Municipal Solid Waste Landfills – Water Quality Issues

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Abstract

When municipal solid waste (MSW) comes in contact with liquid, leachate is formed. Such leachate contains a myriad hazardous and otherwise deleterious chemicals which if introduced into groundwater would impair or destroy the ability to use the groundwater and aquifer. In an attempt to provide some protection of groundwater quality from adverse impacts from MSW landfill leachate, the US EPA (1991) adopted a "dry tomb" approach for the landfilling of municipal solid wastes. These "Subtitle D" requirements specify isolation of the wastes within a plastic-sheeting and compacted-clay-lined tomb, collection of leachate, monitoring of groundwater, collection and management of landfill gas, closure procedures, and provision for funding of maintenance for 30 years after landfill closure. However, the Subtitle D "dry tomb" concept and prescriptive requirements are inadequate to ensure groundwater protection for as long as the wastes represent a threat to public health and the environment. The wastes in a dry tomb landfill will be a threat to generate leachate for thousands of years. The covering will not keep the wastes dry indefinitely. The plastic sheeting and compacted clay composite liner will eventually fail and allow the leachate generated to pollute groundwater. The groundwater monitoring systems allowed have a low probability of detecting polluted groundwater when it first reaches the point of compliance. The 30 years prescribed for postclosure monitoring and maintenance is a small part of the time that postclosure care and funding will be needed. There is an urgent need to revise the US EPA Subtitle D regulations to provide for true long term protection of public health, groundwater resources, and the environment for as long as the MSW will be a threat.

Key Words:
MSW, municipal solid wastes, landfills, groundwater pollution

Introduction

This chapter provides information on significant shortcomings inherent in the management of municipal solid waste (MSW) and industrial "nonhazardous" waste by the Subtitle D "dry tomb" landfilling practiced today. Focus is on why following the prescriptive measures outlined for such landfills cannot be relied upon to provide protection of public health, groundwater resources, or the interests of nearby property owners.

Historically, the goal of municipal solid wastes and industrial "nonhazardous" waste management has been to get the wastes out of sight in the least costly manner. Solid wastes from

*Invited contribution published as, Lee, G. F., and Jones-Lee, A., "Municipal Solid Waste Landfills – Water Quality Issues," **Water Encyclopedia: Water Quality and Resource Development**, Wiley, Hoboken, NJ pp 163-169 (2005).*

urban areas were deposited on nearby low-value lands, frequently wetlands, to create waste dumps. This approach evolved into the deposition of wastes into areas excavated for greater disposal capacity. Wastes in the dumps were often burned to reduce volume. Beginning in some areas in the 1950s, wastes placed in dumps were covered daily with a layer of soil to reduce odors and access to the wastes by vermin, flies, birds, etc. This was the beginning of the "sanitary landfill." While the design of sanitary landfills diminished some environmental and public health concerns, it did not address issues of the potential for the wastes to cause groundwater pollution, for the gas generated in the landfill to cause explosions, or for the wastes' causing other public health or environmental problems. The pollution of groundwater by landfill leachate from conventional sanitary landfills was recognized in the 1950s (ASCE, 1959), but it was not until the 1990s that there were national regulations directed to the control groundwater pollution by landfills.

US EPA Subtitle D "Dry Tomb" Landfilling

Recognizing the pollution of groundwaters by sanitary landfills, Congress passed the Resource Conservation and Recovery Act (RCRA) that directed the US EPA to address the issue. Because this was not accomplished in a timely manner, the US EPA was sued; in response to that suit, the US EPA developed the "dry tomb" approach to landfilling of MSW. Despite its acknowledgment of technical shortcomings in the approach, but under the pressure of the lawsuit, the US EPA delineated the prescriptive standards for "dry tomb" landfills in "Subtitle D" of RCRA. These prescriptive standards have been adopted by some state regulatory agencies as minimum design standards for MSW landfills.

