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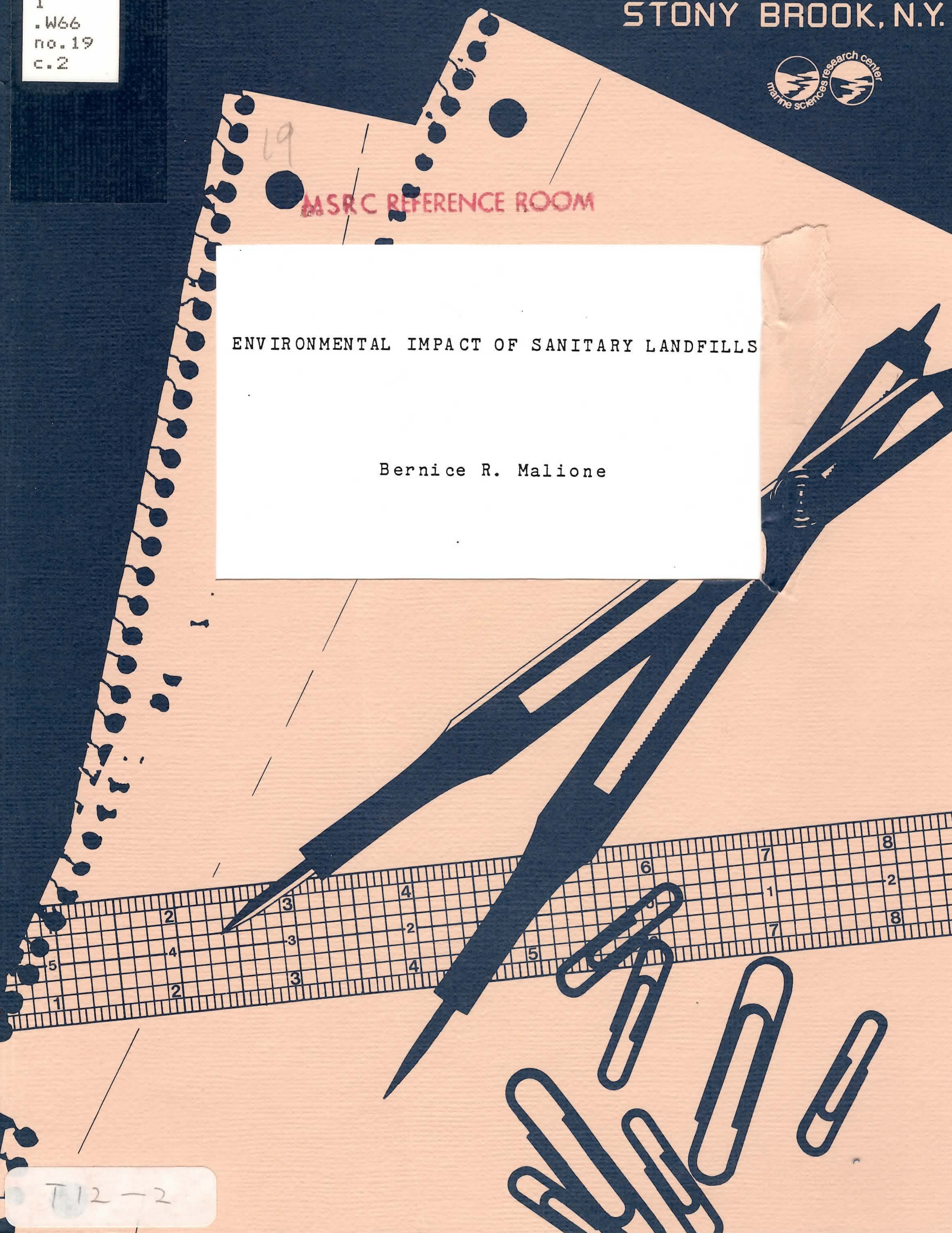

ENVIRONMENTAL IMPACT OF SANITARY LANDFILLS

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INTRODUCTION

Landfilling is a method of solid waste disposal that has been used since prehistoric times. Open dumping, the most primitive disposal method, was widely practiced in the United States prior to the 1940's; during the past thirty to forty years solid waste landfilling has been modified to minimize environmental pollution (Hagerty, et. al., 1973). The method of sanitary landfilling has evolved from open dumping, in response to the hazards associated with open dumps. Dumps degrade the environment in numerous ways. They act as breeding grounds for rats, flies and other vectors that threaten public health. These sites provide a food source for pests, which congregate at dumps. Water and other liquids seep through the degrading refuse, picking up chemicals and bacteria which are carried to rivers, streams and reservoirs. Water percolating through the waste carries these harmful substances into the groundwater. The foul odor and eyesore created by and open dump are aesthetically degrading. Dumping has adverse effects on property and people within a five mile radius (Diaz, et. al., 1982).

The sanitary landfill method was first tried in England in 1916 (Small, 1971). During the 1930's New York City and Fresno, California started sanitary landfills; by 1945 approximately 100 cities had sanitary landfills. In 1984 there were more than 8700 operating sanitary landfills (Office of Resource Recovery and Waste Disposal Planning, City of New York Department of Sanitation (NYC), 1984). A sanitary landfill is "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary;" this is the technical definition formulated by the American Society of Civil Engineers (ASCE). If all landfills were truly sanitary, by definition, there would be no adverse environmental impact. The problem is that most sanitary landfills do not meet these criteria. In 1968, a national survey found that 94% of the existing land disposal operations were unacceptable; only 6% were true sanitary landfills (Van Tassel, 1973). In the mid-1970's at least 80% of United States municipalities with populations of over 5,000 were practicing open dumping. Since then, stringent regulations have been put on new or expanding landfills. The Resource Conservation and Recovery Act (RCRA), of 1976, under section 4004, provides criteria for classification of solid waste disposal sites as open dumps or sanitary landfills. Open dumps are required to upgrade or close by 1985 (Hassett and Conrad, 1981). However, many unsanitary landfills and open dumps are still in existence; most continue to operate without permits.

PROPERTIES OF A SANITARY LANDFILL

The details of existing sanitary landfills are extremely variable. Size varies according to the size of the population served and the period of time the landfill is used. For example, given a typical solid waste density of 1,000 lbs./cubic yd. and a refuse to soil cover ratio of 4:1, a population of 10,000 people would need approximately 10 acre-feet (volume that would cover one acre to a depth of one foot) of space each year for residential and commercial wastes. Densities may vary from 800 to 1,200 lbs./cubic yd. (United States EPA, 1976).

Presently, landfill operations are regulated by individual States. In New York, the Department of Environmental Conservation (DEC) regulates landfill operations; landfill sites are governed by the following guidelines. Baseline water quality conditions (seasonal data) must be obtained before siting the landfill. The horizontal separation from surface waters is determined for each site, as well as hydrogeologic factors, including: soil attenuation characteristics, drainage, and natural or man-made barriers (DEC, 1981). A vertical separation of at least five feet between solid waste and the seasonal high groundwater table or bedrock is required. However, regulations that limit specific hydrogeological factors may be unreasonable, since the combined effect of all the hydrogeologic variables determines the potential success of the landfill.

The distance between landfills and population centers varies greatly. From an economically standpoint, it is best to site a landfill close to the waste generating sources, in order to minimize transportation costs. However, public opposition to locating refuse landfills in close proximity to residential areas is one of the largest obstacles involved in obtaining approval of a site.

REGULATIONS

The RCRA of 1976 gave EPA authority to control solid waste land pollution for the first time. Under the RCRA the EPA released guidelines for solid waste disposal in 1980. The purpose of these guidelines was to assist states in evaluating the environmental acceptability of landfill sites. The guidelines were meant to bridge the gap between state regulations and federal goals, primarily for future sites. Originally, states were to use subtitle D funds to identify sites in violation; however, by October of 1981 federal funds and technical assistance ended (Dawson, 1981). In November 1981 there was no longer a RCRA director or program (The Federal Beat: Agency Vacuum Causes Concern, 1981).

