

(16) Steam cleaning physically extracts contaminants from building walls and floors and from equipment. The steam is applied through hand-held wands or automated systems, and the condensate is collected in a sump or containment area for treatment. This method is currently used by explosives handling and manufacturing facilities. It has also been used to remove dioxin-contaminated soil from vehicles and drilling equipment.

b. Decontamination of Solid Materials and Buildings.

(1) Demolition of a building, structure, or piece of equipment includes complete burndown, controlled blasting, wrecking with balls or backhoe-mounted rams, rock splitting, sawing, drilling, and crushing. Many of these techniques have been employed for nuclear facility decontamination and for the cleanup of military arsenals.

(2) Dismantling refers to the physical removal of selected structures (such as contaminated pipes, tanks, and other process equipment) from buildings or other areas. It can be the sole decontamination activity (e.g.,

removal of contaminated structures from an otherwise clean building), or it can be used in the initial stage of a more complex building decontamination effort (e.g., removal of structures prior to flaming, hydroblasting, or other cleanup techniques).

(3) Asbestos abatement consists of four techniques: removal, encapsulation, enclosure, and special operations (e.g., maintenance and monitoring). In removal operations, all friable asbestos-containing building materials are completely removed to eliminate the release of asbestos fibers into the air. The other techniques leave the asbestos fibers in place but limit potential exposure levels through various treatment, maintenance, and inspection procedures.

(4) Encapsulation/enclosure physically separates contaminants or contaminated structures from building occupants and the ambient environment by means of a barrier. An encapsulating or enclosing physical barrier may take different forms; among them are plaster epoxy and concrete casts and walls. Acting as an impenetrable shield, a barrier keeps contaminants inside and away from clean areas, thereby alleviating the hazard. As a result, contamination of part of a structure will not result in the contamination of adjacent areas. Encapsulation has been used on damaged asbestos insulation, leaky PCB-contaminated electrical transformers, and open maintenance pits and sumps contaminated by heavy metals.

(5) Vapor-phase solvent extraction is a method in which an organic solvent with a relatively low boiling point (such as methyl chloride or acetone) is heated to vaporization and allowed to circulate in a contaminated piece of equipment or an enclosed area. The vapors permeate the contaminated materials, where they condense, solubilize contaminants, and diffuse outward. The contaminant-laden liquid solvent is collected in a sump and treated to allow recycling of the solvent. This method has not yet been applied to building decontamination, although it is believed to have good potential.

c. Data Requirements. Figure 3-14 summarizes the strategy for dealing with building decontamination, including guidance and information for selecting the least costly method that is technologically feasible and that will effectively reduce contamination to predetermined levels.

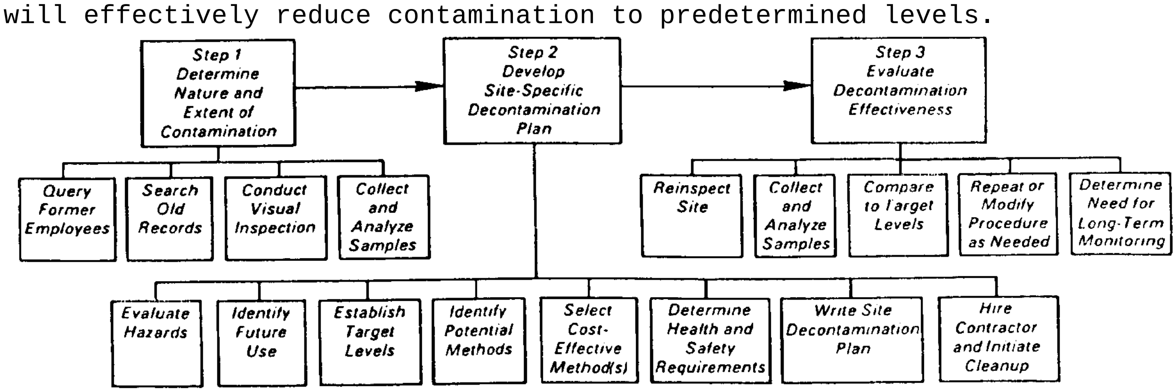


Figure 3-14. Flow Diagram for Developing a Structural Decontamination Strategy

(1) Sampling methods for determining the type and degree of contamination existing on building/structure/equipment surfaces, both before and after cleanup efforts, are poorly developed, documented, and verified. Similarly, subsurface sampling techniques (such as corings) or determining the depth of contamination in porous substances (such as concrete or wood floors) have not been adequately developed and documented. Although "wipe tests" are often referred to in site records, the actual methodology used is rarely described in enough detail to allow simulation or reproduction by others, and the technique itself is known to be inadequate for quantitatively transferring contaminants from surfaces to wipes or swabs.

(2) The applicability and effectiveness of decontamination techniques for treating various contaminant/structural material combinations encountered at Superfund sites have not been fully explored. For example, the degree to which steam cleaning removes dioxin-contaminated soil particles from drilling augers has not been established, even though this method is routinely used to clean equipment at dioxin-contaminated sites.

(3) The individual methods described above should be used as a general guide in evaluating the potential of each technique on a site-specific basis for efficiency, wastes generated, equipment and support facilities needed, time and safety requirements, structural effects, and costs. Also, each method or combination of methods should be pretested in the laboratory or at the site before full-scale implementation to determine the effectiveness of the strategy.

(4) A formal, systematic approach for determining acceptable levels of contaminants remaining in and on building and equipment surfaces does not currently exist. As a result, guidance on how clean is clean and the establishment of target levels must continue to be addressed case by case.

d. Design Criteria. There are no established design criteria for decontamination of structures. Specification of appropriate cleanup strategies depends highly on the professional judgment of the designer.

3-11. Decontamination of Miscellaneous Media. Sanitary sewers located downgradient from uncontrolled hazardous waste disposal sites may become contaminated by infiltration of leachate or polluted ground water through cracks, ruptures, or poorly sealed pipe joints. Typically the vitrified clay pipes (VCP) commonly used for gravity sewers are susceptible to cracking from root intrusion or settling. The interior cleaning of contaminated pipes will facilitate the location of cracks and joint failures which ultimately must be sealed to prevent further infiltration of contaminated soil and water. Available sewer-cleaning techniques include mechanical scouring, hydraulic scouring and flushing, bucket dredging, suction cleaning with pumps or vacuums, chemical absorption, or a combination of these methods. Manholes, flushing inlets, and unplugged residential service connections provide access points to sewers.

a. Mechanical Scouring. This is an effective method to remove pipeline obstacles such as roots, stones, greases, sludges, and corrosion modules.

Solidified masses of toxic chemical precipitates can also be removed by mechanical scouring. Mechanical scouring techniques include the use of power rodding machines ("snakes"), which pull or push scrapers, augers, or brushes through the sewer line. "Pigs" are bullet-shaped plastic balls lined with scouring strips that are hydraulically propelled at high velocity through water mains to scrape the interior pipe surface.

b. Hydraulic Scouring. Contaminated sewer lines can be cleaned by running high-pressure fire hoses through manholes into the sewer and flushing out sections. Hydraulic scouring is often used after mechanical scouring devices have cleared the line of solid debris or loosened contaminated sediments and sludges coating the interior surface of the pipe. When using hydraulic scouring techniques large volumes of contaminated water may be produced.

c. Bucket Dredging and Suction Cleaning. A bucket machine can be used to remove grit or contaminated soil from a sewer line. Power winches are set up over adjacent manholes with cable connections to both ends of the collection bucket. The bucket is then pulled through the sewer line until loaded with debris. The same technique can also be used to pull "sewer balls" or "porcupine scrapers" through obstructed sewer lines. Suction devices such as pumps or vacuum trucks may be used to clean sewer lines of toxic liquids and debris.

Section II. Contaminated Ground-Water Plume Management

3-12. Ground-Water Pumping Systems. Two common ground-water pumping systems use either wellpoints or extraction/injection wells.

3-13. Wellpoint Systems. Wellpoint systems are generally used to control ground-water levels or flow patterns at construction sites. They are inexpensive to install and use techniques and equipment that are readily available. Major disadvantages are the requirement for maintenance and the energy used for pumping.

a. Applications.

(1) Wellpoint systems may be used to lower the water table or to dewater a selected area. They consist of a series of wellpoints with one or more pumping systems and can serve a variety of purposes. The withdrawn water can be discharged with or without further treatment.

(2) These systems are generally used at sites with relatively shallow water tables and fairly permeable soils. In general, if the water table is near the surface and is to be lowered to a depth of 6.1 m (20 feet) or less, wellpoints and suction pumps can be employed. If deeper drawdown is needed, a well system using jet or submersible pumps or eductor wellpoints must be employed.

b. Design and Construction Considerations. The lowering of the water table by using a wellpoint dewatering system is presented in Figure 3-15. The system consists of a group of closely spaced wells, usually connected by a header pipe and pumped by suction centrifugal pumps, submersible pumps, or jet ejector pumps, depending on the depth of pumping and the volume to be dewatered.

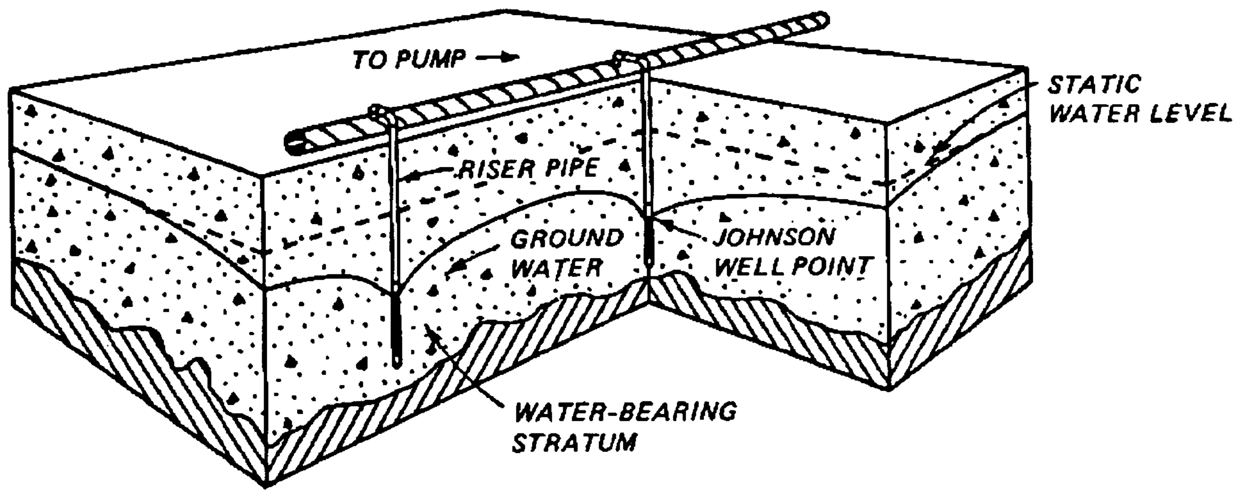


Figure 3-15. Schematic of a Wellpoint Dewatering System

(1) Hydraulic gradient. The hydraulic gradient increases as the flow converges toward a well. As a result, the lowered water surface develops a continually steeper slope toward the well. The form of this surface resembles a cone-shaped depression. The distance from the center of the well to the limit of this cone of depression is called the radius of influence. The hydraulic conductivity (K) is measured using the Darcy, defined as the permeability that will lead to a specific discharge of 1 cm/s for a fluid with a viscosity of 1 cp. It is approximately equal to 10^{-8} cm/s. The value of K depends upon the size and arrangement of the particles in an unconsolidated formation and the size and characteristics of the surfaces of crevices fractures, or solution openings in a consolidated formation. Figure 3-16 shows typical hydraulic conductivity for various soil and rock types. Darcy*s law remains valid only under conditions of laminar flow, involving fluids with a density not significantly higher than pure water.

(2) Transmissivity and storage coefficients. Two other factors, the transmissivity (T) and storage (S) coefficients, also affect the rate of flow. The coefficient of transmissivity indicates how much water will move through a formation and is equivalent to the permeability times the saturation thickness of the aquifer. The coefficient of storage indicates how much water can be removed by pumping and draining and is defined as the volume of water released from or taken into storage per unit area of aquifer per unit change in hydraulic head normal to the surface.

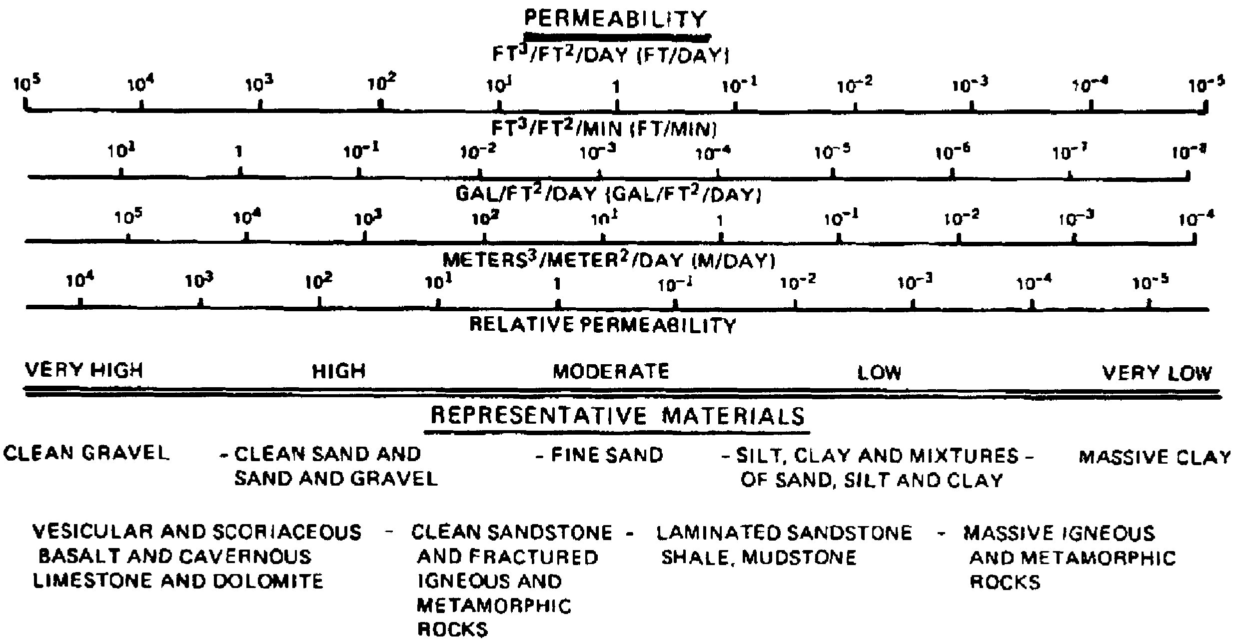


Figure 3-16. Hydraulic Conductivities of Soil and Rock

(3) Cone of depression. Lowering the ground-water level over the complete site involves creating a composite cone of depression by pumping from the wellpoint system. The individual cones of depression must be close together so that they overlap and thus pull the water table down several feet at intermediate points between pairs of wells.

(4) Stagnation points. Stagnation points occur when areas in the wellpoint field lie outside the area of influence of any of the wells. Design of the well-array should strive to reduce or eliminate stagnation points. Their presence leaves zones of high contaminant concentration and greatly lengthens the time necessary to clean the aquifer. The inclusion of injection wells can aid in the elimination of stagnation points.

(5) Drawdown. Once the aquifer properties of transmissivity and storativity have been determined, it is possible to predict the drawdown in hydraulic head in a confined aquifer at a distance (r) from the well and at a time (t) for a given pumping rate (Q). Thus, by determining the drawdown at various radii from the well, one can determine the radius of influence for a given pumping rate. For a given aquifer, the cone of depression initially increases in depth and extent with increasing pumping time until eventually it levels off. Drawdown at any point at a given time is directly proportional to the pumping rate and inversely proportional to aquifer transmissivity and storativity.

(6) Design considerations. Designs of wellpoint dewatering systems can vary considerably, depending on the depth to which dewatering is required, the transmissivity and storativity of the aquifer, the size of the site, and the depth of the waterbearing formation.

(7) Spacing. Wellpoint spacing is based on the radius of influence of each well and the composite radii of influence needed to lower the water table. Once storage and transmissivity coefficients have been determined, the drawdown and area of influence may be calculated. In practice, spacing for a few wellpoints would be determined and then field tested; any necessary adjustments would then be made to account for the fact that wells do not always meet the idealized conditions assumed in equations to estimate drawdown.

(8) Time to clean up. The time to clean up an aquifer is difficult to predict as it depends upon a wide variety of factors:

Contaminant type	Water solubility, volatility, mobility, polarity, absorption characteristics
Site soil type	Permeability, storage capacity, clay type and content, grain size, presence of clay lenses and impermeable barriers
Aquifer characteristics	Rate of flow, depth and thickness, recharge rate, perched water tables, contaminate concentrations

Pumping may be necessary for extended periods of time. Typically the concentration of contaminants in the extracted ground water falls asymptotically toward zero so that the demand on treatment equipment lessens over time. A good design will take into account this effect by incorporating unit operations that can be removed or reworked to be effective on the lower and lower contaminant concentrations. This is especially important to bioremediation systems where contaminant concentrations may soon fall to levels which will not sustain microbe populations. Further, “When is an aquifer clean?” is a difficult question.

(9) Ground-water treatment and disposal. The treatment of the contaminated ground water is a major consideration. Extracted ground water must be treated before discharge or reinjection. Treatment systems have been designed with stripping (air or steam) units for volatiles (perhaps with carbon absorption or incineration units for the stripped air stream), carbon absorption units, ion-exchange units, and/or bioreactors. These can be arranged singly or in series. Treated effluent may be discharged to the local publicly owned treatment works (POTW)(which may remove the need for pretreatment), injection wells incorporated into ground-water cleanup design, and seepage basins or trenches. Disposal of large volumes of extracted ground water over long time periods can be a major consideration and expense.

c. Installation.

(1) Wellpoints are made to be driven in place, to be jetted down, or to be installed in open holes. The most common practice is to jet the wellpoints down to the desired depth, to flush out the fines, leaving the coarser fraction of material to collect in the bottom of the hole, and then to drive the point into the coarser materials.

(2) A method used in some unstable material consists of jetting down or otherwise sinking temporary casing into which the wellpoint and riser pipe are installed. As the casing is pulled, gravel may be placed around the wellpoint.

d. Special Cases.

(1) In special cases, design modifications will be required or at least various methods should be compared for cost-effectiveness. Fine silts and other slowly permeable materials cannot be readily drained by wellpoint systems alone. However, soils can be partially drained and stabilized by vacuum wells or wellpoint systems that create negative pore pressure or tension in the soil. The wellpoints should be gravel packed from the bottom of the hole to within a few feet from the surface of the poorly permeable material. The remainder of the hole should be sealed with bentonite or other impermeable materials. If a vacuum is maintained in the well screen or pack, flow toward the wellpoints is increased. Such a system usually requires closely spaced wellpoints, and pumping capacity is reduced. Vacuum booster pumps may be required on the headers or individual wells for effective operation.

(2) Vertical sand drains may be used in conjunction with wellpoints to facilitate drainage in stratified soils. The drains, usually 406 to 508 mm (16 to 20 inches) in diameter, are installed on 1.8 to 3 m (6- to 10-foot) centers through the impermeable layers that need to be dewatered and are extended to underlying permeable layers where wellpoints are placed.

(3) Two or more wellpoint systems may be required when two or more strata of water-bearing sand are separated by impermeable barriers. The depth for dewatering will be different for each system, and consequently pipe lengths and diameters and pumping requirements will be determined independently.

(4) Potential enhancements of ground-water cleanup may involve the use of in-situ bioremediation. Introduction of nutrients and/or oxygen (or hydrogen peroxide) into the injection wells may greatly increase the rate of in-situ contaminant breakdown and thus enhance cleanup. Steam or hot water injection may help to dissolve or mobilize slightly soluble or adsorbed contaminants and increase their rate of removal.

e. Advantages and Disadvantages. Advantages and disadvantages of wellpoint pumping to adjust the water table are as follows:

Advantages	Disadvantages
High design flexibility	May not adequately drain fine silty soils, and flexibility is reduced in this medium
Good onsite flexibility since the system can be easily dismantled	Higher operation and maintenance costs than for artificial ground-water barriers
Construction costs may be lower than for construction of artificial ground-water barriers	System failures could result in contaminated drinking water
Good reliability when properly monitored	

3-14. Extraction/Injection Well Systems. Extraction/injection control systems have been used at waste sites to alter natural ground-water gradients to prevent pollutants from leaving a site or to divert ground water that might enter a site. Where hazardous wastes are involved, pumped systems may be used in conjunction with ground-water barriers. Pumped systems that result in mixing contaminated and uncontaminated ground waters can create large volumes of contaminated ground water to be treated. In most cases contaminated ground water at waste sites is contained by installing extraction wells to extract ground water from under the site, collecting contaminants leaking from the waste and creating a local gradient toward the site. Water withdrawn from under the site may have to be treated before discharge or reinjection. Two applications of extraction/injection systems to contain a plume are the use of a series of extraction and injection wells that will allow water within the plume to be pumped, treated, and pumped back into the aquifer and pumping and treatment of the plume followed by recharge using seepage basins.

a. Applications.

(1) Hydraulic barriers. Plume containment with the use of extraction/injection wells is an effective means of preventing the eventual contamination of drinking water wells or the pollution of streams or confined aquifers that are hydraulically connected to the contaminated ground water (Figure 3-17). The technique may be particularly useful for surface impoundments. One design would use extraction/injection wells separated by physical barriers (slurry wall or sheet pilings). The extraction wells are placed upgradient from the barrier; the extracted ground water is treated and reinjected on the downgradient side of the barrier. This design can keep contaminated ground water from leaving the site.

