Environmental Impacts of Alternative Approaches for Municipal Solid Waste Management: An Overview[1]

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EXECUTIVE SUMMARY

A review of the approaches that are typically being used for the development of "longterm" solid waste management facilities to provide longterm solid waste management capacity for an area shows that insufficient attention is often given to the current characteristics of the municipal solid waste (MSW) stream and the changes in the MSW characteristics that could occur over the planning period in developing waste management capacity. Typically, solid waste management capacity is planned 15 to 20 years or more in advance. Because of the rapidly changing character of MSW and its management approaches, it is inappropriate to assume that it is in the best interest of the people in an area to rely on lined landfills of the type that can be permitted under the US EPA RCRA Subtitle D regulations (US EPA 1991) as the sole method of management of the residues that remain after practicing the 3 R's (waste reduction, reuse, and recycling) to reduce the waste-stream by 50% or some other designated percent diversion of solid waste stream.

Appropriate Solid Waste Management Capacity Planning

There are significant problems caused by landfilling of MSW both during the active life (waste deposition period) and during the post-closure care period (after waste deposition ceases) of a landfill. The volume and character of wastes needing landfilling are changing with increasing practice of the 3 R's. Owing to those problems and changing conditions and to the costs of proper landfilling of MSW, the planning of longterm landfill capacity for an area should include careful consideration of all alternative waste management approaches, including highly aggressive 3-R practice, for their capability, impacts, and economics prior to site selection for the landfills.

Garbage Truck Traffic Problems

Garbage truck traffic is one of the principal adverse impacts of mega-landfills during their active life. Such landfills, through the increased garbage truck traffic, can readily create significant traffic problems, increased air pollution, roadway deterioration, etc. Frequently, insufficient attention is given to these problems by the waste management authority in formulating the proposed approach for MSW management over the planning period in the area.

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[1] Reference as: Lee, G. F. and Jones-Lee, A., "Environmental Impacts of Alternative Approaches for Municipal Solid Waste Management: An Overview," Report by G. Fred Lee & Associates, El Macero, CA, 52pp, August (1993).

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Odors And Other Gaseous Emissions From Landfills

MSW landfills have significant gaseous emissions that have highly offensive odors and contain hazardous chemicals that are known or suspected human carcinogens. Some of these odors arise from the garbage as it is dumped by the garbage trucks. In addition, landfill gas emissions, which are principally methane and carbon dioxide, contain significant amounts of odorous and hazardous chemicals. While today essentially no attempt is made to control the odors released from the garbage at the time of dumping, odor control of landfill gas emissions is possible through proper flaring or recovery of the gases. The most effective way to control odors associated with the dumping of the garbage is to acquire sufficient buffer lands owned by the landfill owner to dilute the odors before they reach adjacent property owners' lands. Often several kilometers (one mile or more) of land buffer is needed for this purpose.

Litter Problems At Landfills

The areas near MSW landfills typically contain litter that is derived from solid waste transport, illegal dumping along the road, and inadequate control of the solid waste at the point where the garbage trucks dump the waste. At this time, the most effective way to control litter is to frequently police the area to enforce regulations and to pick up any litter found outside the area where waste dumping is taking place.

Dust Problems At Landfills

MSW landfilling operations frequently have problems with airborne dust arising out of truck traffic on dirt roads and daily cover mining and deposition. Dust control can be accomplished by the use of water to wet the areas. The practice of using landfill leachate for this purpose can lead to surface water pollution by constituents in the leachate, however.

Vectors, Vermin And Other Nuisance Organisms

MSW landfills contain appreciable numbers of human pathogens (disease organisms) that can be transported by insects and other vectors to individuals who use properties near the landfill. In addition, MSW landfills can attract large numbers of nuisance organisms such as rodents, seagulls, etc.. These insects and pests are of concern because of their potential to spread disease and to adversely affect the aesthetic quality of the properties near the landfill. Seagulls and other birds are also threats to low-flying aircraft.

While it is possible to control vector and vermin problems of MSW landfills to a considerable degree by appropriate landfilling practices, such as frequent application of "daily cover," it is difficult, if not impossible, to control, with the approaches typically used, the problems that occur from seagulls circling the landfill property, which include seagulls flying over properties adjacent to the landfill property, except through adequate land buffer.

Noise

Truck and other vehicular traffic and equipment used at landfills is noisy and can be damaging and disruptive to those who use properties near the landfill. Through appropriate control of landfill operations and adequate land buffers between the landfill active areas of active deposition and adjacent properties, the noise problems of landfills can be reduced to insignificant levels.

Groundwater Pollution

Moisture within MSW as well as that which enters in precipitation and in groundwaters for those landfills sited below the water table generates landfill leachate (garbage juice). MSW leachate contains a wide variety of conventional and non-conventional contaminants and hazardous chemicals at concentrations where small amounts of leachate in a groundwater renders the groundwater unusable for domestic water supply and many other purposes. Regulatory attention today is directed toward controlling, or at least postponing, groundwater pollution by landfill leachate. Regulatory agencies in the US are attempting to control MSW leachate pollution of groundwaters through the use of compacted soil and plastic sheeting layers in the form of a composite liner in accord with US EPA Subtitle D requirements. Municipal solid wastes are a threat to groundwater quality forever. The liner materials used today have finite periods of time during which they can, under optimum conditions, function effectively to prevent MSW leachate from passing through the liner. It is clear that a single composite liner of the type that is allowed today in MSW landfills will, at best, only postpone groundwater pollution; it will not prevent it.

The inevitable groundwater pollution that arises from liner failure is supposed to be detected by the groundwater monitoring systems required by the US EPA and the local regulatory agencies for the landfill. However, the groundwater monitoring systems that are allowed by regulatory agencies were designed for unlined landfills and have a very low ability to detect groundwater pollution by landfill leachate arising from liner failure before widespread pollution occurs. Rather than relying on the detection of groundwater pollution, liner failure is more appropriately detected by measuring failure directly, utilizing a double composite liner system.

Another significant deficiency in the way in which MSW landfills are permitted today in accord with the US EPA Subtitle D requirements is the failure to recognize that post-closure care funding for liner failure monitoring, groundwater pollution monitoring, liner cover maintenance, and remediation of contaminated groundwaters will be required forever in today's lined "dry tomb" landfills. Typically today, regulatory agencies only require 30 years of post-closure care of MSW landfills. This is an infinitesimally small part of the time during which post-closure care funding of considerable magnitude will be needed. The post-closure funding needs can best be achieved through dedicated trust funds developed from disposal fees charged to those who generate the wastes.

It is becoming widely recognized that the "dry tomb" lined landfill of the type specified by the US EPA under Subtitle D is a flawed technology for MSW management. Increasing attention is being given to alternative approaches for landfilling of MSW that involve treatment of the waste and therefore do not lead to inevitable groundwater pollution. Particular attention is being given today to the "wet cell" *in situ* landfill approach in which leachate and clean water is added to the landfill to ferment and leach the waste under controlled conditions and thereby, within a few years, produce a waste residue that will not be a threat to groundwater quality *ad infinitum*.

While the "wet cell" approach can, if properly implemented, eliminate the longterm pollution potential of MSW in "dry tomb" landfills, it does not address many of the other problems associated with MSW management by landfilling.

Decreased Property Values

MSW landfills are well-known to be poor neighbors and, as a result, significantly decrease property values for distances of a several kilometers (a mile or more) from the landfill. While acquisition of adequate land buffers between the landfilling operation and adjacent properties can significantly reduce the problems that have led to the poor neighbor reputation of landfills, there are non-mitigatable impacts of MSW landfills such as truck traffic and impaired viewshed on adjacent property owners and users which can best be addressed through financial compensation of those impacted by the siting of a landfill in their area. In addition to appropriately providing more than the fair market value for the property, those who generate the waste that do not want the landfill in their backyard should pay those who own properties that are adversely impacted by the landfill for these adverse impacts. In addition to direct financial support, the public health, environmental protection, welfare and economic interests within the zone of potential impact of the landfill should be protected. Adoption of this approach could readily change the justifiable NIMBY opposition to landfills being sited in their area to one in which the residents of the area would willingly work with those responsible for developing waste management capacity for urban and rural areas in siting a landfill that will meet the capacity needs without significantly adversely impacting those who own or use properties in the vicinity of the landfill without appropriate compensation.

Reuse of Landfill Area

While it is sometimes advocated by proponents of "dry tomb" landfills that once the landfill is filled (closed), it will be possible to convert the landfill area into a public park, botanical garden, golf course, shopping center, or some other significant beneficial use, it is clear that such claims are highly inappropriate. MSW "dry tomb" landfills require that the cover of the landfill significantly reduce the amount of leachate that is produced by moisture that infiltrates the covers of the landfill in perpetuity. There is no possibility that anything other than a shallow-rooted vegetative cover, such as grasses, or armoring with rocks can be used in perpetuity as a top-layer for the landfill. Other types of vegetation will increase the potential for moisture to enter the landfill, causing increased leachate production and groundwater pollution. Therefore, "dry tomb" landfills of the type being developed today as well as "wet cell" landfills will have very limited reuse of the landfill area for beneficial purposes. This means that the neighboring property owners and users' viewshed of the landfill area will be significantly diminished in perpetuity. Those who generate the wastes who create such situations should financially compensate those who have to experience the situation because of the siting of a landfill in their area.

Leachate Treatment

MSW landfills, during their active life, typically produce leachate that has a significant potential to pollute surface and groundwaters. The treatment of the leachate that is collected in the leachate removal system can be a significant cost of MSW management by landfilling. With increased regulatory attention to the potential for toxic chemicals to cause adverse impacts on the beneficial uses of surface waters which receive treated MSW, greater degrees of treatment and, therefore, costs will be experienced.

Composting

The aerobic composting of the complete MSW waste stream is not possible because of the large amounts of contaminants present in this waste stream. However, composting of yard (green) waste is technologically and economically feasible provided that adequate attention is given to the adverse environmental impacts of truck traffic and odors, and that proper evaluation and use of the compost is made so that it does not represent a significant threat to public health, groundwater and the environment.

Environmental Impact of The 3 R's

It is in the best interests of society to practice the 3 R's (waste reduction, reuse, and recycling) to the maximum extent readily obtainable. It appears that suburban areas can readily achieve on the order of 50% reduction in the solid waste stream through waste recycling and reuse. The development of a waste management program for an area that is designed to provide 15 years or more waste management capacity must include careful evaluation of the possible role of the 3 R's in the quantity and quality of wastes that will have to be managed by landfilling and other approaches. In addition, careful evaluation needs to be made of whether sufficient markets will be developed to justify MSW recycling and reuse to the extent readily attainable today, and whether the processing of the 3 R diverted waste will be significantly detrimental to the public health, environmental impacts and welfare of those who own or use properties in the vicinity of 3-R handling and processing facilities.

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INTRODUCTION

Many solid waste management agencies are in the process of siting landfills in their area to accommodate the municipal solid waste (MSW) for the people of the area over the required period which is typically at least 15 to 20 years. This report presents the results of an overview review of the potential public health and environmental impacts of various methods of solid waste management. Included is a generic discussion of the potential environmental impacts of the various alternative approaches that have been or could readily be used for MSW management, as well as a discussion of how these impacts can be mitigated to imperceptible and insignificant levels to those who own property or otherwise use lands in the zone of potential impact of the waste handling/management facility. Further, proposed approaches for compensation of the unmitigatable impacts are presented. This report provides some of the information that should be used in developing the regional waste management program/plan that a waste management authority should consider in determining how best to manage MSW in an area while protecting public health, the environment and the interests of those in the potential zone of impact of the waste management facility(s).