The EPA guidelines were arrived at after examining each state's practices. Clear trends among the states were incorporated as guidelines. When trends were not clear the most successful method was adopted. Technical and scientific state-of-the-art methods were incorporated as guidelines if state practices did not meet federal intentions (Cummings and Wigh, 1980). The original idea was to eliminate all open dumps by mid-October 1985. State inspecters visit sites and determine if they are open dumps, according to the established EPA guidelines. Sites classified as open dumps are required to upgrade or subject to closure under the RCRA. The ban on open dumps is not enforcable by any federal agency. The states are left with the task of implementation, and only citizens can bring suit against a noncomplying disposal site through federal courts (Nollet and Sherwin, 1982).

The EPA regulations include provisions for groundwater protection. No solid waste facility can contaminate underground drinking water sources or aquifers where total dissolved solids were below 10,000 mg./L. before construction; this cut-off is meant to protect possible, future drinking water sources. Contamination is assessed at refuse boundaries to allow for natural attenuation processes and dilution of leachate directly below the landfill. Contamination is defined by the Safe Drinking Water Act; levels of pollutants in leachate cannot exceed maximum levels set in this Act (Nollet and Sherwin, 1982).

The guidelines cover most landfill issues. Surface water is protected by the prohibition of direct landfill discharge. Air pollution guidelines include: banning open burning, and methane regulations. Under the RCRA methane must be below 25% of the lower explosive limit (LEL) in landfill buildings and below the LEL at the rest of the site. Vents must be installed if the possibility of lateral migration of gases exists. Guidelines dictate that vectors must be controlled, which includes elimination of all standing water, a breeding requirement for many insects, from landfill sites (Nollet and Sherwin, 1982).

Almost 80% of landfills in New York State are operating without permits because they violate at least one of the state regulations. Approximately fifty percent of New York landfills are polluting water supplies, according to a State audit released in 1984. There are about 420 landfills in the State and DEC lacks the personnel to inspect them, due to Federal cutbacks (Landman, 1984).

METHODS OF SANITARY LANDFILLING

There are three methods of sanitary landfilling: (1) trench (2) area and (3) ramp. Each method has advantages; the method used at a particular site should be the one that is best suited for the characteristics of that site. All three methods have some common practices. Refuse is delivered to the site; it is dumped at the "workface" (the area of the landfill where refuse is being deposited), spread and compacted in thin layers within a small area. At the end of each day the solid waste is covered with soil that is spread evenly over the refuse and compacted to a high density. The resulting structure is called a refuse cell. The depth of the cell is referred to as the "lift". When numerous cells have been constructed and the height of the landfill reaches the intended elevation, a layer of final cover is spread and compacted over all cells; this layer is usually 3 to 4 feet deep (Hagerty, et. al., 1973).

Compaction of refuse cells is an important aspect of sanitary landfilling. Compressing wastes reduces settling and creates a firm base for equipment. Compacting thin layers is most successful because the weight of the compacter is dissipated over a broad area with deeper layers; therefore, less pressure is applied per unit volume of refuse. Typically, waste cells are compacted when they reach a depth of 12 to 20 inches (Diaz, et. al., 1982). Without compaction, accelerated settling creates fissures in the cover material, exposing the wastes.

A disadvantage of compaction is that it prolongs landfill stabilization. Compaction decreases the interstitial spaces between the refuse, which lowers the amount of air in the fill. In response, the aerobic phase of decomposition is shortened, causing a significant reduction in the initial rate of decomposition. Therefore, the time needed for fill contents to stabilize is prolonged. However, the advantages outweigh the disadvantages. Compaction is also beneficial with respect to methane recovery. Since compaction inhibits aerobic microbes, the anaerobic methane producers are enhanced (Diaz, et. al., 1982).

The application of daily and final cover to sanitary landfills is important because the cover will restrict infiltration of precipitation, minimize methane escape and odors, prevent vectors from obtaining food and harborage, and greatly reduce surface blown litter. Cover also sustains plant growth at completed landfills. A mixture of clay and sand is best for daily cover. The appropriate mixture can be thoroughly compacted, allowing for equipment passage and preventing fissures. Clay, alone, is problematic because it hinders equipment passage when it is wet. Dry clay tends to crack; creating fissures that can extend to the underlying refuse. Methane can diffuse through sand, which also cannot be compacted sufficiently to support equipment. Also, vectors can penetrate sand cover (Diaz, et. al., 1982).

Trench Method

In the trench method, waste is dumped into long narrow excavations (Figure 1). The soil, removed to form the trenches, is stockpiled for future use as cover material. The garbage is spread on a shallow incline, compacted and then covered at the end of the work day (Pavoni, et. al., 1975). Trenches vary from 100 to 400 feet in length, 3 to 4

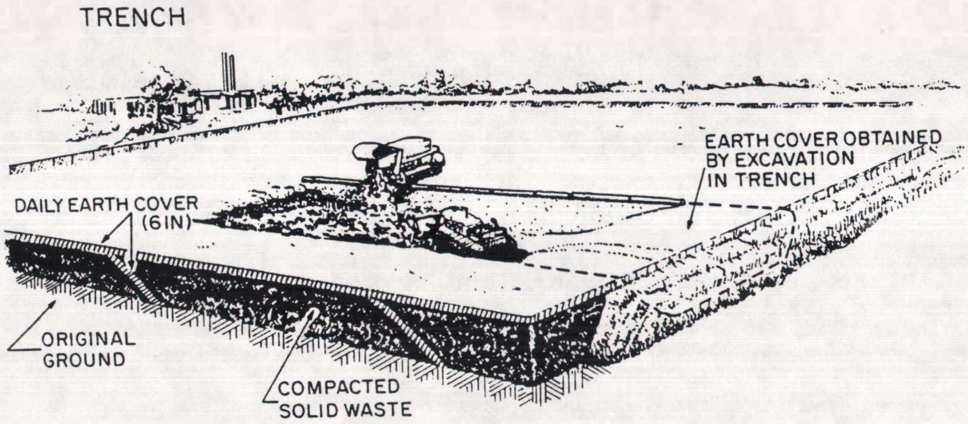

Figure 1. Trench Method of Sanitary Landfilling

Source: (Pavoni, et. al., 1975)

feet in depth. The total landfill depth usually ranges from 15 to 25 feet.

This method is best suited for sites where the a deep excavation will not penetrate the groundwater. There should be a deep layer of suitable cover soil and flat topography in order for this method to be successful (Pavoni, et. al., 1975). Trenching works best when soil is highly cohesive so that refuse cells can be constructed close together with only a thin wall of soil between.

Area Method

The only preliminary excavation that is done for use of the area method entails removing the topsoil for future use as final cover. Solid waste is spread on the ground in uniform layers, compacted to high density and covered at the day's end or when the workface area is filled (Figure 2). Usually, cover material is brought to the site from another location (Pavoni, et. al., 1975). The depth of refuse cells is typically 16 to 30 inches; total landfill height ranges from 6 to 10 feet.

This method is used when the groundwater table is shallow, prohibiting deep excavations. Area filling is also the best method for sites with irregular or rough topography (Pavoni, et. al., 1975). Special large depression sites such as: canyons, quarries and gravel pits utilize this method (Diaz, et. al., 1982). Usually, the workface is kept as small as possible to minimize surface blown litter but large enough to accommodate the refuse truck traffic.