(2) Plume and floating product recovery. Extraction wells are used to directly recover separate liquid phases such as petroleum products which are floating at the water table. Well screens are placed such that the product can be collected and separated from any contamination ground water at the land surface in standard oil-separation units. Separated ground water usually must be treated to remove any soluble organics, carbon absorption, or biotreatment being used. Soluble materials dissolved in the ground water can also be

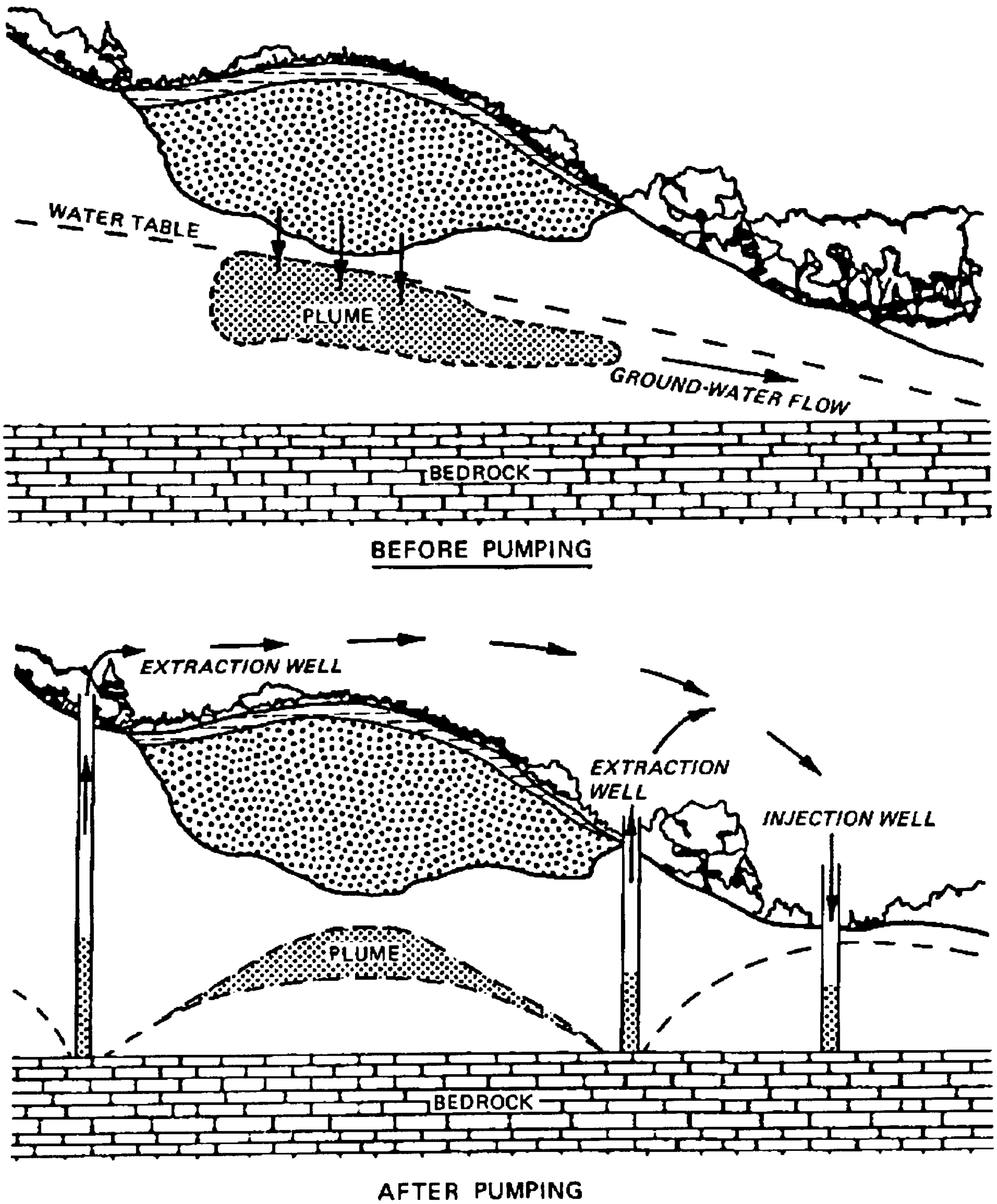


Figure 3-17. Use of Extraction/Injection Wells for Plume Containment (Source: EPA 1982)

separated and recovered using extraction wells followed by carbon absorption or reverse osmosis, or they can be destroyed using biotreatment. Judicious placement of injection wells can increase the rate of cleansing of the aquifer.

b. Design and Construction Considerations.

(1) Definition of the plume area, depth, and flow rate and direction must be determined before any further design considerations can be addressed. Pump tests should include determination of transmissivity and storage coefficients, and radii of influence of test wells. The presence of perched water tables or other anomalies must also be assessed.

(2) The basis of plume management by pumping depends upon incorporating the plume within the radius of influence of an extraction well. Such a system requires careful monitoring to determine the extent of the plume and any changes that may occur in the plume as pumping continues.

(3) The effect of the injection wells on the drawdown and radius of influence of the extraction wells is illustrated Figure 3-18. As the cone of depression expands and eventually encounters the cone of impression from the recharge well, both the rate of expansion of the cone and the rate of drawdown are slowed. With continued pumping, the cone of depression expands more slowly until the rate of recharge equals the rate of extraction and the drawdown stabilizes. Thus, the effect of the injection well is to narrow the radius of influence and to decrease the drawdown with increasing distance from the well.

(4) By combining extraction and injection wells in the design, the rate of cleanup of the aquifer and the amount of groundwater contaminated may be decreased. The cone of impression (Figure 3-18) of the injection well will serve to isolate the extraction wells from the surrounding ground water and increase the rate of flow (head gradient) toward the extraction well.

(5) The simplest extraction/injection well systems are designed so that the radii of influence do not overlap. Another important reason for placing the wells distant enough so that their radii of influence do not overlap is that any changes that must be made in pumping as a result of changes in the plume due to age of the landfill, quantity of precipitation, and physical changes in the size of the landfill, due to compaction or excavation, would be complicated by the effect of the overlap of the areas of influence.

(6) In some instances site limitations may require that the extraction and injection wells be placed so close together that the radii of influence overlap. Overlapping injection/extraction well zones of influence may be used to increase the rate of flow of ground water through the contaminated site in order to increase the rate of flushing of the contaminants.

(7) An example of an effective system for plume containment is currently operating at the Rocky Mountain Arsenal. Ground water is extracted, treated, and recharged through injection wells to the downgradient side of an impermeable barrier (slurry wall). The completed system will handle a flow of

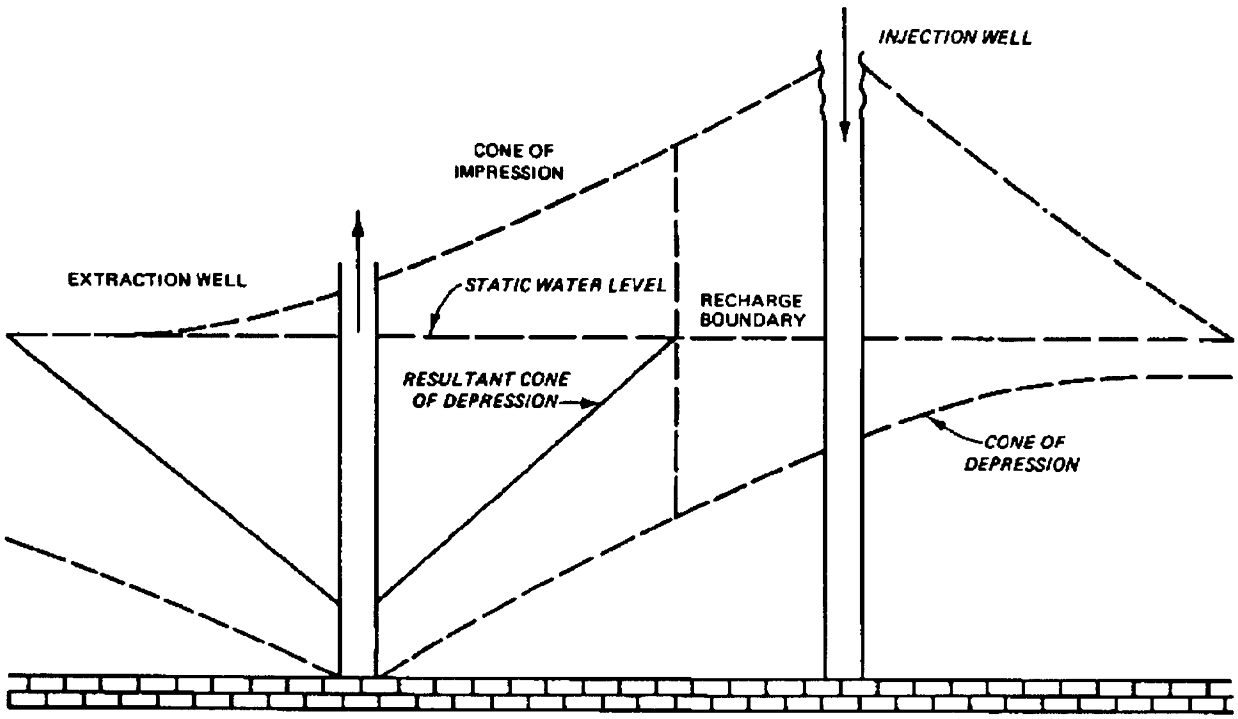


Figure 3-18. Effect of an Injection Well on the Cone of Depression

28 ℓ/s (443 gpm) and extend for 1585 m (5,200 feet). The system will consist of about 33 extraction wells, most of which are 203 mm (8 inches) in diameter, and approximately 40 injection wells with a diameter of 406 to 508 mm (16 to 18 inches). The extraction and injection systems are separated by an impermeable barrier to prevent mixing of contaminated and uncontaminated water.

c. Ground-water Pumping with Recharge through Seepage Basins.

(1) As a less costly alternative to recharging water through injection wells, seepage basins or recharge basins can be used. Since seepage basins require a high degree of maintenance to ensure that porosity is not reduced, they would not be practical where several basins are required for recharge of large volumes of water or where adequate maintenance staff is not available.

(2) As is the case for extraction/injection well systems, the effects of recharge on the cone of depression must be accounted for in designing a system that will contain the plume. Ideally, the recharge basins should be located outside the area of influence of the extraction wells.

(3) The dimensions of a recharge basin vary considerably. The basin should be designed to include an emergency overflow and a sediment trap for run-off from rainwater. The side walls of the basin should be pervious since considerable recharge can occur through the walls.

d. Advantages and Disadvantages. The advantages and disadvantages of the extraction/injection systems used for plume containment are as follows:

Advantages	Disadvantages
System may be less costly than construction of an impermeable barrier	Plume volume and characteristics will vary with time, climatic conditions, and changes in the site resulting in costly and frequent monitoring
High degree of design flexibility	System failures could lead to contamination of drinking water
Moderate to high operational flexibility, which will allow the system to meet increased or decreased pumping demands as site conditions change	O&M costs are higher than for artificial barrier

3-15. Subsurface Barriers. The most common subsurface barriers are slurry-trench cutoff walls, grout curtains, sheet pile cutoff walls, membranes and synthetic sheet curtains, and combination barrier pumping systems.

3-16. Slurry-trench Cutoff Walls. Slurry trenching is a method of constructing a passive subsurface barrier or slurry wall to impede or redirect the flow of ground water. This practice covers a range of construction techniques from the simple to the quite complex, and though it is becoming more common, is still performed by only a few specialty contractors. In recent years the success and economy of slurry trench cutoffs has largely brought about the replacement of other methods such as grout curtain and sheet piling cutoffs.

a. Description.

(1) Slurry walls are fixed underground barriers formed by pumping slurry into a trench as excavation proceeds. The slurry is usually a soil or cement, bentonite, and water mixture pumped into the trench to maintain a slurry-full trench condition. The cement-bentonite slurry is allowed to set. The soil-bentonite trench filling is produced by backfilling the trench with a suitably engineered backfill which often includes local or excavated site soil.

(2) The slurry used in the soil-bentonite is essentially a 4 to 7 percent by weight suspension of bentonite in water. Bentonite is a clay of the montmorillonite group of 2:1 expanding lattice clays. Excavated materials that are removed from the slurry-filled trench are placed at the trench sides and excess slurry drains back into the trench. Selected backfill material is dumped into the trench and sinks through the bentonite forcing some slurry out of the trench. Excess slurry is pumped to a holding area where the slurry can be “desanded” if necessary and adjusted to the specified density for reintroduction into the trench. No compaction of a finished slurry trench is required.

3) For proper displacement of slurry by the backfill material, the unit weight of backfill material should be 240.3 kg/m^3 (15 lb/ft^3) greater than that of the slurry (soil-bentonite). Typical soil-bentonite unit weights are 1442 kg/m^3 to 1682 kg/m^3 (90 to 105 lb/ft^3) and for cement-bentonite slurry 1922 kg/m^3 (120 lb/ft^3). Density requirements for a cement-bentonite slurry are less important because it is not backfill displaced; however, a 90-day minimum set time is important.

b. Applications.

(1) Slurry walls were first used to effect ground-water cutoff in conjunction with large dam projects. In recent years, they have found use as both ground-water and leachate barriers around hazardous waste disposal sites. Placement of the wall depends on the direction and gradient of ground-water flow as well as location of the wastes. When placed on the upgradient side of the waste site, a slurry wall will force the ground water to flow around the wastes. In some instances, it may be unnecessary to sink the wall down to an impervious stratum. A wall sunk far enough into the water table upgradient from the wastes can reduce the head of the ground-water flow, causing it to flow at greater depth beneath the wastes.

(2) Most commonly, the trench is excavated down to, and often into, an impervious layer in order to retard and minimize a ground-water flow. This may not be the case when only a lowering of the water table is required. The width of the trench is typically from 0.61 to 1.5 m (2 to 5 feet) and can be up to 24.4 m or 30.5 m (80 or 100 feet) deep. Typically, a backhoe, clamshell, or dragline is used for excavation.

(3) Grades of 10 percent and higher provide problems for slurry-trench construction.

(4) Ground-water chemistry can severely affect the behavior at the bentonite slurry. Adverse reactions such as thickening or flocculation may result if grout and ground water are not compatible. Compatibility tests have been conducted to determine the ability of bentonite slurry walls to withstand the effects of certain pollutants, and the results are encouraging. Of the chemicals tested, only alcohols were found to completely destroy the slurry wall. To determine the probable effectiveness of a slurry wall for a particular site, however, compatibility tests should be conducted using the actual leachate from the site.

(5) In certain settings, a slurry wall can be installed to completely surround the site. In some cases, the ground water inside the slurry wall is extracted and treated, and in some cases replaced with the treated ground water.

(6) Where slurry cutoffs are used in conjunction with a cap, the wall-cap tie-in should facilitate construction and be of adequate thickness to prevent separation as a result of long-term settlement of the wall. Tie-in with an impervious layer beneath the wall is also important if ground-water cutoff is the objective.

(7) A slurry trench cutoff wall was designed and constructed to contain migration of contaminated ground water from the Lipari Landfill in Pitman, New Jersey, in October 1983. The trench was approximately 883.4 m (2,900 feet) long and 15.2 m (50 feet) deep. The bottom of the trench was keyed into a Kirkwood clay layer. The design drawing illustrating the position of the trench is presented in Figure 3-19. Depending on the grade and the position of the trench in relation to the batch-mixing operation performed in a clean area onsite, between 22.9 and 45.7 m (75 and 150 feet) of slurry trench could be constructed each day. The entire trench was constructed in two months.

c. Design and Construction Considerations.

(1) Slurry trenching must be preceded by thorough hydrogeologic and geotechnical investigations. A good hydrogeologic study will tell the designers the depth, rate, and direction of ground-water flow, and the chemical characteristics of the water. A geotechnical investigation will provide information on soil characteristics such as permeability, amount of stratification, and depth to bedrock or an impervious layer. In addition, it will tell the nature and condition of the bedrock. When the slurry wall is intended to provide total water cutoff, rather than just to lower the water table, particular attention must be paid to the soil/rock interface.

(2) The type of equipment used to excavate a slurry trench depends primarily on the depth. Hydraulic backhoes can be used to excavate down to 16.8 m (55 feet). Beyond that depth, a clamshell shovel must be used. If it is necessary to install the slurry wall into hard bedrock, drilling or blasting may have to be used to excavate the rock. Special blasting techniques would be required to maintain the integrity of the bedrock.

(3) Backfilling of a trench is often accomplished with the equipment used to excavate the trench. A bulldozer can be used to mix the soil with the slurry alongside the trench as well as to backfill the upper portion of the trench. Care must be taken to ensure that no pockets of slurry are trapped during the backfilling, as these can greatly reduce the wall*s effectiveness and permanence.

(4) For maximum permeability reduction, the soil/bentonite mixture used for backfilling should contain 20 to 25 percent fines (soil particles that will pass a 0.075 mm (200-mesh) sieve). To ensure long-term permeability reduction, as much as 40 to 45 percent fines may be required. In the event the onsite soils are too coarse, imported fines or additional bentonite must be added.

(5) The bentonite must be completely hydrated and well mixed with the soil or cement before being placed into the trench.

d. Advantages and Disadvantages. The process outlined above includes a number of variables that can affect the long-term effectiveness of a slurry wall. The extent to which these variables, such as ground water, soil, and rock characteristics, can influence the integrity of a wall can usually be determined by a variety of preconstruction tests. From the results of these

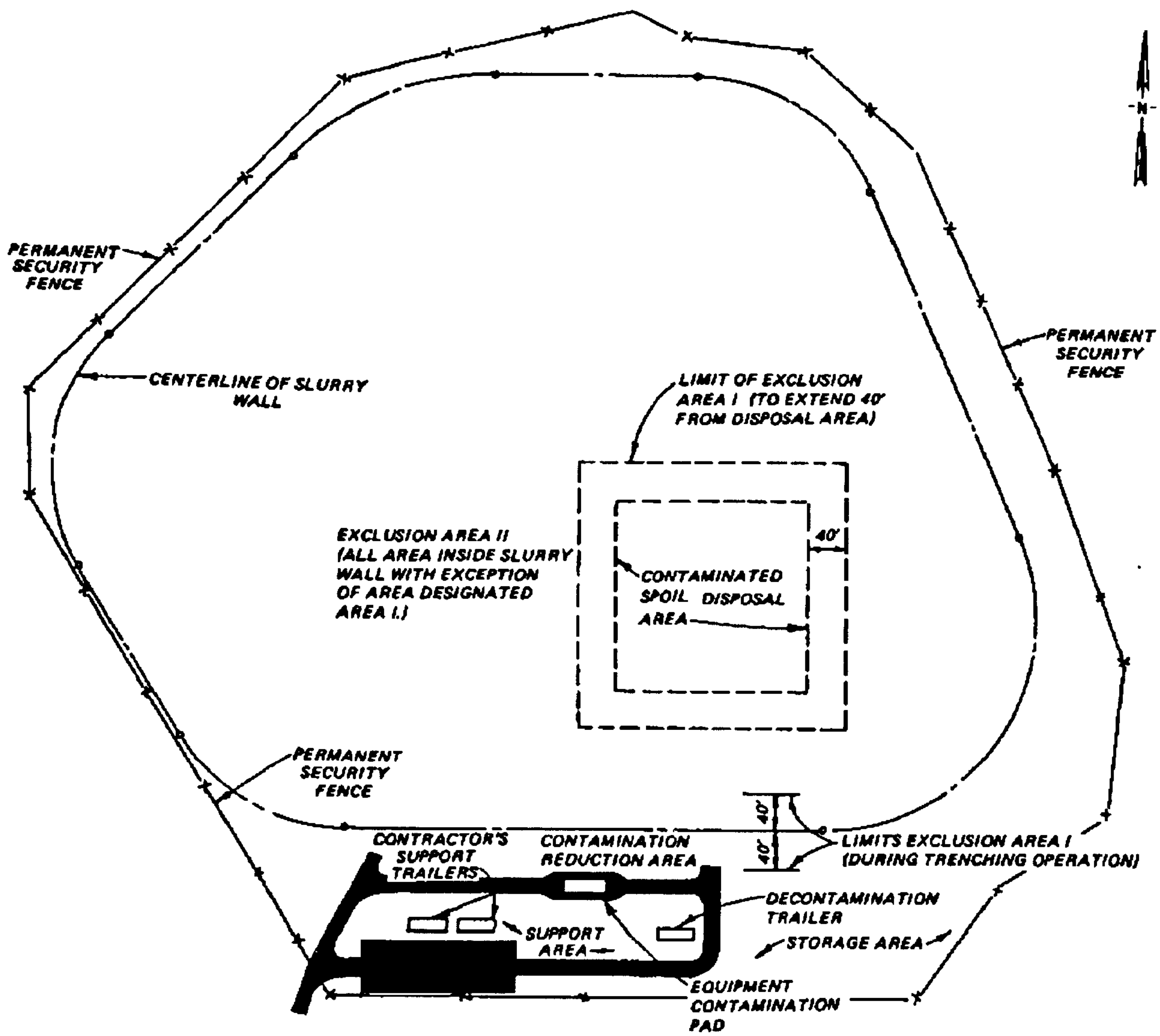


Figure 3-19. Design Drawing for Lipari Landfill Slurry-Trench Cutoff Wall

field and laboratory tests, more site deficiencies can be identified and corrected prior to construction. A properly designed and installed slurry wall can be expected to provide effective ground-water control for many decades with little or no maintenance. Advantages and disadvantages of slurry trenches are summarized below:

Advantages	Disadvantages
A long-term, economical method of ground-water control	Ground water or waste leachate may be incompatible with slurry material
No maintenance required over long term	Lack of near-surface impermeable layer, large boulders or underground caverns may make installation difficult or impractical
Materials inexpensive and available	Not practical with over 10 percent slope
Technology well proven	

3-17. Grout Curtains. Another method of ground-water control is the installation of a grout curtain. Grouting in general consists of the injection of one of a variety of special fluids or particulate grouts (Table 3-5) into the soil matrix under high pressure. The injection of the specific grout type is determined by conditions of soil permeability, soil grain size, chemistry of environment being grouted (soil and ground-water chemistry), and rate of ground-water flow. Grouting greatly reduces permeability and increases mechanical strength of the soil zone grouted. When carried out in the proper pattern and sequence, this process can result in a curtain or wall that can be an effective ground-water barrier. Because a grout curtain can be three times as costly as a slurry wall, it is rarely used when ground water has to be controlled in soil or loose overburden. The major use of curtain grouting is to seal voids in porous or fractured rock where other methods of ground-water control are impractical.

a. Description. The pressure injection of grout is as much an art as a science. The number of United States firms engaged in this practice is quite limited. The injection process itself involves drilling holes to the desired depth and injecting grout by the use of special equipment. In curtain grouting, a line of holes is drilled in single, double, or sometimes triple staggered rows (depending on site characteristics) and grouting is accomplished in descending stages with increasing pressure. The spacing of the injection holes is also site specific and is determined by the penetration radius of the grout out from the holes. Ideally, the grout injected in adjacent holes should touch (Figure 3-20) along the entire length of the hole. If this is done properly, a continuous, impervious barrier is formed (Figure 3-21).

b. Application.

(1) In general, grouts can be divided into two main categories- - suspension grouts and chemical grouts. Suspension grouts, as the name implies, contain finely divided particulate matter suspended in water. Chemical grouts, on the other hand, are true Newtonian fluids. Most of the grouting in the United States is done with suspension grouts, whereas about half of the grouting in Europe is done with chemicals. The principal grouts in use today are briefly described below.