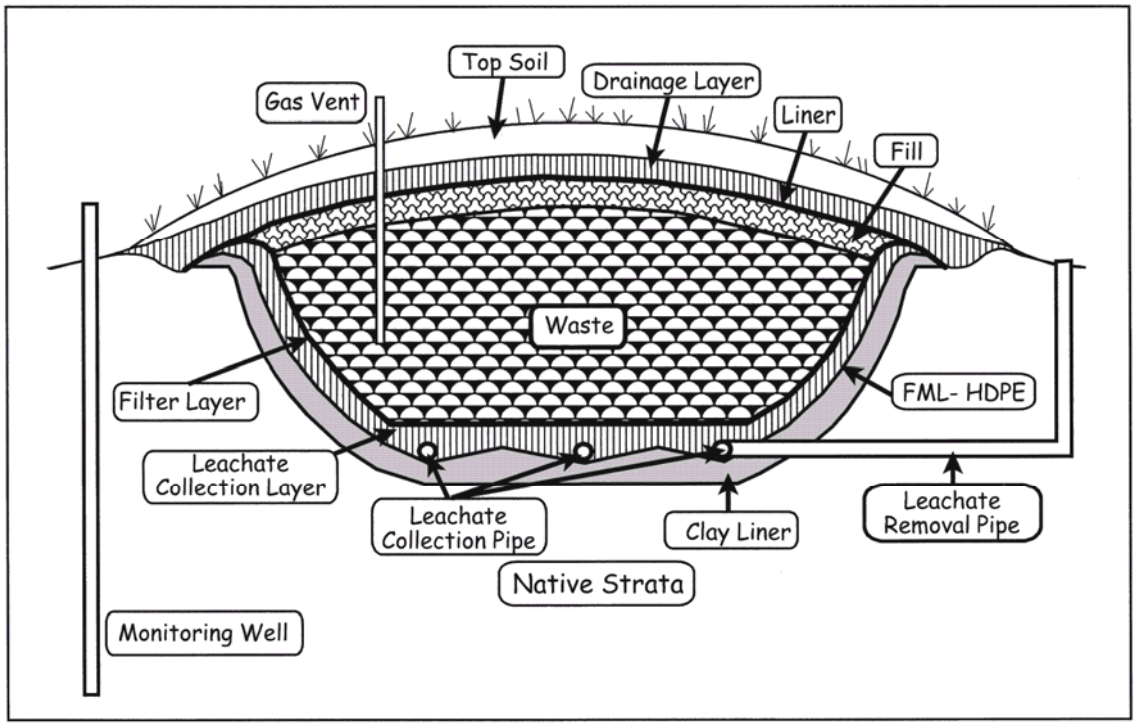
The concept of "dry tomb" landfilling was built on the premise that since water in contact with the wastes led to the formation of leachate that traveled to groundwater, isolation of the wastes in "dry tombs" would prevent groundwater pollution by landfill leachate. A dry tomb landfill, as implemented by the US EPA, is illustrated in Figure 1. It relies on a liner and cap to keep the wastes dry, leachate collection and removal systems to keep the wastes from polluting groundwater, and gas collection and removal systems. It also relies on groundwater monitoring to signal incipient pollution of groundwater by landfill leachate and specifies a "postclosure" period of 30 years during which time the facility is to be maintained and monitored.

These provisions notwithstanding, the US EPA realized in its development of these requirements that such a system would not, in itself, ensure the protection of groundwaters forever. As part of adopting the RCRA Subtitle D regulations, the US EPA stated in the draft regulations (US EPA, 1988a),
"First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills."

Further, the US EPA (1988b) Criteria for Municipal Solid Waste Landfills state,
"Once the unit is closed, the bottom layer of the landfill will deteriorate over time and, consequently, will not prevent leachate transport out of the unit."

Thus, even if the "dry tomb" system could be installed without flaw, it will eventually fail to isolate the wastes. This is significant since many of the contaminants in MSW landfills do not decompose to inert forms (e.g., heavy metals) and are hence a threat forever. Furthermore, while many organics can eventually be bacterially decomposed, such decomposition requires water, which is excluded from the landfill under ideal "dry tomb" landfill conditions. It is therefore important to consider the characteristics and shortcomings of the components of a "dry tomb" landfill to provide protection of groundwater quality for as long as the wastes in the landfill remain a threat, and how they can be improved to provide more reliable protection.