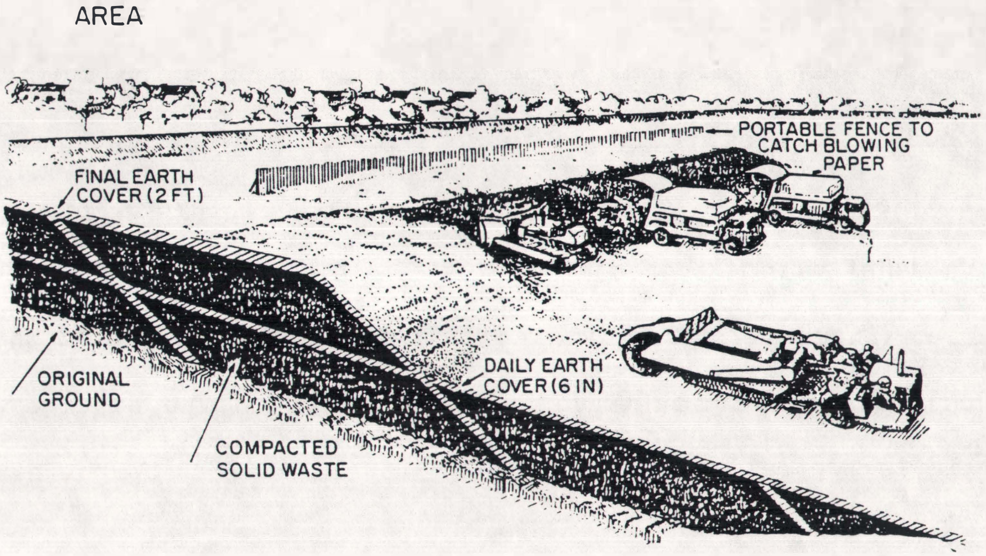

Figure 2. Area Method of Sanitary Landfilling

Source: (Pavoni, et. al., 1975)

Ramp Method

The ramp method is a combination of the trench and area methods (Figure 3). A small excavation is made before dumping. Refuse is deposited on the face of the slope, spread, compacted and covered with soil taken directly from the front of the workface (Pavoni, et. al., 1975). This process is repeated at the face of the new slope, resulting in a succession of slopes across the landfill. This method is also referred to as the progressive slope method (Pavoni, et. al., 1975). The ramp method is suitable for most any topography. This method is best for small communities since it can be accomplished using one piece of equipment (Diaz, et. al., 1982).

EQUIPMENT

Equipment needs for sanitary landfilling depend on the amount and type of waste involved, the method used and soil conditions (Table 1). A facility for weighing the incoming waste, personnel facilities and utilities are necessary at all landfill sites (Diaz, et. al., 1982). A front-end loader is used at very small landfills, where one piece of mobile equipment is all that may be economically feasible. Tracked bulldozers, which spread refuse rapidly, are used at larger sites. Both of these types of equipment operate well in all weather conditions (Pavoni, et. al., 1975). Speacialized equipment are used for large sanitary landfills. Steel-wheeled compactor-loader-dozers are used for compaction of heterogeneous wastes. The amount of compaction achieved decreases with each pass of the vehicle; more than four to

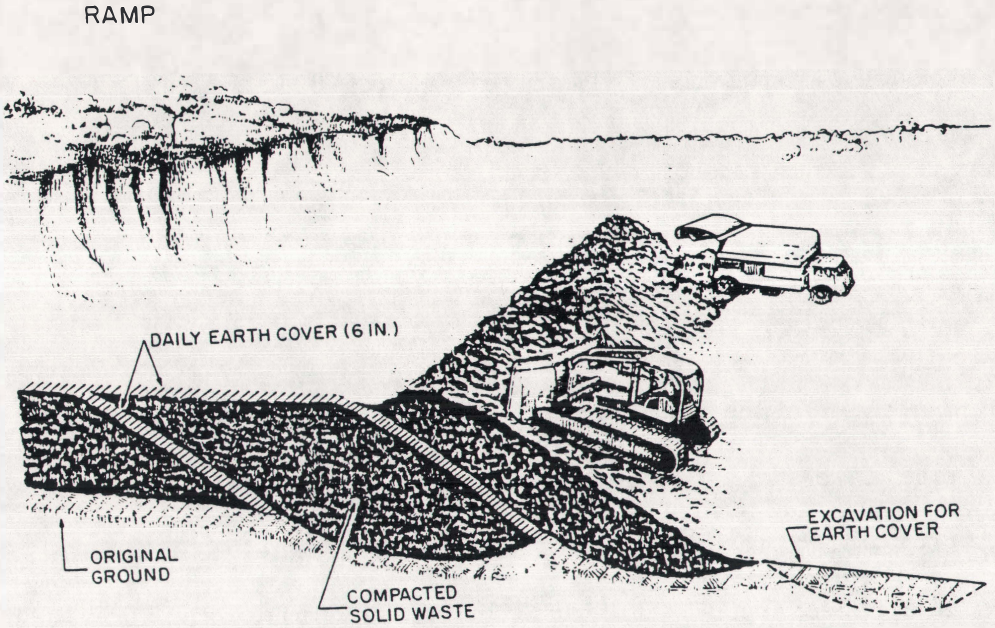

Figure 3. Ramp Method of Sanitary Landfilling

Source; (Pavoni, et. al., 1975)

Table 1. Average Sanitary Landfill Equipment Requirements

Population	Daily Tonnage	Quantity	Type	Equipment Requirements Size (lb)	Accessories[a]
0 to 15,000	0 to 40	1	Tractor-crawler or rubber-tired	10,000 to 30,000	Dozer blade Front end loader (1 to 2 cu yd) Trash blade
15,000 to 50,000	40 to 130	1	Tractor-crawler or rubber-tired	30,000 to 60,000	Dozer blade Front end loader (2 to 4 cu yd) Bullclam Trash blade
		[a]	Scraper		
		[a]	Dragline		
		[a]	Water truck		
50,000 to 100,000	130 to 260	1 to 2	Tractor-crawler or rubber-tired	30,000 or more	Dozer blade Front end loader (2 to 5 cu yd) Bullclam Trash blade
		[a]	Scraper		
		[a]	Dragline		
		[a]	Water truck		
100,000 or more	260 or more	2 or more	Tractor-crawler or rubber-tired	34,000 or more	Dozer blade Front end loader Bullclam Trash blade
		[a]	Scraper		
		[a]	Dragline		
		[a]	Water truck		
		[a]	Road grader		
		[a]	Steel-wheel compactor		

[a] Optional, dependent on individual need.

Source: "Sanitary Landfill Facts," HEW, USPHS, Publ. No. 1792.

Source: (Hagerty, et al. 1973)

five passes is uneconomical. These large toothed steel-wheeled machines achieve densities about 10% greater than traditional equipment (Hagerty, et. al., 1973). However, they lack the traction of dozers in wet weather conditions or on steep slopes. Also, they are not particularly useful for site preparation. A self-propelled scaper or rubber-tired loader is needed if cover material must be moved more than a few thousand feet (Pavoni, et. al., 1975).

All mobile equipment used at landfills must be fitted with special engine and radiator guards or screens. Reversible fans to blow paper of of the radiator and underchassis guards to protect the transmission and engine are necessary. Covers must be installed to protect any hydraulic lines. Heavy-duty tires must be used on equipment to prevent blow-outs. Special air intake filters must be used at sites where persistent dust is a problem (Pavoni,et. al., 1975).

AIR POLLUTION

Air pollution is limited to the immediate vicinity of the landfill site in properly operated sanitary landfills (United States Dept. of Health Education and Welfare, 1966). Landfill air pollution is caused by: methane production, odors, dust and vehicle emissions at the site.

Gases

The production of gases in landfills creates a potential for explosions, fires, and health hazards. Methane and carbon dioxide are the primary gases released to the atmosphere from landfills. Nitrogen, hydrogen and hydrogen sulfide are also products of the decomposition of refuse. More than 150 volatile organic compounds have been identified in landfill gas (LFG); concentrations are typically below 100 ppm, by volume, at the fill site. Generally, municipal waste LFG is not considered to be toxic.