Table 3-5. Significant Characteristics of Types of Grout

Type	Characteristic
Portland cement or particulate grouts	Appropriate for higher permeability (larger grained) soils Least expensive of all grouts when used properly Most widely used in grouting across the United States (90 percent of all grouting)
Chemical grouts	
Sodium silicate	Most widely used chemical grout At concentrations of 10-70 percent gives viscosity of 1.5-50 cP Resistant to deterioration by freezing or thawing Can reduce permeabilities in sands from 10^{-2} to 10^{-8} cm/sec Can be used in soils with up to 20 percent silt and clay at relatively low injection rates Portland cement can be used to enhance water cutoff
Acrylamide	Should be used with caution because of toxicity First organic polymer grout developed May be used in combination with other grouts such as silicates, bitumens, clay, or cement Can be used in finer soils than most grouts because low viscosities are possible (1 cP) Excellent gel time control due to constant viscosity from time of catalysis to set/gel time Unconfined compressive strengths of 344-1378 KPa (50-200 psi) in stabilized soils Gels are permanent below the water table or in soils approaching 100 percent humidity Vulnerable to freeze-thaw and wet-dry cycles, particularly where dry periods predominate and will fail mechanically Due to ease of handling (low viscosity), enables more efficient installation and is often cost-competitive with other grouts
Phenolic (Phenoplasts)	Rarely used due to high cost Should be used with caution in areas exposed to drinking water supplies, because of toxicity Low viscosity Can shrink (with impaired integrity) if excess (chemically unbound) water remains after setting; unconfined compressive strength of 344-1378 KPa (50-200 psi) in stabilized soils

(Continued)

Table 3-5. (Concluded)

Type	Characteristic
Urethane	Set through multistep polymerization Reaction sequence may be temporarily halted Additives can control gellation and foaming Range in viscosity from 20 to 200 cP Set time varies from minutes to hours Prepolymer is flammable
Urea-Formaldehyde	Rarely used due to high cost Will gel with an acid or neutral salt Gel time control is good Low viscosity Considered permanent (good stability) Solution toxic and corrosive Relatively inert and insoluble
Epoxy	In use since 1960 Useful in subaqueous applications Viscosity variable (molecular weight dependent) In general, set time difficult to regulate Good durability Resistant to acids, alkalis, and organic chemicals
Polyester	Useful only for specific applications Viscosity 250 to several thousand cP Set time hours to days Hydrolyzes in alkaline media Shrinks during curing Components are toxic and require special handling
Lignosulfonate	Rarely used due to high toxicity Lignin can cause skin problems and hexavalent chromium is highly toxic (both are contained in these materials) Cannot be used in conjunction with portland cement; pH*s conflict Ease of handling Loses integrity over time in moist soils Initial soil strengths of 344-1378 KPa (50-200 psi)

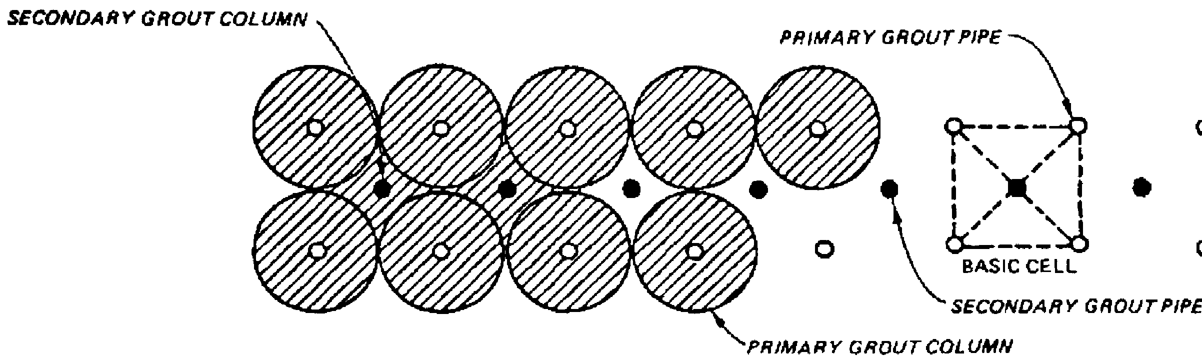


Figure 3-20. Grout Pipe Layout for Grout Curtain

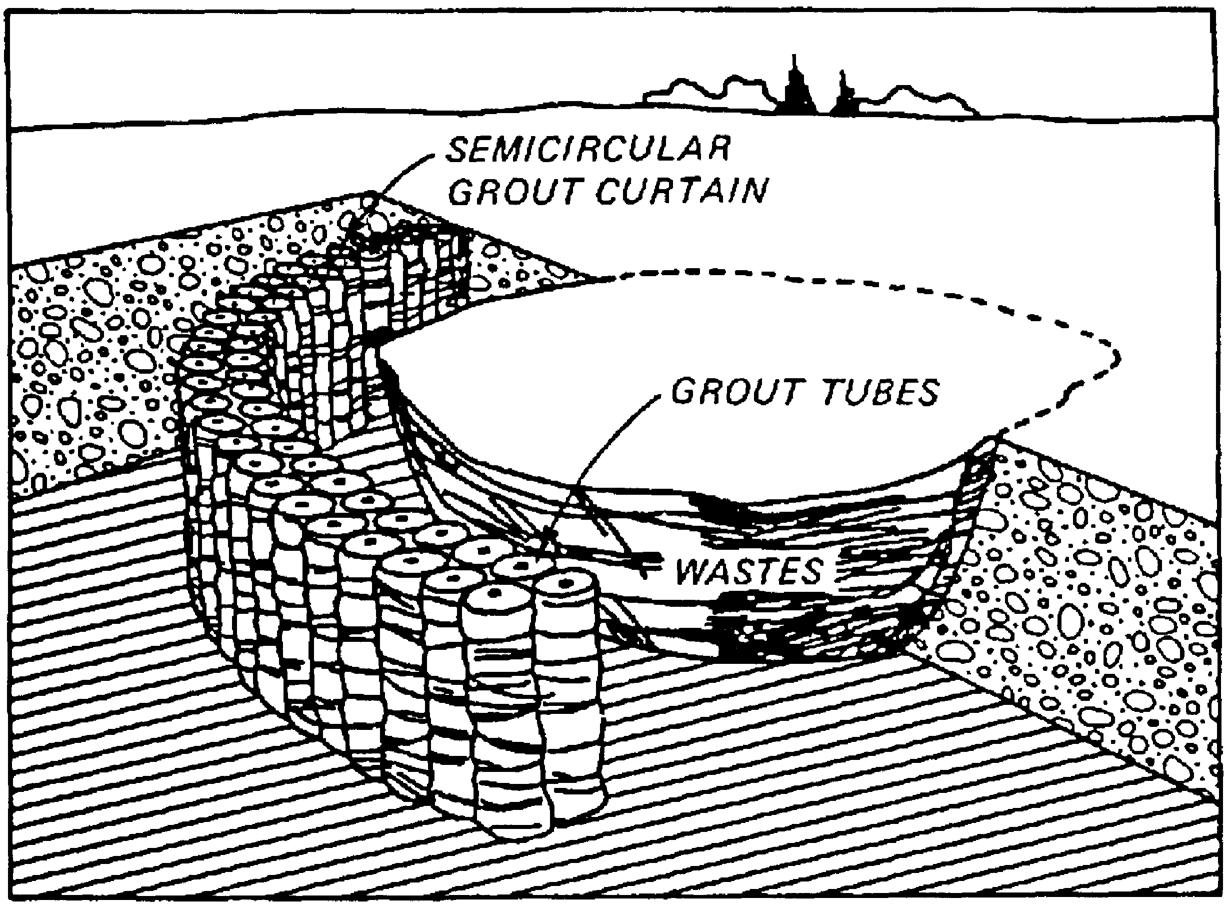


Figure 3-21. Semicircular Grout Curtain Around Waste Site

(2) Suspension grouts are for the most part either portland cement, bentonite, or a mixture of the two. Ultra-fine cement grouts are also available. Their primary use is in sealing voids in materials with rather high permeabilities, and they are often used as “pregrouts” with a second injection of a chemical grout used to seal the fine voids. If a suspension grout is injected into a medium that is too fine, filtration of the solids from the grout will occur, thus eliminating its effectiveness. Portland cement, when mixed with water, will set up into a crystal lattice in less than 2 hours. For grouting, a water-cement ratio of 0.6 or less is more effective. The smallest voids that can be effectively grouted are no smaller than three times the cement grain size. For this, it is clear that a more finely ground cement makes a more watertight grout. Portland cement is often used with a variety of additives that modify its behavior. Among these are clay, sand, fly ash, and chemical grouts.

(3) Of the clay minerals used for grouting, bentonite is by far the most common. Other locally available clays, especially those of marine or river origin, may be used but must be extensively tested and often chemically modified. Bentonite, however, because of its extremely small particle size (one micron or less), is the most injectable, and thus the best suited for grouting into materials with lower permeabilities. Medium- to fine-textured sands, with permeabilities of around 10^{-3}-10^{-4} cm/sec, can be sealed with a bentonite grout. Dry bentonite is mixed with water onsite at a rate of 5 to 25 percent by dry weight. In these ratios, bentonite will absorb large amounts of water and, with time, form a gel. This gel, although it imparts little if any structural strength, is an extremely effective water barrier.

(4) Placement of a grout curtain downgradient from or beneath a hazardous waste site requires consideration of the compatibility of the grout to waste leachate or other extremes of ground-water chemistry. Little information is available concerning the resistance of grouts to chemical attack. Should a case arise where grout must contact leachate or ground water of extreme, field tests should be performed to verify grout resistance.

(5) Quality control is a difficult issue since even small voids or breaks can greatly lessen the effectiveness of a grout curtain. By definition, a grout curtain is not amenable to inspection.

c. Design and Construction Considerations.

(1) Pressure grouting is a high technology endeavor. As with slurry trenching, extensive geotechnical and hydrologic testing must precede the placement of a grout curtain. Boring, pumping, and laboratory tests will determine whether or not a site is groutable and will provide the necessary ground-water, rock, and soil information to allow for the choice of the best-suited grout or grouts. They will further provide the designer with the information needed to plan the pattern and procedure for injection.

(2) For all grouts the closer the viscosity is to that of water (1.0 cP), the greater the penetration power. Grouts with a viscosity less than 2 cP, such as many of the chemical grouts, can penetrate strata with permeabilities less than 10^{-5} cm/sec. Higher viscosity grouts, like

particulate and some chemical grouts with a viscosity greater than 10 cP, can only penetrate coarse strata having permeabilities greater than 10^{-2} cm/sec. For suspension particulate grouts, the particle size will also influence the ability to penetrate voids.

(3) Short-term deterioration of the grout can be caused by rapid chemical degradation or by an incorrect setting time. The effect on setting time can be caused by a miscalculation of the grout formulation, dilution of the grout by ground water, or changes caused by chemicals contained within the grouted strata.

(4) Once a grout has set in the voids in the ground, it must be able to resist hydrostatic forces in the pores that would tend to displace it. This ability will depend on the mechanical strength of the grout and can be estimated by the grout*s shear strength. The shear strength of a grout will depend not only on its class, but also on its formulation. Thus, a class of grouts, such as silicates, can possess a wide range of mechanical strengths depending on the concentration and type of chemicals used in its formulation. The strength of the gel, then, can be adjusted, within limits, to the specific situation.

d. Advantages and Disadvantages.

(1) The advantage of grout curtain emplacement is the ability to inject grout through relatively small diameter drill holes at unlimited depths. The size of the pod or grouted column is a function of pore space volume and volume of grout injected. Grout can incorporate and/or penetrate porous materials in the vicinity of the injection well such as boulders or voids. Variable set times and low viscosities are also advantages.

(2) The major disadvantages of grouts are the limitations imposed by the permeability of the host material (soil or rock) and the uncertainty of complete cutoff, Specifically with particulate grouts only the most permeable units are groutable.

3-18. Sheet Pile Cutoff Walls. Sheet pile cutoff walls may be used to contain contaminated ground water, divert a contaminant plume to a treatment facility, and divert ground-water flow around a contaminated area. They constitute a permeable passive barrier composed of sheet piling permanently placed in the ground. Each section interlocks with an adjacent section by means of a ball/socket (bowl) union. The connection (union) may initially be a pathway for ground-water migration which may abate or cease if the ball/socket section is naturally or artificially filled with impermeable material. Sections of pilings are assembled before being driven into the ground (soil conditions permitting).

a. Description.

(1) Various sheet piling configurations are available. Application of specific configurations and fittings can be used for site-specific needs such as partitioning different sections of a waste-contaminated area or combination

of areas. Piling weight may vary from 1054 to 1820 Pa (22 to 38 lb/ft^2) depending upon the driving depth and soil materials.

(2) Keying in to a subsurface impermeable barrier is limited by depth to the barrier and composition of the barrier. Pile driving to a relatively shallow clay deposit and keying in to the clay without driving completely through the clay is relatively common in construction practices. However, keying in to a rock unit such as shale or other sedimentary unit is difficult. The physical tightness of such a bedrock/piling key is poor and may require additional sealing (grout, etc.). Pile testing and borings to an impermeable horizon can be used to determine the effectiveness of the barrier and piling interlock (ball/socket) damage.

b. Applications.

(1) As a remedial action at a hazardous waste site, sheet piling cutoff walls can be used to contain contaminated ground water. Piling driven to an impermeable layer can retain an existing contaminant(s) that may be released during cleanup actions.

(2) If ground-water flow rates and volume moving toward a hazardous waste site are sufficient to potentially transport a contaminant plume or impede site cleanup operations, a piling barrier can be used to divert the ground-water flow.

(3) Installation of sheet pilings at a hazardous waste site may present special problems related to buried tanks or drums that may be ruptured, unless care is taken to investigate the proposed piling alignment with magnetometers or other metal-locating devices. Drums at depth may not be detected and pose special problems.

c. Design and Construction.

(1) Maximum effective depth is considered to be 14.9 m (49 feet). Although under ideal conditions, pile sections have been driven up to depths of 29.9 m (98 feet).

(2) Steel sheet piling is most frequently used. Concrete and wood have also been used. Concrete is expensive but is attractive when exceptional strength is required, and, although less expensive, wood is relatively ineffective as a water barrier.

(3) Sheet piles are typically used in soils that are loosely packed, and predominantly sand and gravel in nature. A penetration resistance of 13 to 33 blows/m (4 to 10 blows/foot) for medium- to fine-grained sand is recommended. Cobbles and boulders can hinder pile placement.

(4) Piling lifetime depends on waste characteristics and pile material. For steel piles pH is of particular importance. A pile life up to 40 years (depending on other leachate characteristics) can be expected where pH ranges between 5.8 and 7.8. A pH as low as 2.3 can shorten the lifetime to 7 years or less.

d. Advantages and Disadvantages.

(1) Sheet pilings require no excavation. Thus, the construction is relatively economical. In most cases, no maintenance is required. The disadvantages of sheet pilings are the lack of an effective seal between pilings and problems related to piling corrosion.

(2) At hazardous waste sites, corrosion of sheet pilings can be a severe problem. Many sites contain mineral acids that react readily with iron. Standard cathodic protection may not be effective if local concentrations of acid materials are present. Any reaction of metal with acid can produce hydrogen gas that may diffuse from the soil and create a fire or explosion hazard at the surface.

3-19. Membranes and Synthetic Sheet Curtains. Membranes and other synthetic materials have been used extensively as pond and lagoon liners. The impervious nature of the liner and its general resistance to corrosive chemicals have been proven to exceed the qualities typical of clay liner material used in landfills. The key factor in the use of membrane liners is to produce an effective seal between adjacent sheets of membrane.

a. Description. Synthetic membrane materials (PVC, butyl rubber, polyethylene) may be used in a manner similar to clay or sheet pile cutoff walls. The membrane can be inserted in a slit or a V-shaped trench to facilitate anchoring at the top of the trench. Membrane liners require some special handling for effective use. Membrane materials are usually not laid with any stress on the membrane. All seams are heat- or solvent-welded using manufacturer-approved techniques to ensure the seams are as strong as the material itself.

b. Applications. Membrane curtains can be used in applications similar to grout curtains and sheet piling. The membrane can be placed in a trench surrounding or upgradient (ground water) from the specific site, thereby enclosing the contaminant or diverting the ground-water flow. Placing a membrane liner in a slurry trench application has also been tried on a limited basis.

c. Compatibility. Compatibility of the membrane material with contaminated ground water or soil should be considered before emplacement of the membrane.

d. Design and Construction. Emplacement of the liner in conventional style requires a trench of sufficient size and slope that crews can lay the liner and transverse the liner with sealing equipment. The trench needs to be excavated to an impervious zone wherein the membrane is keyed in and sealed to prevent leakage at the membrane bottom. In conditions of contaminated, unstable, or saturated soils, special safety and construction practices must be established. Lowering a prepared liner into a narrow vertical trench is not feasible. The narrow trench in most cases will not be able to remain open without caving debris interfering with keying in conditions. Suspending the lines may cause stretching or tearing.

e. Advantages and Disadvantages.

(1) The membrane provides an effective barrier if it can be emplaced without puncture or imperfect sealing. Sealing is a difficult process that requires material handling and manipulation not afforded by trench emplacement. Keying the membrane adequately to the impervious layer is also difficult. The key zone must be disturbed and membrane material may not be conducive to adhering to concrete or other sealing material.

(2) Installation of liners is also restricted to climatic conditions. Liner membranes generally should not be installed at temperatures colder than about 45°F. Soil temperature as well as atmospheric temperatures affect the flexibility as well as sealing character of the membrane. Adverse moisture conditions also may inhibit successful sealing of seams.

3-20. Combination Barrier/Pumping Systems. Barrier and pumping systems can be used in combination to ensure containment of contaminated ground water. When used in combination, the general approach is to use the barrier system to minimize the quantity of ground water that must be pumped and treated. The most common application of a combination barrier/pumping system is the use of a circumferential slurry wall, keyed into an underlying aquiclude, combined with an interior pumping system to maintain an inward hydraulic gradient. Design criteria are similar to those previously discussed for the individual systems.

3-21. Subsurface Drains and Drainage Ditches.

a. Background.

(1) Subsurface French drains are trenches filled with gravel that are used to manage surface or ground-water flows in shallow subsurface materials. At most hazardous waste sites, standard French drains are of limited use because close control of ground-water flow is required, and care must be exercised in preventing contaminated water from reaching lower aquifers.

(2) Well-designed underdrains that can intercept ground water flowing into a waste site have been helpful in reducing the water treatment problem where extraction systems are employed. Where the water table is relatively shallow (30 feet below the surface or less), a waste site can be isolated by trenching down into the water table and introducing a barrier and a vertical permeable layer with a drain at the bottom. This system acts to intercept small springs or seepage that may enter a buried waste pit. By diverting the ground water before it enters the site, the growth of the pollution plume exiting the site is reduced without pumping.

(3) When applicable, the barrier/underdrain system is a permanent low-cost remedial option. It requires small maintenance efforts to ensure the drains are clear. The intercepted ground water is usually tested periodically to ensure that no pollutant is discharged. The only disadvantages observed with this system relate to possible movement of contaminant through the ground-water barrier and into the drains. If this occurs, all of the discharge from the underdrains may require treatment before discharge. This

problem can be minimized by having the system built in unconnected segments with separate outfalls.

b. Applications.

(1) Subsurface drains can be used to intercept leachate or infiltrating water in any clay or silty clay soil where the permeability is not adequate to maintain sufficient flow and at sites where the leachate is not too viscous or gummy to prevent flow to the drains. Other conditions, such as a deep frost zone, may also restrict the use of underdrains in certain soils.

(2) Drainage ditches can be an integral part of a leachate collection system in that they may be used as collectors for surface water runoff, collectors leading from subsurface drains, or as interceptor drains.

(3) Surface drainage may be essential for flat or gently rolling landfills underlain by impermeable soils where subsurface drainage may be impractical or uneconomical.

(4) Open ditches may be used as interceptor drains to collect lateral surface seepage, thus preventing it from percolating into ground water or flowing laterally to an area that should be protected. The choice between using an open drain or subsurface drain depends upon the slope of the flow. For steep slopes, open drains are generally more desirable. An open ditch may be used in certain circumstances to intercept subsurface collectors and carry the leachate to its ultimate disposal.

(5) Drains or trenches may be useful in collecting contaminants floating on the ground-water surface. Where the ground water is shallow, and the slope adequate, drains may be more economical and effective than extraction wells.

c. Design and Construction Considerations.

(1) Subsurface drains.

(a) Subsurface leachate collection systems (Figure 3-22) have been proposed or constructed at several existing landfills. The drainage systems are generally constructed by excavating a trench and laying tile or pipe sections end to end in strings along the bottom. The trench is then backfilled with gravel or other envelope material to a designated thickness; the rest of the trench is then backfilled with soil. Often the gravel is lapped with geotextile fabric to prevent fine soil from entering the gravel and clogging the drain. The front view of a subsurface leachate collection system is illustrated in Figure 3-23.

(b) In some instances, gravel-packed wet wells may be used. Wells are constructed similarly to trenches.

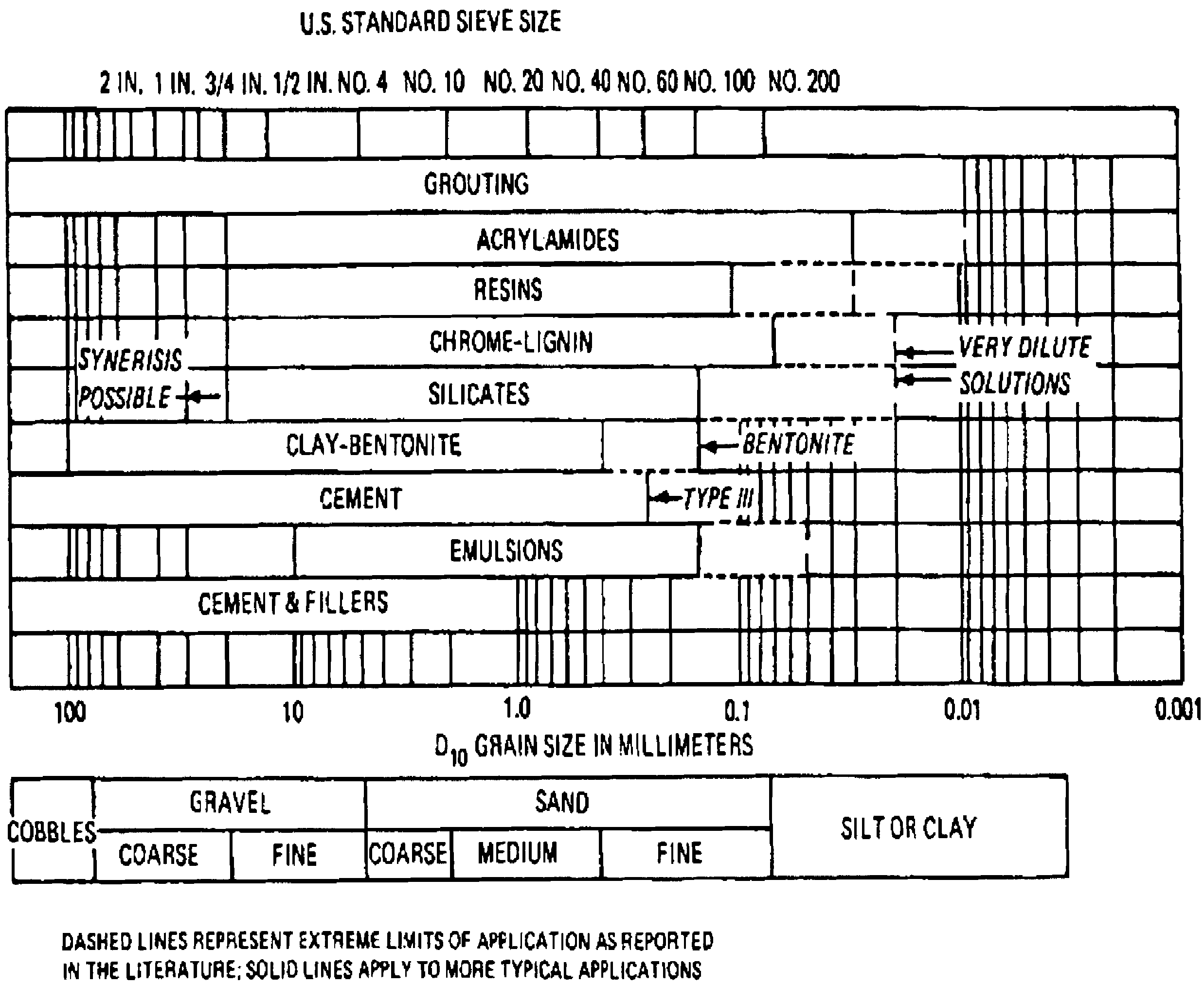


Figure 3-22. Subsurface Leachate Collection (Source: EPA 1979)

(c) An impermeable liner may be required on the downgradient end of the subsurface drain to prevent flow-through of intercepted and contaminated ground water if the surrounding materials have a moderate to high permeability.