A review of the landfill capacity development planning for an area typically shows that some arbitrary decisions are often made regarding the magnitude and characteristics of the waste stream that will have to be managed in the proposed landfill(s). One aspect of concern is the assumptions made about the amount of wastes that will need to be managed by landfilling. In some areas it is assumed that there would be a 50% reduction in the MSW waste stream by the year 2000 due to waste reduction, recycling, and reuse (the "3 R's"). Such a reduction appears to be readily possible in suburban areas through the diversion of aluminum and steel cans, various types of glass bottles, certain types of plastics, newspaper and some other "clean" paper, yard ("green") waste, and some construction waste and demolition debris. A number of political jurisdictions in the US, such as California, and other countries, such as the Toronto, Canada area, have mandated 50% waste stream reduction by the year 2000. In addition, considerable efforts are being made to change the packaging of some commercial products in order to further reduce the amount of solid waste that must be managed by landfilling or other means.

It is likely that through aggressive 3 R action, including, where necessary, legislation concerning packaging, additional significant reductions in the magnitude of the municipal solid waste stream can be achieved by the year 2000. It is clear that any planning for landfills should include a detailed analysis of the realistically anticipated waste stream with conventional waste reduction efforts, as well as that which could be achieved through highly aggressive waste stream diversion efforts. It is possible that such an analysis would reveal that the amount of waste in need of management by landfilling is considerably less than is currently anticipated by the waste management authority of the region.

It is typically concluded, without adequate review, that development of one or more large (“mega”) landfills is the approach of choice for managing the MSW residues that cannot be addressed through the 3 R's. As discussed in this report, mega-landfills can have significantly greater adverse impacts on those who own or use property within the zone of impact of the landfill than smaller landfills. For example, concentrating the waste from a city in one landfill could result in significant traffic problems in the vicinity of the landfill due to one or more garbage trucks having to enter the landfill each minute. Garbage truck traffic and the associated air pollution, etc. is one of the significant adverse impacts of large landfills.

A detailed review could show that it would be far more appropriate (less environmentally and socially damaging) to manage the non-3 R's-controllable residues in a number of smaller landfills appropriately located within the area. It is the authors' experience that waste management agencies typically do not conduct the in-depth review of alternative solid waste management options and their associated impacts that should have been conducted prior to concluding that one or more landfills need to be constructed in the area to manage this area's MSW over the next 15 to 20 years or more.

Another aspect of concern is the limitations made on the waste management alternatives that are to considered for an area. The exclusion of railhaul to a landfill located at a geologically suitable site located at considerable distances and/or incineration as methods of MSW management is often related to political considerations. It is becoming widely recognized that railhaul of MSW is a technically valid approach that can be used to cost-effectively manage MSW at geologically suitable sites. There are sites in North America where untreated MSW can be managed by landfill disposal without significantly threatening adjacent or nearby property owners/users or the groundwater resources of the region. Using railhaul, it is possible to use such sites at considerable distances from where the wastes are generated, at costs far less than those that would be required to properly manage municipal solid wastes at more local, but geologically unsuitable sites.

There is considerable controversy about the environmental impacts of incineration of MSW. If properly conducted, incineration is a cost-effective method of MSW treatment that significantly reduces the volume and produces a residue (ash) that is readily manageable. Lee and Jones-Lee (1993a) discussed environmental quality concerns associated with incineration and approaches that can be used to incinerate municipal solid wastes while protecting public health and the environment. Unfortunately, the experience in some areas with incineration of MSW has resulted in blanket banning of this method of MSW management in some areas. It is likely that when the true impacts of other MSW management methods and their costs are understood, both railhaul and MSW incineration will be included in the methods that should be considered for use for managing MSW in an area.

OVERVIEW OF THE ENVIRONMENTAL ISSUES OF MSW LANDFILLS

Owing to the physical, chemical, and biological characteristics of MSW and many of the landfilling approaches that have been used, the management of MSW can and unfortunately typically does have a significant adverse impact on those who own or otherwise use properties near the waste management location. Table 1 lists many of the common problems associated with MSW landfills. The impacts of MSW landfills can be divided into two periods: the active life when the landfill receives waste, and the post-closure period after the landfill has stopped receiving waste. Typically today, the active life of an MSW landfill is often on the order of 20 years; a number of political jurisdictions, require that communities have solid waste management capacity of at least 15 to 20 years. That period of time is commonly specified because it often requires 10 years or more to bring a new landfill on line. Because of the difficulties in siting landfills, those responsible for MSW management would prefer to site landfills that have active lives of over 50 to 100 years.

Table 1
Adverse Impact Issues:
Municipal "Dry Tomb" Landfills on
Users and Owners of Adjacent and Narby Properties

- Groundwater and Surface Water Quality – *Public Health, Economic, Aesthetic*
- Migration of Methane and VOC's – *Public Health Hazards, Explosions, Toxicity to Plants*
- Illegal Roadside Dumping and Litter near Landfill – *Aesthetic, Public Health Economic*
- Truck Traffic
- Noise, Odors
- Impaired View
- Dust and Wind-Blown Litter
- Vectors, Insects, Rodents, Birds – *Nuisance, Public Health*
- Condemn Adjacent Properties for Future Uses
- Decrease Property Values
- **Perpetuate Garbage Management Crisis**

There are, however, drawbacks to the development of community landfills with long active lives. Such landfills could readily become regional landfills, having to accept wastes from long distances. This is especially of concern now that railhaul and large truck transport of MSW has proven to be cost-effective. A community that has a landfill with a projected active life of 50 to 100 years based on its rate of waste generation could find that the active life would be cut to a much shorter period of time as a result of waste being imported from considerable distances.

There are situations in which decisions made regarding the funding of MSW management projects affect the way in which the facility is ultimately operated. The economics of funding such projects require assumptions to be made about the rate of payback, which require assumptions about the disposal fees that will be generated at the landfill, which, in turn, require assumptions about the availability of garbage flow into the facility.

There have been examples over the past several years where local jurisdictions have constructed waste management facilities such as landfills, incinerators, etc., in which, as part of securing funding, the jurisdiction was obligated to a certain income derived from the fees generated by waste disposal in the facility. However, once in operation, the waste management unit did not receive the anticipated waste load because of waste reduction, recycling and/or cost of operation. This resulted in insufficient income generated from disposal fees to meet the payback schedule. In order to secure the needed waste load, the facilities have had to expand their service area. A number of incinerator projects which, in order to meet the financial obligations associated with acquisition of funds for support of the project, had to become regional facilities, accepting garbage from other areas beyond those they were originally intended to serve.

The characteristics of the municipal solid waste stream will change significantly in character and quantity over the next 5 to 15 years. It is very important in developing MSW management programs for a region to give adequate consideration to the possible range of changes that could take place during this period, focusing on plausible worst-case scenarios, and their impact on the management approach(es) that could be used in the region. It is also clear that the costs of MSW landfilling, as well as of many other MSW management methods, will be increasing significantly from those that have been experienced in the past in order to reliably and adequately address the impacts of landfills of the type listed in Table 1 on nearby property owners/users.

IMPACTS OF LANDFILLS DURING THEIR ACTIVE LIFE

Mega-landfills can be distinguished from other landfills by the rate at which garbage is deposited in the landfill each day, the area of the landfill in which wastes are deposited, and the duration over which the landfill receives wastes. These factors all influence the manifestation of adverse impacts of the facility on nearby property owners/users. There are several impacts of municipal solid waste management approaches which are common to several management systems. These include truck traffic, odor and fugitive litter, as noted in Table 1. Large landfills that receive large amounts of solid waste each day over a long period of time will be expected to cause greater potential adverse impacts on nearby property owners and users than small landfills that are active for a few years and that receive only a few truckloads of garbage per day.

Truck Traffic

Truck traffic is one of the major causes of adverse impacts of large, highly intensely used landfills and other waste management units on those who own or use properties near the waste management unit. With the trend towards mega-landfills, which receive large amounts of garbage each day, it is becoming increasingly clear that the transport of the garbage in trucks will be one of the principal sources of adverse impacts to nearby property owners/users. It is typically found that the solid waste management operations begin at about the same time each morning; a flow of garbage trucks begins at about the same time. The frequency of truck arrival depends on the amount of garbage accepted and trucking patterns; depending on the rate at which they are accommodated at the facility, lines of trucks can accumulate at the facility. Depending on the frequency of passage of trucks on the access streets, truck traffic can significantly adversely affect the use and enjoyment of properties and roadways near a landfill. Some have indicated that more than about one garbage truck every five minutes or so can represent a significant adverse impact; for some uses, that rate is excessive.

In addition to noise and annoyance concerns of truck traffic, increased truck traffic can have adverse impacts on traffic flow and therefore, public safety. Unless the roads and traffic patterns were planned and developed specifically to accommodate the anticipated truck traffic for a particular landfill, few roads, especially in rural areas, would be expected to effectively handle large garbage trucks at rates of one or so per minute without significant adverse impacts on traffic flow, public safety, etc.

Furthermore, because of their size and weight, garbage trucks significantly accelerate the rate of deterioration of highways and roads, again especially in rural areas where the roads are not constructed to handle large numbers of trucks over short periods of time. In some areas ruts and scallops in roads have been attributed to garbage truck traffic. While the deteriorated roadways can be maintained, such maintenance rarely keeps up with rates of deterioration. While it could be possible to recover the cost of accelerated roadwear due to large numbers of garbage trucks from increased disposal fees, this is also rarely done. Instead, road maintenance is paid out of vehicular licensing fees and fuel taxes; the increased number of garbage trucks and their impacts on specific local roadways near the waste management unit are rarely addressed in an appropriate and timely manner so that the people who use the roads impacted by the trucks are adversely affected in that way by the truck traffic.

While today's garbage trucks typically do not litter highways with garbage, many of them leak liquid wastes and liquids that have come in contact with the garbage on the roadways. It is not uncommon, especially during wet periods, to see a trail of "garbage juice" behind a garbage truck after the truck has picked up the garbage from the area. If garbage is picked up once each week from a particular location, the trail of "garbage juice" from that truck is of little concern in the pick-up area. However, when large number of garbage trucks travel roadways, especially if they stop at a stoplight or stop sign, the leakage of garbage juice can become not only an unsightly nuisance in the area, but also a health hazard; the leaked material can attract flies and other insect disease vectors, vermin, and can possibly be highly odorous. It is the authors' experience that this kind of problem is unusual since there is typically sufficient travel time between the last garbage pick-up and when large numbers of garbage trucks pass an area in a short time near the waste management unit to allow the drainage of the garbage on the highways and streets between the two locations.

Large numbers of garbage trucks can also have an adverse impact on local air quality due to exhaust and other emissions. Such emissions of odors, soot, and particulate emissions from diesel-burning vehicles not only adversely affect the aesthetic quality of the area but also represent increased health hazards to the public in the vicinity of the area where large numbers of garbage trucks pass each day.

One of the unique aspects of adverse impacts caused by truck traffic compared to other adverse impacts listed in Table 1 is in the ability to mitigate or effectively remove the adverse impact. While most of the adverse impacts listed in Table 1 can be readily eliminated, or at least significantly reduced, for a relatively small cost per person per day to those who generate the waste, most of the problems caused by truck traffic cannot.

Reduction of the frequency at which large garbage trucks pass a particular point and therefore the impacts of those trucks on the use, enjoyment, and healthfulness of the area is not readily controllable. Rarely are there major freeways connecting pick-up points to the edge of the landfill. With few exceptions, garbage trucks must use one or more two-lane roads in traveling to the landfill. It is in these areas that the principal adverse impacts of the garbage trucks occur. While in some areas problems of this type could be addressed to a considerable extent by new road construction, rarely do the tipping fees for landfills include sufficient funds to significantly alleviate the truck traffic problems.