The relative abundance of different landfill gases changes as the fill ages (Table 2). Initially carbon dioxide predominates, but later methane becomes more important. Initially nitrogen accounts for almost 5% of the total gas volume (Hagerty, et. al., 1973). After the first year, methane ranges from 55 to 65% of the total gas volume produced at landfills, carbon dioxide ranges from 35 to 45%, and other gases are found to compose 1 to 2% of the total. Methane is hazardous at concentrations greater than 5% by volume (Stearns and Beizer, 1985).

Methane diffuses into the atmosphere from soils due to pressure and concentration gradients. Methane also moves laterally from landfills to adjoining soils, especially if the cover is relatively impermeable; it may also seep into nearby buildings. Soil diffusive permeability is the main factor determining if and how gases will migrate. Migration is greatest in porous soils. If a site is surrounded by a dry, permeable soil, gases will migrate, laterally, out of the landfill when the interface exchange is blocked (Nosanov, 1980). Soil cover increases the concentration of methane in a landfill by slowing diffusion of methane and inflow of oxygen and nitrogen (Ham, et. al., 1982). Cover also postpones active methane production due to the effects of limited gas exchange on decomposition processes within the refuse. Saturated soils and impermeable strata

Table 2. Change in Landfill Gas Composition with time

Time Interval Since Start of Cell Completion (Months)	Average % by Volume		
	N_2	CO_2	CH_4
0-3	52	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

Source: (Hagerty, et. al., 1973)

inhibit migration, which is also slower through fine soils.

The rate of gas production depends on the composition of the solid waste and microrganisms present as well as the abundance of oxygen and moisture. An average of 5 cubic feet of LFG per pound of refuse to 8 cubic feet per pound is generated, over an extended period of time (Hassett and Conrad, 1981).

Recent explosions and fires caused by landfill gas (LFG) have initiated stricter regulations. Federal standards have been set, RCRA subtitle D(a), to restrict subsurface gas migration on landfills (Stearns and Beizer, 1985). As a result many landfills have installed control systems to collect the gas and dispose of it safely. Migration beyond landfill boundaries can be prevented by lining the fill and installing active or passive venting systems (NYC, 1984).

Twenty homes were evacuated near a landfill site in California when methane was found in concentrations of 1 ppm. During the testing process, polyvinyl chloride was discovered at concentrations near 1 ppm. This discovery extended the evacuation period to five months; vinyl chloride is a known carcinogen, produced by the breakdown of plastics. Although this incident occured at a co-disposal site, used for both hazardous and municipal wastes, plastics are prevalent in all municipal fills. Therefore, the possiblity for vinyl chloride emissions exists at all landfills; there is no known safe threshold level for continuous exposure to vinyl chloride. The RCRA dictates that the Environmental Protection Agency (EPA) must set ambient air quality standards for landfills by mid-1986. In Richmond, Virginia two landfills were found to contain subsurface gas concentrations that were much higher than the lower explosive limit (LEL); both sites were in residential areas. One building exploded as a result of gas migration from one of the fills (Nuttall, 1980). Methane usually escapes over the landfill surface in non-hazardous amounts. However, when buildings are constructed over landfills methane may be trapped below the foundations, creating an explosive hazard.

Smog

Trace landfill gases include organic compounds that can undergo photochemical reactions in the atmosphere to produce ozone, a smog enhancer. Smog is a known public health hazard; it has been linked to respiratory problems and even death.

Currently, there are no hydrocarbon regulations for landfills but the South Coast Air Quality Management District (SCAQMD) near Los Angeles, has proposed that a standard of 20 ppm. should be established for both active and completed landfill surfaces (Stearns and Beizer, 1985). Landfill and LFG recovery operators protest this standard, arguing that collection systems would have to increase suction to the point of drawing air into the landfill. They contend that this would reduce the energy content of recovered gas, possibly poison anaerobic microorganisms and even increase the risk of fire within the landfill (Stearns and Beizer, 1985).

LFG As An Energy Source

Landfill gas, or biogas, is a mixture of methane and carbon dioxide, with trace amounts of: water, oxygen, nitrogen, hydrogen, hydrogen sulfide, carbon monoxide, and other low molecular weight hydrocarbons (Raab, 1985). Biogas is also produced in swamps, compost piles and treatment plants. Natural gas is almost pure methane; its source is decomposed organic matter that is millions of years old. A study by the United States Department of Energy (DOE) found that landfills in the United States produced 200 billion cubic ft. of biogas in 1980. Because of the high methane content of this gas it may be used as fuel and would potentially supply 1% of the country's energy needs (Stearns, 1980). Before the 1981 Federal budget cutbacks, the Department of Energy supported projects to improve LFG recovery.

In 1983, 26 LFG recovery systems were underway on Long Island, New York, which accounts for the bulk of LFG activities in the United States (Light, 1985). A 1980 study on 23 sites, in California, developing LFG recovery systems provides statistical data. The depths of the landfills ranged from 20 to 300 ft. with an average of 100 ft. The average landfill size was 160 acres, but the range was 38 to 1,214 acres. Assuming an average solid waste density of 1,200 pounds of refuse per cubic yard, an average gas recovery rate of 0.055 cubic ft./lb per year was obtained. The observed average recovery rate for the 6 operating plants was 0.08 cubic ft./lb. per year.

Freshkills landfill on Staten Island, New York has the world's largest methane recovery facility. The plant, which is capable of processing almost 10 million cubic ft./day of raw LFG, began operating in 1983 (ASTM Subcommittee D18.14, 1981). Gas is withdrawn from over 100 wells, 65 to 75 ft. deep, on 400 acres of the landfill. The site yields almost 1.3 billion cubic ft. of LFG per year. The LFG is transported by vacuum to a plant by an underground collection system. The raw gas is processed to remove trace elements, carbon dioxide and moisture. The final product is nearly pure methane, with a heating capacity equilvalent to that of natural gas - 1,000 Btu/cubic ft. The heating capacity of the untreated gas, or biogas, ranges from 400 to 700 Btu/cubic ft. The purified LFG is mixed with natural gas and distributed to customers by Brooklyn Union's west shore facility.

The EPA - RCRA requirements for controlling the migration of LFG stipulate that methane gas may not exceed 5% by volume at the site property and methane must be below 1.5% by volume in facility structures (Raab, 1985). In order to meet these requirements many landfills will need control systems. Control systems require some of the same facilities as recovery systems. Site owners are expected to look towards profitable removal by recovering the methane. As energy costs continue to rise, landfill gas recovery becomes more profitable. Tapping landfill methane for resource recovery helps prevent seepage; however, extraction for recovery may not meet all gas migration control requirements (Raab,1985).

Odors

The breakdown of organic matter in landfills is accomplished by both aerobic and anaerobic bacteria and fungi. The rapid aerobic processes utilize free oxygen, producing heat and odorless gases. Anaerobic fermentation occurs when free oxygen is depleted. Anaerobic processes may be slow, utilizing organically and inorganically bound oxygen. Noxious organic gases, containing sulfur and nitrogen are produced. The volatile gases produced during anaerobic decomposition are short-chain fatty acids, including: formic, acetic, propionic, butyric, valeric, caproic and isovaleric acids. These gases are highly malodorous (Diaz, et. al.,1981).