(d) The major design problem for subsurface drains is to determine the optimum spacing, depth, and hydraulic capacity. Determination of these criteria is usually based on practical experience, experimental data, and calculations using drainage formula. Spacing between drain lines and wet wells depends upon the depth of the drain below the surface, the hydraulic conductivity of the soil, the amount of subsoil to be drained, and the potential for constructing underdrains beneath the landfill. Orientation of the trenches perpendicular to the flow lines would make spacing irrelevant, provided the trenches capture the flow at all required depths.

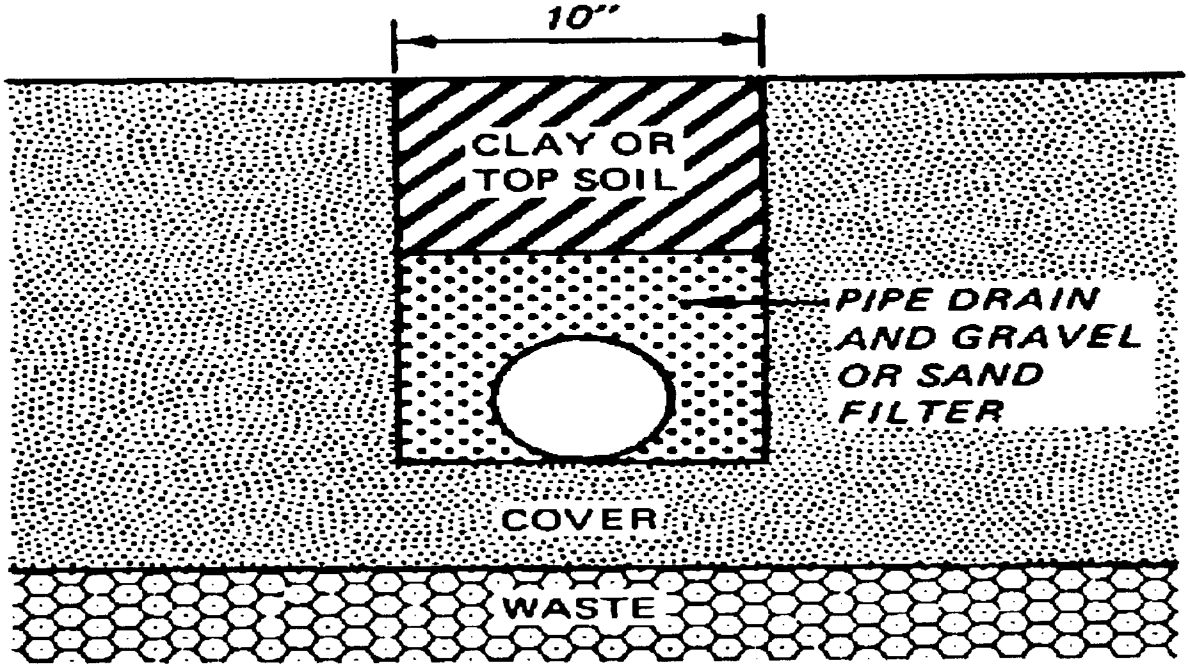


Figure 3-23. Typical Design Plan for Leachate Collection System

(e) Design equations that have been developed for flow to a drainage pipe indicate that a greater depth allows for wider spacing. These formulae are considered in relation to spacing. The simplest formula for estimating drain spacing assumes homogeneous soils and one-dimensional flow. Drain spacing can be estimated from Hooghoudt*s formula as follows:

$$S = \frac{4K}{Q}\left[(D + H)^2 - (D + h)^2\right] \tag{3-1}$$

where

S = drain spacing, m (feet)

k = hydraulic conductivity, m/day (feet/day)

Q = design flow to the drain, m^3/day/m of ditch (cubic feet per day per foot

D = depth of flow layer beneath the drains, m (feet)

H = height of ground-water table above the plane through the drains and midway between two drains, m (feet)

h = height of water level in the drain, m (feet)

(f) The cone of depression observed around a well becomes a trough along the line of the drain. The spacing of the drains must be such that the water table at its highest point between drains intercepts all leachate-generating wastes, and does not interfere with plant growth or zone of aeration, if these factors play a part in proper operation of the fill.

(g) In actual practice, spacing of underdrains may be restricted by the boundaries of waste in such a way that the composite cones of depression of the drains do not completely overlap and some leachate escapes the collection system. This may occur where ideal spacing requires that underdrains be constructed beneath a waste site. Since the drain spacing is influenced by depth and hydraulic conductivity, it may be possible to increase spacing and still intercept all leachate by increasing drain depth and by adjusting envelope thickness to increase hydraulic conductivity so that underdrains beneath the site are not necessary.

(h) Horizontal drilling is now available without the need to jack or drill from a pit. This drilling technique allows drilling to start from the surface (at an oblique angle) and then turn horizontal at a certain depth. Though limited to depths of greater than about 6.1 m (20 feet), this technology shows promise for placing drains under landfills, lagoons, and tanks.

(i) Minimum grade or slope is determined on the basis of site conditions and size of the drains. Some designers wish to specify a minimum velocity rather than a minimum grade. It is generally desirable to have a slight slope in order to obtain a velocity sufficient to clean the drain during discharge and to speed up emptying of a drain after a discharge period. Slopes of about 0.1 percent can be obtained with present trench digging equipment accurate to within 1 centimeter of the prescribed depth.

(j) Drains have a relatively small area of inflow, causing an entrance resistance. Failures of tube drains are often due to the high resistance of approach of the envelope material and soil; the type of tube is usually less critical. Application of the proper envelope material in sufficient quantities can significantly reduce the effect of resistance. The most commonly used envelope materials include sand and fine gravel, and to a lesser extent straw, woodchips, and fiberglass. Recommendations for drain envelope thickness have been made by various agencies. The Bureau of Reclamation recommends a minimum thickness of 10 centimeters around the pipe, and the Soil Conservation Service recommends a minimum of 8 centimeters for agricultural drains. In actual practice, much thicker envelopes may be used to increase hydraulic conductivity. An 203 mm (8-inch-diameter) perforated pipe used for leachate collection at Love Canal is surrounded with about 0.61 m (2 feet) of gravel.

(k) After the trench is backfilled with the appropriate thickness of envelope material, it may be desirable to wrap the gravel with a fabric to prevent clogging of the gravel and drains with soil. One such available material is Typar, a strongly woven fabric that allows liquids to pass through but prevents soil from getting into the pipeline.

(1) The design and construction of leachate collection systems can be exemplified by the Love Canal (Figure 3-24). The heart of the collection system at Love Canal is a series of drains with 152 to 203 mm (6- to 8-inch-diameter) perforated, vitrified clay pipe backfilled with about 2 feet of gravel envelope. The ditches run roughly parallel along the north and south borders of the canal, as shown in Figure 3-24. The trenches are approximately 3.7 m (12 feet) below grade, dropping to a maximum of 4.6 m (15 feet). With a gradient of 0.5 percent, they empty leachate into precast concrete wet wells. Leachate is pumped from wet wells by vertical submersible pumps to an 203 mm (8-inch-diameter) gravity main, from which it descends into concrete holding tanks. Drains of different elevations are connected by manholes. To hasten dewatering from the canal, lateral trenches have also been dug between the canal boundaries and the main drainage system.

(2) Drainage ditches.

(a) Open ditches are on the order of 1.8 to 3.7 m (6 to 12 feet) deep. When they are connected to subsurface drains, they must be deep enough to intercept the underdrains.

(b) The water level in a ditch is determined by the purpose the ditch has to serve. Surface drains require sufficient freeboard when running at full capacity. The flow velocity should be kept within certain limits in view of scouring of the bed and side slopes and of sediment deposition. Important factors governing the desired flow velocity are soil type, type of channel,

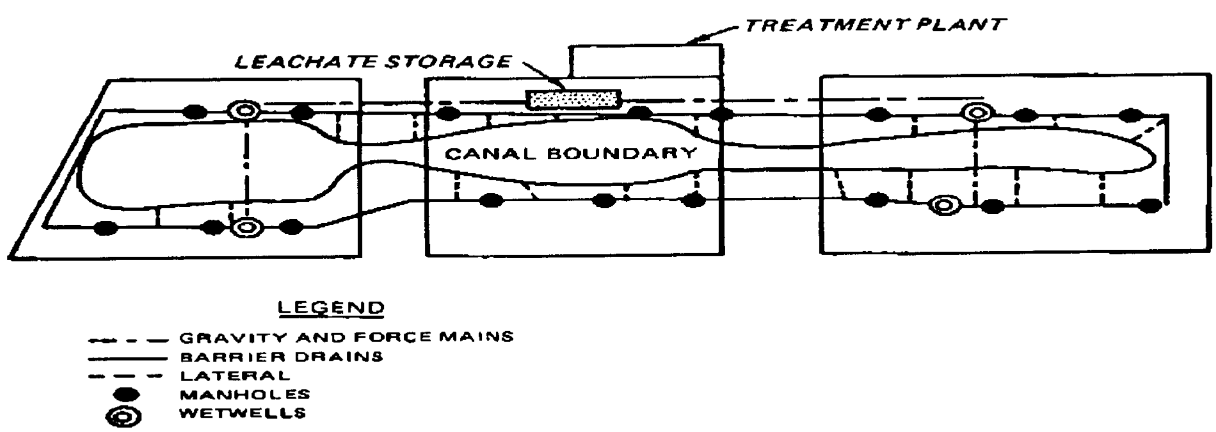


Figure 3-24. Leachate Collection System for Love Canal, Transverse View (Source: Glaubinger et al. 1979)

well roughness, and sediment load. The size of the ditch necessary to carry the estimated quantity of water can be determined from the Manning velocity equation and is dependent upon the slope, depth, and shape of its cross section.

(c) The selection of side slopes is based on stability of soil and on the hazard of scour, taking into account possible ground-water pressures and vegetative cover. The stability of side slopes may be improved by tamping or rolling. Trapezoidal cross sections are generally most efficient. In fine-grained soils such as heavy clays, ½ to 1 slopes (0.15 to 0.3 m (0.5 foot to 1 foot vertical)) and 1-1/2 to 1 are common. In coarser textured soils, 1 to 1 or 2 to 1 may be advisable.

(d) Ditch bottoms at junctions should be at the same elevation to avoid drops that may cause scour. Right-angle junctions encourage local scour of the bank opposite the tributary ditch, and the smaller ditch should be designed to enter the larger at an angle of about 30 degrees. The scour will also occur at sharp changes in ditch alignment, so long radius curves should be used where change is necessary.

(e) An open ditch can be kept in efficient working condition by careful maintenance. A drain allowed to become obstructed by brush, weed growth, or sediment can no longer be efficient; it should be cleaned to its original depth when efficiency is curtailed.

d. Advantages and Disadvantages. The advantages and disadvantages of subsurface drains and drainage ditches are summarized below:

Advantages	Disadvantages
Subsurface Drains	
Operation costs are relatively cheap since flow to underdrains is by gravity	Not well suited to poorly permeable soils
Provides a means of collecting leachate without the use of impervious liners	In most instances it will not be feasible to situate underdrains beneath the site
Considerable flexibility is available for design of underdrains; spacing can be altered to some extent by adjusting depth or modifying envelope material	System requires continuous and careful monitoring to ensure adequate leachate collection
Systems fairly reliable, providing there is continuous monitoring	

(Continued)

Advantages	Disadvantages
Drainage Ditches	
Low construction and operating cost	Requires extensive maintenance to maintain operating efficiency
Useful for intercepting landfill side seepage and runoff	Generally not suited for deep disposal sites or impoundments
Useful for collecting leachate in poorly permeable soils where sub-surface drains cannot be used	May interfere with use of land
	May introduce need for additional safety/security measures
Large welted perimeter allows for high rates of flow	

Section III. Surface Water Controls

3-22. Surface Water Diversion.

a. Background.

(1) A major consideration at any hazardous waste site is water management. Minimizing the amount of water moving through a site reduces the spread of potentially toxic materials and the requirements to treat leachate or drainage from the area. Many sites are in low-lying areas adjacent to natural watercourses. In some instances, it has been necessary to divert drainage around a landfill or reinforce or dike streambanks to prevent the waste from being washed into the stream and contaminating the water downstream. Run-on is generally controlled using ditching, channelization, or construction of berms and dikes.

(2) Run-on diversion can be implemented at a hazardous waste site by using many of the same remedies used to control run-on at a construction site. This remedial activity is applicable when it can be demonstrated that water is entering the disposal site from adjacent slopes or that streams moving across the site are contributing water to the site or washing wastes out of the site.

(3) Where minimizing ground-water infiltration is important to prevent the water table under the site from rising, lined trenches should be considered in drainage design. Lined trenches typically are constructed of concrete, shotcrete, asphaltic concrete, metal culvert (half sections), or synthetic membrane materials (polyvinylchloride or polyethylene).

(4) The data requirements for design of drainage systems on or around a hazardous waste system are similar to those required for construction drainage, including area to be drained, type of drain proposed, grade of the proposed drainway, and maximum capacity based on rainfall and snowmelt records. Additional considerations would be the lifetime of the system. Some systems will be required only until wastes can be excavated and transported;

at other sites, the waste will remain in place, and the surface water control system will have to be maintained indefinitely.

(5) Design criteria for drainage systems at landfills are not specifically provided in regulations. The performance requirements are for most complete diversion of water possible. The Department of Agriculture and EPA guidance for sizing diversion drainage systems around a waste disposal area calls for carrying capacities equal to at least the peak run-off from a 10-year, 24-hour storm. In most cases, carrying capacities should be greater.

(6) Design procedures are typically undertaken in much the same way as those for drainage or diversion planning--from estimation of carrying capacity requirements to specific requirements as to the type of drainage and specific types of material (sod, riprap, concrete, etc.) to be employed. Models, such as Storage Treatment Overflow and Run-off Model (STORM) from the Corps* Hydrologic Engineering Center (HEC), Chemical Runoff and Erosion from Agricultural Management Systems Hydrologic Model (CREAMS) from the Department of Agriculture, and Hydrologic Evaluation of Landfill Performance (HELP) from the Corps* Waterways Experiment Station can be helpful in determining the quantity and quality of run-off from areas surrounding a waste site. Several well-established construction techniques are available for diverting and handling surface water flow in critical areas. Those methods most applicable as remedial measures at uncontrolled disposal sites are addressed below.

b. Dikes and Berms.

(1) Description and applications.

(a) Dikes and berms are well-compacted earthen ridges or ledges constructed immediately upslope from or along the perimeter of disturbed areas (e.g., disposal sites). These structures are generally designed to provide short-term protection of critical areas by intercepting storm run-off and diverting the flow to natural or man-made drainageways, to stabilized outlets, or to sediment traps. The terms “dikes” and “berms” are generally used interchangeably; however, dikes may also have applications as flood containment levees.

(b) Dikes and berms may be used to prevent excessive erosion of newly constructed slopes until more permanent drainage structures are installed or until the slope is stabilized with vegetation. Dikes and berms will help provide temporary isolation of uncapped and unvegetated disposal sites from surface run-off that may erode the cover and infiltrate the fill. These temporary structures are designed to handle relatively small amounts of runoff; they are not recommended for unsloped drainage areas larger than 5 acres.

(2) Design and construction considerations.

(a) Specific design and construction criteria for berms and dikes will depend upon desired site-specific functions of the structures. An interceptor dike/berm may be used solely to shorten the length of exposed slopes on or above a disposal site, thereby reducing erosion potential by intercepting and diverting run-off. Diversion dikes/berms may be installed at the top of the steeper side slopes of unvegetated disposal sites to provide erosion protection by diverting runoff to stabilized channels or outlets.

(b) Dikes and berms ideally are constructed of erosion-resistant, low-permeability, clayey soils. Compacted sands and gravel, however, may be suitable for interceptor dikes and berms. The general design life of these structures is on the order of one year maximum; seeding and mulching or chemical stabilization of dikes and berms may extend their life expectancy. Stone stabilization with gravel or stone riprap immediately upslope of diversion dikes will also extend performance life.

(c) All earthen dikes should be machine compacted. In addition:

! Diverted runoff should discharge directly onto stabilized areas, grassed channel, or chute/downpipe.

! Periodic inspection and maintenance should be provided.

! Diversion dikes must be seeded and mulched immediately after construction.

(3) Advantages and disadvantages. Advantages and disadvantages of dikes and berms are summarized below:

Advantages	Disadvantages
Uses standard construction techniques and equipment usually already on site	Periodic inspections and maintenance required to ensure structural integrity
Required fill dirt usually available on site	May increase seepage if installed improperly, increasing soil instability and leachate generation
Temporary control of erosion until further stabilization	Only suitable for small drainage areas (less than 2 hectares (5 acres))
Runon water reduced, and therefore leachate production	

c. Ditches. Diversions, and Waterways.

(1) Description and applications.

(a) Ditches (or swales) are excavated, temporary drainageways used above and below disturbed areas to intercept and divert runoff. They may be constructed along the upslope perimeter of disposal areas to intercept and carry storm run-off into natural drainage channels downslope of the site. Ditches may also be installed downslope of covered disposal sites to collect and transport sediment-laden flow to sediment traps or basins. Ditches should be left in-place until the disposal site is sealed and stabilized with cover vegetation.

(b) Diversions are permanent or temporary shallow drainageways excavated along the contour of graded slopes and having a support earthen ridge (dike or berm) constructed along the downhill edge of the drainageway. Essentially, a diversion is a combination of a ditch and a dike. Diversions are used primarily to provide more permanent erosion control on long slopes subject to heavy flow concentrations. They may be constructed across long slopes to divide the slope into nonerosive segments. Diversions may also be constructed at the top or at the base of long graded slopes at disposal sites to intercept and carry flow at nonerosive velocities to natural or prepared outlets. Diversions are recommended for use only in slopes of 15 percent or less.

(c) Grassed waterways (or channels) are graded drainageways that serve as outlets for diversions or berms. Waterways are stabilized with suitable vegetation and are generally designed to be wide and shallow in order to convey run-off down slopes at nonerosive velocities. Waterways may be constructed along the perimeter of disposal sites located within natural slopes, or they may be constructed as part of the final grading design for disposal areas that have been capped and revegetated.

(2) Design and construction considerations.

(a) Ditches, diversions, and waterways are generally of V-shaped, trapezoidal, or parabolic cross-section design. The specific design will be dependent on local drainage patterns, soil permeability, annual precipitation, area land use, and other pertinent characteristics of the contributing watershed. In general, such drainageways should be designed to accommodate flows resulting from rainfall events (storms) of 10- or 25-year frequency. More importantly, they should be designed and constructed to intercept and convey such flows at nonerosive velocities.

(b) Figure 3-25 depicts the effect of drainage channel shape on relative velocity of conveyed flows. In general, the wider and shallower the channel cross section, the less the velocity of contained flow and therefore the less the potential for erosion of drainageway side slopes. Where local conditions dictate the necessity of building narrower and deeper channels , or where slopes are steep and flow velocities are excessive, the channel will require stabilization through seeding and mulching or the use of stone riprap to line channel bottoms and break up flow.

(c) Table 3-6 presents maximum permissible design velocities for flow in ditches and grassed waterways, based on the channel grade and stabilizing cover material.

(d) These structures are designed for short-term application only, for upslope drainage areas of less than 2 hectares (5 acres). A minimum grade of 1 percent, draining to a stabilized outlet such as a grassed waterway or, where necessary, to a sediment basin or trap, is recommended for temporary ditches. For channel slopes greater than 5 percent, stabilization with

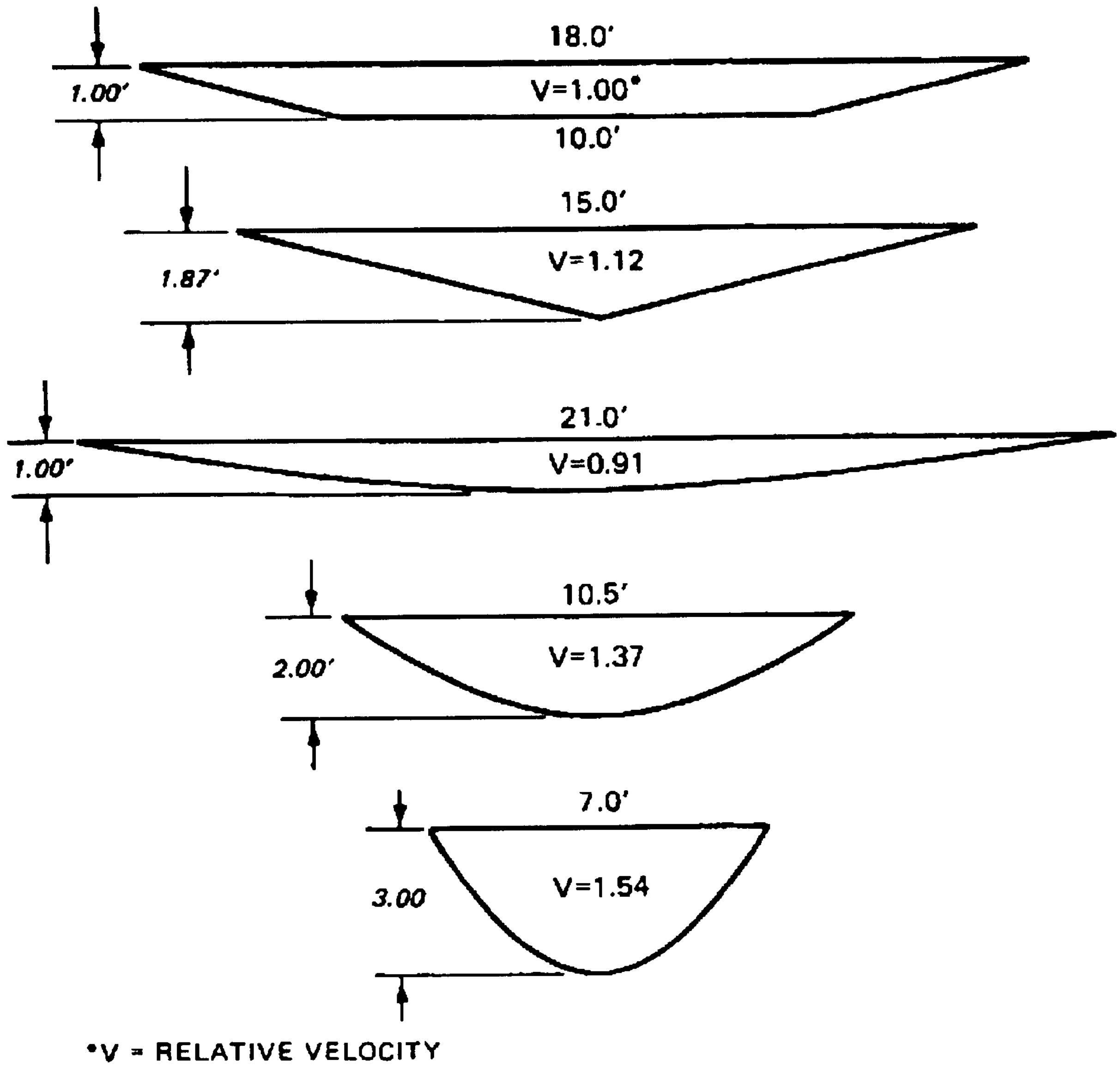


Figure 3-25. Effect of Drainage Ditch on Velocity

grasses, mulches, sod, or stone riprap will be necessary. As with all temporary structures, periodic inspection and maintenance are required to ensure structural integrity and effective performance.