The number of garbage trucks that reach the landfill during a period of time should be carefully evaluated and become one of the deciding factors in the establishment of the "size" of a landfill. The siting of landfills, especially mega-landfills, that receive sufficient waste each day so that garbage trucks arrive at the landfill at a rate of one every few minutes, must have adequate road capacity and structural integrity as well as a proper maintenance program to mitigate to some extent the adverse impacts of the truck traffic.

In some areas, such as New York and New Jersey, garbage is transported hundreds to a thousand miles or more to the deposition points in the Midwest. This has been a result of during the late 1980's and early 1990's, state regulatory agencies in those areas have closed many of the state's MSW landfills and have been unable to site new landfills. The increased transportation costs increased the collection and disposal fees to the average homeowner by a $100 or so per year (about 30/person/day). While the cost increase was significant compared to what the residents had been paying when they used their local landfills (which had tipping fees in the order of $20 to $30/ton), they were accepted by the public since there was no alternative.

However, despite their increase, those costs still are only the initial costs of garbage disposal; they do not consider the longterm costs associated with the liability and adverse impacts that are caused by placing those wastes in an MSW landfill that was not designed, constructed, operated, closed, and maintained with post-closure care *ad infinitum*, to prevent groundwater pollution by leachate, albeit in another jurisdiction. When regulatory agencies start to enforce the regulations that exist in many parts of the US for control of groundwater pollution by MSW landfills and the clean-up of existing pollution to the maximum extent practical, there will have to be massive expenditures of public funds derived from those who deposited waste in the landfill or, as discussed below, from those who now generate waste in political jurisdictions that had deposited wastes in the landfill.

Plumes of landfill-derived contaminants are spreading from many MSW landfills in the US at the rate of hundreds of feet per year without control, even though existing regulations in most areas require such control. This lack of control arises in large part from the "high" cost of trying to control groundwater pollution by MSW landfill leachate. While the magnitude of the costs are highly site-specific, the authors have been involved in the investigation of one 80-acre MSW landfill in southern California which over a ten-year period destroyed more than $100 million dollars of groundwater. The pollution from that landfill is still spreading at the rate of more than 500 ft/year even though the state of California regulations explicitly state that such pollution should have been stopped 8 years ago when it was first discovered. The US can not continue to allow the unimpeded pollution of groundwaters by landfill leachate that is occurring in many areas. Analogous to the "Superfund" program developed to control the potential impacts of "hazardous" chemicals on groundwater quality, an "MSW-Superfund" program will have to be developed in the nearterm in order to begin to protect the groundwater resources of the US from further deterioration due to MSW landfill leachate.

Odors

Municipal solid wastes are highly odorous. Any doubts about that truth can be resolved by smelling one's own garbage can - or the neighbor's garbage can - as the garbage truck arrives to make it "disappear." Typically by the end of the week when the garbage is picked up, the odors can be so offensive as to cause one who is adding to his garbage can to hold his breath. Several tons of such odorous materials are deposited into a landfill at one time as part of unloading a truck containing an area's garbage at the landfill, transfer station, or materials recovery facility.

In addition to the odors associated with the newly collected garbage, odors are generated in MSW landfills from the aged garbage. What are now known as "classical" sanitary landfills (unlined landfills) included in their design, "daily cover;" this is a few inches of soil placed over a day's garbage deposition to reduce the odorous emissions from the landfill that are still being released from that day's garbage as well as the previous days' garbage. After a landfill is "closed" (a low-permeability cover is placed over the landfill and a gas collection system is constructed and operated), the odors are primarily associated with the release of landfill gases. Landfill gas is principally composed of methane and carbon dioxide, but also contains a wide variety of other volatile chemical contaminants, some of which are highly odorous. Neither methane nor carbon dioxide has an odor; therefore, the odors associated with "landfill gas" are caused by components other than methane and carbon dioxide. Improper management of landfill gases can result in severe odor problems in the vicinity of the landfill.

The principal concern about odors among those who own or use lands near a landfill, is the odor associated with the active life of the landfill. During the active life of a landfill, a considerable part of these odors is derived from the daily dumping of garbage. In addition, if the landfill contains cells that have already been closed, the landfill gaseous emissions can be a significant source of odor if they are not properly managed. It is readily possible to control odors associated with landfill gases that have been collected in a gas collection system by efficient flaring (burning) of the gases or through gas collection and utilization as part of an energy recovery effort. However, it is difficult, if not impossible, to control the odors associated with the garbage that is being dumped using approaches normally followed in the dumping of garbage at the active face of the landfill. The reason that those odors are not controlled is strictly economics and tradition. This would add to the cost of MSW management. Since the earliest efforts to collect the garbage that the medieval urban-dwellers threw out their windows into the streets, it has been well-known that the garbage transport, and especially the area where the garbage was dumped, would be highly odorous. This situation is simply taken for granted; garbage is odorous, landfills are odorous, and anyone who happens to be near a landfill can be expected to be periodically exposed to odorous conditions.

There are two approaches that could be used to control the odor emissions from garbage being disposed in a landfill. One would be to collect all gases emitted from the waste, including those emitted during the dumping operation, and treat them to remove the odorous components. It would be readily possible to conduct the dumping of garbage under a dome where all gases emitted would be treated for odor removal. However, by tradition, and to reduce the expense of landfilling, no efforts are made to try to control the release of odors to the ambient air at the time of dumping of the waste.

The alternative is to eliminate the impact of the odors by dilution. To do this it is necessary to incorporate into the landfill property a sufficiently large land buffer so that the odorous emissions from the landfill are diluted below detectable amounts at the edge of the landfill property. Often several kilometers (a mile or more) are needed between the point of waste deposition and adjacent properties to achieve sufficient odor dilution. That notwithstanding, various political jurisdictions still allow landfill owners/operators to deposit waste within a hundred to a few hundred meters (~yards) or so of adjacent properties. Under those conditions there can be no doubt that highly odorous conditions will occur on the adjacent properties that will significantly adversely affect those who own or use these properties.

While typically landfill odors are dissipated within several kilometers of the areas of active waste deposition, there are situations where much greater distances are required for odor dissipation. Those situations are associated with certain types of meteorological conditions such as inversions with relatively stable air masses, and/or canyon or valley settings where there is little dilution of the odorous compounds emitted from the landfill as the air masses move down the canyon-valley. It is therefore necessary for site-specific analyses to be conducted of the potential aerial extent of odor problems under plausible worst-case conditions, and the acquisition of sufficient land buffers as part of landfill development to sufficiently isolate the landfill from adjacent properties so that those who use adjacent properties are protected from landfill-derived odors. This is typically not done today because it adds to the cost of developing a landfill. The acquisition of several kilometers of buffer lands around a landfill to allow proper dilution of odors and other adverse impacts of the landfilling operation requires that those who generate the waste pay more for waste disposal to cover these costs. However, unless proper analyses of this type are done, and the necessary buffer lands provided, the principal waste generators (urban dwellers) will continue to have subsidized garbage disposal, paying less than is required to properly manage the wastes at the expense of property owners and users in the vicinity of the landfill. As long as the current approach prevails, there will be justifiable opposition to the siting of landfills in an area based on the failure of those who generate the waste to pay the costs associated with controlling the odors of the waste so that they are not adverse to the use and enjoyment of nearby properties to the landfill.

Mega-landfills, especially those that receive large amounts of garbage each day, can have highly significant odor problems due to the large numbers of garbage trucks that dump their waste over short periods of time. As a result, mega-landfills may require even larger landfill-owned buffer lands than small community landfills in order to effectively control the odor emissions from the landfill so that they are not adverse to nearby property owners/users.

Until the odor problems associated with active landfills are resolved, either by treatment or dilution, MSW landfills will continue to adversely affect those who own or use nearby properties. Those who oppose the siting of a landfill near their property are often labeled, "NIMBY's" - "not in my back yard," and are often presumed to be opposing landfill siting without justification. However, based on past practices and the outlook for future practice, those who own or use properties near landfills are indeed justified in their concerns over impacts of the facility on their health and welfare and the value of their properties because of the odor problems of MSW landfills.

Litter

One of the significant adverse impacts of municipal solid waste landfills on owners and users of lands near the landfill is off-site litter (paper, plastic, garbage, etc.). As one approaches a landfill entrance, it is rare that the roadway does not contain large amounts of litter. This litter can represent a significant degradation of the aesthetic quality of the area and in some instances, a public health hazard. While most of the litter is paper and plastic, some of it contains food wastes and other material that could attract rodents and insects that can serve as vectors of disease.

The litter present in the vicinity of an MSW landfill may be derived from a variety of sources. Some of it falls from the trucks and other vehicles that transport the solid waste to the landfill. Most political jurisdictions that host landfills have ordinances that require garbage trucks to be covered. In some areas, however, such ordinances are not sufficiently enforced. Open or inadequately covered garbage trucks can readily lose materials during transport.

A special form of littering by garbage trucks that has frequently been observed by the authors occurs at the point where the garbage is transferred from the homeowners' containers to the truck. On many occasions, the authors have observed that this transfer results in broken glass being left in the roadway. Such broken glass is obviously a significant hazard as a result of damage to automobile tires, people and animals walking in the streets, etc.

A significant source of roadside litter associated with landfilling operations is the public's illegal dumping of garbage near the entrance to the landfill. It is a common occurrence to find garbage deposited at a landfill gate illegally, especially after hours.

Another source of litter around landfills is the inadequate litter control by the landfill operator in the area where the garbage is dumped from the trucks. Typically, litter-control fencing is used near the active face of the landfill. Frequently however, the fencing is not adequate to prevent airborne transport of paper and other components of the garbage beyond the fencing. Unless the operator of the landfill is highly diligent in policing for fugitive litter, papers and other materials from the dumped garbage can be carried for considerable distances, detracting from the aesthetic quality of the area.

The control of litter near a landfill so that it does not adversely affect nearby property owners and users is an economic issue. If those who generate the garbage provided sufficient funds to the landfill owner/operator as well as to the regulatory agencies responsible for regulating the landfill's operations to effectively police the landfill operations, control of inappropriate transport, illegal dumping, and litter could be readily achieved. The operator of the landfill must assign personnel to periodically (e.g., at least three times a day) pick up all litter along the roadways or that has escaped from the disposal operations.

Dust

Some landfill operations contribute significant dust to the ambient air near the operation. Truck traffic over dirt roads during drier parts of the year and within the area of dumping can result in appreciable airborne dust. Dust can also arise at the locations where daily cover is mined and where it is dumped. Dust can be controlled through efficient watering of the roadways and other areas where dust is generated. At some landfills, this is difficult to accomplish, however, because of the shortage of water and its cost. Under those conditions, a landfill operator may conduct dust control to the least extent possible to just get by the local regulatory requirements as enforced.

A disturbing practice that is becoming frequently encountered at landfills where water for dust control is difficult or expensive to obtain, is the use of landfill leachate for dust control. Such a practice should be prohibited. The operator of a landfill normally looks with favor on the use of leachate for dust control, since not only is it an inexpensive source of moisture, but it is also a very cheap method of disposing of leachate. Landfill leachate contains a wide variety of conventional, non-conventional, and hazardous chemical contaminants and biological/infectious agents. The spreading of leachate on roadways and other areas for dust control can result in the transport of leachate-associated contaminants from the roadways to nearby watercourses during precipitation runoff events. As a result of new US EPA national stormwater quality regulations, runoff from landfills in the US is required to be monitored and will ultimately be required to be managed so that the contaminants in the runoff do not adversely affect the designated beneficial uses of the surface waters that receive the runoff. If landfill leachate is allowed to be disposed of by spreading on roadways for dust control, a highly effective and comprehensive monitoring program should be required to ensure that the contaminants in the leachate do not pollute surface and groundwaters in the vicinity of the landfill.