Landfill odors occur when volatile organic compounds have formed and are in the vapor phase at levels above the sensory threshold limit value (TLV). The TLV is the limit at which the odor is perceived by humans. The most common malodorous compounds are perceived at TLV's from 5.8 x 10^{-6} to 1^{-2} parts per million (ppm); they are formed during anaerobic decomposition (Baker, et. al., 1983). There are three anaerobic stages: anaerobic non-methanogenic, anaerobic methanogenic (unstable) and anaerobic methanogenic (stable). Most odorous compounds are formed during the non-methanogenic and the methanogenic (unstable) stages. No significant odor problem is associated with the methanogenic (stable) stage, the final stage of decay. Methane and carbon dioxide are formed during this stage; they are odorless. However, the presence of methane has been shown to enhance perception of malodorous compounds. The TLVs are defined for pure compounds; synergisms may occur in landfills, causing lower perception levels.

Control of odors is a major problem at landfill sites. Odors can be classified as a statitory nuisance if they are "prejudicial to health" or a "nuisance" (Baker, et. al., 1983). The Public Health Act, 1936, requires abatement of such nuisances. The Public Health (Reoccuring Nuisances) Act of 1969 allows closure of landfills if steps are not taken to control odors. However, extensive odor abatement is usually practiced at industrial landfills only.

Landfill odors are difficult to control. A sweetish pervading odor is characteristic of decomposing municipal waste. At some sites wind dispersion and atmospheric dilution reduce the concentration of malodorous compounds to below the TLV. Odors become a nuisance, especially when residential areas are down-wind of the landfill and in areas where topography is such that odors are concentrated and intensified by wind effects (Baker, et. al., 1983). In sanitary landfills that meet the ASCE definition, those that are covered daily, odors should not be a nuisance; surface cracks that develop will be sealed quickly to prevent escape of malodorous gases.

Most garbage is in the first stages of anaerobic decomposition when it arrives at the landfill due to transportation in containers where available oxygen is rapidly depleted. Wastes maybe aerated during handling and the water content minimized to reduce odor problems. Water enhances rates of oxygen utilization in wastes. Minimal handling after the waste becomes anaerobic helps prohibit emissions of odorous gases, since disturbing the refuse may cause gases to be emitted. Covering with a relatively impermeable or inert layer is a tremendous aid in odor abatement since the cover limits diffusion of gases.

LEACHATE

Leachate is produced when water migrates into a fill and collects chemicals and bacteria as it percolates through the wastes. The suspended and dissolved solids in leachate are potential health hazards (Pavoni et. al.,, 1975). The production of leachate at municipal sanitary landfills is a threat to surface and groundwater (Figure 4). Even at the most cautiously managed landfills leachate is produced (Leachate Control Doesn't Come Easy, 1980).

Criteria have been established to protect groundwater and surface water as mandated by 1008(a) and 4004(a) of the Resource Conservation and Recovery Act (RCRA) of 1976. Landfills which do not meet these

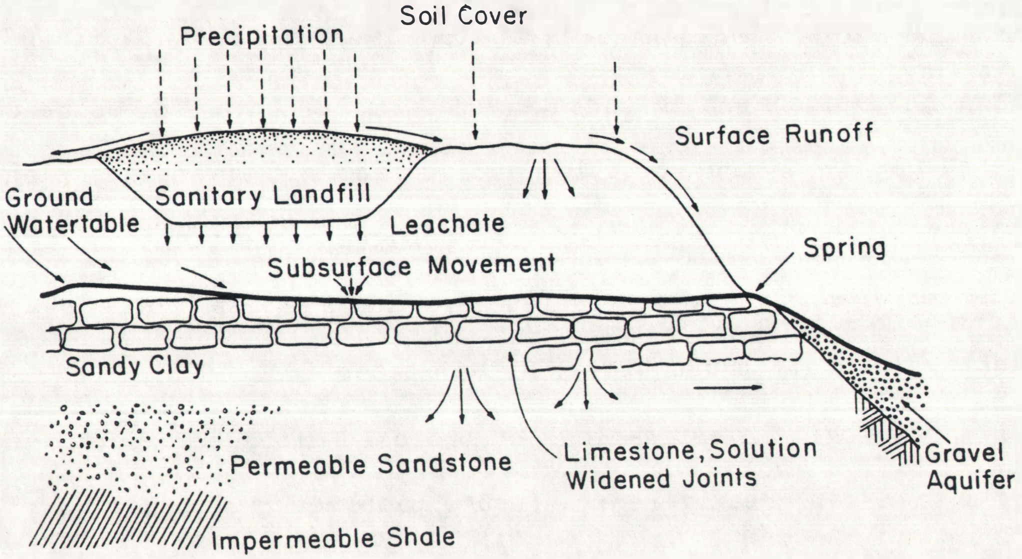

Figure 4. Interrelationship Between Topographical, Hydrological, and Geological factors in terms of Leachate Migration

Source: (Diaz, et. al., 1982)

criteria are classified as open dumps and must be upgrading or closed (Burns and Karpinski, 1980). The EPA has also published proposed guidelines for leachate control. The State of New York requires closure of all landfills on Long Island by 1990 due to the threat of groundwater contamination by leachate (Table 3). However, closing landfills does not stop leachate production.

Leachate production depends on the amount of moisture in the refuse. If the amount of precipitation is greater than the combined amount of evaporation and transpiration (the moisture taken up by plants) there will be excess water in the landfill which will infiltrate the decomposing garbage and form leachate. Exposure of uncovered wastes to precipitation and surface runoff enhances leachate production. Landfills with direct hydrologic connection to groundwater or surface water bodies have the greatest problems with respect to leachate production (United States EPA, 1976).

Hydrogeologic investigations of proposed sites before choosing a landfill site can greatly reduce future problems due to leachate generation. Usually, a site which does not receive surface water runoff from upland areas and which does not extend to the groundwater table is chosen. The permeability of underlying rock formations is another important factor. Permeability of porous or highly fractured sediments is likely to be high; therefore, siting in these areas is problematic. Provisions can be made to prevent water contamination in less ideal sites but the equipment necessary is costly. Leachate collection and treatment is another option, which is often necessary even at ideal sites; since this alternative is also costly, it is best to begin by choosing a site that will promote minimal leachate

Table 3. Groundwater Quality Near a Landfill

Parameter	Ambient (mg/l)	Landfill (mg/l)	Monitor Well[a] (mg/l)
Total dissolved solids	636	6712	1506
pH	7.2	6.7	7.3
COD	20	1863	71
Total hardness	570	4960	820
Sodium	30	806	316
Chloride	18	1710	248

[a] Monitoring well located downstream, approximately 150 ft from the landfill, at a depth of 11 ft in sandy clayey silt.

Source: (Hagerty, et. al., 1973)

production.

Water entering a landfill does not produce significant leachate until all refuse layers reach field capacity. Field capacity exists when all spaces between soil and refuse are filled with water (Schoenberger and Suffet, 1981). By this time decomposition is almost entirely anaerobic. Prior to reaching field capacity small amounts of leachate may be produced intermittantly. After significant leachate production begins the overall moisture of the landfill remains nearly constant. Leachate is then formed at nearly a one to one ratio with additional water infiltration. Average field capacities of landfills are 0.3 cm./cm. (water/total) to 0.4 cm./cm (Straub and Lynch, 1982). There are many studies showing that leachate decreases in organic and inorganic strength with age, after significant field production begins. Dilution and uptake of organics by microrganisms are responsible for the decrease (Straub and Lynch, 1982).

The amount of leachate produced from a landfill can be estimated by several different methods. The water, or moisture, balance method can provide estimates by determining the amount of infiltration. An estimate of the amount of water that will infiltrate the landfill is obtained by the equation:

Infiltration = precipitation - runoff - evapotranspiration

Since infiltration is the major cause of leachate the amount of leachate produced can be approximated by estimating the amount of infiltration for a site.

Leachate quanity and quality vary according to waste composition and will also vary with landfill age; it continues to be produced for years after the sites are closed (Leachate Control Doesn't Come Easy, 1980). In addition, temperature, precipitation, soil and hydrologic conditions effect leachate production.