Figure 1 - Single Composite Liner Landfill Containment System



Landfill Cover

Allowed closure of Subtitle D landfills is begun by covering the waste with soil that is placed and shaped to serve as the base for a low-permeability plastic sheeting layer. The plastic sheeting is overlain by a one- to two-foot deep drainage layer. The drainage layer is overlain by a few inches to a foot or so of topsoil that serves as a vegetative layer designed to promote the growth of vegetation to reduce erosion of the landfill cover. In principle, water that enters the vegetative layer would either be taken up by the vegetation or penetrate through the root zone to the porous (drainage) layer. When the moisture reaches the low-permeability plastic sheeting layer of the cover, it is supposed to move laterally to the outside of the landfill (see Figure 1).

However, in addition to deficiencies introduced during the installation of the plastic sheeting, landfill covers are subject to a variety of factors that can breach their integrity, including burrowing animals, differential settling of the wastes beneath the cover, and deterioration of the plastic sheeting. The typical approach to monitoring landfill covers for integrity in keeping moisture out of the landfill, that is advocated by landfill owners and operators and allowed by regulatory agencies, involves visual inspection of the surface of the vegetative soil layer of the landfill cover. If cracks or depressions in the surface are found, they are filled with soil. Such an approach, however, will not detect or remediate cracks in or deterioration of the plastic sheeting layer which is the basis for the moisture removal system for the cover. As a result, moisture that enters the drainage layer and comes in contact with the plastic sheeting layer will penetrate into the wastes rather than be directed off the landfill. If this occurs during the postclosure care period, the increased leachate generation could be detected. However, it could also readily occur in year 31 after closure or thereafter, when there could well be no one monitoring leachate generation.

Leachate Collection and Removal System

The key to preventing groundwater pollution by a dry tomb landfill is collecting all leachate that is generated in the landfill, in the leachate collection and removal system. As shown in Figure 1, a Subtitle D system prescribes a relatively thin (0.06-in) plastic sheeting layer (high-density polyethylene – HDPE) and a 2-ft thick compacted soil/clay layer which together, in intimate contact, form a "composite" liner beneath the wastes. Atop the liner is the leachate collection system consisting of gravel or some other porous medium, which is intended to allow leachate to flow rapidly to the top of the HDPE liner for removal. This porous layer is overlain by a filter layer which is supposed to keep the solid waste from migrating into the leachate collection system. Thus in principle, leachate that is generated in the solid waste passes through the filter layer to the leachate collection layer beneath. Once it reaches the sloped HDPE liner, it is supposed to flow across the top of the liner to a collection pipe, where it would be transported to a sump from which it could be pumped from the landfill. According to regulations, the maximum elevation of leachate ("head") in the sump is to be no more than 1 ft.

However, leachate collection and removal systems, as currently designed, are subject to many problems. Biological growth, chemical precipitates, and "fines" derived from the wastes all tend to cause the leachate collection system to plug. This, in turn, increases the head of the leachate above the liner upstream of the area that is blocked, which further stresses the integrity of the system. While there is the potential to back-flush some of these systems, this back-flushing will not eliminate the problem.

One of the most significant problems with leachate collection systems' functioning as designed is that the HDPE liner, which is the base of the leachate collection system, develops cracks, holes, rips, tears, punctures and points of deterioration. Some of these are caused at the time of installation, and HDPE integrity deteriorates over time. When the leachate that is passing over the liner reaches one of these points, it starts to pass through the liner into the underlying clay layer. If the clay layer is in intimate contact with the HDPE liner, the rate of initial leakage through the clay is small. If, however, there were problems achieving or maintaining intimate contact between the clay and HDPE liner, such as the development of a fold in the liner, the

leakage through the HDPE liner hole can be quite rapid. Under those conditions, the leachate can spread out over the clay layer and can leak at a substantial rate through the clay. As noted above, even in the establishment of the Subtitle D regulations, the US EPA recognized that such a liner will deteriorate over time.