(e) Figure 3-26 presents general design features of parabolic and trapezoidal diversions. A formal design is not required for diversions used as temporary water-handling structures. General design and construction criteria for permanent diversions and waterways include the following:

Table 3-6. Permissible Design Velocities for Stabilized Diversions and Waterways

Vegetation	Channel grade (%)	Maximum design velocity (ft/sec)	(m/sec)
Bermuda grass	0-5	6	1.8
	5-10	5	1.5
	10	4	1.2
Reed canary grass	0-5	5	1.5
Tall fescue	5-10	4	1.2
Kentucky bluegrass	10	3	0.9
Grass-legume mix	0-5	4	1.2
	5-10	3	0.9
Red fescue	0-5	2.5	0.8
Redtop, sericea lespedeza			
Annuals; small grain (rye, oats, barley); ryegrass	0-5	2.5	0.8

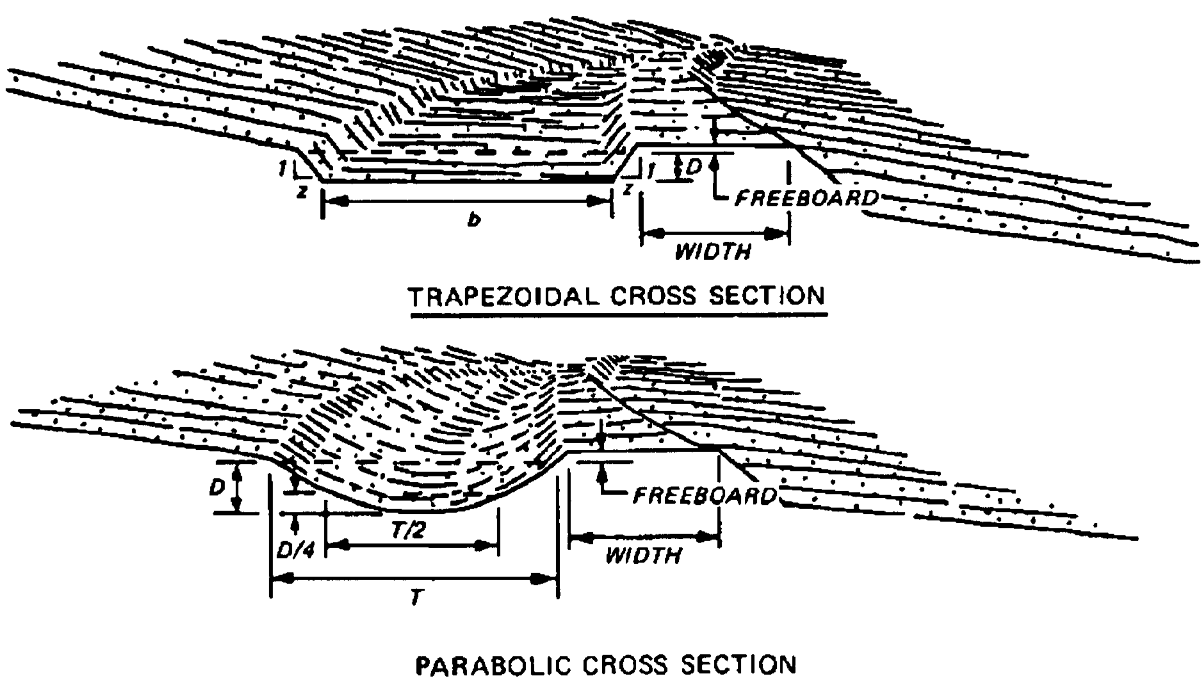


Figure 3-26. General Design Features of Diversions

! Diversion location will be determined on the basis of outlet conditions, topography, soil type, slope length, and grade.

! Constructed diversion will have the capacity to carry peak discharge from the 25-year design storm.

! The maximum grade of the diversion may be determined by using design velocity of the flow based on stabilization by cover type (Table 3-6).

! The diversion channel will be parabolic or trapezoidal in shape, with side slopes no steeper than 2:1.

! Each diversion will have a stable outlet such as a natural waterway, stabilized open channel, chute, or downpipe.

! For channels that carry flow during dry weather (base flow) due to ground-water discharge or delayed subsurface run-off, the bottom should be protected with a stone center for grassed waterways. Subsurface drainage with gravel/stone trenches may be required where the water table is at or near the surface of the channel bottom.

(3) Advantages and disadvantages.

(a) When they are carefully designed, constructed, and maintained, ditches, diversions, and grassed waterways will control surface erosion and infiltration at disposal sites by intercepting and safely diverting storm run-off to downslope or offsite outlets. When situated at the base of disposal site slopes, they function to protect offsite habitat from possible contamination by sediment-laden run-off. These structures are generally constructed of readily available fill, by well-established techniques.

(b) Temporary ditches and diversions, however, entail added costs because they require inspections and maintenance. Grassed waterways must be periodically mowed to prevent excessive retardation of flow and subsequent ponding of water. Also, periodic resodding, remulching, and fertilizing may be required to maintain vegetated channels.

(c) If fertilization is used, an additional disadvantage is introduced in that nitrogen and phosphorus are added to drainage wastes, which then contribute to the problem of accelerated eutrophication in receiving water bodies.

(d) It may also be necessary to install temporary straw-bale check dams, staked down at 15.2 to 30.5 m (50- to 100-foot) intervals, across ditches and waterways in order to prevent gulley erosion and to allow vegetative establishment.

(e) Permanent diversions and waterways are more cost-effective techniques than temporary structures for controlling erosion and infiltration on a long-term basis at inactive disposal sites.

d. Terraces and Benches.

(1) Description and applications.

(a) Terraces and benches are relatively flat areas constructed along the contour of very long or very steep slopes to slow run-off and direct it into ditches or diversions for offsite transport at nonerosive velocities. These structures are also known as bench terraces or drainage benches.

(b) Although benches and terraces are slope-reduction devices, they are generally constructed with reverse or natural fall to divert water to stabilized drainageways. Benches and terraces may be used to break up steeply graded slopes of covered disposal sites into less erodible segments. Upslope of disposal sites, they act to slow flow and divert storm run-off around the site. Downslope of landfill areas, they act to intercept and divert sediment-laden run-off to traps or basins. Hence, they may function to hydrologically isolate active disposal sites, to control erosion of cover materials on completed fills, or to collect contaminated sediments eroded from disposal areas. For disposal sites undergoing final grading (after capping and prior to revegetation), construction of benches or terraces may be included as part of the integrated site closure plan.

(2) Design and construction considerations.

(a) Benches and terraces generally do not require a formal design plan. Figure 3-27 presents the design for a typical drainage bench located on the slope of a covered landfill. This particular bench is designed with a natural fall. It is intended for long-term erosion protection as the associated V-shaped channel is asphalt-concrete lined. Diversions and ditches included in bench/terrace construction may be seeded and mulched, sodded, stabilized with riprap or soil additives, or stabilized by any combination of these methods. Lining the channels with concrete or grouted riprap is a more costly alternative.

(b) The width and spacing between benches and terraces will depend on slope steepness, soil type, and slope length. In general, the longer and more erodible the cover soil, the less the distance between drainage benches should be. For slopes greater than 10 percent in steepness, the maximum distance between drainage benches should be approximately 30.5 m (100 feet), i.e., a bench every 3 m (10 feet) of rise in elevation.

(c) When the slope is greater than 20 percent, benches should be placed every 20 feet of rise in elevation. Benches should be of sufficient width and height to withstand a 24-hour, 25-year storm.

(d) Bench terraces do not necessarily have to be designed with diversions or ditches to intercept flow. Reverse benches and slope benches may be constructed during final site grading on well-stabilized slopes (e.g., vegetated) to enhance erosion control by reducing slope length and steepness. At sites where an effective cap (e.g., clay or synthetic liner) has been constructed, or for sites located in arid regions, these nondrainage benches

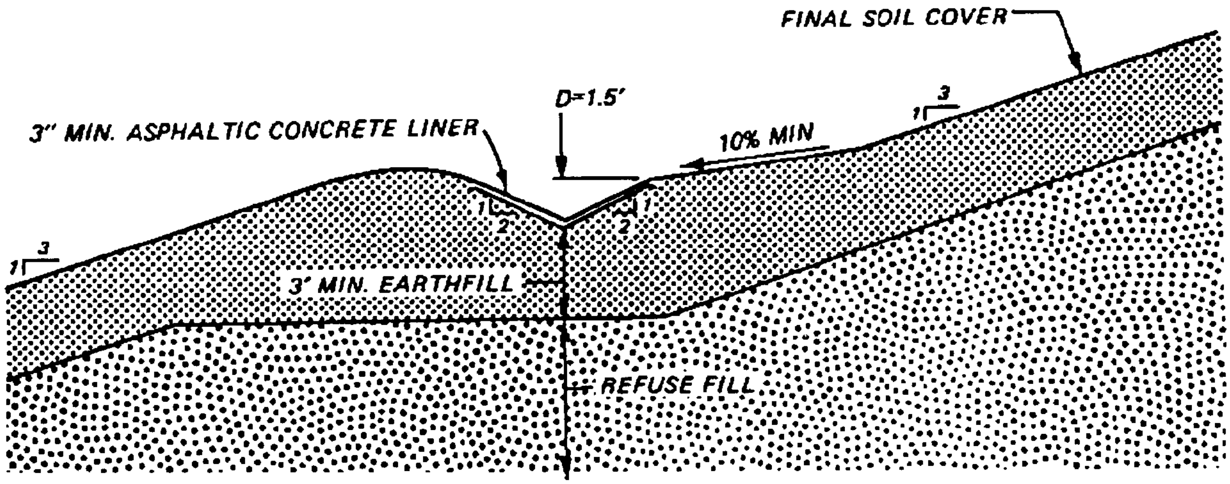


Figure 3-27. Typical Drainage Bench

will function to slow sheet run-off and allow greater infiltration rates, which will aid in the establishment of a suitable vegetative cover. For most disposal sites in wet climates, however, where leachate generation and cover erosion are major problems, benches and terraces should be designed in association with drainage channels that intercept and transport heavy, concentrated surface flows safely offsite.

(e) As with other earthen erosion control structures, benches and terraces should be sufficiently compacted and stabilized with appropriate cover (grasses, mulches, sod) to accommodate local topography and climate. They should be inspected during or after major storms to ensure proper functioning and structural integrity. If bench slopes become badly eroded or if their surfaces become susceptible to ponding from differential settlement, regrading and sodding may be necessary.

(3) Advantages and disadvantages.

(a) In areas of high precipitation, drainage benches and terraces are proven effective in reducing velocity of storm run-off and thereby controlling erosion. For excessively long and steep slopes above, on, or below disposal sites, these structures are cost-effective methods for slowing and diverting run-off. They may also be used to manage downslope washout of disposal site sediments that may be contaminated with hazardous waste components. Terraces and benches are easily incorporated into final grading schemes for disposal sites and do not require special equipment or materials for their construction.

(b) If improperly designed or constructed, bench terraces will not perform efficiently and may entail excessive maintenance and repair costs. It is important that these structures be stabilized with vegetation as soon as possible after grading and compaction, or they may become badly eroded and require future resodding or chemical stabilization. Benches and terraces also require periodic inspections, especially after major rainfall events.

e. Chutes and Downpipes.

(1) Description and applications.

(a) Chutes and downpipes are temporary structures used to carry concentrated flows of surface runoff from one level to a lower level without erosive damage. They generally extend downslope from earthen embankments (dikes or berms) and convey water to stabilized outlets located at the base of terraced slopes.

(b) Chutes (or flumes) are open channels, normally lined with bituminous concrete, portland cement concrete, grouted riprap, or similar nonerodible material. Temporary paved chutes are designed to handle concentrated surface flows from drainage benches located near the base of the long, steep slopes at disposal sites.

(c) Downpipes (downdrains or pipe slope drains) are temporary structures constructed of rigid piping (such as corrugated metal) or flexible tubing of heavy-duty fabric. They are installed with standard prefabricated entrance sections and are designed to handle flow from drainage areas of 5 acres or less. Like paved chutes, downpipes discharge to stabilized outlets or sediment traps. Downpipes may be used to collect and transport run-off from long, isolated outslopes or from small disposal areas located along steep slopes.

(2) Design and construction considerations.

(a) Chutes and downpipes are temporary structures that do not require formal design.

(b) Paved chute construction considerations include the following:

- The structure will be placed on undisturbed soil or well-compacted fill.

- The lining will be placed by beginning at the lower end and proceeding upslope; the lining will be well compacted, free of voids, and reasonably smooth.

- The cutoff walls at the entrance and at the end of the asphalted discharge aprons will be continuous with the lining.

- An energy dissipator (riprap bed) will be used to prevent erosion at the outlet.

(c) For downpipes, the maximum drainage area will be determined from the diameter of the piping, as follows (U.S. EPA 1976):

Pine/Tube diameter, D		Maximum drainage area	
(inches)	(mm)	(acres)	(hectares)
12	300	0.5	0.2
18	460	1.5	0.6
21	530	2.5	1
24	610	3.5	1.4
30	760	5.0	2

(d) General construction criteria for both rigid and flexible downdrains include the following:

! The inlet pipe will have a slope of 3 percent or greater.

! For the rigid downpipe, corrugated metal pipe with watertight connecting bands will be used.

! For the flexible downdrain, the inlet pipe will be corrugated metal; the flexible tubing will be the same diameter as the inlet pipe, securely fastened to the inlet with metal strapping or watertight connecting collars.

! A riprap apron of 152 mm (6-inch-diameter) stone will be provided at the outlet.

! The soil around and under the inlet pipe and entrance sections will be hand-tamped in 102 mm (4-inch) lifts to the top of the earth dike.

! Follow-up inspection and any needed maintenance will be performed after each storm.

(3) Advantages and disadvantages. The advantages and disadvantages associated with the construction and maintenance of chutes and downpipes are summarized below:

Advantages	Disadvantages
Construction methods are inexpensive and quick; suitable for for emergency measures	Provide only temporary erosion control while slopes are stabilized with vegetative growth
No special materials or equipment are required	Entail extra cost for periodic inspections and maintenance and ultimate removal
Effective in preventing erosion on long, steep slopes	If improperly designed, may overflow and cause severe erosion in concentrated areas
Can be used to channel storm runoff to sediment traps, drainage basins, or stabilized waterways for offsite transport	

(Continued)

Advantages	Disadvantages
Can be key element in combined surface control systems	Downpipes are suitable for drainage areas 2 hectares (5 acres) in size limited applications in general

f. Levees and Floodwalls.

(1) Description and applications.

(a) Levees are earthen embankments that function as flood protection structures in areas subject to inundation from tidal flow or riverine flooding. Levees create a barrier to confine flooding waters to a floodway and to protect structures behind the barrier. They are most suitable for installation of flood fringe areas or areas subject to storm tide flooding, but not for areas directly within open floodways.

(b) Flood containment levees may be constructed as perimeter embankment surrounding disposal sites located in floodplain fringe areas, or they may be installed at the base of landfills along slope faces that are subject to periodic inundation.

(c) Levees are generally constructed of compacted impervious fill. Special drainage structures are often required to drain the area behind the embankment. Levees are normally constructed for long-term flood protection, but they require periodic inspection and maintenance to ensure proper functioning. They may be costly to build and maintain, but if properly designed on a site-specific basis, levees will reduce flooding hazards at critical waste disposal areas.

(2) Design and construction considerations.

(a) To provide adequate flood protection, levees should be constructed to a height capable of containing a design flood of 100-year magnitude. Elevation of 100-year base flood crests can be determined from floodplain analyses typically performed by state or local flood control agencies. A minimum levee elevation of 0.6 m (2 feet) above the 100-year flood level is recommended.

(b) Figure 3-28 presents design features of a typical levee constructed at the toe of a landfill slope. This design is appropriate for new or incomplete disposal sites; filled wastes may eventually be placed on the inboard slope of the levee.

(c) Ideal construction of levees is with erosion-resistant, low permeability soils, preferably clay. Most levees are homogeneous embankments; but if impermeable fill is lacking, or if seepage through and below the levee is a problem, then construction of a compacted impervious core or sheet-pile cutoff extending below the levee to bedrock (or other impervious stratum) may

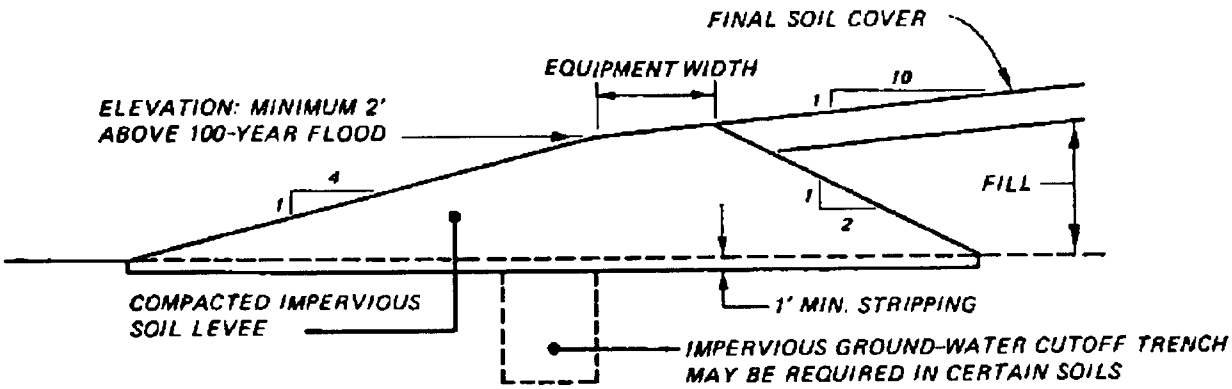


Figure 3-28. Typical Levee at Base of Disposal Site

be necessary. Excess seepage through the levees should be collected with gravel-filled trenches or tile drains along the interior of the levee. After draining to sumps, the seepage can be pumped out over the levee. Levee bank slopes, especially those constructed of less desirable soils (silts, sands), should be protected against erosion by sodding, planting of shrubs and trees, or use of stone riprap.

(d) Storm run-off from precipitation falling on the drainage area behind the levee may cause backwater flooding.

(e) Because of the relatively long, flat side slopes of levees, an embankment of any considerable height requires a very large base width. For locations with limited space and fill material, or excessive real estate costs, the use of concrete floodwalls is preferred as an alternative to levee construction.

(f) Floodwalls are designed to withstand the hydrostatic pressure exerted by water at the design flood level. They are subject to flood loading on one side only; consequently, they need to be well founded. Figure 3-29 presents typical floodwall sections. Like levees, floodwalls may require subsurface cutoffs and interior drainage structures to handle excessive seepage or backwater flow.

(3) Advantages and disadvantages. The advantages and disadvantages associated with flood protection levees at waste disposal sites are summarized below:

Advantages	Disadvantages
Can be built at relatively low cost from materials available at site	Flooding from storm runoff behind levee may be a problem

(Continued)

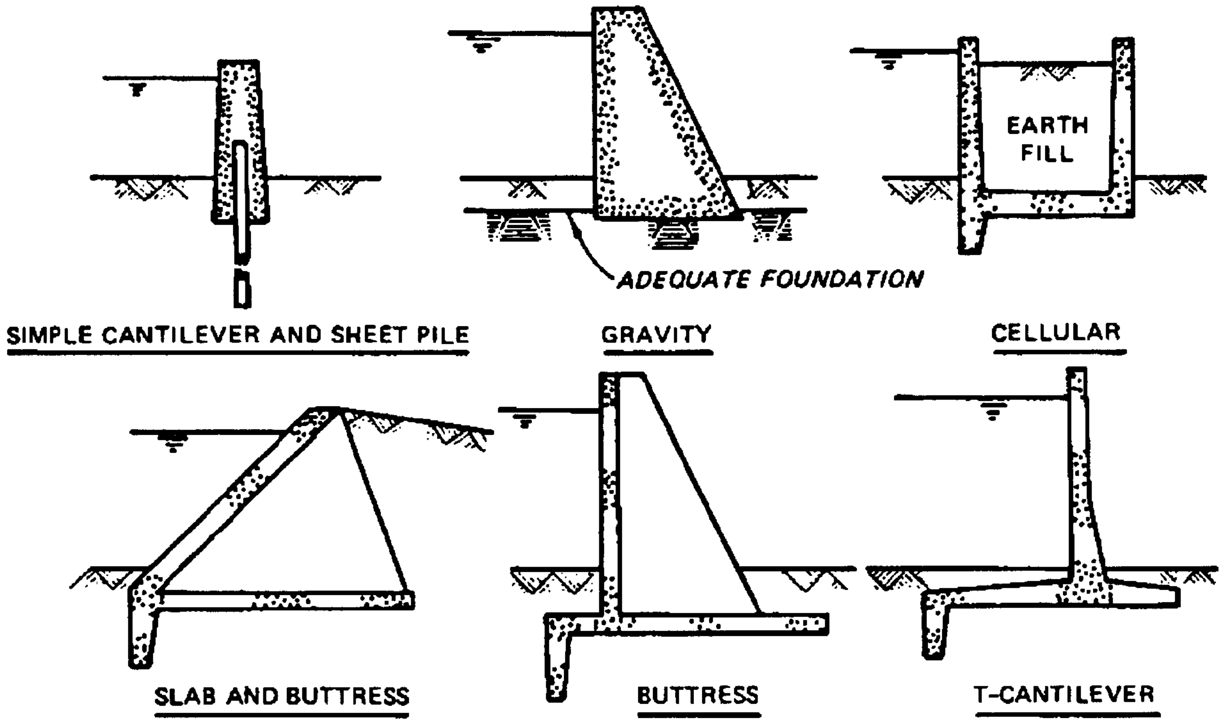


Figure 3-29. Some Typical Floodwall Sections

Advantages	Disadvantages
Will privide long-term flood protection if properly designed and constructed	Loss of flow storage capacity, with greater potential of downstream flooding
Control major erosive lossed of waste and cover material; prevent massive leachate production and subsequent contamination from riverine or tidal flooding	Levee failure during major flood will require costly emergency measures (emergency embankments; sand bags) and rebuilding of structure
	Require periodic maintenance and inspections
	Special seepage cutoffs or interior drainage structures (e.g., pressure conduits) will add to construction costs

g. Seepage Basins and Ditches.