Even though municipal solid waste does not contain the degree of toxic substances common in industrial or hazardous wastes; many of the materials found in municipal solid waste decompose to form hazardous substances. Leachate has all the characteristics of strong industrial wastewater (Pavoni, et. al., 1975). Biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids and turbidity of leachate usually exceed that of raw municipal wastewater (Table 4). Low pH, low dissolved oxygen (DO), toxic chemicals and heavy metal ions are characteristic of leachate.

Biological decomposition yields carbon dioxide and organic acids which undergo chemical oxidation reactions. These reactions are limited by the amount of oxygen trapped in the fill when it was constructed. Metallic ions and salts are formed and may be incorporated in leachate, many are potential contaminates (Diaz, et. al., 1982).

Untreated leachates are highly toxic within landfill sites and usually remain toxic, even at the point of discharge to receiving streams (Cameron, 1980). Leachate toxicity also decreases with time as the landfill ages, but will be increased during conditions of high precipitation. The natural attenuation characteristics of soils has been found to reduce leachate toxicity. Leachate recycling through the landfill can reduce toxicity by up to five times (Cameron, 1980).

Three groups of compounds make up the soluble organic matter of leachate from fresh refuse cells: short chain fatty acids with low molecular weight account for up to 90%; this group is the most easily

Table 4. Composition of Leachate

Item	Leachate Year 1 (mg/ℓ)	Leachate Year 2 (mg/ℓ)	Raw sewage[a] Strong (mg/ℓ)	Raw sewage[a] Weak (mg/ℓ)
Total solids	45,070	13,629	1,793	796
Suspended solids	172	220	1,190	640
Dissolved solids	44,900	13,409	603	156
Total hardness (as $CaCO_3$)	22,800	8,930	339	204
Calcium (as $CaCO_3$)	7,200	216	239	137
Magnesium (as $CaCO_3$)	15,600	8,714	100	67
Total alkalinity ($CaCO_3$)	9,680	8,677	335	245
Ammonia (N)	0.0	270	53.3	23.4
Organic N	104	92.4	24.6	19.2
BOD (O)	10,900	908	538	385
COD (O)	76,800	3,042	957	329
Sulfate (SO_4)	1,190	19	225	81
Total phosphate (PO_4)	0.24	0.65	11.7	7.2
Chloride (Cl)	660	2,355	312	97
Sodium (Na)	767	1,160	267	100
Potassium (K)	68	440	24	12.3
Boron (B)	1.49	3.76	0.54	0.43
Iron (Fe)	2,820	4.75	0.66	1.12
pH	5.75	7.40	8.05	7.40

[a] Los Angeles County Sanitation Districts—1971.

Source: (Diaz, et.al. 1982)

degraded. Humic acids with high molecular weight are next in abundance and degradability. A small fraction of soluble organics are fulvic acids. However, in older landfills fulvic acids predominate and humic acids are found to a lesser extent (Scott, 1981).

Protecting Groundwater

Groundwater can be protected from landfill leachate by prohibiting water infiltration and containment and/or collection and treatment of the leachate. Capping of fills with an impermeable substance prevents leachate production by inhibiting infiltration. Silts and clays are widely used as final cover, due to their low permeabilities. An experiment at the Dutch Institute for Land and Water Management Research indicated that a 100 part sand to 15 part bentonite mixture is the best cover material (Shimell, 1985). In Windham, Connecticut the EPA contracted SMC - Martin to design a cap for a landfill that was contaminating five ponds in the surrounding area. A 20-mil polyvinyl chloride cover was used, with four inches of fine sand below and eighteen inches of sand and gravel above to prevent puncturing. The seal was installed in 1979; it has successfully mitigated the leachate problem (Emlich, 1981).

In order to treat leachate it must first be collected. Collection systems are often used in conjunction with lining. The liner is an impermeable material that covers the bottom and sides of the refuse cells. Leachate is collected at the liner and withdrawn for treatment. The DEC, of New York, now requires that all new or expanding landfills install natural, usually clay, or artificial liners that restrict infiltration to the equivalent of five feet of soil with the hydraulic conductivity of 10^{-5} cm./sec. or less. New and expanding landfills must also install collection systems (DEC, 1981). Leachate treatment has been accomplished by wastewater treatment plants in the past. Recycling leachate through landfills represents another type of treatment option that has been used successfully in the last several years.

Recycling leachate through the refuse uses the landfill as a treatment process for the leachate it generated. Since leachate treatment requires both biological and physical/chemical treatment, conventional methods are not reliable. Recirculating leachate through the landfill has numerous benefits. Studies show a significant reduction in pollutant strength during recycling. Each time leachate is recirculated through a fill more compounds are removed from solution by adsorption and other reactions (Diaz, et. al., 1982). The recycled leachate may be discharged to receiving waters or further treated. In addition, recycling, coupled with neutralization, decreases the time for stabilization of the organic waste constituients of the refuse from years to months, significantly reducing BOD, COD and TOC (Tittlebaum, 1982). Neutralization of leachate for pH control promotes microbial decomposition of the organic components of waste. Early fill stabilization allows the site to be reclaimed comparatively soon after closure.

Protecting Surface Water

Protection of surface water from leachate requires less effort from landfill operators than does groundwater protection. Surface water entering the landfill site must either be rerouted around the ladfill or collected and treated if allowed to pass through.

Typically, rerouting is the prefered method, due to costs and difficulties associated with leachate collection and treatment (Hagerty, et. al., 1973). Adequate grading and compacting of the fill are necessary to minimize water retention and maximize surface runoff. The most commonly used drainage techniques are: surface grading; construction of earthen, half-rounded pipes, sodded, grass or stone channels; construction of berms and swales; and installation of culverts and sewers (Hassett and Conrad, 1981).

BIRDS AND AIR TRAFFIC

Gulls are scavengers and landfills are prime scavenging grounds. It has been determined that the proximity of two garbage dumps is a major cause of gull concentration at Kennedy Airport. Not only do the landfills provide an adequate food source but gulls can obtain large amounts of food in a short time, giving them more time to loiter at the airport (Burger, 1982). When birds collide with planes they not only damages the planes but create the threat of a crash. Seventy-five percent of all collisions occur near airports. About 35% of the collisions between birds and planes occurring during take-off and 5% of other collisions cause significant plane damage (Burger, 1982). Kennedy Airport records from 1973 to 1981 show 0.37 to 1.03 strikes per 10,000 plane movements. Canada reported 2.5 to 6 strikes in the mid-1970's and one European airport reported 876 strikes in 1976.

Strikes occur when birds fail to recognize the threat of the airplane or when they are unable to avoid collision. The new, wider jets are quieter and therefore not easily detected by birds, which tend to habituate to noise. Birds usually face the wind; at Kennedy Airport this would mean they usually face away from oncoming airplanes. Studies show that birds can usually avoid planes moving at speeds below 150 kph., an adaptation believed to have evolved in response to the fact that predators obtain speeds up to 110 kph. However, planes may obtain speed of up to 200 kph. when taking off.

Gulls are the most serious threat at airports worldwide, and they are increasing in number and range due to their increased food source - garbage dumps. The probability of a gull strike at Kennedy Airport in 1975 was 1 in 75,000 plane movements. The Federal Aviation Administration (FAA) reports that seagulls cause 20 to 40 million dollars worth of damage to airplanes and airport facilities annually (Long, 1984).

Airport authorities have tried removing or killing gulls as a management method, but they were always replaced by more gulls. Habitat destruction appears to be the only way to depress these pests. Landfills near airports are probably the single most important underlying cause of gull-plane collisions. A study by Soloman (1973) indicated that birds at open dumps were the cause of strikes in 15 countries. He also noted that bird problems are not limited to open dumps because gulls find ample food before refuse is covered at sanitary landfills (Burger, 1982). In Australia refuse is dumped at night, when gulls are not usually feeding. The refuse is covered by morning, essentially eliminating bird problems (Burger, 1982).