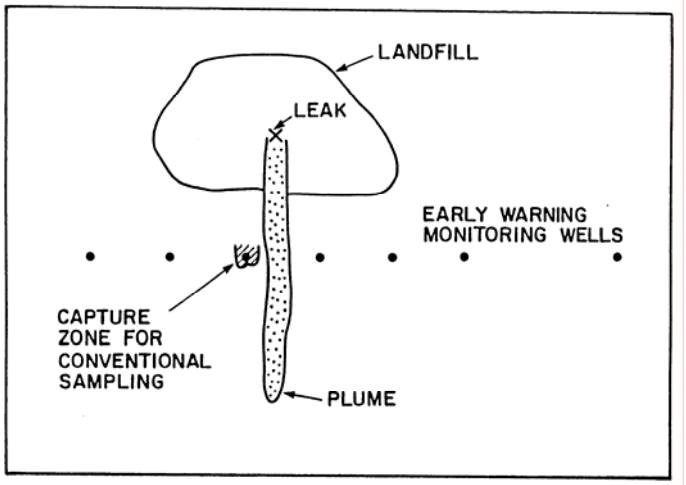
Groundwater Monitoring

US EPA Office of Solid Waste Emergency Response senior staff members have indicated that the fact that HDPE liners will fail to prevent leachate from passing into the underlying groundwaters does not mean that the Subtitle D regulations are fundamentally flawed because of the groundwater monitoring system requirement. They claim that when leachate-polluted groundwaters first reach the point of compliance for groundwater monitoring, they are detected by the groundwater monitoring system with sufficient reliability so that a remediation program can be initiated. The point of compliance for groundwater monitoring at Subtitle D landfills is specified as being no more than 150 meters from the downgradient edge of the waste deposition area, and must be on the landfill owner's property. However, there are serious technical deficiencies in that position.

It was pointed out by Cherry (1990) that initial leakage through HDPE-lined landfills will be through areas where there are holes, rips, tears or points of deterioration of the HDPE liner. As illustrated in Figure 2, this can lead to relatively narrow plumes of polluted groundwaters at the point of compliance for groundwater monitoring. The typical groundwater pollution plume in a sand, gravel or silt aquifer system will likely be on the order of 10 to 20 ft wide at the point of compliance. In order to detect incipient leakage from a Subtitle D landfill, therefore, these narrow plumes would have to be detected by the groundwater monitoring well array at the point of compliance. Typically, federal and state regulatory agencies allow monitoring wells to be placed 100 or more feet apart at the point of compliance; each monitoring well has a zone of capture of about 1 ft. Thus, if the wells were 200 ft apart, there would be 198 ft between wells where a 10 to 20-ft wide plume of leachate-polluted groundwater could pass undetected. It is virtually impossible to reliably monitor groundwater for leachate contamination in fractured rock or cavernous limestone areas. There, leachate can travel great distances and in unexpected directions via cracks and caverns.

It is because of the unreliability of groundwater monitoring systems that are based on vertical monitoring wells at the point of compliance that some states (such as Michigan) require that a double-composite liner be used at municipal solid waste landfills. In that system, a leak detection system is in place between the composite liners to detect leakage through the upper composite before the lower liner is breached. While this approach is not foolproof in its ability to detect when both liner systems fail, it has a much greater probability of detecting when the upper composite liner fails. It is for this reason that Lee and Jones-Lee (1998a) recommended that all Subtitle D landfills incorporate a double-composite liner with a leak detection system between the two liners.

Figure 2. Leakage from HDPE-Lined Landfill



Landfill Gas

Some organics in municipal solid wastes can serve as a source of food for bacteria that will, in a moist landfill environment, produce methane and CO_2 (landfill gas). MSW landfills also release a number of other volatile chemicals, including highly hazardous VOCs and odorous compounds, which are a threat to the health and welfare of those within the sphere of influence of the landfill. This sphere can extend for several miles, depending on the topography of the area and the tendency for atmospheric inversions to occur.