(1) General description and applications. Seepage or recharge basins are designed to intercept run-off and recharge the water downgradient from the site so that ground-water contamination and leachate problems are avoided or minimized.

(2) Design and construction considerations.

(a) There is considerable flexibility in the design of seepage basins and ditches. Figures 3-30 and 3-31 illustrate possible design variations. Where seepage basins are used (Figure 3-30), run-off will be intercepted by a series of diversions, or the like, and passed to the basins. As illustrated, the recharge basin should consist of the actual basin, a sediment trap, a bypass for excess run-off, and an emergency overflow. A considerable amount of recharge occurs through the sidewalls of the basin, and it is preferable that these be constructed of pervious material. Gabions are frequently used to make sidewalls. An alternative design for a seepage basin is shown in Figure 3-31; it is usually used where the aquifer is shallow.

(b) Seepage ditches (Figure 3-32) distribute water over a larger area than can be achieved with basins. They can be used for all soils where permeability exceeds about 2.94×10^{-5} cm/sec (0.9 inch per day). Run-off is disposed of by a system of drains set in ditches of gravel. Depth and spacing of drains depend on soil permeability. A minimum depth of 1.2 m (48 inches) is generally recommended, and ditches are rarely less than 3 m (10 feet) apart. The ditches are backfilled with gravel, on which the distribution line is laid. Sediment is removed prior to discharging run-off into the seepage ditches by use of a sediment trap and distribution box.

(3) Advantages and disadvantages. Advantages and disadvantages of drainage systems are listed below:

Advantages	Disadvantages
Cost-effective means of intercepting run-off and allowing it to recharge	Seepage basins and ditches are susceptible to clogging
Systems can perform reliably if well maintained	Deep basins or trenches can be hazardous
	Not effective in poorly permeable soils

h. Sedimentation Basins/Ponds.

(1) General description and application. Sediment basins are used to control suspended solids entrained in surface flows. A sedimentation basin is constructed by placing an earthen dam across a waterway or natural depression, or by excavation, or by a combination of both. The purpose of installing a sedimentation basin is to impede surface run-off carrying solids, thus

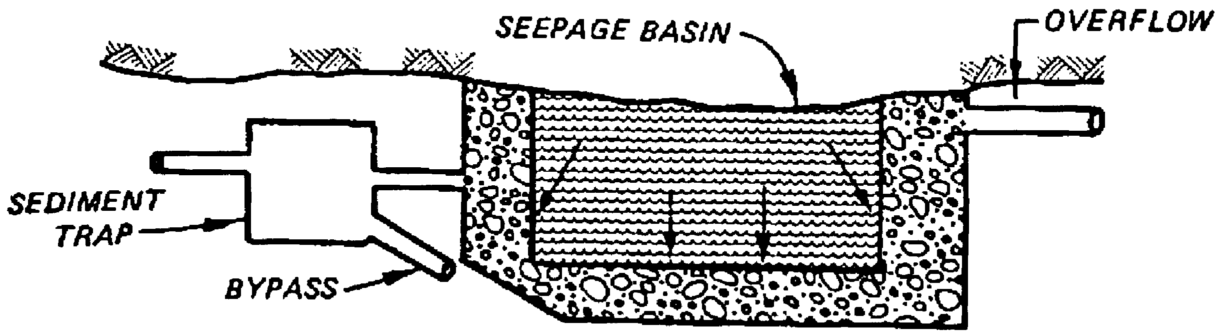


Figure 3-30. Seepage Basin; Large Volume, Deep Depth to Ground Water

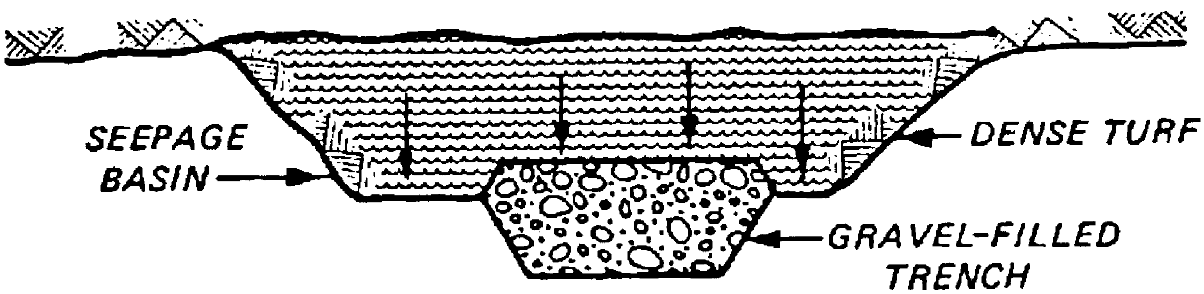


Figure 3-31. Seepage Basin: Shallow Depth to Ground Water

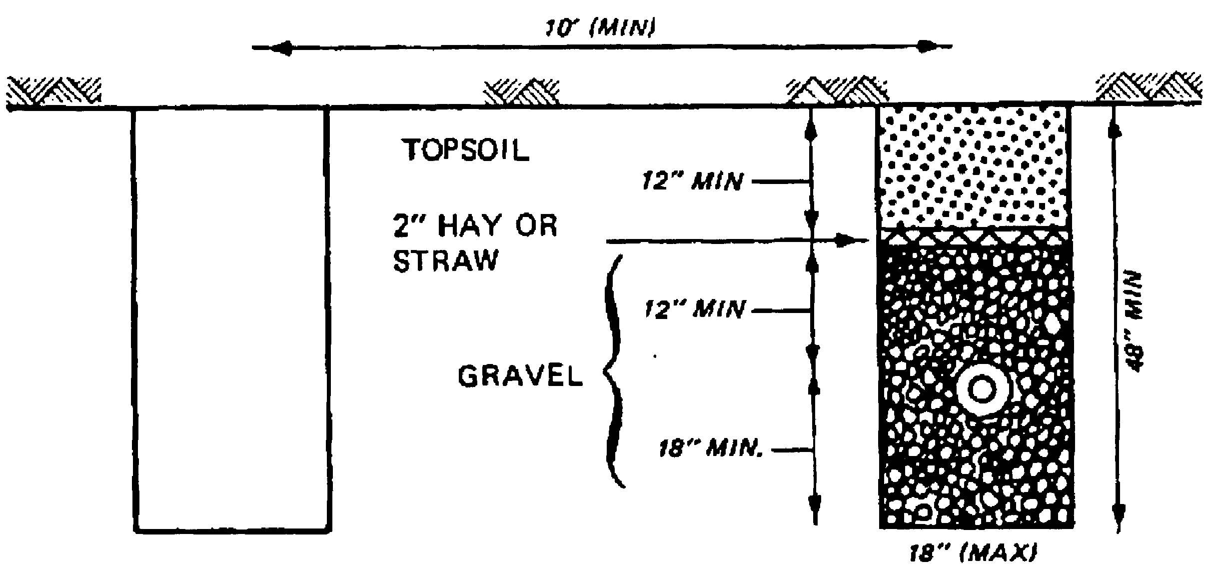


Figure 3-32. Seepage Ditch

allowing sufficient time for the particulate matter to settle. Sedimentation basins are usually the final step in control of diverted surface run-off, prior to discharge into a receiving water body. They are an essential part of any good surface flow control system and should be included in the design of remedial actions at waste disposal sites.

(2) Design and construction considerations.

(a) The removal of suspended solids from waterways is based on the concept of gravitational settling of the suspended material.

(b) The size of a sedimentation basin is determined from characteristics of flow such as the particle size distribution for suspended solids, the inflow concentration, and the volumetric flow rate. To calculate the area of the sedimentation basin pond required for effective removal of suspended solids, the following data on the flow characteristics are needed:

- The inflow concentration of suspended solids.

- The desired effluent concentration of suspended solids. The desired effluent concentration is usually regulated by local and/or Federal government authorities. For example, for coal mines, the proposed EPA “Effluent Guidelines and Standard” limits are as follows: total suspended solids concentration maximum for any one day shall not exceed 70 milligrams per liter, and average daily values for 30 consecutive days shall not exceed 35 milligrams per liter.

- The particle-size distribution for suspended solids.

- The water flow rate (Q) to the pond. For a pond receiving direct run-off, the run-off volume over a certain period of time must be determined. As an example, EPA has chosen the 10-year, 24-hour precipitation event as a design criteria for the overflow rate determination.

(c) A typical installation of a sedimentation basin embankment is illustrated in Figure 3-33. As shown, the pond consists of a dike which retains the polluted water flow. For water drawdown purposes, a principal spillway is also needed.

(d) Emergency spillways are also suggested in the design of a sediment basin. They are provided to convey large flows safely past an earth embankment, and they are usually open to channels excavated in earth, rock, or reinforced concrete.

(e) The efficiency of sedimentation ponds varies considerably as a function of the overflow rate. Sedimentation ponds perform poorly during periods of heavy rains and cannot be expected to remove the fine-grained suspended solids. If the sedimentation pond is expected to remove sediments that may have been contaminated by waste materials, consideration should be given to improving removal efficiencies by modifying basin or outlet design.

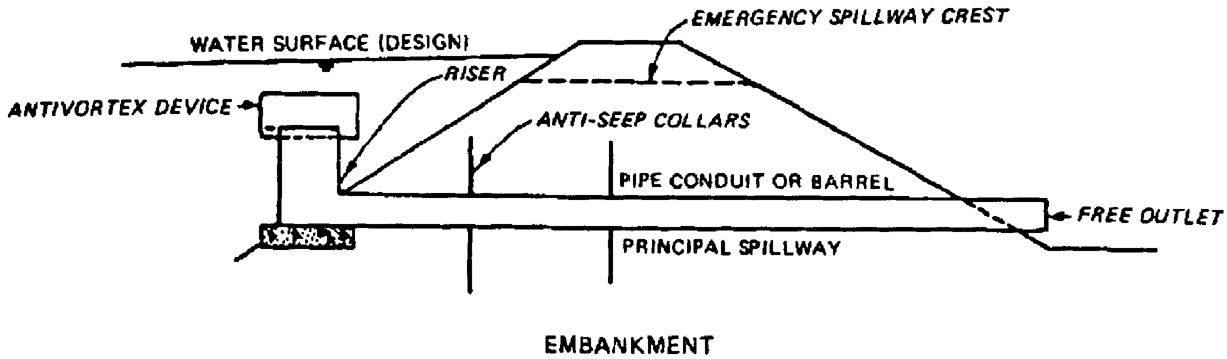


Figure 3-33. Typical Design of a Sediment Basin Embankment

(f) The quantity of material to be stored is also an important consideration in the construction of the sedimentation basin. The required storage capacity can be calculated by multiplying the total area disturbed by a constant sediment yield rate.

(3) Advantages and disadvantages. The advantages and disadvantages of the sedimentation basin in the control of water flow contaminated with suspended solids are listed below.

Advantages	Disadvantages
Easy to design and install, proven technology	Ineffective on dissolved solids
Require low operational and maintenance effort	Faulty design or structural failure may result in extensive damages
Remove suspended solids very effectively	

3-23. Surface Grading.

a. Background.

(1) Grading is the general term for techniques used to reshape the surface of covered landfills in order to manage surface water infiltration and run-off while controlling erosion. The spreading and compaction steps used in grading are techniques practiced routinely at sanitary landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary by site. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated landfill closure plan.

(2) The major goals in surface grading of an uncontrolled waste site are to:

(a) Reduce ponding on the site and consequently minimize infiltration of water into any buried wastes.

(b) Reduce the rate of contaminant leaching from soils.

(c) Reduce erosion of cover soils that isolate any buried waste.

(3) Proper site grading is in almost all cases an advantage in the control of the potential contaminants. Since standing water in a waste site will leach contaminants from the surface materials, it is generally more likely to create a treatment problem than water collected running from the area. Ponding also creates aesthetic and trafficability problems.

(4) Finished grades at waste sites are designed on the basis of natural site topography, soil type, slope stability, rainfall intensity, size of the site, and type of final vegetative cover proposed.

b. Description and Applications.

(1) Grading techniques modify the natural topography and run-off characteristics of waste sites to control infiltration and erosion. The choice of specific grading techniques for a given waste disposal site will depend on the desired site-specific functions of a graded surface. A graded surface may reduce or enhance infiltration and detain or promote run-off. Erosion control may be considered a complicating variable in the design performance of a grading scheme.

(2) For disposal sites in wet climates (i.e., where precipitation annually exceeds evaporation and transpiration) and where subsurface hazardous leachate generation is a major problem, control of surface water infiltration is of primary importance. Manipulation of slope length and gradient is the most common grading technique used to reduce infiltration and promote surface water run-off. A slope of at least 5 percent is recommended as sufficient to promote run-off and decrease infiltration without risking excessive erosion.

(3) At landfill and dump sites where an effective surface sealing has been applied (e.g., clay cap or synthetic membrane and a topsoil layer), various grading techniques can be used to prepare the covered surface for revegetation. The grading methods- -scarification, tracking, and contour furrowing- -create a roughened and loosened soil surface that detains run-off and maximizes infiltration. Such techniques are especially important for establishing vegetation in arid regions.

c. Design and Construction Considerations.

(1) The design of graded slopes at waste disposal sites should balance infiltration and run-off control against possible decreases in slope stability and increases in erosion. The design of specific slope configurations, the choice of cover soil type, the degree of compaction, and the types of grading equipment used will all depend on local topography, climate, and future land use of the site.

(2) Improperly graded slopes may deform or fail, opening cracks, exposing waste cells, and allowing lateral seepage of leachate. Soils used to cover graded slopes should be selected on the basis of shear strength and erodibility. Soils high in silt and fine sand and low in clay and organic matter are generally most erodible. Also, the longer and steeper the slope is, and the sparser the vegetation cover, the more susceptible it is to erosive forces.

(3) In grading a landfill surface before construction of a seal, two important considerations apply. First, bulky and heavy waste objects should not be filled near the surface of the site because they may settle unevenly and deform or crack graded cover. Also, to provide a firm subgrade and prevent seal failure, existing cover material should be compacted to a Proctor density of 70 to 90 percent of maximum.

(4) The equipment types used to construct graded slopes consist of both standard and specialized landfill vehicles. Excavation, hauling, spreading, and compaction of cover materials are the major elements of a complete grading operation.

(5) Specialized landfill vehicles include compactors and scrapers. Steel-wheeled landfill compactors are excellent machines for spreading and compacting on flat to moderate slopes. Scrapers are effective in excavating, hauling, and spreading cover materials over relatively long distances.

d. Advantages and Disadvantages.

(1) Surface grading of covered disposal sites, when properly designed and constructed to suit individual sites, can be an economical method of controlling infiltration, diverting run-off, and minimizing erosion. A properly sealed and graded surface will aid in the reduction of subsurface leachate formation by minimizing infiltration and promoting erosion-free drainage of surface run-off. Grading can also be used to prepare a cover soil capable of supporting beneficial plant species.

(2) There may be certain disadvantages associated with grading the surface of a given site. Large quantities of a difficult-to-obtain cover soil may be required to modify existing slopes. Suitable sources of cover material may be located at great distances from the disposal site, increasing hauling costs. Also, periodic regrading and future site maintenance may be necessary to eliminate depressions formed through differential settlement and compaction, or to repair slopes that have slumped or become badly eroded.

3-24. Surface Sealing.

a. Background.

(1) Landfill covers or caps prevent water from entering a landfill, thus reducing leachate generation, and also control vapor or gas produced in the water. Landfill covers can be constructed from native soils, clays, synthetic membranes, soil cement, bituminous concrete, or asphalt/tar materials. In most cases, the cap is constructed using the same equipment

used in construction and grading. The cap should be designed to have sufficient thickness to accommodate the anticipated settlements, deformations, desiccation cracking, and constructibility. Where native soil is used for the cap, soil additives or specialized construction techniques may be necessary to obtain the required plasticity and permeability. A permeability of 10^{-7} to 10^{-8} cm/sec is considered appropriate.

(2) A cover is a useful option at sites where the major pathway for contaminant transport is percolation of infiltrating precipitation or in cases where control of gases or volatile compounds in the waste is a serious consideration. When a cap is designed for toxic or flammable gas control, gas venting and disposal systems should be considered an integral part of the capping system.

(3) Capping systems are an advantage at any site where incoming precipitation can be minimized and leach rates reduced. In areas where the wastes are buried below the water table and lateral flow of ground water is evident, capping may not be completely effective in reducing contaminant transport. In a capped landfill at Windham, CT, that was partly below the water table, a definite decrease in the degree of contamination in ground water downgradient from the site was noted. Capping is usually an economical system, and because the top of the landfill is accessible, the cap can be maintained and repaired.

b. Description and Applications.

(1) Clays and soils.

(a) Cover soils are spread over waste layers at most operating landfills on a daily or intermediate basis prescribed by state and local standards in order to control vectors, odors, and windblown rubbish. These soils are generally supplied from onsite excavated fill and are not selected for special qualities. Soil used for final cover on completed fills or for capping uncontrolled waste sites, however, must be relatively impermeable (low permeability coefficient, k) and erosion-resistant. Fine-grained soils such as clays and silty clays have low k values and are therefore best suited for capping purposes because they resist infiltration and percolation of water. These fine-grained soils, however, tend to be easily eroded by wind, especially in arid climates where coarse, heavy-grained gravels and sands provide more suitable cover.

(b) Blending of different soil types broadens the grain-size distribution of a soil cover and minimizes its infiltration capacity. Well-graded soils are less permeable than those with a small range of grain sizes, and mixing of local coarse and fine-grained soils is a cost-effective method of creating stronger and less porous cover soil. For example, when fine soils are not available locally, the addition of gravel or sand to fine-grained silts and clays enhances strength and reduces percolation.

(c) Similarly, additions of clay to sandy or silty cover material will lead to dramatic reductions in the k value of the soil. Blending can often be accomplished in place using a blade or harrow to turn and mix the soil to suitable depths.

(d) The Atterberg limits are a good first approximation of the mechanical behavior of a clay-type soil. The limits are defined by the water content of the soil that produces a specified consistency. In themselves the Atterberg limits mean little; however, when used as indexes to the relative properties of a clay-type soil they are very helpful.

(e) The most important soil property that will affect the performance of a cover is its permeability. Mechanical compaction is used to alter the soil properties and develop a permeability suitable for the cover being constructed. Design parameters for compaction are based on a unique density value (maximum density) and a corresponding moisture content (optimum moisture content). Generally it can be assumed that the more granular the soil (the more sandy it is), the higher the maximum density and the lower the optimum moisture content. Also the finer the soil (the more clayey it is), the less defined the maximum density is as a function of the moisture content. Typically soils used for covers will have a clay content in excess of 25-30 percent which will have a poorly defined maximum density.

(f) Density quality control in the field is very important and requires a great deal of attention and skill. When compacting a cover material on the relatively soft base of the refuse, problems in obtaining the proper compaction can result. Also, the possibility of penetrating a cap with large pieces of refuse upon compaction should be considered. For these reasons a strict field testing and quality control program should be followed during construction.

(g) When constructing the final landfill cap, normal construction techniques will apply. It is very important that the buffer layer between the refuse and barrier be thick and dense enough to provide a stable base and prevent large pieces of refuse from penetrating the barrier. The barrier layer should be covered immediately after compaction is complete to prevent drying and crack formation. The final top soil layer should not be compacted and should be seeded and mulched as soon as possible to prevent erosion.

(2) Asphalt and admixed materials.

(a) There is a variety of admixed materials that can be formed in-place to fabricate a liner and cover. These materials include asphalt, concrete, soil cement, soil asphalt, catalytically blown asphalt, asphalt emulsions, lime, and other chemical stabilizers. Many of these materials can be sprayed directly on prepared surfaces in a liquid form. This material then solidifies to form a continuous membrane.

! Hydraulic asphalt concrete is a hot mixture of asphalt cement and mineral aggregate. It is resistant to the growth of plants and weather extremes and will resist slip and creep when applied to side slopes. The material should be compacted to less than 4 percent voids to obtain the low permeability needed.

! Soil cement is a compacted mixture of portland cement, water, and selected in-place soils. The soil used should be nonorganic and well graded with less than 50 percent silt and clay. The soil should also have a maximum size of 0.75 inch and a maximum clay content of 35 percent. Soil cement has the disadvantage of cracking and shrinking upon drying.

! Soil asphalt is similar to soil cement; however, the soil used should be a low plasticity, gravelly soil with 10-25 percent silty fines. The membrane must be waterproofed with a hydrocarbon or bituminous seal.

! Catalytically blown asphalt is manufactured from asphalts with high softening points by blowing air through the molten asphalt in the presence of a catalyst such as phosphorus pentoxide or ferric chloride. The material can then be sprayed on a prepared surface regardless of cold or wet weather. As with soil asphalt the membrane must be waterproofed with a hydrocarbon or bituminous seal.

! Asphalt emulsions can also be sprayed directly on prepared surfaces at temperatures above freezing. These membranes are less tough and have lower softening points than hot air-blown asphalt. However, the toughness and dimensional stability can be increased by spraying onto supporting fabrics.

(b) A summary of spray-on chemical stabilizers for cover soils is shown in Table 3-7.

(c) Sprayed-on liners and covers require a more carefully prepared subgrade than other liner and cover membranes. If a smooth surface cannot be obtained with the subgrade, a fine sand or soil padding may be necessary. Even with a properly prepared subgrade, care must be taken in placing the material to make it pinhole free.

(d) Cover soils treated with lime, which contributes pozzolanic (cementing) properties to the resulting mixture, optimize the grain-size distribution and reduce shrink/swell behavior. Lime applied as 2 to 8 percent (by weight) calcium oxide or hydroxide is suitable for cementing clayey soils. Rotary tiller mixing followed by water addition and compaction is the general application sequence for these mixtures. Also, additions of lime are recommended for neutralizing acidic cover soils, thereby reducing the leaching potential of heavy metals. If a synthetic liner is present, liner life can be prolonged by lime addition to supporting soil.

(e) Other cover soil-chemical additives may include chemical dispersant and swell reducers. Soluble salts such as sodium chloride, tetrasodium pyrophosphate, and sodium polyphosphate are added primarily to fine-grained soils with clay minerals to deflocculate the soils, increase their density, reduce permeability, and facilitate compaction. Additives are more effective with montmorillonite clay than with kaolinite or illite. Because soils in the northeast and midwest continental United States are usually low in montmorillonite, site-specific testing should be undertaken before using additives with soils in these areas.

(3) Synthetic membranes.