Vectors, Vermin, and Other Nuisance Organisms

A classical public health concern associated with municipal solid waste management is vectors for human pathogens that are present in the solid wastes deposited in the landfill. Municipal solid waste contains appreciable quantities of human pathogens from the deposition of human fecal material in the garbage. Pathogens are organisms that cause disease, including certain bacteria, viruses, protozoa and intestinal worms. Certain of those organisms cause diseases such as amoebic dysentery and typhoid fever. Of particular concern are the cyst-forming protozoans that cause giardiasis and amoebic dysentery. The cyst forms of these organisms are extremely persistent in the environment and can be transported via vectors for considerable distances and still remain infectious. It would be rare that the human pathogens in municipal solid wastes that are of concern because of their potential for vector transport would be of concern because of the potential for pollution of groundwaters, rendering the polluted groundwater unsafe to use for domestic purposes without disinfection. This is because typically these organisms are not transported easily within groundwater systems since the organisms tend to be readily removed through filtration in the aquifer and also tend to die off.

One of the sources of human fecal material in garbage is disposable diapers. While disposable diapers do not contribute more than a few percent of the total volume of solid wastes that are present in the landfill, they do increase the amount of human fecal material that enters the landfill, thereby contributing to the potential for disease organisms to be transported from the wastes to those who live, work or otherwise use lands near the landfill.

Another source of human pathogens in landfills in many areas is septic tank septage (the semi-solid materials pumped from a septic tank). While such materials have been and continue to be deposited in municipal landfills in many areas, this practice has come under increased regulatory scrutiny because of its addition of moisture to the landfill, which, in turn, increases the potential for leachate generation. To the extent that septic tank septage is permitted for deposition in a landfill, there is an increased potential for human enteric pathogens, such as the organisms that cause dysentery and typhoid, to be carried by vectors to adjacent properties.

In the past, medical waste from hospitals and other sources were disposed of in municipal landfills. Today in the US such wastes are "red-bagged" and must be disposed of by incineration or other methods that are effective in the control of disease organisms. Occasionally, however, some hospitals and other medical units illegally dispose of red-bagged wastes in local municipal landfills. Such practices could lead to increased public health concerns about vector transmission of disease organisms from the landfill operation to nearby residents.

One of the reasons that daily cover came to be used in sanitary landfills was to reduce the availability of disease organisms in the waste to flies and other insects that could transport those organisms from the waste to humans who live or use lands near the landfill. A few inches of soil cover applied each day over the filling area can reduce the availability of the disease organisms in the waste to the period of time that the wastes are exposed to the atmosphere, i.e., from the time that the wastes are dumped in the landfill until they are covered with soil. While inadequate placement of cover material can result in increased insect problems, such problems can be readily controlled by prompt and effective covering of the waste before flies and other insects can develop within them.

Another problem of classical garbage dumps was the presence of various animals (typically called vermin), such as rats, that live on the food scraps in the garbage. The classical garbage dumps could develop large rodent populations that could be not only a significant nuisance to those who live, work or use lands near the dump, but also, since some of these rodents are carriers of endemic diseases, such as bubonic plague, represent a health threat to those within the zone of impact of the dump. In some areas, bubonic plague and other human diseases are endemic in the populations of rodents and other small animals. Recently the finding that the rodent-borne hantavirus has been found to cause deaths of people in several states who come in contact with rodent feces raises additional concerns about increased populations of rodents near landfills. If a landfill can serve as a source of food for those animals, and thereby contribute to the sustaining of the overall animal population in a region, there is an increased human health hazard to those in the vicinity of the landfill where the increased populations are prevalent. The daily cover of the sanitary landfill, if appropriately applied and managed, can be highly effective in controlling vermin associated with the landfill by eliminating their food source.

Probably the most significant animal problem associated with landfills today is the large number of seagulls that are attracted to landfills. Landfill areas located considerable distances from any major bodies of water where seagulls would typically be found can, and frequently do, maintain large populations of seagulls that can be seen circling the landfill area. Seagulls that feed on landfilled materials can become vectors of disease for those who use lands near the landfill above which seagulls fly. The seagull defecation (droppings) is of concern from a public health perspective as well as from an aesthetic point of view. In addition to seagull populations that develop in the vicinity of the landfill owing to the landfill, a landfill can attract seagulls from area waterbodies such as lakes, rivers, and the oceans. There is concern about the impact of seagulls and especially their droppings in the flight way between the landfill and the waterbody.

Another important concern about seagulls around landfills is the hazard they represent to aviation. Through collision with the aircraft, bird populations such as seagulls can cause sufficient damage to aircraft to increase the hazard of crashes. The problem of landfill-associated seagulls is of sufficient magnitude to cause the US EPA to restrict the siting of landfills near airports in its Subtitle D regulations for landfilling of MSW. While the US EPA regulations focus on maintaining a certain distance between the landfill and airports, the same consideration should be given to siting landfills which would cause increased seagull traffic in an airport area located a considerable distance from the landfill which is in the flight path between the landfill and a major body of water that the seagulls inhabit.

It is extremely difficult, if not impossible, to eliminate seagulls from landfill areas. Some landfill owner/operators construct wires or other devices to try to reduce seagulls' feeding on the garbage shortly after it is dumped each day. It is the authors experience that even if such devices are effective in preventing seagulls from landing on the garbage, they do not prevent large numbers of seagulls from flying above the landfill and nearby lands, and thereby represent significant hazards and nuisance to those who use lands near a landfill. While it is impossible to effectively control the seagulls associated with landfills, the impacts of the seagulls can be controlled to a considerable extent by proper siting of landfills away from areas where seagulls would represent hazards to aircraft and people. This would involve the incorporation of adequate land buffers around the landfill and beneath flight paths so that the seagull populations that circle the landfill fly above lands owned by the landfill owner. In this way, many of the problems associated with seagull droppings on nearby property users can be significantly reduced. Distances of several kilometers (a mile or more) from the landfill should in most locations be adequate to cover the areas where large numbers of seagulls would circle.

Noise

The heavy equipment used in landfill operations can significantly increase noise levels on adjacent and nearby properties so that they are damaging to public health and welfare. The typical approach to mitigation of the noise problem is to restrict the hours of operation of the heavy equipment. While this approach can obviously be effective for those whose only concern is to have low noise levels during the night, it does not address the problems for those who wish to use their properties with low noise during the day. The noise problems of landfills can be reduced somewhat through proper equipment design and operation. However, appropriate control of noises requires the presence of sufficient buffer lands between the areas of the landfill where waste deposition takes place and adjacent properties. The land buffer needed to allow dissipation of odors of few kilometers or so in width should also normally be adequate to dissipate the noise associated with normal landfill operations.

LANDFILL GAS EMISSIONS

While some presume that landfill odor problems are aesthetic in impact, it is known that MSW landfills release a variety of hazardous chemicals in their gaseous emissions. There have been a few studies of the chemical characteristics of gaseous emissions from landfills. Hodgson et al.(1992) reported on the results of a study of the volatile organic compound (VOC) emissions from municipal landfills. They found, as would be expected, that municipal landfills emit in gas a variety of chlorinated solvents and benzene, many of which are suspected or known human carcinogens, at concentrations that are of potential significance to public health of those exposed to these emissions.

In a recent study of the potential cancer hazard of airborne emissions from the Puente Hills Landfill, operated by the Los Angeles County Sanitation Districts, it was found that the increased cancer risk was in excess of one additional cancer in a hundred thousand people who reside on properties near the landfill (Los Angeles County Sanitation Districts, 1992). Many regulatory agencies, including the state of California Department of Health Services, regulate carcinogen exposure to one additional cancer in a million people exposed to the source of carcinogens over their lifetime. The gaseous emissions from the Puente Hills Landfill represent an increased cancer risk for those who live or extensively utilize properties near the landfill that is a factor of ten greater than what is considered today in many areas to be an acceptable incremental increase in cancer risks.

The determination of incremental increase in cancer risk due to landfill gas emissions considers only those few chemicals that are regulated today by air quality standards. It is well-known that municipal solid wastes today contain a variety of volatile organic contaminants whose composition is unknown and therefore whose impact on public health and the environment is yet uncharacterized. These chemicals (the non-conventional volatile pollutants) could readily contain a variety of hazardous chemicals that are not currently regulated. There are on the order of 60,000 chemicals in commerce today in North America. Typically fewer than 200 of these are analyzed in air quality surveys. The remainder of the volatile organics which are known to be present based on measurements of the total organic content of the atmosphere near landfills, are uncharacterized and unregulated. There could readily be highly hazardous chemicals within the group of volatile non-conventional pollutants. Many of these chemicals would be non-odorous at concentrations that are hazardous to public health, and therefore would not be perceived to be present by the public who utilize lands near the landfill.

There can be no doubt that those who experience significant odors near a landfill are being exposed, not only to an aesthetic degradation of their environment, but also to a potentially significant though uncharacterized public health hazard. While this is not generally recognized today, it is of sufficient concern that those who generate waste for deposition in a landfill should be required to control odors that can be perceived by those who use properties near the landfill. It is prudent public health policy to control the odorous emissions from landfills either through off-gas collection and treatment and/or providing sufficient landfill-owned buffer lands so that the odorous components are diluted below detectable levels on adjacent properties.

There is no assurance that the elimination of all landfill odors on nearby properties will control potentially hazardous chemicals to a sufficient degree so that their hazards are minimal to those who use properties near a landfill. However, it can generally be assumed that the public health risks would be less if the potentially hazardous volatile compounds were diluted to the point at which the odorous components of landfill gases are no longer detectable. Subsequent investigations could prove that that indicator of dilution is insufficient to protect public health, especially of those who are more sensitive, from health hazards from airborne contaminants. Until that work is done, it is appropriate for those who generate municipal solid waste to pay the necessary funds to control gaseous emissions at least to the point at which odors are not detectable on adjacent properties. This would be a significant step in controlling the potential public health hazards associated with landfill gaseous emissions and the degradation of the aesthetic quality of adjacent properties.

Landfill Gas Collection and Impact Control

A variety of approaches are used for collection of landfill gases from closed sections of MSW landfills. These range from passive systems in which gas is collected in trenches and pipes and released to the atmosphere for dilution, to those with active mechanical gas collection devices in which the collection system is under a reduced pressure. The gases collected from either system can be released to the atmosphere for dilution but are more typically "flared" in which the methane in the gaseous emissions is burned in a flare. Supplemental fuel is usually added to these flares to maintain combustion when the methane content of the gas is not sufficient to sustain combustion.

It is often claimed by landfill applicants that the flaring of landfill gases controls obnoxious odors and chemicals that could be detrimental to public health and the environment. However, the temperatures and residence times of chemicals in such flares are such that they are relatively inefficient combustion units for control of deleterious and hazardous chemicals in landfill gases. The flares that are used for landfill gas combustion were designed to control the concentration of methane in the flare exhaust to below those concentrations that could result in explosions due to the ignition of methane in the presence of oxygen in air. The flare conditions needed to achieve that goal are significantly less than those that are known to be needed to destroy some highly odorous chemicals and a wide variety of potentially hazardous chemicals that are present in municipal landfill gaseous emissions that are a threat to public health and the environment. It is well-known today that higher temperatures and greater residence times in the combustion zone of a flare are needed to achieve high degrees of removal of many hazardous chemicals. It should not be assumed that the flaring of landfill gases as is typically practiced today is protective of public health and the environment from any chemical other than methane.