It is evident that dumps and non-stringent sanitary landfills attract gulls. Up to 6000 gulls were found at a dump site in Boston before the disposal method was changed to incineration. Afterwards, when only processed refuse was dumped, the number of gulls dropped to 100 in two weeks. In an Ontario airport, birds were not a significant problem until the city incinerator was replaced by a landfill and as many as 2000 herring gulls invaded the airport. Later, the landfill was closed and the bird problem became insignificant again (Burger, 1982). Another problem involving gulls and landfills is that gulls typically fly 3000 feet over the landfills on thermals. This poses a problem since landfills, and therefore numerous flying gulls, are often in the flight path of airplanes.

Officials concerned with air safety are aware of the hazard to airplanes caused by nearby landfills. There is no generally agreed upon "safe" distance between landfills and airports that will guarantee elimination of bird problems. Studies report that gulls will fly up to 50 or even 80 miles to food sources. Solomon (1973) recommended that sanitary landfills be at least 6 miles from airports and not in an area where gulls would have to cross the airport to get to the landfill. FAA regulations state that landfills must be at least 5,000 ft. from piston-type aircraft runways and 10,000 ft. from turbo-jet runways. DEC requires that operators of existing landfills prove that the sites do not create bird hazards to planes before permits are reissued (DEC, 1981).

VECTORS

At least 22 prevalent diseases causing pathogens are associated with solid wastes (Van Tassel, 1973). Rodents, insects and birds migrate from mismanaged landfills to nearby communities. These vectors are irritating pests but, more significantly, they may be a threat to human health.

Insects

Flies, mosquitos, cockroaches, fleas, mites and ticks are the most common insects found at landfills. The breeding requirements of most of these insects, including food, moisture and heat, are found at landfills. Up to 70,000 flies can emerge from one cubic foot of of solid waste (Anderson, 1964). These insects are hosts to numerous pathogens, which can be transmitted to humans. Insects are carriers of the following human diseases: cholera, polio, tuberculosis, pinkeye, diarrhea, dysentary, anthrax, salmonellosis, hepatitis and encephalitis (Linton,, 1970). The role of the housefly as a vector was first realized in the sixteenth century, when Soares de Souza associated flies with the tropical disease, yaws (Chanlett, 1979).

Rodents

In 1968, there were 14,000 reported rat bites in the United States; most occurred in areas where mismanaged solid waste provided food and harborage for the rodents (Van Tassel, 1973). In addition to carrying pathogens, rats cause 500 million to a billion dollars of damage to goods each year (Linton, 1970). The only established method for controlling rat populations is through improvements in collection and disposal methods for solid wastes (Chanlett, 1979).

Malaria, plague, tapeworm, rat-bite fever, Rocky Mountain spotted fever, murine typhus and trichinosis can all be transmitted by rats, either directly or through transfer by fleas, ticks and mites (Linton, 1970). The rat is especially susceptable to plague bascillus, which is transmitted and carried by parasitic fleas. Fleas from infected wild rats carry the disease to domestic rats, which migrate to residential areas. When the infected domestic rat dies the fleas seek a new host, which may be a human. Most diseases are transferred from rodents to humans by pathogen-carrying insects.

Insects and rodents should not be problems at sanitary landfills. Compaction of refuse and a six inch daily cover prevents fly emergence and restricts rodent burrowing (United States EPA, 1976). Adequate cover is crucial for vector control. Common housefly emergence is prevented by compacted soil; however, they can emerge through five feet of loose soil (Anderson, 1964).

Birds can also function as vectors: bird droppings may contain pathogens that can be transmitted to humans. Residents near the Oceanside landfill in Hempstead, New York are concerned about the adverse health effects imposed by an abundance of gulls that feed at the landfill. They plan to install a grid of wire and fiber lines over and around the landfill to confuse and deter the birds (Long, 1984).

Transmission of Diseases

Disease may be transmitted by vectors in two ways: mechanical and biological. Mechanical transmission refers to the transport of pathogens on the body surface of the vector; transmission occurs when these body surfaces come in contact with susceptible humans, animals or their food. Mechanical transmission also occurs when the vector ingests pathogens, which are retained in feces or regurgitation that subsequently come in contact with people or food. Insects usually pick up pathogens from infected human discharges.

Pathogens are transferred to humans, by biological transmission, when an insect punctures the skin and draws its blood meal. Biological transmission by bloodsucking insects propogates diseases; many of which have effected economic and political development around the world and which have influenced major military campaigns (Chanlett, 1979).

SURFACE BLOWN LITTER

Blowing paper, plastic and other light materials are a nuisance, eyesore and possible fire hazard. Blowing litter is one of the most common operational problems encountered at sanitary landfills. This problem can be minimized by proper selection of sites, taking into account local wind speed and direction (Sorg, 1968).

Surface blown litter is greatly reduced by daily cover. Portable litter fences are often placed near the unloading and spreading areas at landfills. Blowing litter can be further reduced by keeping the workface area at a minimum, regular removal of litter from fences and surronding areas, and prohibiting hauling of uncovered loads (Collard, et. al., 1980).

SPECIALIZED LANDFILLS

Ashfills

Incineration is an refuse disposal method in which refuse is combusted at high temperatures, usually 1200 to 1500 C., in specially designed plants. Five to fifteen percent of the refuse, by volume, remains as ash. Residual ash constitutes 20 to 30%, by weight, of the original solid waste (Diaz, et. al.,, 1982). As plant efficiency increases the amount of residual ash decreases.

Ash is a collective term for flyash and bottom ash. Flyash is light ash which becomes embodied in hot flue gases that rise through the incinerator. Most flyash settles or is removed by pollution control devices on the way to the stacks (Essex County Resource Recovery Facility EIS, 1983). Bottom ash is the heavy portion that remains on the incinator grate after combustion. This ash is composed of unburned waste and inert materials (Diaz, et. al., 1982).

Ash is typically discharged to a quench basin where water cools the ash and aids in reducing dust emissions (Essex County Resource Recovery Facility EIS, 1983). An incinerator that handles 100 tons per day (TPD) of refuse will produce an estimated 45 TPD, wet weight, of ash: a volume of 60 cubic yards (Diaz, et. al., 1982).

The majority of existing or planned incineration facilities use, or plan to use, landfills for disposal of the ash residue. Ashfills are an environmental concern: they pose new threats in addition to those of conventional landfills. Ash may contain elevated levels of many heavy metals (Table 5). Cadmium, cobalt, lead and zinc may be present at concentrations above 1000 ppm. (Diaz, et. al., 1982). High levels of beryllium and mercury have also been found in ash (Albert, 1983). Although incineration reduces the waste stream coming into the landfill by up to 90%, the remaining 10% is precarious. Some possible metal sources within the wastes include: printed ink, yielding lead and zinc when burned; titanium, chromium and lead from paints; and tin and cadmium from plastic stabilizers (Taylor, et. al., 1982).

Ash may be classified as a hazardous waste. EPA has found toxic levels of cadmium and lead in flyash. The Extraction Procedure toxicity test (EP toxicity test) was developed by EPA to "identify wastes likely to leach hazardous constituients into groundwater under conditions of improper management" (EIS, 1983). If leachate generated by this test contains certain heavy metals or pesticides in concentrations greater that 100 times those allowed by the National Interim Drinking Water Standards the ash is classified as hazardous. Therefore it cannot be disposed of in a conventional landfill. Since flyash contains a greater concentration of toxicants, most operators mix fly and bottom ash, which usual passes the EPA toxicity test.