Table 3-7. Summary of Chemical Stabilizers for Cover Soil

Name	Soil stabilizer	Mulch	Mulch tack	Erosion resistance: Water	Erosion resistance: Dust/wind	Description	Product information
Aerospray® 52	x	x		x		Water dispersible, alkyd resin emulsion; forms hard crust; nontoxic; nonphytotoxic, pH 8-9; \$0.75/ℓ (~\$2.85/gal)	American Cyanamid Co., Industrial Chemicals and Plastic Div. Wayne, NJ 07970
Aerospray® 70	x	x	x	x		Water dispersible polyvinyl acetate resin emulsion; effective in sand; \$0.66/ℓ (\$2.50/gal)	American Cyanamid Co., Industrial Chemicals and Plastic Div. Wayne, NJ 07970
Aquatain	x	x		x		Water dispersible, concentrate of chemicals and pectin; forms fragile crust; nontoxic; nonflammable; \$0.61/ℓ (\$2.30/gal)	Larutan Corp., Anaheim, CA 02805
Curasol® AE	x	x	x		x	Water dispersible, polyvinyl acetate latex emulsion; hard crust; nontoxic; nonphytotoxic; pH 4-5; \$0.69/ℓ (\$2.60/gal)	American Hoechst Corp., Bridgewater, NJ 08876

(Continued)

Table 3-7. (Concluded)

Name	Soil stabilizer	Mulch	Mulch tack	Erosion resistance: Water	Erosion resistance: Dust/wind	Description	Product information
Curasol® AH	x		x		x	Water dispersible; high polymer synthetic resin; flexible crust; nontoxic; nonphytotoxic; pH 4-5	American Hoechst Corp., Bridgewater, NJ 08876
DCA - 70	x	x	x		x	Water dispersible; polyvinyl acetate emulsion; can be reinforced with fiberglass filaments; nontoxic; nonphytotoxic; nonflammable; pH 4-6	Union Carbide Corp., Chemicals and Plastics New York, NY 10017
Petroset®	x	x	x	x	x	Water dispersible oil emulsion; effective in particles below gravel size; nontoxic; nonflammable; pH 6 ± 0.5; \$0.42/ℓ (\$1.60/gal)	Phillips Petroleum Co. Chemical Dept., Bartlesville, OK 74003

(Sources: Lutton et al. 1979 and EPA 1976).

(a) The use of synthetic membrane in surface water control is new, and a wide variety of synthetic materials and compounds are being manufactured, tested, and marketed. The various membranes being produced vary not only in physical and chemical properties but also in installation procedures, costs, and chemical compatibility with waste fluids. Not only are there variations in the polymers being used but also with the compounding agents such as carbon black, pigments, plasticizers, crosslinking chemicals, antidegradients, and biocides. The sheeting is then joined or seamed together into panels as large as 30 m (100 feet) by 61 m (200 feet) depending on weight and handling limitations. The various seaming techniques include: heat seaming, dielectric seaming, adhesive seaming, and solvent welding. The four types of polymers generally considered for use in membranes are vulcanized rubbers, unvulcanized plastics such as PVC, highly crystalline plastics, and thermoplastic elastomers. The thicknesses of the polymeric membranes used in landfill applications range from 0.5 to 3 mm (20 to 120 mil), with most in the 0.5 to 1.5 mm (20- to 60-mil) range. Most membrane liners and covers are manufactured from unvulcanized polymeric (thermoplastic) compounds. The thermoplasticity allows the material to be heated for fusing or seaming without losing its original properties when cooled.

(b) One of the most important components in the installation of a synthetic membrane is the preparation of the subgrade. The subgrade must provide even support for the membrane, or the unsupported membrane could very easily fail. The in-situ soil that will be used for the subgrade should be tested for its physical, mechanical, and chemical character. These tests should determine, among other things, the shrink/swell properties of the soil and the density, strength, settlement, and permeability of the subgrade*s soil. Soils with high shrink/swell characteristics will tend to weaken earthen structures or cause void spaces which will cause membrane failure. Organic matter in the subgrade can cause membrane failure by leaving void spaces or by generating gases during the decaying process which collect under the membrane and cause a ballooning effect. Surface diversion ditches should be used to prevent the erosion of cover material on a membrane cap. Temperature extremes can make membrane placement difficult. Low temperatures can make a membrane brittle while high temperatures can cause a membrane to stretch easily.

(c) Anchoring a membrane can be accomplished in two ways. The liner can be anchored to a concrete structure, or a more economical and simpler method is the trench-and-backfill method. In this method the membrane is temporarily secured in the anchor trench while the seaming takes place, and then the trench is backfilled.

(d) Field seaming is the most critical factor in membrane installation. The membrane manufacturers have recommended sealing procedures and adhesives. If there are no recommended bonding systems, then the use of that specific material should be questioned. As with the membrane material, the integrity of the seam depends on the compatibility of the finished seam with the waste fluids with which it comes in contact. As a general rule, field seams should run vertically on side slopes where possible without decreasing panel size or increasing field seaming. Field seaming should not be done during precipitation, and the number of panels placed in one day should not exceed the number of panels seamed that day.

(4) Waste materials. Another class of available cover materials includes waste materials such as nonhazardous industrial residues, dredged sediments, and wood chips. Fly ash and lime/fly ash mixtures have also been considered for cover materials; however, the hazardous contaminants in most fly ash have discouraged its use. Furnace slag and incinerator residue are two additional waste martials of gravelly and sandy size that may be suitable for blending into soil cover for slope erosion protection. Rocky overburden from mines, quarries, and sand and gravel pits may also be locally useful as soil cover substitutes. Heavy applications of durable crushed stone, gravel, or clinkers (overcooked bricks) may be used to stabilize contaminated surface soils at landfills and dumps. Nontoxic industrial sludges such as paper mill sludge, dredged materials such as reservoir and channel silt, and composted sewage sludge are other waste materials that may be applied as substitutes or supplements to conventional cover material. Dried sludge can also provide nitrogen and organic plant nutrients in a final capping situation which will aid in establishing a vegetative cover.

c. Design and Construction Considerations.

(1) The design and implementation of a cost-effective capping strategy involves first the selection of an appropriate cover material. Site-specific cover functions- -control of water infiltration and gas migration, water and wind erosion control, crack resistance, settlement control and waste containment, side slope stability, support of vegetation, and suitability for further site use- -may be ranked in order of importance to facilitate this selection. For soils that may potentially be used in capping, laboratory and field testing of physical and chemical properties may be necessary when the choice is not clear-cut. Void ratio, porosity, water content, liquid and plastic limits, shrinkage limit, pH and nutrient levels, shear resistance, compaction, permeability, shrink/swell behavior, and grain size are some of the properties that may have to be determined for competing soil types.

(2) Where soil erosion control is a major consideration, the USDA Universal Soil Loss Equation (USLE) may be useful for comparing the predicted effectiveness of different cover soils.

(3) For information regarding soil sampling and testing, for local data on soils and climate, or for any form of technical assistance regarding selection of cover materials, regional and county Soil Conservation Service (SCS) offices should be consulted.

(4) Placement and compaction of cover materials are techniques affected by site-specific considerations such as the type of cover materials being applied and the local availability of equipment and manpower. For cover soils, compaction is generally desirable in order to increase the strength and reduce the permeability of the cap. Compactor vehicles include rubber-tired loaders and various rollers. For compaction of most solid waste covers, the conventional track-type tractor is effective. The number of passes over the surface required to achieve sufficient compaction depends on the equipment

type (size, weight, and width of compactor), the water content of the soil cover, and the base density and resilience of the covered refuse.

(5) Layering is an effective, but underutilized technique for final cover at waste disposal sites. This technique is essentially a cover system that combines several layers of different materials that serve integrated functions— —support of vegetation protection of barrier layers of membranes control of water infiltration and gas exfiltration, filtering, etc., depict examples of two-layered covered systems. A typical layered cover system may be composed of the following layers:

(a) Topsoil - usually loose, uncompacted surface layer of loams for vegetative support; may be treated with fertilizers or conditioners.

(b) Barrier layer or membrane - usually clayey soil with low k value, or a synthetic membrane; restricts passage of water or gas.

(c) Buffer layer - above and/or below barrier layer; protects clays from drying or cracking, synthetic membranes from punctures or tears; provides smooth, stable base; often a sandy soil.

(d) Water/gas drainage layer or channel - poorly graded (homogeneous) sand and gravel; channels subsurface water drainage; intercepts and laterally vents gases.

(e) Filter - intermediate grain-size layer to prevent fine particles from penetrating the coarser layer; controls settlement, stabilizes cover.

(6) A membrane and geotextile system may be used as the barrier and drainage layers under appropriate conditions. In this system a geotextile (nonwoven filter fabric) is used under a synthetic membrane to provide venting and a suitable base for membrane placement.

d. Advantages and Disadvantages.

(1) An evaluation of selected cover materials and cover systems must be made on a site-specific basis. However, certain general advantages and disadvantages of different surface-sealing techniques can be mentioned here.

(2) Fine-grained soils composed predominantly of clay are well suited for final cover in humid climates because of their low permeability. However, such soils tend to shrink and crack during dry seasons. The construction of a two-layer cover system may be useful in solving such problems.

(3) Local soils generally are much less expensive than non-native cover materials that have to be transported to the site. Where local soils are poorly graded (homogeneous grain size), blending is an effective technique for creating more suitable cover soils.

(4) Soil additives and cements have relatively high unit costs and may require special mixing and spreading methods. Also, soils modified by additions of cement, bitumen, or lime become rigid and more susceptible to

cracking due to waste settlement or freeze-thaw stresses. Patching repairs may become necessary to seal cracks that allow for escape of volatiles and allow surface water infiltration. Also, cemented soil systems may deteriorate upon extended exposure to corrosive organic and sulfurous waste products in landfill environments.

(5) Rigid barriers such as concrete and bituminous membranes are also vulnerable to cracking and chemical deterioration, but the cracks can be exposed, cleaned, and repaired (sealed with tar) with relative ease. Concrete covers may have a design life of about 50 years, except when applied to chemically severe or physically unstable landfill environments.

(6) Synthetic membranes are vulnerable to tearing, sunlight, exposure, burrowing animals, and plant roots. They also require special placement and covering procedures. Among the commercially available synthetic liners, polyethylene may be the most economical, based on both performance and cost. Locally generated waste materials such as fly ash, furnace slag, and incinerator residue may be inexpensive (or free) and, therefore, useful as cost-effective cover materials or additives. However, such materials may leach soluble trace pollutants (e.g., sulfur, heavy metals) and may actually contribute to environmental contamination.

3-25. Revegetation. The establishment of a vegetative cover may be a cost-effective method to stabilize the surface of hazardous waste disposal sites, especially when preceded by surface sealing and grading. Vegetation reduces raindrop impact, reduces run-off velocity, and strengthens the soil mass with root and leaf fibers, thereby decreasing erosion by wind and water. Revegetation will also contribute to the development of a naturally fertile and stable surface environment. Although the soil*s infiltration capacity is increased by vegetation allowing considerable water to enter the disposal site, this increased infiltration is offset at least partly by vegetative transpiration. The relative importance of these offsetting processes is a complicated question that has not been conclusively answered (Lutton et al. 1979). Revegetation can also be used to upgrade the appearance of disposal sites that are being considered for re-use options. Short-term vegetative stabilization (i.e., on a semiannual or seasonal basis) can also be used as a remedial technique for uncontrolled disposal sites.

a. Applications and Design Considerations.

(1) Revegetation may be part of a long-term site reclamation project, or it may be used on a temporary or seasonal basis to stabilize intermediate cover surfaces at waste disposal sites. Revegetation may not be feasible at disposal sites with high cover soil concentrations of phytotoxic chemicals, unless these sites are properly sealed and vented and then recovered with suitable topsoil. A systematic revegetation plan will include: (a) selection of suitable plant species, (b) seedbed preparation, (c) seeding/planting, (d) mulching and/or chemical stabilization, and (e) fertilization and maintenance.

(2) Long-term vegetative stabilization generally involves the planting of grasses, legumes, and shrubs. The establishment of short-term, seasonal

vegetative cover is limited principally to species of grasses. The selection of suitable plant species for a given disposal site depends on several site-specific variables.

(3) Grasses such as fescue and lovegrass provide a quick and lasting ground cover, with dense root systems that anchor soil and enhance infiltration. Legumes (lespedeza, vetch, clover, etc.) store nitrogen in their roots, enhancing soil fertility and assisting the growth of grasses. They are also readily established on steep slopes. Shrubs such as bristly locust and autumn olive also provide a dense surface cover, and certain species are quite tolerant of acidic soils and other possible disposal site stresses. Trees are generally planted in the later stages of site reclamation, after grasses and legumes have established a stable ground cover. They help provide long-term protective cover and build up a stable, fertile layer of decaying leaves and branches. A well-mixed cover of grasses, shrubs, and trees will ultimately restore both economic and aesthetic value to a reclaimed site, providing suitable habitat for populations of both humans and wildlife.

(4) Seedbed preparation is necessary to ensure rapid germination and growth of the planted species. Applications of lime will help neutralize highly acidic topsoils. Similarly, fertilizers should be added for cover soils low in essential plant nutrients. Optimum soil application rates for lime and fertilizers should be determined from site-specific soil tests. Where required, lime should be worked to 152 mm (6-inch) depths into the soil by discing or harrowing. For dense, impervious topsoils, loosening by tillage is recommended.

(5) Seeding should be performed as soon as possible after final grading and seedbed preparation. The most common and efficient method of seeding large areas of graded slopes is with hydroseeders. Seed, fertilizer, mulch, and lime can be sprayed from hydroseeders onto steep outslopes and other areas of difficult access. Rear-mounted blowers can be attached to lime trucks to spread seed and fertilizers over such areas. Grass or grain drills may be used to apply seed on gently rolling or level, stone-free terrain. Hand planting, a time-consuming and costly project, may be required for trees and shrubs.

(6) Mulches or chemical stabilizers may be applied to seeded soils to aid in the establishment of vegetative cover and to protect it from erosion before the plants become established. Organic mulches such as straw, hay, wood chips, sawdust, dry bark, bagasse (unprocessed sugar cane fibers), excelsior (fine wood shavings), and manure protect bare seedbed slopes from erosion prior to germination. Also, thin blankets of burlap, fiberglass, and excelsior can be stapled down or applied with asphalt tacks to form protective mulch mats for germinating seedbeds.

(a) Mulches conserve soil moisture, dissipate raindrop energy, moderate soil temperatures, prevent crusting, increase infiltration, and generally control wind and water erosion. Mulches are usually applied after seeding and fertilization, although certain mulch materials (e.g., wood fibers) may be applied as hydroseeder slurries mixed with seed, fertilizer, and lime. Mulch application rates will vary depending on local climate, soil characteristics, and slope steepness.

(b) Loose straw and hay mulches are the most common and most cost-effective temporary soil stabilizer/mulching materials available. These mulches are best applied using a mulch blower, at rates from 1120 to 8960 kg/hectare (0.5 to 4 tons) per acre. Straw/hay mulches can be anchored to the soil by asphalt, chemical binders, or jute netting.

(c) Chemical stabilizers are binders and tacks that are sprayed on bare soils or mulches to coat, penetrate, and bind together the particles. Stabilizers reduce soil water loss and enhance plant growth by temporarily stabilizing seeded soils against wind and water erosion. They can also be used to stabilize graded soils in the off-season until spring seeding. Stabilizers are used extensively in arid regions to help dry, permeable soils retain soil moisture.

(7) Chemical soil stabilizers include latex emulsions, plastic firms, oil-in-water emulsions, and resin-in-water emulsions. Table 3-7 summarizes pertinent characteristics of seven commercially available stabilizers, including cost data (where available).

(8) In field tests comparing the effectiveness of these chemical additives in controlling erodibility of several regional soil types in Virginia, none of the stabilizers tested were determined to be as cost-effective as conventional mulches of straw and asphalt-emulsions.

(9) Periodic reliming and fertilization may be necessary to maintain optimum yearly growth on seeded plots. Soils with poor buffering capacity may require frequent liming to achieve suitable pH levels; these are generally soils high in organic matter or clay content. Annual fertilization of nitrogen-, phosphorus-, or potassium-deficient soils will also aid reclamation efforts. Fertilizer application rates will vary with the nutrient content and pH level of the seeded cover soil. Twice yearly mowing and the judicious use of selective herbicides will help control undesirable weed and brush species. Grass sodding and remulching or planting new shrubs and trees are recommended for sparsely covered, erosion-prone areas.

(10) The selection of suitable plant species for purposes of revegetating a given disposal site will depend on cover soil characteristics (grain size, organic content, nutrient and pH levels, and water content), local climate, and site hydrology (slope steepness and drainage characteristics). Individual species must be chosen on the basis of their tolerance to such site-specific stresses as soil acidity and erodibility and elevated levels of landfill gases or phytotoxic waste components (e.g. , heavy metals, salts) in cover soil. Other important considerations include the species compatibility with other plants selected to be grown on the site, resistance to insect damage and diseases, and suitability for future land use.

(11) The optimum time for seeding depends on local climatic considerations and the individual species adaptations. For most perennial species in most localities, early fall seeding is recommended. Annuals are

usually best seeded in spring and early summer, although they can be planted for quick vegetation whenever soil is damp and warm. In mild climates (e.g., southeastern United States) the growth of both summer and winter grasses will extend the range of evapotranspiration and erosion resistance for cover soils.

b. Advantages and Disadvantages. A well-designed and properly implemented revegetation plan--whether for long-term reclamation or short-term remedial action--will effectively stabilize the surface of a covered disposal site, reducing erosion by wind and water, and will prepare the site for possible reuse. Evapotranspiration and interception of precipitation by vegetative cover will also control leachate generation at landfills by drying out the water near surface layers of refuse and soil. This effect, however, is more or less offset by enhanced soil infiltration capacity due to the increased detention of surface flow by the vegetation and to effects of the root systems on the cover soil (increased permeability). If subsurface liners of clay or synthetic membranes are constructed, infiltration of water into buried wastes (and subsequent leachate production) will be greatly reduced. This illustrates the importance of a layered surface sealing system and properly graded slopes, which, in combination with suitable vegetative cover, will isolate buried wastes from surface hydrologic input.

Section VI. Gas Control

3-26. Gas Generation and Migration. Uncontrolled hazardous waste sites are unusual in that they can contain a wide variety of materials that can generate toxic or explosive gases (H_2S, H_2, CH_4, HCN) and many organic compounds with low vapor pressure that volatilize, forming toxic, flammable, or explosive vapors. Gas generation and migration from disposal operations can be grouped with two categories: methane generation and toxic vapor generation.

a. Gas Generation.

(1) Methane.

(a) The decomposition of any organic material in an anaerobic environment results in part in the production of methane gas. Typically, municipal solid waste (MSW) is largely degradable organic materials (50 to 80 percent). Since MSW is quite porous when placed and compacted in a landfill environment, large amounts of air (with 20 percent oxygen) are present. The result of the initial aerobic decomposition phase is the development of an anaerobic environment with a wide variety of cellulose- -glucose and organic acid breakdown products. This phase of refuse decomposition will last from a few months to a year. The methane-forming bacteria or methogens then use the organic acids as substrate to produce methane and carbon dioxide. The transition in landfill gas composition is illustrated in Figure 3-34.

(b) The methogens are slow-growing organisms and are very sensitive to environmental conditions. The aerobic decomposition phase produces a great deal of heat which will usually bring the internal temperature of a landfill within the optimum temperature range for methane production (29° to 37°C). The optimum moisture content for gas production in MSW is greater than

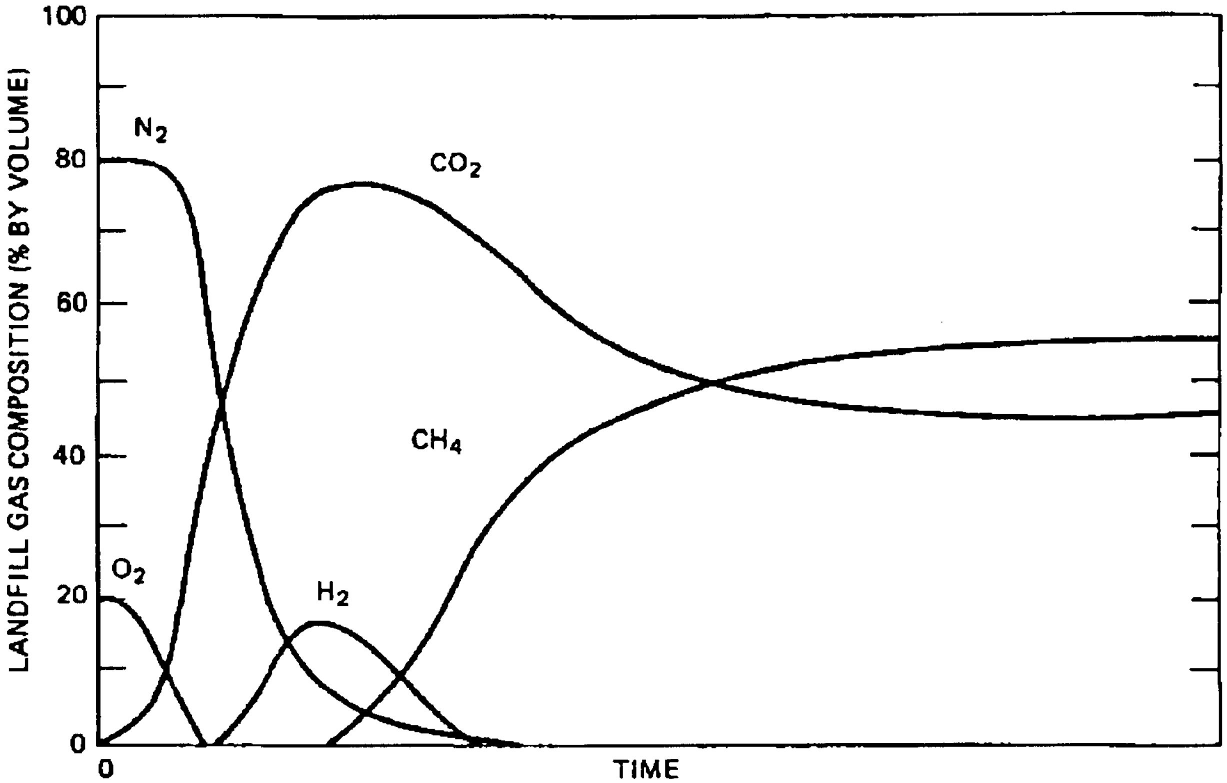


Figure 3-34. Landfill Gas Composition Transition

60 percent (on a weight basis). If the landfill is not in an arid environment, the refuse will usually become wet and the internal environment of the landfill will meet the conditions required for methane-forming bacteria.

(c) Landfills over two years old will usually contain methane in substantial concentrations in the interstitial gases. The time required for methane generation to begin in substantial quantities in a typical landfill is site specific and generally unpredictable. Environmental conditions such as temperature and precipitation and the composition of the refuse, especially the initial moisture content and density, as placed, are very important in determining when methane generation will begin. Also the mode of construction at the landfill and the type of final cover can significantly affect the time for an anaerobic environment to develop in the landfill and support methanogenic activity. The volume of gases produced in any particular landfill is very difficult to predict.