Because of economic considerations, small landfills typically do not attempt to recover the energy (BTU) value of the methane released in the landfill gases. However, at larger landfills, at least the classical sanitary landfills, collection and use of landfill gas is an economically viable process. It is important that any gas utilization process be evaluated to determine whether the emissions from the gas recovery process do not represent significant odor and/or public health threats. Landfill gas methane is known to be highly contaminated with a wide variety of chemicals that are highly odorous, corrosive, or can represent significant public health and environmental hazards. Some landfill methane recovery processes clean up the gas so that the methane can be more readily used as a BTU source. It is important to consider as part of the landfill gas clean up and energy recovery process whether off-gases from the process could be offensive, hazardous, or otherwise deleterious as public health or environmental hazards to those who use properties near the landfill gas recovery operations. In many areas such operations continue to be allowed to operate without proper public health and environmental evaluation. In the future, as more is learned about the hazards of landfill gases, and as attempts are made to site, construct, operate, and close landfills so that they do not have significant adverse impacts on nearby property owners/users, efforts should be made to evaluate and control gaseous emissions from landfill gas recovery activities that could be detrimental to public health, the environment, or the welfare of those who use or own properties near the landfill.

Overall, landfill gaseous emissions represent significant public health, environmental, and aesthetic quality threats to adjacent and nearby property owners/users. Typically in the past and still today, those who generate the wastes from urban areas have not been required to provide the funds necessary to prevent odors - and their aesthetic and potential public health consequences - from adversely affecting those who own or use properties near the landfill. The potential adverse impacts of the gaseous emissions from the landfill on nearby property owners/users should be adequately and reliably considered in the landfill siting process. Generally, much larger land buffers around areas of waste deposition will be required to mitigate the adverse impacts of the gaseous emissions from MSW landfills, especially mega-landfills, than are typically provided today. The size of the land buffer needs to be determined based on site-specific, plausible worst-case conditions, but would generally be expected to be at least several kilometers (a mile or more) or more between the areas of deposition of waste and adjacent property owners' lands. The cost of proper control of gaseous emissions from landfills, whether by collection and treatment or dilution within landfill owner-owned land buffers, should be part of the cost of developing and managing municipal solid waste at a landfill.

GROUNDWATER POLLUTION AT LINED LANDFILLS

Lee and Jones-Lee (1993b) discussed in detail groundwater pollution by municipal solid waste landfill leachate and the ability of today's lined "dry tomb" landfills (soil and plastic-sheeting-lined landfills for waste storage) to prevent groundwater pollution by leachate for as long as the MSW components represent a threat to groundwater quality. They concluded that the "dry tomb" landfilling approach is a flawed technology that will not protect the groundwater resources in the vicinity of the landfill. This section reviews key technical issues upon which that conclusion was drawn.

Groundwater Pollution by MSW Landfills

The principal problem of municipal solid waste landfills that has received regulatory attention is the pollution of groundwater by landfill leachate. The "city dumps" and the classical sanitary (unlined) landfills were sited, operated, and closed largely without regard to the potential for groundwater pollution; indeed many were sited in low-lying wet areas. However, in developing new MSW landfills today, considerable attention is usually given, at least superficially, to the potential for the leachate formed in the landfill to pollute groundwaters, impairing their use for domestic water supply purposes.

Few landfills have been sited in areas where the natural geologic strata provide a reliable barrier that will prevent the leachate generated in the landfill from being transported to the groundwater system hydraulically connected to the landfill area. While the natural strata may be of a low permeability, e.g., 10^{-6} cm/sec (0.3 m/yr, 0.1 ft,yr), even with such a low rate of transport, groundwater under adjacent properties will eventually be polluted by leachate and its use for domestic purposes impaired if not destroyed. It is rare that natural strata have permeabilities that do not exceed several meters per year (10 or more ft/yr). Many natural strata that can be used for domestic water supply purposes have groundwater flows on the order of a few centimeters to a few tenths of a meter per day (a foot or so per day). It is therefore not surprising to find that groundwaters near existing classical sanitary (unlined) landfills have been polluted by landfill leachate.

With few exceptions, essentially every MSW landfill, whether an old city dump or a classical sanitary landfill, has been polluting and continues to pollute groundwater in the vicinity of the landfill. The US EPA has estimated that there are about 55,000 landfills in the US, more than 75% of which are polluting groundwater. The California Water Resources Control Board Solid Waste Assessment Test (SWAT) results indicate that more than 80% of the landfills that have been investigated in California are polluting groundwater. Todd and McNulty (1974) reviewed the technical literature and reported a number of well-documented cases of groundwater pollution by municipal landfills, beginning in the 1950's. The senior author (Lee) first became involved in landfills and groundwater pollution in the 1960's through work on pollution of a domestic water supply well by municipal landfill leachate in Wisconsin. Since that time, he has found significant groundwater pollution in the vicinity of every landfill that he has investigated.

The Resource Conservation and Recovery Act (RCRA), adopted by the US Congress in 1976, was originally developed to address problems of groundwater pollution by municipal landfills. It was soon found that not only were municipal solid waste landfills causing groundwater pollution, but also industrial landfills, lagoons, waste disposal areas, and industrial waste placed in municipal landfills were responsible for widespread groundwater pollution near the waste disposal areas. That finding caused the US EPA to shift the focus of RCRA to industrial pollution sources and to municipal landfills that contained contaminants derived from industrial activities.

In 1984, as part of revising RCRA, the US Congress mandated that the US EPA develop regulations governing the landfilling of MSW to protect groundwaters from pollution by landfill leachate. Finally in 1991, the US EPA promulgated RCRA Subtitle D requirements which become effective on October 9, 1993. After that date, all MSW landfills and lateral expansions of landfills must be constructed, operated, and closed in compliance with certain requirements such as a liner system, leachate collection and removal system, groundwater monitoring, and provisions for at least 30 years of maintenance after the landfill is closed, all of which are designed to prevent or minimize groundwater pollution by landfill leachate.

Evolution of Landfill Liners

In the 1970's, when it became clear that industrial chemicals were widespread pollutants in groundwater, a professional organization representing the chemical industry claimed that chemical landfills could be made "secure" by lining them with a layer of compacted soil. The organization went so far as to advertise in Time Magazine in an effort to convince the public that that was a technically valid approach. However, those familiar with the elements of Darcy's Law governing fluid flow through porous media (groundwater movement) knew that a few tenths of meters of compacted soil would, at best, only delay transport of leachate out of the landfill by a few months to a few years. In addition, the authors and their colleagues found, as have others subsequently, that pure organic solvents could cause compacted soil (clay) layers to desiccate and crack. This caused the US EPA to abandon prescription of compacted soil layers as liners for landfills. Instead, the agency started to promote the use of plastic sheeting (flexible membrane liners - FML's) as liners for landfills. By the mid-1980's, it became clear that FML's of the type being used then could leak leachate at even greater rates than compacted soil layers. This led the US EPA to recommend the use of "composite liners," which consist of a compacted soil layer overlain by and in intimate contact with plastic sheeting. While such a system may provide greater retardation of leachate migration through it, it has been well-known since the mid-1980's that a single composite liner of the type used today is not reliable to prevent leachate transport through it. Nevertheless, in its 1991 RCRA regulations, the US EPA adopted a minimum prescriptive standard for a single composite liner for all US MSW landfills. After October 9, 1993, all new landfills or lateral expansions of existing landfills will have to have at least a single composite liner of certain design characteristics as the primary barrier between the landfill wastes and the groundwater system in the vicinity of the landfill.

The evolution of liner requirements for MSW landfills has been a progression of attempts by the regulatory agencies to demonstrate attention to the groundwater pollution issue while minimizing the cost of landfilling of MSW. The reason that compacted soil-clay liners were first prescribed was not their demonstrated performance as effective barriers to contaminant transport through them, but rather that they were the next cheapest thing to doing nothing that could be readily found that would give the appearance of providing some protection of groundwater. The reason that plastic sheeting - FML was prescribed was, again, not that it had demonstrated or even expected properties that would prevent leachate-migration through them for as long as the waste represented a threat, but rather that it was the next cheapest thing for lining landfills that gave the appearance of protection. While the US EPA has still not meaningfully faced up to the realities of properly managing municipal solid wastes in landfills so that they will not eventually pollute groundwaters, it is well-known in the technical field that single composite liners of the type the US EPA is now recommending for MSW landfills will, at best, only postpone groundwater pollution by a few decades. Such liners will obviously not prevent groundwater pollution by leachate from those landfills sited on or within geological strata hydraulically connected to groundwaters that are or could be used at any time in the future for domestic water supply purposes.

This was, in fact, recognized by the US EPA in its development of its MSW solid waste regulations. US EPA (1988a), stated:

"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."

In the development of its Criteria for Municipal Solid Waste Landfills, US EPA (1988b) stated: *"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."*

The obvious significant deficiencies in the ability of a single composite liner to serve as an effective barrier to leachate transport through it for as long as the wastes represent a threat were recognized as early as the mid-1980's. At that time several states, including New York and New Jersey, noted failure of such liners shortly after installation. While the problems were associated with poor quality construction, the failures led the states to develop requirements for double composite liners for MSW landfills. A double composite liner consists of two composite liners with a leak detection system (typically a sand layer) between them.

One of the reasons that single composite liners have been and continue to be used to the extent that they are is that, with reasonable care in quality construction, liner leakage will not be detected for a number of years after liner installation. While there can be no doubt that most single-composite-lined landfills leak some leachate shortly after the landfill is put in operation, the detection of that failure depends on the detection of polluted groundwater in the vicinity of the landfill. As discussed by Lee and Jones-Lee (1993c), groundwater monitoring programs for landfills are grossly inadequate to detect incipient leachate pollution of groundwater. It is therefore not surprising that there are currently few recorded instances where a single-composite-lined landfill has been found to be polluting groundwater. This does not mean that pollution is not occurring. In fact, it is obvious that it is. It does mean, however, that the approach used to detect liner failure for a single-composite-lined landfill, which is based on monitoring groundwater for pollution by landfill leachate, is highly unreliable.

Monitoring MSW Landfill Leachate-Pollution of Groundwater

The approach that is used today to monitor lined landfills evolved out of the pollution studies that first began to be conducted to a significant extent in the 1970's for unlined landfills, industrial lagoons, etc. Typically, several monitoring wells placed a few hundred feet or so from the edge of the landfill or other waste management unit would detect polluted groundwater in the direction of groundwater flow. Since most unlined landfills tend to leak leachate uniformly across the bottom of the landfill, one or more monitoring wells located downgradient from the landfill would be sufficient to detect groundwater pollution. However, examination of how lined landfills will leak shows that at least initially, and, in some cases, for many decades, leachate leakage will occur first through holes in the FML that occurred at the time of construction and/or after the wastes were first placed in the landfill; for clay-lined systems, the initial leakage will be through small areas of the liner that have higher permeabilities. Therefore, rather than leaking over much of the bottom of the landfill (as would occur with an unlined landfill), lined landfills will leak first from point sources a few centimeters or so in diameter.