While landfill advocates claim that the practice of daily cover of the wastes will reduce the gaseous (odorous) releases from landfills, even diligent covering does not prevent them. Further, when landfill owners/operators become sloppy in operations, greater-than-normal landfill gas emissions occur, which are typically detected through landfill odors. While some attempt to minimize the significance of smelling landfill gas on adjacent properties as only being an aesthetic problem, in fact, as discussed by Shusterman (1992), it is now known that noxious odors can cause illness in people. Odors should be controlled so that they do not trespass across the landfill adjacent property owner's property line.

The only way at present to reliably ensure the protection of adjacent and nearby property owners/users from landfill gas is to provide a sufficient landfill-owner-owned buffer land about the landfill. If an adjacent or nearby property owner/user can smell the landfill, then there is inadequate buffer land between the landfill and adjacent properties, which should make it necessary for the landfill owner/operator to either acquire adjacent buffer land or to use more than the minimum approach for controlling gaseous releases from the landfill. It is also important to control future land use within the landfill area so that releases from the landfill would not be adverse to the land use. For example, agriculture in these areas should be restricted, since releases from the landfill could contaminate some crops. As long as landfill owners are allowed to use adjacent properties for their waste disposal buffer zones, there will be justified NIMBY ("not in my back yard") issues by adjacent property owners.

A common misconception held by landfill applicants and some regulators is that landfill gas production will cease after a comparatively short time after closure of a dry tomb landfill. Estimates of landfill gas production rate and duration are typically based on a model assuming unbagged, homogeneous wastes that are allowed to interact with moisture. This is not the situation that is found in Subtitle D dry tomb MSW landfills. The key to landfill gas production is the presence of sufficient moisture to allow bacteria to metabolize certain of the organic materials in the landfill to methane and CO_2 (landfill gas). Thus, the rate of moisture penetration through the cover and the mixing of that moisture with the waste components control the rate and duration of landfill gas production. Once the landfill is closed, Subtitle D landfills aim to keep moisture out of contact with the buried waste; the dryer the waste is kept, the slower the rate of landfill gas production. Furthermore, as discussed by Lee and Jones-Lee (1999), since much of the municipal waste that is placed in Subtitle D landfills is contained within plastic bags, and since those plastic bags are only crushed and not shredded, the crushed bags will "hide" fermentable components of the waste. Thus, once moisture does breach the cover and is allowed to contact with the wastes, the period of landfill gas production will be prolonged further, until after the plastic bags decompose and the bagged wastes allowed to interact with the moisture. This can extend gas production many decades, to a hundred or more years.

Postclosure Monitoring and Maintenance

The Subtitle D relies on the 30-year postclosure period of monitoring and maintenance to continue the protection of groundwater. There was the mistaken idea that 30 years after closure, the waste in a dry tomb landfill would no longer be a threat. From the characteristics of wastes and their ability to form leachate, as well as the processes than can occur in a landfill, it is clear that 30 years is an infinitesimally small part of the time that waste components in a landfill, especially a dry tomb landfill, would be a threat to cause groundwater pollution through leachate formation. A critical review of the processes that can take place in a MSW landfill that can generate leachate shows that the containment system of a dry tomb landfill, for which there is at least an initial effort to reduce the moisture entering the wastes, will eventually fail to prevent groundwater pollution for as long as the wastes are a threat. The municipal solid wastes in a classical sanitary landfill where there is no attempt to prevent moisture from entering the wastes have been found to generate leachate for thousands of years. Dry tomb landfilling delays and then prolongs leachate generation.