Incinerator flyash is a major potential dioxin source. Dioxin contaminated flyash has been deposited in Canada for over 30 years. Estimates of dioxin containing wastes in New York landfills are overwhelming; these landfills are a significant source of dioxin contamination of Lake Ontario (Report of the Minister's Expert

Table 5. Concentrations of Metals in Flyash and Bottom Ash

	Concentration, ppm	
	fine bottom ash[a]	Flyash[b]
Ag	38 ± 8	130 ± 30
A	49 000 ± 800	121 000 ± 12 000
Ba	1 400 ± 600	1 500 ± 400
Ca	40 000 ± 18 000	23 000 ± 10 000
Cd	41 ± 15	64 ± 16
Co	70 ± 10	100 ± 30
Cr	520 ± 240	1 160 ± 720
Cu	450 ± 190	510 ± 180
Fe	16 000 ± 6000	24 000 ± 8000
Hg	0.4	0.9 ± 1.7
K	6 300 ± 1400	12 200 ± 1800
Li	19 ± 3	34 ± 4
Mg	12 800 ± 2600	9 700 ± 1700
Mn	3 100 ± 1700	1 500 ± 600
Na	8 200 ± 1400	16 000 ± 2000
Ni	210 ± 250	1 800 ± 2800
Pb	1 700 ± 800	7 200 ± 3200
Sb	120 ± 90	340 ± 290
Sn	400	1 250 ± 650
Zn	5 500 ± 1500	10 000 ± 2000

Data from the Alexandria, Virginia Municipal Incinerator

[a] - Does not include bulk metal, glass and other objects larger than about 3 mm diameter.

[b] - Collected by a wet scrubber.

Source: (Essex County Resource Recovery Facility, EIS, 1983)

Advisory Committee on Dioxins, 1983). The amount of precipitated flyash is 100 times that emitted to the air. Landfilled flyash represents a severe, local, long-term dioxin input. There is a large possibility of contaminating groundwater beyond the landfill since even a small release of dioxin containing leachate would a cause local health hazard (Report of the Minister's Expert Advisory Committee on Dioxins, 1983).

Balefills

Bales are made by a machine that compresses waste into high density cubes; generally, bales are 1.2 to 1.8 meters (m) long and 0.9 to 1.2 m. in cross section. Balefill lifts are usually 2 or 3 bales high (Diaz, et. al., 1982). Baled refuse density ranges from 1600 to 1800 lbs./ cubic yards and void space may be as little as 6% in properly constructed balefills (Bale Out of Solid Waste Problems, 1980). Another benefit of balefilling is that less, or possibly no, cover in necessary. The tight blocks of refuse are not amendable to rodent burrowing and fly emergence. Blowing paper is also minimized, which decreases public opposition. When cover soil is used, it is usually removed and reused each day. There is also less wear and tear on equipment at balefills than at conventional landfills (Bale Out of Solid Waste Problems, 1980).

Balefills generate more leachate during a short time, the first 18 months, than conventional fills. Since moisture does not readily penetrate compacted refuse, water initially runs down between the bales. Once the periphery of a bale decomposes the interior remains intact, so that overall leachate generation is low relative to conventional landfills (Bale out of Solid Waste Problems, 1980).

Shredfills

There are numerous advantages to shredfills. Shredding of refuse can achieve 25% greater densities than conventional landfills. The volume of waste a site can accomondate may be increased by up to 20% (United States EPA, 1976). The need for cover may be greatly reduced since rodents cannot live on or in shredded refuse. Also, most insect larvae and eggs are destroyed by shredding.

The disadvantages of shredfills include the possibility of explosions or fires if volatiles get into the shredder. Also, gas and leachate production are accelerated; contaminates are concentrated. However, since decomposition is accelerated, stabilization occurs more rapidly (United States EPA, 1976).

Landfills on Distinct Sites

Sanitary landfills may be used to reclaim land lost due to other activities. Abandoned clay pits, sand quarries, gravel quarries and limestone quarries are amendable to this waste disposal method (Pavoni, et. al., 1975). A limestone quarry, near Chicago, is being used for waste disposal (Solid Waste Management, 1980).

Strip mines are well suited to sanitary landfilling. Usually the underlying stata is impermeable clay or shale (Pavoni, et. al., 1975). A strip mine near Pittsburg is being filled with residential wastes. The fill receives 700 tons of refuse per day, which is compacted in eight foot lifts; wastes are covered with two feet of compacted daily cover, and twelve feet of final cover will be used. The substatum is impervious clay. Landfilling of strip mines usually presents no problem with respect to siting considerations because mines are never located in populated or valuable areas. Also, landfilling is a profitable method of mine reclamation (Solid Waste Management, 1981).

Canyons and ravines are also used as landfills. All surface water must be intercepted before the sites can be used since these topographies were created by flowing water. Terrace Heights Canyon, in Washington, will be used as a county park when landfilling is completed. The canyon landfill receives 675,000 cubic yards of refuse annually; it serves 75% of the county residents. Cells are eight feet deep with six inches of cover, two feet of final cover will be added upon completion (Solid Waste Management, 1982).

Sanitary landfills should never be constructed in tidal flats, marshes or any type of wetland. Dumping wastes in these water-saturated environments is unacceptable from an engineering point of view (Hagerty, et. al., 1973). Contaminants are readily leached into the surrounding waters. Furthermore, the high natural productivity of these areas cannot be ignored. Wetlands are extremely valuable ecosystems; they are nesting grounds for waterfowl and nurserys for finfish and shellfish (Small, 1971).

FINAL USE OF LANDFILLS

Final use of a completed landfill should be determined during the planning stage. The characteristics of the deposited refuse must be taken into consideration when deciding the final use of the site. The density of a landfill will vary according to waste type, climate, topography and adequacy of the landfill design. Settlement of landfills ranges from 2 to 40%, usually settlement is 20% of the initial height (Hagerty, et. al., 1973).

Building of all but very light structures on completed landfills is discouraged. Continued settlement and the low bearing capacity of landfills restricts building. Even light structures must include foundations which extend through the cells to the original soil or rock base so that the load is adequately supported. Penetration of foundations through the refuse cells may increase the gas emmissions from the fill into the buildings, which restrict the outflow of LFG, and may cause fires and explosions. Also, leachate is highly corrosive, making most foundation materials unsuitable (Hagerty, et. al., 1973). Buildings can be constructed on completed landfills after, roughly, 20 years; which is the estimated length of time necessary for stabilization (NYC, 1984).

Most complete landfill sites are used for recreational purposes or remain as open space. Maintenance is necessary even for these uses. Periodic grading of cover material is necessary to prevent ponding and erosion. Vegetation is limited by the type of cover used. Vegetation that requires irrigation is not suited for landfill sites, since irrigation will enhance leachate production. Landfill gas in the root zone may reduce vegetation growth or even kill the plants. Therefore, adequate cover and gas ventilating systems are necessary for successful planting (Hagerty, et. al., 1973). For these reasons agriculture has not been very profitable on completed landfills. There is the added problem of a lack of public acceptance; people suspect that pathogens migrate from wastes to crops (Pavoni, et. al., 1975).

CONCLUSION

Sanitary landfills are satisfactory from a sanitary and aesthetic point of view if they are properly designed, operated and maintained (Linton, 1970). The only valid objection to sanitary landfills that are properly designed, operated and maintained is that they constitute a huge loss of a natural resource - land. The sites can be reclaimed, but open space or recreation are the only sensible immediate uses for completed landfills.

Disposal of solid waste is fundamentally a health problem. The first basic requirement for developing waste disposal methods was "the absence of danger to public health" (Anderson, 1964). The problems faced by landfill operations are engineering, operational, economic and jurisdictional, but the reason we are concerned is for the protection of human health (Anderson, 1964). There are numerous violations of the sanitary landfill criteria which threaten public health; many landfills in existence today are violators. But the technology to construct sanitary landfills that are not a threat to human health or the environment exists today. The only obstacles hindering upgrading to sanitary landfills are economic and lack of enforcement.

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