J. Cherry (1990), of the University of Waterloo, was the first to point out that the monitoring well array that is typically being used today for the monitoring groundwater associated with lined landfills has little probability of detecting groundwater pollution by landfill leachate before widespread pollution of the aquifer occurs. As Cherry discussed, leachate-pollution of groundwater from point sources that would arise out of initial landfill liner leakage will result in fingers of leachate no more than a few tenths to a meter or so wide for considerable distances (hundreds of meters) downgradient from the landfill. This pattern would be expected in a well-defined homogeneous, isotropic sand aquifer system. For other systems, such as those with clay lenses, fractured rock, cavernous limestone, etc., the ability to detect groundwater pollution by landfill leachate for landfills that pollute such areas is virtually nonexistent until widespread pollution has occurred.

Haitjema (1991) described monitoring well systems in fractured bedrock underlying aquifers. He stated,

> *"The design of monitoring well systems in such an environment is a nightmare and usually not more than a blind gamble."*

* * *

"Monitoring wells in the regional aquifer are unreliable detectors of local leaks in a landfill."

Parsons and Davis (1992) described the development of a groundwater monitoring strategy for lined landfills and other waste management units. They discussed that the zones of capture of the monitoring wells need to intersect the plumes of contaminated groundwater that can arise from leaks in the waste management unit liners. Since plumes of leachate-contaminated groundwater from lined landfills would not be expected to be more than a few tenths of meters in width at the point of compliance (typically within a hundred meters or so of the waste management unit), and since the zones of capture of typical groundwater monitoring wells of the type used today are only about 0.3 meter (1 foot), it would be necessary to have monitoring wells spaced like a picket fence every few meters along the point of compliance in order to have a high probability of detecting incipient groundwater pollution.

Typically today, US and state regulatory agencies allow landfill owner/operators to space downgradient monitoring wells to a hundred meters (100 feet to a 1000 feet or so) or more apart. It is therefore obvious that a groundwater monitoring approach based on vertical monitoring wells is not reliable for detecting landfill liner failure before widespread groundwater pollution occurs. It is obvious that the groundwater monitoring systems used today for lined landfills are a flawed technological approach that, while suitable for unlined landfills, are grossly inadequate for lined landfills.

Lee and Jones-Lee (1993c) recently developed a comprehensive discussion of these problems with the typical groundwater monitoring approach used for landfills. They recommended that instead of trying to monitor groundwater for evidence of landfill liner leakage, all municipal landfills should be required to have a double composite liner with a leak detection system between the two liners. The lower composite liner would not serve as a containment liner, but rather as part of the liner leak detection system. This approach would significantly improve the ability to detect the inevitable failure of the upper composite containment liner system required by the US EPA in its Subtitle D regulations.

Water Quality Significance of Groundwater
Pollution by MSW Landfill Leachate

Landfill applicants and proponents often claim during permitting consideration that the proposed landfill will accept only "non-hazardous waste" and will not accept any "hazardous waste." The implication is that there is, therefore, little reason to be concerned about groundwater pollution by landfill leachate. That argument is not supported by an understanding of the nature of the MSW waste-stream, the categorization of wastes as "hazardous wastes," the nature of MSW landfill leachate, and the impacts of MSW landfill leachate components on the suitability of groundwater for domestic water supply purposes.

The Resource Conservation and Recovery Act adopted in the US in the 1970's, prohibited the disposal of what are now classified as "hazardous wastes" in municipal landfills. Prior to that time, industrial and commercial establishments could deposit highly hazardous wastes in municipal landfills; it is for that reason that many of the USA's Superfund sites are former municipal landfills. Wastes were classified, for the purposes of RCRA, as "hazardous" or "non-hazardous" using protocols prescribed by RCRA. As discussed by Jones-Lee and Lee (1993) owing to the manner of classification prescribed by RCRA, many materials classified as "non-hazardous" for the purposes of RCRA can significantly adversely affect the quality and usability of a water for domestic water supply purposes.

In their development of RCRA, the US Congress and the US EPA chose to focus waste management programs on those chemicals that are considered to be the most hazardous to man. Particular attention has been given to a group of contaminants that comprise what has become known as the list of "Priority Pollutants." The chemicals in that group were specified in accordance with requirements set forth in the 1972 amendments to the Clean Water Act; in that Act, the US Congress mandated that the US EPA develop a list of the most important chemicals that affect water quality and develop water quality criteria for those chemicals. Congress, however, did not provide the US EPA with the funding necessary to do that work. The delay in developing that list eventually led several environmental groups to file suit against the US EPA for failing to properly implement the Clean Water Act. The Priority Pollutants were named in the mid-1970's through a consent decree; representatives of several environmental groups and a limited number of US EPA Washington, D.C. staff, selected without proper peer review, a group of 129 chemicals of greatest concern in water.

At the time the Priority Pollutants list was developed, considerable attention was beginning to be given to potential carcinogens in drinking water and in the tissue of fish that are used as human food. The Delany Clause of the regulations governing carcinogens in food additives states that there shall be no synthetic carcinogens in food; the manner of determination of the carcinogenic character of a chemical is principally testing on rodents. Thus the chemicals on the list of Priority Pollutants are dominated by chemicals that then, and for that matter, today, are "rodent carcinogens," i.e., chemicals that can cause cancer in rats and other rodents at very high concentrations. Unfortunately, the emphasis on the Priority Pollutants, and especially the rodent carcinogens, has significantly distorted the US and other countries' approach towards water quality management. Rather than addressing those chemicals in water that impair uses of the water for domestic or other purposes, the regulatory programs at the US federal and state level have been focused to a considerable extent on the control of a few chemicals that have been found to cause tumors in rodents, but that have not been found, even today, almost 20 years later, to cause cancer in man at the concentrations to which society is typically exposed through consumption of water and eating fish.

There is widespread consensus among many professionals in the water pollution control field that the way the Priority Pollutant list was developed and the chemicals that are on that list has been significantly detrimental to water pollution control programs in the US and other countries. Rather than forcing the development of a list of chemicals through a court-ordered decree, as was done by the environmental groups that brought suit against the US EPA, they should have focused their efforts on working with the US EPA and Congress to provide the agency with the necessary funding to properly develop a list of Priority Pollutants.

The Priority Pollutant list has a very significant impact on the approach used today to manage municipal solid waste pollution of groundwaters at landfills. The US EPA's approach, in accordance with the requirements of RCRA, is to focus leachate-pollution evaluation and control efforts on Priority Pollutants for which drinking water standards (MCL's) have been developed. US EPA RCRA Subtitle D regulations prescribe consideration of those Priority Pollutants in the assessment of groundwater pollution by landfill leachate. Chemicals that may be hazardous or otherwise deleterious in drinking water, but that do not have MCL's, are not, in general, considered. Furthermore, Subtitle D allows the pollution of groundwater by chemicals that have MCL's as long as the MCL's is not exceeded. As discussed by Jones-Lee and Lee (1993), a groundwater polluted with MSW leachate can meet all drinking water standards for Priority Pollutants and yet not be suitable for domestic water supply use. The public is highly concerned about odorous waters, and waters that cause staining of their fixtures, corrosion of their plumbing, shortening of the useful lifetimes of dishwashers, water heaters, coffee makers, etc. Furthermore, MSW landfill leachate contains a wide variety of conventional and non-conventional pollutants that are not on the Priority Pollutant list that can readily cause a groundwater polluted by MSW leachate to be considered unusable for domestic water supply purposes.

Jones-Lee and Lee (1993) described the chemical contaminants in MSW leachate in three categories, conventional pollutants, Priority Pollutants, and non-conventional pollutants. As described elsewhere in this report, non-conventional pollutants are unidentified organic compounds whose presence in MSW landfill leachate is known by the difference between the total organic carbon content of leachate and the sum of the individual organic chemicals quantified in standard analytical programs. Since these chemicals are not identified, their impacts on public health are not known. There are approximately 60,000 chemicals in use in the United States today; fewer than 200 of these are regulated with respect to domestic water supply water quality. The unidentified and uncharacterized non-conventional pollutants are an important, although frequently overlooked group of chemicals in MSW landfill leachate. Since there are known to be unidentified, uncharacterized contaminants that could be of public health concern in MSW landfill leachate, it is prudent public health policy to assume that any contamination of a groundwater by municipal landfill leachate could represent a significant public health threat to those who use the contaminated groundwater as a domestic water supply source, even if the concentrations of measured constituents do not exceed any of their respective MCL's. No one can be certain that it is safe to consume water with any concentration of municipal landfill leachate in it.

The regulatory focus on the Priority Pollutants has caused regulatory agencies to largely ignore the non-conventional pollutants even though within that group could readily be the next dioxin, which is far more hazardous to man than any of the Priority Pollutants. So much attention is devoted to Priority Pollutant analysis, that little money is available for the urgently needed studies to determine the nature and significance of the non-conventional pollutants in municipal landfill leachate and other sources of pollution.

While the US EPA is to some extent precluded by RCRA from regulating the pollution of groundwater by the conventional and non-conventional contaminants in MSW leachate, the agency recognizes that the pollution of groundwaters by MSW leachate typically renders the groundwater unusable for domestic purposes. In its discussion of the proposed Subtitle D regulations (US EPA, 1988a) and in the discussion of the final regulations (US EPA, 1991) the agency acknowledged that once a groundwater is polluted by landfill leachate it will typically be necessary to abandon the well and construct a well at another location, where that pollution has not occurred. While this approach may be possible in some areas where there are large groundwater reserves that are not being used, it is not possible in other areas and it is certainly inappropriate to adopt an approach that allows for groundwater pollution by landfill leachate and wasteful of public funds in playing "musical wells" where, every time a well becomes polluted, a new well has to be constructed.

Duration of Landfill Leachate Production

The typical regulations governing municipal landfill closure require that the landfill owner/operator install a low-permeability cover when the landfill is full and provide funding for 30 years of post-closure care. However, as discussed by Lee and Jones-Lee (1992a), 30 years is an infinitesimally small part of the time during which post-closure care will have to be provided for "dry tomb" landfills of the type being developed today if there is to be any significant possibility of preventing massive groundwater pollution. As they discussed, the 30-year post-closure care period specified in Subtitle D regulations was based on a technically incorrect analysis of the period of time during which municipal solid wastes in a lined landfill would represent a threat to groundwater quality. It evolved out of the belief that gas production (fermentation of fermentable organics with production of landfill gas (carbon dioxide and methane) occurs for a period of about 30-years after a classical, unlined sanitary landfill has stopped receiving wastes. That estimate has essentially no relevance to the period of time during which today's municipal solid wastes deposited in lined "dry tomb" landfills undergo fermentation-gas production, or to the period of time during which leachate will be generated by such an MSW landfill.

The manner in which much garbage is now frequently packaged in the home - in plastic bags - greatly extends the period over which gas production can occur because of the inability of moisture that enters the classical sanitary landfill without a low permeability cover to come in contact with all of the garbage, thereby allowing gas production to proceed. The bacteria that produce landfill gas need moisture to carry out the process. As discussed by Lee and Jones-Lee (1992a; 1993b), a "dry tomb" landfill is developed in concept to minimize entrance of moisture into the landfill, at least for the first 30 years after closure; well-designed, constructed, and maintained covers, especially those that incorporate flexible membranes (plastic sheeting), can be effective in reducing entrance of moisture into a landfill as long as the landfill is above the watertable and the plastic sheeting has no holes in it through which moisture could pass. It is entirely possible that gas production that occurs in the landfill prior to closure will terminate or proceed at only a very low rate following closure due to the low moisture content of the waste; this stasis of gas production could continue for as long as the landfill cover is effectively maintained. Gas production will resume, however, when the owner/operator or individuals responsible for the maintenance of the cover fail to prevent the entrance of sufficient precipitation moisture into the landfill to provide the bacteria the moisture needed for their fermentation processes.