(d) On a wet-weight basis, the theoretical cubic feet of gas generated per pound of solid wastes was determined to be 6.5 for CO_2 and CH_4, and 3.3 for CH_4 alone. Studies assuming constant gas loss rates have estimated the duration of the methane-forming stage in landfill decomposition to be as short as 17 years. Other studies based the methane-generating capability on the rate at which carbon leaves the landfill, assuming that the initial amount of carbon in the refuse was “available.” These studies estimated that it would take 57 years for 50 percent of the carbon to leave the landfill and 950 years for 90 percent to leave. With the uncertainties involved one should assume the active biological decomposition in a landfill to continue indefinitely.

(2) Toxic vapor.

(a) Organic compounds in hazardous industrial waste will volatilize under favorable conditions to produce toxic vapors. Waste volatilization can occur at landfills, surface impoundments, and land treatment sites. Since the volatilization and degradation processes are very slow, the emission of hazardous volatile organic compounds may persist for many years. Gas generation rates at landfills containing industrial wastes have not been studied because of the complexity and characteristic variation to be found in the wastes. While the waste composition is the most important factor affecting the rate of gas generation, other factors affecting gas generation are the surrounding climate and soil.

(b) The principal mechanisms of toxic vapor generation at disposal sites are waste volatilization, biological degradation, and chemical reaction. The toxic property of the waste will inhibit biological activities, and most toxic organic wastes such as chlorinated hydrocarbon are relatively inert. Therefore, the amount of toxic vapor production in hazardous waste landfills resulting from biological and chemical processes appears relatively small compared with volatilization. For this reason estimates of toxic vapor generation are usually based on waste volatilization or vapor loss of organic compounds and treated as a diffusion controlled process.

b. Gas Migration.

(1) Landfill-generated methane and toxic-vapor migration are the result of two processes, convection and diffusion. Convection is the movement of landfill gas and toxic vapors in response to pressure gradients developed in the landfill, while diffusion is the movement of gas and vapors from high to lower concentrations. The normal landfill construction practice of alternating layers of refuse with 152 mm (6-inch) soil layers and finishing the landfill with a compacted clay cap of 305 mm (1 foot) or more can present substantial barriers to vertical migration and can increase lateral gas migration. Gas and vapor migration is also restricted by the relative insolubility of the gas in water. The presence of a high or perched water table, which is relatively common under landfill sites, can inhibit the depth of gas migration and increase lateral gas movement.

(2) Natural and man-made corridors for gas and vapor migration are quite common around landfill sites. Most landfill explosions are fueled by these corridors. Sewers, drainage culverts, and buried utility lines running near landfills can all provide corridors for gas and vapor migration. In addition, breaks in subsurface utility structures such as manholes, vaults, catch basins, or drainage culverts near landfills not only provide corridors for gas and vapor migration but also provide areas for potentially dangerous concentrations of gas to accumulate. Natural corridors for gas migration

include gravel and sand lenses and void spaces, cracks, and fissures resulting from landfill differential settlement.

3-27. Passive Gas Control Systems. Passive control systems include gravel-filled trenches, perimeter rubble vent stacks, and/or combinations of these. Passive systems will usually incorporate impermeable barriers. Passive venting systems should be deeper than the landfill to make sure they intercept all lateral gas flow. If possible the system should be tied into an impermeable zone such as the permanent water table or continuous impermeable geologic units. The systems should be backfilled with crushed rock, gravel, sand , or similar material that is graded to prevent infiltration and clogging by adjacent soil carried in by water. Passive systems without an impermeable liner can control convective gas flow; however, they are less effective in controlling diffusive gas flow.

a. Application.

(1) Vent stacks. These can be employed to control lateral and vertical migration for both methane and volatile toxics. The basic configurations in Figure 3-35 cover, or can be modified to cover, most of these applications. Atmospheric vents, both mushroom and “U” type, are used for venting methane at points where gas is collecting and building up pressure. Control of lateral migration of methane by an array of atmospheric vent stacks is believed to have little success unless vents are located very close together.

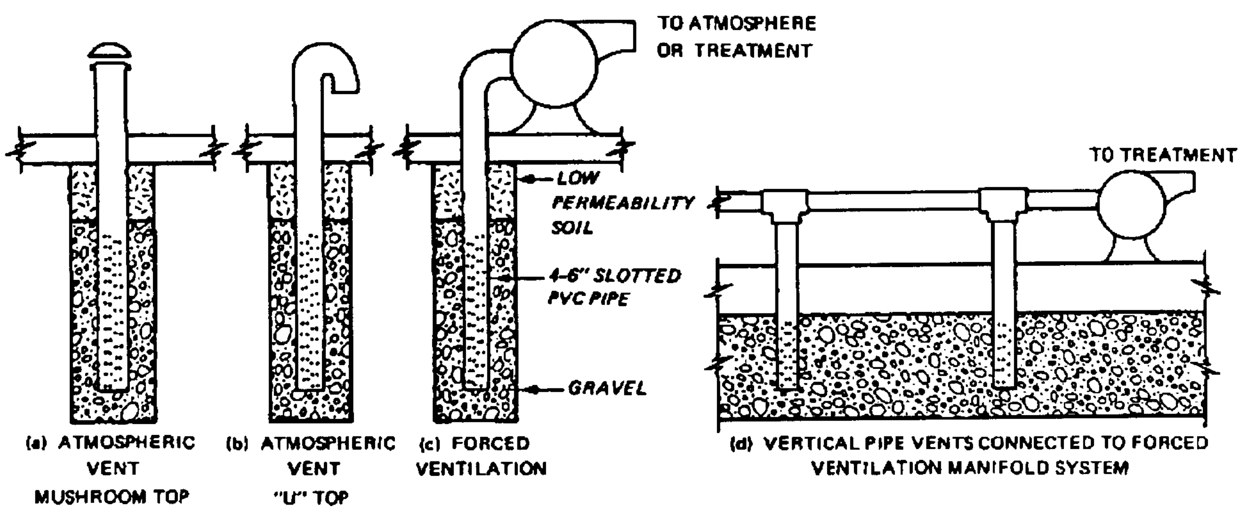


Figure 3-35. Design Configuration of Pipe Vents

(2) Trench vents.

(a) Trench vents are used primarily to attenuate lateral gas or vapor migration. They are most successfully applied to sites where the depth of gas migration is limited by ground water or an impervious formation. If the trench can be excavated to this depth, trench vents can offer full containment and control of gases and vapors.

(b) As with pipe vents, the applicability of different trench vent systems depends on whether methane generation is occurring or whether the problem at the site is limited to the control of toxic vapors. Passive open trenches (drawings (a) and (b) in Figure 3-36) may be applicable to the control of toxic vapors in an emergency situation where immediate relief is required. They also can be employed as a permanent control for methane migration; however, their efficiency is expected to be low. An impervious liner can be added to the outside of the trench to increase control efficiency. Open trenches are more suitable for sparsely populated areas where they will not be accidentally covered, planted over, or otherwise plugged by outsiders.

(c) Passive trench vents may be covered over by clay or other impervious materials and vented to the atmosphere. Such a system ensures adequate ventilation and prevents infiltration of rainfall into the vent. Also, an impervious clay layer can be used as an effective seal against the escape of toxic vapors.

b. Design and Construction Considerations.

(1) Vent stacks.

(a) When designing installations of atmospheric pipe vents for methane control, proper placement of vent stacks is the chief consideration. Preliminary sampling should be conducted to determine gas collection points for proper vent placement. Methane concentrations vary widely depending on the specific landfill configuration. The highest methane concentration (70 percent is the theoretical limit) is expected in the most anaerobic section of the filled material. In many cases, this is at the bottom of the landfill. Optimum effectiveness will be obtained if vents are placed at maximum concentration and/or pressure contours. To ensure proper ventilation, vent depth should extend to the bottom of the fill material.

(b) Proper spacing of vents is important to ensure adequate ventilation of large areas where methane is concentrated. The distance between vents will depend on soil permeability; however, this distance can be estimated for a typical soil.

(c) A general rule to ensure adequate ventilation would be to locate wells 15.2 m (50 feet) apart. Atmospheric vent wells are not recommended for control of lateral migration of gas.

(d) Pipe wells are usually constructed of 100 to 150 mm (4- or 6-inch) PVC perforated pipe. Other material, such as galvanized iron, may be required if PVC is not compatible with the waste materials. A surrounding layer of gravel pack should be installed to prevent clogging. The pipe vent should be sealed off from the atmosphere with a cement or cement/soil grout so that excess air is not introduced into the system, and methane or volatile toxics cannot be leaked. Pipe vents may be installed through a clay cap, as shown in Figure 3-36(c and d) to prevent emission of gases or vapors to the atmosphere.

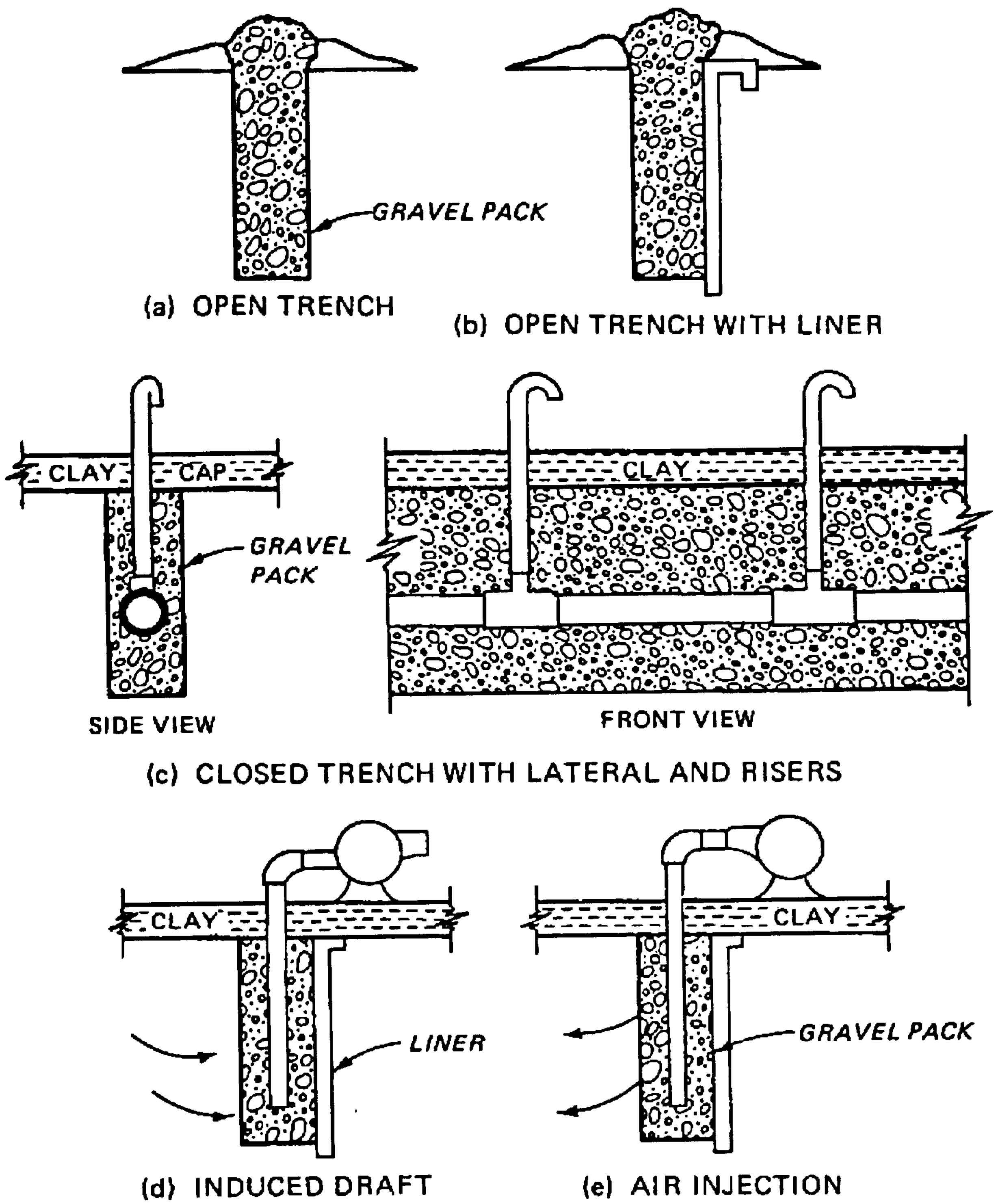


Figure 3-36. Design Configuration of Trench Vents

(2) Trench vents.

(a) Open vents are subject to infiltration by rainfall run-off and could become clogged by solids. Hence, they should not be located in an area of low relief. It is advisable to construct a slope with some of the excavated soil to direct run-off away from the trench as in drawings (a) and (b) of Figure 3-36. Also, if possible, open trenches should be constructed within controlled areas to prevent any safety or vandalism problems.

(b) The gravel pack in the trench will be permeable enough, relative to the surrounding strata, to transport the gas adequately. Also, in areas of relatively high permeability or wherever safeguards are needed, a liner should be installed on the outside of the trench to prevent bypass.

(c) In passive closed trench vents, good ventilation can be ensured by proper design of laterals and risers. One successful design consisted of 300 mm (12-inch) perforated corrugated lateral pipe with 2.4 m (8-foot) corrugated risers spread at 15.2 m (50-foot) intervals.

(d) There are three types of impervious liners for containing gas flow: synthetic liners, admixed materials, and natural soil. Synthetic liners are manufactured using rubber or plastic compounds. Polyvinyl chloride liners are frequently used because they are more impermeable to methane when compared to polyethylene and are relatively inexpensive. The membranes must be put down as to avoid punctures , and usually layers of soil or sand must be placed on both sides. Admixed materials such as asphaltic concrete have the advantages of being universally available, relatively inexpensive, and can maintain their integrity under structures. However, they are more permeable than synthetic membrane liners, and they have a tendency to crack under differential settlement. Natural soil, particularly clay, can be used as a barrier to gas movement. Clay liners are inexpensive and readily available; however, the soil must be kept nearly saturated to be effective. Clay barriers like admixed materials have a tendency to crack under differential settlement and if exposed to air for prolonged periods will dry, shrink, and crack.

c. Advantages and Disadvantages. Passive vent stacks are an effective means of control when used in situations where gases freely migrate to a collection point and there is little or no lateral migration. Passive trench vents without a barrier are not very effective in controlling migrating gases. The addition of an impermeable liner may offer the required degree of effectiveness; however, the installation of a liner will generally be economical only if the required depth is 3 m (10 feet) or less. Trench vents may become plugged by soil particles with time, thereby reducing their long-term effectiveness.

3-28. Active Control Systems. Active gas control systems can be divided into extraction and pressure systems. Both systems will usually incorporate some type of impermeable gas barrier system. Extraction systems usually incorporate a series of gas extraction wells installed within the perimeter of the landfill. Extraction wells are similar to gas monitoring wells, only larger, and construction and materials are the same. The number and spacing needed for the extraction wells for any particular landfill are site dependent. Often a pilot system of only a few wells will be installed first to determine the radius of influence in the area of the wells. Once the wells are installed, they are connected using gas valving and condensation traps to a suction system. A centrifugal blower creates a vacuum on the manifold, drawing gas from the wells and causing the gas in the refuse and soil to flow toward each well. Depending on the location, the gas is either exhausted to the atmosphere, flared to prevent malodors, or recovered and treated. A pressure gas control system is sometimes considered when structures are built or already exist on abandoned landfills. The system uses a blower to force air under the building*s slab to flush away any gas that has collected and develop a positive pressure to prevent gas from migrating toward the structure.

a. Application.

(1) Methane migration control can be more effectively accomplished by installing forced-ventilation systems in which a vacuum pump or blower is connected to the discharge end of the vent pipe. A drawdown with a radius of influence of 45.7 m (150 feet) can be accomplished with a pumping rate of 23.6 liter/sec (50 cubic feet per minute) dependent upon soil type, compaction, and other site conditions. Such a system is applicable for controlling both vertical and lateral movement of methane in the landfill by installing vents along the perimeter of the site. The collected gas and vapor can be vented to the atmosphere, flared, or recovered and treated.

(2) In landfills containing volatile toxics, a closed forced-ventilation system is required to prevent any toxic vapors from migrating laterally or vertically through the cover material to the atmosphere. Figure 3-36, section (d), depicts a series of pipe vents installed in a trench connected to a manifold that leads to a blower and finally to gas treatment. Such a configuration can be used to prevent emission of toxics to the atmosphere across the entire area of the site. A forced-ventilation system utilizing a series of extraction wells is illustrated in Figure 3-37.

(3) Another type of forced ventilation in a trench for methane migration control is air injection; in this method, air injected into the trench by a blower forces the gas or vapor back. This system should work well in conjunction with pipe vents installed close to the landfill and inside the circumferences of the trench.

b. Design and Construction Considerations.

(1) Forced ventilation is a more effective means of controlling the lateral and vertical migration of methane or toxic vapors. The flow rate for venting should be high enough to collect all gases being generated, i.e., it should be at least equal to the gas generation rate. Also, the flow rate should be high enough to ensure a fairly large radius of influence, so as to minimize the number of wells needed to vent the area. Blowers, pumps, etc., should be explosion-proof for this type of application.

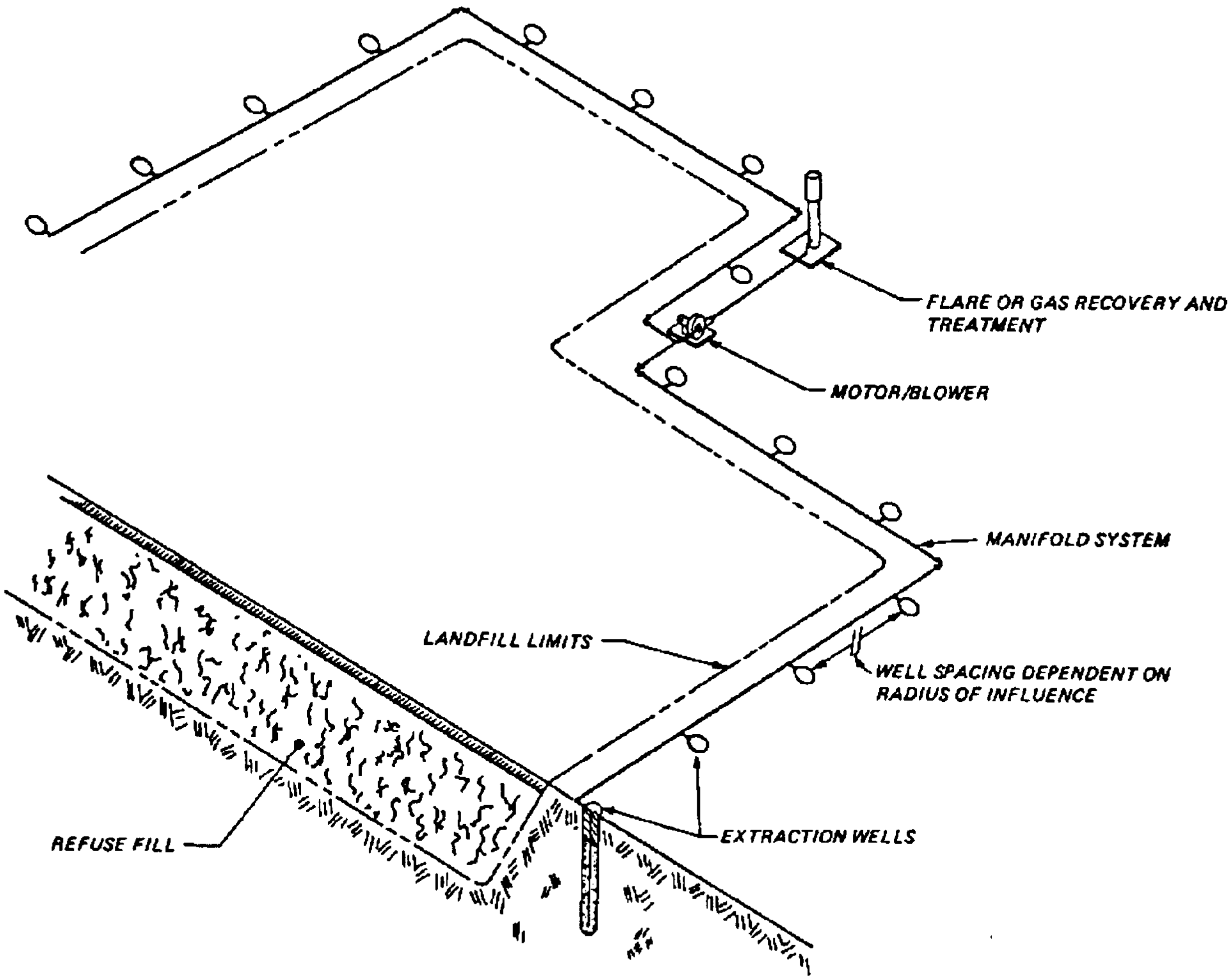


Figure 3-37. Forced-Ventilation System for Landfill Gas Control

(2) Studies at three municipal landfills in California indicated a range in gas production rates from 22 to 45 milliliters per kilograms of refuse per day. Assuming a bulk density of 250 kilograms per cubic meter for ground domestic garbage, these values convert to a range of 5.5 to 11.25 liters per cubic meter per day. If the average anaerobic layer of the fill is assumed to be 10 meters, then 55 to 113 liters of methane per day per square meter of fill area can be expected. This translates to a ventilation requirement of at least 6 to 11 cubic feet per minute per acre. In an actual demonstration for recovering methane from a municipal landfill, a steady state flow was obtained at 23.6 ℓ/s (50 cubic feet per minute) with the radius of influence at about 39.6 m (130 feet). This translates to a ventilation rate of 128 ℓ/s/hectare (107 cubic feet per minute) per acre, which means a substantial portion of excess air was introduced into the system. However, it was determined that methane production was not inhibited by this amount of air, and maximum oxygen levels in the gas were only 4 percent.

(3) Diffusion rates for volatile toxics can be calculated to determine requirements for ventilation of hazardous waste landfills. However, these estimates need more field verification.

(4) When designing a forced ventilation system for a trench, pipes can probably be placed at greater distances than extraction wells since the trench fill is composed of very permeable material. If a liner is used, the spacing can be at even greater distances since the normal radial influence of the pipes will be channeled along the trench.

d. Advantages and Disadvantages. Atmospheric vents are effective means of control when used in situations where gases freely migrate to a collection point and there is little or no lateral migration. Forced ventilation is a very effective method for controlling migration of gas and toxic vapors. If forced ventilation is used, the flow rate can be increased or decreased as the gas generation or vapor flux rate increases or decreases. This offers a great deal of flexibility of control inherent in the system. At a hazardous waste site where volatile toxics are present, the mass flux rate will decrease with time as the volatiles are dissipated. Thus, ventilation rates can be reduced with time and operating costs will decrease. It is expected that gas vents from forced ventilation are more apt to clog after time, and will need to be replaced. Also, it is expected that more maintenance will be required for forced ventilation than for passive atmospheric vent systems.