Subtitle D regulations also require that a small amount of assured funding be available for 30 years of postclosure monitoring and maintenance. Some regulatory agencies will allow landfill companies to be self-insured or insured through an insurance company that is backed by a landfill company. Such approaches should not be allowed, since landfill companies are amassing large liabilities for the ultimate failure of the landfill liner systems and the groundwater pollution that will occur as a result of those failures. It is well-understood that, ultimately, private landfill companies will not likely be able to comply with Subtitle D regulations for funding of remediation. The amount of postclosure monitoring and maintenance funding that is currently required is grossly inadequate compared to the funding levels that could be necessary during the 30-year mandatory postclosure period, much less the extended period over which the wastes in the landfill will be a threat. While Congress through Subtitle D required that the regulations include provisions to potentially require additional funding at the expiration of the

30-year postclosure care period, the likelihood of obtaining this funding from private landfill companies, even if they still exist 30 years after a landfill has been closed, or from a public agency that developed or owns landfill, is remote.

Lee (2003) discussed the importance of solid waste management regulatory agencies' requiring that landfill owners, whether public or private, prepare for the inevitable failure of the landfill containment system and provide for funding to address this failure. Designation of a 30-year postclosure assured funding period in RCRA, which is implemented not as a minimum but rather as a definitive period, leaves the public to pay the significant balance of the cost of landfilling; the public is left to deal with the long-term impacts of MSW landfills on public health and the environment, and eventual remediation of the landfill. This significant deficiency in Subtitle D regulations is recognized not only in the technical community but also by various other groups and individuals who have reviewed this issue. For example, in the Executive Summary of its report *"Funding of Postclosure Liabilities Remains Uncertain,"* in a section labeled, "Funding Mechanisms Questionable," the US Congress General Accounting Office (GAO) (1990) concluded,

"Owners/operators are liable for any postclosure costs that may occur. However, few funding assurances exist for postclosure liabilities. EPA only requires funding assurances for maintenance and monitoring costs for 30 years after closure and corrective action costs once a problem is identified. No financial assurances exist for potential but unknown corrective actions, off-site damages, or other liabilities that may occur after the established postclosure period."

Further, the US EPA Inspector General (US EPA, 2001) in a report entitled, "RCRA Financial Assurance for Closure and Postclosure," came to similar conclusions:

"There is insufficient assurance that funds will be available in all cases to cover the full period of landfill postclosure monitoring and maintenance. Regulations require postclosure activities and financial assurance for 30 years after landfill closure, and a state agency may require additional years of care if needed. We were told by several state officials that many landfills may need more than 30 years of postclosure care. However, most of the state agencies in our sample had not developed a policy and process to determine whether postclosure care should be extended beyond 30 years, and there is no EPA guidance on determining the appropriate length of postclosure care. Some facilities have submitted cost estimates that were too low, and state officials have expressed concerns that the cost estimates are difficult to review."

Landfill Siting Issues

In the development of Subtitle D landfill regulations, the US EPA failed to address one of the most important issues that should be addressed in developing a minimum Subtitle D landfill – namely, the need to site landfills at geologically suitable sites for a landfill of this type. While the Agency does require that minimum Subtitle D landfills not be sited too close to airports where there could be major bird problems for aircraft, too near an earthquake fault, or within a flood plain, the Agency does not address the issue of siting minimum Subtitle D landfills where the underlying geological strata do not provide natural protection of the groundwaters from

pollution by landfill leachate when the landfill liner systems eventually fail. In accordance with current regulations, minimum Subtitle D landfills can be sited over highly important aquifers that serve as domestic water supply sources. They can also be sited in fractured rock and cavernous limestone areas, where it is impossible to reliably monitor for the pollution of groundwaters by landfill leachate using vertical monitoring wells.

Subtitle D landfill regulations also fail to address one of the most important causes for people to object to landfills; the deposition of wastes is allowed very near the landfill property owner's property line. Under these conditions, the landfill gases, blowing paper, birds, rodents, vermin, etc., associated with the landfill can impinge on adjacent properties. For example, it is well-established that landfill gas can readily travel a mile or more from a landfill, and thereby be adverse to the adjacent property owners' use of their properties. It is recommended that at least a mile, and preferably two miles, of landfill-owned buffer lands exist between the area where wastes are deposited and adjacent property owners' property lines. This would provide for dissipation of releases from the landfill on the landfill owner's property. Such an approach would greatly reduce the trespass of waste-derived materials from the landfill onto adjacent properties.