Another fundamental error made by the US EPA in its establishment of a 30-year post-closure care period was its assumption that once fermentation - gas production - ceases, the buried wastes are no longer a threat to groundwater quality. First, fermentation only acts on certain fermentable organics; not all organics are subject to fermentation; many hazardous and otherwise deleterious components in an MSW landfill (e.g., heavy metals, salts, and some organics) are not rendered innocuous by fermentation.

Second, the longterm impacts of a municipal solid waste landfill are not restricted to those associated with fermentation gas formation. The US EPA did not properly consider the chemistry of the processes that occur in lined MSW landfills that result in the leaching of chemicals that lead to groundwater pollution. Like fermentation, the generation of leachate also depends on moisture, but leachate is generated by a significantly different and separate set of chemical and biochemical reactions. While gas production in the classical sanitary landfill in which the wastes were not bagged in plastic, would take place from 20 to 50 years or so, the generation of leachate from such facilities is well-known to take place for hundreds to thousands of years. As discussed by Lee and Jones-Lee (1992a), the literature shows that landfills developed in the Roman Empire more than 2,000 years ago are still producing leachate. An analysis of the chemical processes that occur within a classical sanitary landfill shows that leachate generation should proceed for at least hundreds and more likely several thousand years or more. In a "dry tomb" landfill in which entrance of moisture is initially restricted, the potential for leachate generation remains. Once moisture is allowed to enter the wastes, whenever that occurs, leachate will be generated. The longer the engineered containment components maintain their conceptual integrity, the longer leachate generation will be postponed. Without question, the 30-year post-closure provision of the US EPA RCRA requirements is short-sighted and will not ensure protection of groundwater quality and resources for as long as the wastes in a lined "dry tomb" landfill represent a threat.

The incorporation of a 30-year post-closure care period in landfilling regulations reflects a lack of understanding or concern about longterm impacts of MSW landfills on groundwater quality. There is no question about the fact that a landfill cover will not function effectively for as long as the wastes represent a threat to prevent moisture from entering the landfill. There is also no question about the fact that the leachate collection removal system and the liner containment system under the landfill will not be effective in collecting all leachate that will be generated within the landfill. It is expected that some leachate leakage through the liner will start to occur shortly after the landfill is put in operation. Over time the liner properties will continue to deteriorate; the barrier to leachate transport to the underlying aquifer system provided in concept by the liner system will diminish with time.

Dr. Robert Ham at the University of Wisconsin has worked for many years on municipal landfill issues and recently stated (Ham, 1993),

> *"While modern landfills incorporate many improvements over previous facilities, the driving forces shaping landfill design now and in the future are unfortunately not based on sound technical and managerial principles and could lead to future problems. The trend to drier landfills, thereby prolonging decomposition, is of special concern in this regard."*

It is clear that a "dry tomb" MSW landfill will require maintenance and provisions for periodic cover replacement for as long as the wastes represent a threat, i.e., forever.

One of the most significant deficiencies in post-closure care is the failure to provide the necessary funds, *ad infinitum*, to address the contingency of ultimate groundwater pollution at the landfill. Lee and Jones-Lee (1992a) recommended that the post-closure care funding be developed from disposal fees from those who generate the waste and that these funds be secured in a dedicated trust fund that can only be used to address post-closure care needs of the landfill for as long as the wastes represent a threat. It is often asserted as part of landfill permitting that since a public agency is responsible for funding these contingencies, there is no need to develop a dedicated trust fund derived from disposal fees to ensure that funds will in fact be available when needed to address (i.e., stop and clean up) the groundwater pollution that will likely occur at every "dry-tomb" landfill. The authors strongly disagree. The tendency of public agencies to spend the necessary funds to clean up groundwater polluted by landfill leachate is limited, especially if the pollution affects the water supply of only a few rural residents.

We recommend that one of the best ways to judge whether a public agency will meet the needs of those who use groundwaters near a landfill that could be polluted by it is to examine how well the agency is addressing pollution by the landfills that are currently managed by it. If the landfill owner/operators and the regulatory agencies responsible for managing a particular landfill are not now spending the funds necessary to clean up existing groundwater pollution from landfills under their jurisdiction, there can be little reason to believe that that public agency or landfill owner/operators in the future will be any more willing and able to develop the funding necessary to prevent further groundwater pollution by the landfill once it is detected, and to spend the massive amount of funds that will be needed at many locations to attempt to clean up the contaminated groundwater and aquifer to the maximum extent possible. Clearly, the people who generate the waste that ultimately pollutes groundwaters in the vicinity of the landfill should be responsible for developing the funding needed to clean up the contaminated groundwater and aquifer. This can best be done by a dedicated trust fund of sufficient magnitude to ensure that funds will be available ad infinitum to maintain the landfill cover for as long as the landfill exists, and to eventually clean up the contaminated groundwater and aquifer when pollution occurs. The magnitude of funding should include the eventual exhumation (removal) of the wastes, treatment of the wastes, and the reburial of the non-recyclable treated residues that have been treated to a sufficient extent that they will no longer be a threat to groundwater resources.

Jones-Lee and Lee (1993) have discussed the impossibility of ever cleaning up of MSW landfill leachate contaminated groundwaters once leachate pollution occurs. Some landfill applicants, as part of obtaining a permit to construct a new or expanded landfill, acknowledge that the landfill liner system will ultimately fail, but they claim that such failure is not of major significance since the groundwater monitoring system used will detect the failure and the polluted groundwaters can be cleaned up. As discussed above, the groundwater monitoring systems that are used to monitor lined landfills have a low probability of detecting incipient leachate-contamination of groundwater before widespread pollution occurs. Further, it is now well-known that an aquifer that has been polluted by MSW leachate cannot be cleaned up to the point at which it could be considered to be reliable for domestic water supply purposes.

Summary

Those who own and use lands near an existing or proposed MSW landfill have ample justification for vigorously opposing the siting or expansion of a landfill in their area based on the fact that today's so-called "high-tech," "modern" lined landfills of the "dry-tomb" type at best only postpone groundwater pollution; they will not in general prevent it. The liner systems used today will obviously not prevent leachate migration through them for as long as the MSW components represent a threat to groundwater quality. Today's groundwater monitoring systems have little ability to detect liner leakage before widespread pollution of groundwaters occur. The 30-year post-closure care period for which funds are typically provided is an infinitesimally small part of the total period during which post-closure care funding will be needed. Further, once a groundwater aquifer system is polluted with MSW leachate, there is little or no possibility of ever cleaning up the aquifer so that it can be again considered safe for domestic water supply use.

Alternative Landfilling Approaches

Increasing attention is being given to alternative approaches for landfilling of municipal solid waste, such as the fermentation/leaching wet-cell approach discussed by Lee and Jones-Lee (1993d). The concept of this approach is to create conditions conducive to the rapid fermentation of fermentable organics in the landfill and then to actively leach out the leachable components that could otherwise pollute groundwater in perpetuity. During the initial period after landfill closure (nominally about 5 years) landfill leachate would be recycled through the landfill to accelerate the fermentation of the anaerobically biodegradable organic wastes and thereby produce methane to the maximum extent possible in a short period of time. Then, clean water would be passed through the landfill to leach those components from the waste that represent a significant threat to groundwater pollution. It is anticipated that the leaching period will be on the order of 10 to 20 years. Once leaching is completed, further contact of the waste residuals with water would result in a leachate that would represent little threat to groundwater quality. The unit in which this process would be conducted would be a double-composite-lined system which could include a reverse groundwater gradient liner system that has a high degree of reliability for preventing groundwater pollution for 50 or so years of operation/treatment.

As discussed by Lee and Jones-Lee (1993d), the fermentation/leaching wet-cell approach provides a low-cost method of MSW management that can, if operated properly, eliminate the longterm problems of "dry tomb" landfills of inevitable groundwater pollution by landfill leachate. The cost of construction of such a "wet-cell" would be about the same as those for a double-composite-lined "dry tomb" landfill system. The fermentation/leaching approach would require near-term expenditures for treatment of the leachate collected in the leachate collection and removal system during the leaching period, which can, in some locations, cost on the order of cents/gallon. The perpetual costs for cover maintenance and those associated with groundwater pollution and lost groundwater resources would be largely eliminated. A key difference in the economics of the fermentation/leaching wet-cell approach compared with today's "dry tomb" landfilling, would be that those who contribute waste to the wet-cell landfill would be paying the costs for leachate treatment; with the "dry tomb" approach, the far more expensive cost of trying to clean up leachate-contaminated groundwater would have to be borne by future generations unless a dedicated trust fund, derived from disposal fees, were set aside during the active life of the landfill to meet the contingency of groundwater pollution that will likely occur in a "dry tomb" landfill.

Leachate Treatment and Disposal

One of the areas of particular concern about the landfilling of municipal solid wastes with either the "dry-tomb" or "fermentation/leaching wet-cell" approach is the management of the leachate that is generated in the landfill. The same issue arises for above-ground landfills. With both "dry-tomb" and "fermentation/leaching wet-cell" landfills, a leachate collection and removal system is constructed to collect leachate in a sump and transfer it to a holding tank. It is then treated on-site or taken to a treatment facility via truck or pipeline. Because of the presence of high concentrations of a wide variety of conventional, non-conventional, and hazardous chemicals in MSW leachate, and the potential for many of those contaminants to cause adverse impacts at very low concentrations, the treatment of MSW landfill leachate can be very expensive. Treatment costs in some areas can run up to tens of cents/gallon and can be several hundred times the cost of typical domestic wastewater treatment. It is possible, however, to dispose of MSW landfill leachate at very low cost through blending with municipal waste waters at a publicly-owned treatment works (POTW). Many POTW's can take up to about 5% by volume MSW leachate without experiencing significant adverse effects on the operations of the plant or on the characteristics of the wastewaters discharged from the plant for the commonly considered wastewater effluent characteristics. However, with increasing regulatory attention to POTW effluent characteristics, especially potentially toxic chemicals and, in some locations, total salts, POTW owner/operators are becoming increasingly reluctant to accept MSW landfill leachate.

Lee et al. (1985; 1986) conducted a comprehensive review of MSW leachate management. They concluded that on-site leachate management will typically require a combination of anaerobic PACT (powdered activated carbon treatment) and aerobic PACT biological treatment followed by chemical treatment, including chemical precipitation, activated carbon columns and, at some locations, reverse osmosis. Buehler and Berrigan (1990) and Copa (1992) described an MSW treatment process system which includes many of the components that Lee et al. concluded would have to be used to properly treat MSW leachate. While such treatment approaches have not typically been used in the past for MSW leachate, they will become common practice in the future, except for those locations where large POTW's are willing to accept and can treat and dilute the leachate components to levels below those which could cause adverse impacts.

There is a significant difference between the impact of MSW landfill leachate on groundwater quality and on surface water quality. In groundwater systems, there is the potential for significant attenuation of some of the components of leachate, especially heavy metals and higher molecular weight organics by the aquifer solids. Typically the greatest concern about leachate-derived contaminants in groundwater is for the low molecular weight solvents and their transformation products, as well as some of the common salts, which are readily transported in many groundwater systems. In surface waters, however, the low molecular weight solvents typically present in MSW leachate are usually rapidly lost to volatilization in the treatment works or in the waters receiving the wastewater effluent. The high levels of salts in MSW landfill leachate are typically diluted in the treatment works or in the receiving waters for the effluent. However, the heavy metals and higher molecular weight organics that are present in MSW landfill leachate are of concern in surface waters because a number of them are highly toxic to aquatic life and/or bioaccumulate within aquatic organism tissue, rendering the organisms unsuitable for human food and a hazardous to higher trophic-level organisms that use fish and other aquatic life as food. Of particular concern are the fish-eating birds. It is now well-documented that fish-eating bird populations have been significantly adversely impacted by contaminants present in industrial and municipal waste waters that are discharged to surface waters. Since many of those contaminants would be present in MSW landfill leachate, the inadequate treatment of leachate could result in significant water quality problems for man, aquatic life, fish-eating birds, etc.