Role of 3 Rs in MSW Landfilling

Considerable efforts are being made in many parts of the country to increase reuse, recycling and reduction (the "3Rs") of MSW as part of conserving natural resources and landfill space. As discussed by Lee and Jones-Lee (2000) the 3 Rs should be practiced to the maximum extent practicable to reduce the number of new and expanded Subtitle D landfills that will eventually pollute groundwaters.

Justified NIMBY

"NIMBY" is an acronym for "Not in my backyard," a commonly dismissed plea presumed to be made by those who, without justification, simply oppose having a landfill nearby. However, Lee and Jones-Lee (1994) and Lee et al. (1994) discussed many of the technical issues that, in fact, justify a "NIMBY" position for Subtitle D landfills. Table 1 presents typical, real, adverse impacts of landfills on nearby property owners/users.

Improving Landfilling

The degree of protection of public health and the environment from adverse impacts of MSW disposed of in "dry tomb" landfills can be improved to address some of the deficiencies of the approaches and specifications currently commonly accepted.

Table 1
Adverse Impacts of "Dry Tomb" Landfills on
Adjacent/Nearby Property Owners/Users

- public health, economic and aesthetic impacts on groundwater and surface water quality
- methane and VOC migration - public health hazards, explosions and toxicity to plants
- illegal roadside dumping and litter near landfill
- truck traffic
- noise
- dust and wind-blown litter
- odors
- vectors, insects, rodents, birds
- condemnation of adjacent property for future land uses
- decrease in property values
- impaired view

(from Lee et al., 1994).

Siting. Landfills should be sited so that they provide, to the maximum extent possible, natural protection of groundwaters when the liner systems fail. Siting landfills above geological strata that have groundwater whose flow paths are not readily amenable to monitoring for leachate-polluted groundwaters should be avoided. Of particular concern are fractured rock and cavernous limestone areas, as well as areas with sandy lenses.

Design. MSW landfills should incorporate double-composite liners with a leak detection system between the two liners.

Closure. MSW landfills should incorporate leak-detectable covers that will indicate when the low-permeability layer of the landfill cover first fails to prevent moisture from entering the landfill.

Monitoring. The primary monitoring of liner leakage should be associated with the leak detection system between the two composite liners. If vertical monitoring wells are used, the spacing between the vertical monitoring wells at the point of compliance should be such that a leak in the HDPE liner caused by a 2-ft-wide rip, tear or point of deterioration at any location in the landfill would be detected based on the plume that is generated at the point of compliance with a 95 percent reliability.

Landfill Gas Collection. For those landfills that contain wastes that can produce landfill gas, a landfill gas collection system should be designed, installed and maintained for as long as the wastes in the "dry tomb" landfill have the potential to generate landfill gas, giving proper consideration to how and for how long gas will be generated in the system. The landfill gas collection system should be designed to have at least a 95 percent probability of collecting all landfill gas generated at the landfill.

Maintenance. The maintenance of the landfill cover, monitoring system, gas collection system, etc., should be conducted for as long as the wastes in the landfill will be a threat, with a high degree of certainty of detecting landfill containment system and monitoring system failure. This will extend well-beyond the 30-year period typically established, especially with improved provisions for excluding moisture.

Funding. The funding for closure, postclosure monitoring, maintenance, and groundwater remediation should be established at the time the landfill is established, in a dedicated trust fund of sufficient magnitude to address plausible worst-case scenario failures for as long as the wastes in the landfill will be a threat. Unless appropriately demonstrated otherwise, it should be assumed that the period of time for which postclosure care funding will be needed will be infinite.

Buffer Land. At least several miles of landfill owner owned buffer lands should exits between where wastes are deposited and adjacent properties.

Adoption of these approaches (or as many of them as possible) will improve the protection of groundwater quality, public health, and environmental quality from adverse impacts of the dry tomb landfilling of MSW.

Further information on the topics discussed is provided by Jones-Lee and Lee (1993), Lee and Jones-Lee (1994, 1995, 1998a,b) and Lee (2002), Lee and Jones-Lee (2004).

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