There can be little doubt that the cost of MSW landfill leachate management will be increasing significantly over what has been typically paid in the past. It is clear that, as part of developing an MSW management plan for an area, careful consideration must be given to leachate management to be certain that the approaches adopted will be protective of public health and the environment and that adequate funds are made available to properly treat the leachate before release to surface waters.

Re-Use of Landfill Space

The authors have repeatedly observed landfill proponents claim in the permitting of a proposed landfill that once the landfill is closed, the landfill area will be converted into a public park, botanical garden, golf course, etc. Such claims are often made to try to convince the public that does not reside or use property near the landfill that the adverse impacts of the landfill during its "few" years of active life will be more than compensated for by the highly desirable character of the area once the landfill is closed. However, those familiar with the characteristics of landfill covers for "dry tomb" type landfills that must be maintained after the landfill is closed, know that there is no possibility of developing botanical gardens, golf courses, or other activities on the areas of the landfills where wastes have been deposited due to the fact that such activities would significantly increase the potential for moisture to enter the landfill through the cover and thereby generate leachate that can lead to groundwater pollution.

While there are numerous examples of classical sanitary landfills that have been converted to useful areas such as parks, airports, and shopping centers once the landfill has been closed, the US EPA's adoption of the "dry tomb" landfilling approach in which the waste must be isolated from moisture in perpetuity, requires that a significantly different approach be used in development of the area of the landfill after it is closed than was possible for the classical sanitary landfill. The development of golf courses, botanical gardens, etc. associated with classical sanitary landfill areas was and continues to be done at the expense of continued groundwater pollution. There can be no doubt that the areas above "dry tomb" landfills of the type being developed today (i.e., covered by low-permeability covers), will have to be meticulously managed forever if the cover is to function effectively to minimize the amount of moisture that enters the landfill. While it is sometimes said that the area of the landfill cover can be used for cattle and other domestic animal grazing, even that use is questionable since large domestic animals' use of an area could readily impair the ability of the cover to impede the entrance of moisture into the landfill.

There is no possibility that trees, shrubbery, water features, etc. associated with botanical gardens, golf courses, etc. can be constructed on the cover of a "dry tomb" landfill and maintain the integrity of the cover. In fact, there are some professionals who recommend that rather than covering a "dry tomb" MSW landfill with topsoil and planting grass as is typically envisioned today to reduce the potential for erosion of the low-permeability layer within the cover, the landfill be covered with a rock armor where the rocks on the surface of the landfill would be boulders of sufficient size so that they could effectively prevent erosion of the low-permeability layer within the cover.

It can be concluded that there will be little likelihood that the areas of the landfill beneath which wastes have been previously deposited will be anything other than grass in a wet climate, or anything other than dry grass in a dry climate during the periods between major precipitation events. While those areas will not necessarily be aesthetically displeasing, they will certainly stand out from the rest of the area and generally be considered to be detrimental to the viewshed for those who own or use properties near the landfill.

The redevelopment of the land area above a fermentation leaching wet-cell landfill could be somewhat different than that from a "dry tomb" landfill. While as discussed above, great care has to be taken to maintain the low-permeability cover of a "dry tomb" landfill *ad infinitum*, there would be no need to install a low-permeability cover on a fermentation/leaching wet-cell landfill. There would also be no need to maintain in perpetuity the gas collection system in such a "wet-cell" landfill, since all of the fermentable organics would have been converted to methane during the fermentation step of treatment. It would still not be advisable to plant certain deep-rooted shrubbery and trees on a "wet-cell" landfill cover, since the roots could penetrate into the waste and mobilize hazardous components that were not leached during the leaching period. Therefore, while the "wet-cell" landfill area could be made somewhat more attractive after closure, it would still likely be considered to be impaired from a visual perspective compared to the view that landfill owner/users had prior to the construction of the landfill.

Viewshed Impairment

Many people purchase rural lands because of the view that they can enjoy. Most people consider the view of a several tens to hundreds of feet high garbage mountain as offensive, often less enjoyable than the view that was present before the landfill was constructed. While, as discussed above, closed landfills are often portrayed as aesthetically pleasing areas, the fact is that in most instances, the construction of a landfill in an area significantly adversely affects the viewshed of properties at considerable distances from the landfill, in perpetuity. The distance of impact can readily extend for more than several kilometers. There is little that can be done to mitigate the damaged viewshed that occurs when a landfill is constructed in a rural area other than to increase the buffer lands around the landfill that are needed to decrease the impacts of odors and other impacts of the landfill during its active life.

Lee and Jones-Lee (1993e) discussed approaches for addressing NIMBY concerns associated with MSW landfills. They concluded that property owners should be compensated for impacts that cannot be mitigated within the zone of impact, such as decreased quality of the view that adversely affect the property value. As they indicated, if the public health, environment, groundwater resource and air quality of those affected by a landfill were properly protected *ad infinitum* from the potential adverse effects of the landfill, and if every property owner/user were financially compensated for the impacts of the landfill that cannot be mitigated, then the significant problems that exist today in siting new landfills could be largely overcome. These provisions would have to be outlined at the time of landfill siting and planning.

There are situations associated with intangible values of property, such as a long-standing familial tie to the property through several generations, that cannot be mitigated through financial compensation. However, it is felt that most members of the public would accept landfills in their area if their public health interests were truly protected, if other controllable adverse impacts were truly controlled, and if they received substantial financial compensation for the truly non-controllable aspects, such as viewshed, truck traffic, etc. Lee and Jones-Lee suggested that those who generate solid wastes from suburban and urban areas should pay a sufficient additional garbage fee that could be paid to the rural area resident as financial compensation for the decreased value of the resources available to them, then the opposition to landfills would significantly decrease. They suggest that the proper controls noted above, plus a payment in the order of $1,000 to $5,000 per home per year would change "NIMBY" to "GIVE ME." Such financial compensation to rural dwellers in the zone of impact of landfills would represent a very small increase in the garbage fees paid by the principal generators of the waste (urban dwellers). For the typical rural landfill setting and urban areas, the cost to the urban dweller would be on the order of less than one to several cents/day. If everyone who contributed garbage to the landfill also contributed a cent or two per day per person to a fund to compensate those in the zone of impact of a landfill, and if the health and welfare of those in the zone of impact were truly protected ad infinitum, as can be readily done with increased disposal fees, it would be possible to eliminate many of the landfill siting problems that exist today.

One of the major obstacles to siting landfills associated with financial compensation for decreased property values is the issue of assessing the "fair market value" of the property. It is well-known that the market value of property is only established by determining what someone will, in fact, pay for the property. Attempts to develop fair market value before sale are often highly speculative and subjective. Landfill owner/operators will typically find appraisers who will determine that the market value of a property potentially impacted by a landfill is less than that which would be determined by appraisers who represent the property owner. This situation usually leads to confrontation, which significantly impairs the ability to site a landfill in an area. It is suggested that rather than trying to pay the least possible compensation for impacted property values, etc., landfill owners should hire an independent group of appraisers to develop a consensus on the value of the properties without the presence of the landfill and pay the property owners two to three times the consensus un-impacted value of the property. This additional financial remuneration would contribute to compensation for the property owners' anxiety, time spent in addressing the impacts of the landfill, and lost appreciation of the property that could have been enjoyed had the landfill not been located in their area. Adopting this approach for financial remuneration for decreased property values would likely change the attitude of those in the potential zone of impact
from one of vigorously opposing the landfill to one where they would willingly cooperate with the development of the landfill.

Decreased Property Values

It is obvious that the construction of a landfill in an area can and usually does significantly decrease the value of the properties near the landfill. While landfill owners and proponents frequently claim as part of permitting of new or expanded landfills that there is no evidence for decreased property values near landfills, such claims are without significant technical merit. All that needs to be done to understand the validity of such claims is to ask oneself or the members of the public whether they would be interested in purchasing properties near an existing or proposed landfill at the same price as they would pay if the landfill were not present or proposed for the area. There are few members of the public who would consider purchasing properties near landfills if the cost of the land were not depressed because of the landfill.

Typically, in a landfill siting dispute between proponents and opponents, each side will have one or more studies done on property values that claim to support the position of those who commissioned the study. Hirshfeld et al. (1992) have conducted one of the few definitive independent studies of the impact of landfills on nearby properties. In a paper entitled, "*Assessing the True Cost of Landfills*" they reported that the siting of a landfill in an area significantly decreases property values within two to four kilometers (one to two miles) of the landfill. In some areas, decreased property values were found up to about eight kilometers from the landfill.

It is important to understand also, that property values are determined not only by real adverse impacts on property uses caused, for example, by landfills (which are usually felt within a couple of kilometers of a landfill), but also by the perceived impacts of landfills derived from the public's impressions of the classical garbage dump and the accounts that they read or hear of opposition to landfills in the popular press. In general, the public justifiably perceives landfills as poor neighbors. This can readily, and does, depreciate property values at distances beyond those at which there are any real impacts of the landfill operations. Whatever the proportionate real and perceived impacts of landfills on nearby properties, it is clear that the landfill causes depressed market values.

Hirshfeld et al. stated,

> *"Although landfilling is a well established waste disposal method, many municipalities (and other landfill owners) significantly underestimate their landfill costs. This is primarily a result of failure to place reasonable costs on the physical and social impacts associated with landfills.*
>
> * * *
>
> *Losses in property values typically are borne unfairly by residents living close to new landfills. In fact, public opposition to the siting of new landfills is due largely to anticipated losses in property values."*

There can be little doubt that siting a landfill in an area can and usually does significantly depress the economic value of lands within several kilometers (a mile or more) of the landfill.

There are landfill applicants, and proponent members of the public who assert that adjacent lands, not owned by the landfill owner, can serve as land buffer around the landfill. Basically that approach condemns future property owners' uses and is effectively a taking of property without appropriate compensation. Attitudes such as these are major contributors to the solid waste management crises that exist in the US and other countries. It is readily possible today, at a relatively small increase in cost to those who generate most of the waste in urban areas, to fund landfill operations and landfill isolation through landfill owner-owned buffer lands so as to develop landfills today that are good neighbors.

When assessing the impact of a landfill on nearby property uses and property values, it is important to distinguish between the impacts during the active life of the landfill, when wastes are being received, and the post-closure period, after the landfill is closed and no further wastes are deposited in the landfill. As discussed in this report, the impact problems of the landfill during these two periods are likely to be significantly different. The large land buffer needed to dissipate the impacts from conventional landfill operations during the active life such as litter, truck traffic, odor, seagulls, etc., can be significantly reduced once the landfill is closed.

The adverse impacts of landfills after closure are largely related to the potential for gas migration and groundwater pollution. A kilometer (about half a mile) of buffer land would not likely be needed during the post-closure period, since it would be indeed rare that gas migration and especially groundwater pollution would adversely impact surface land uses after the landfill is closed. This is not to say that groundwater pollution cannot extend beyond a kilometer from the former active area of a landfill. With typical groundwater velocities on the order of a few centimeters to tens of centimeters per day or so, it will be only about 15 years from after significant liner failure that groundwaters more than a kilometer from the landfill have been polluted by landfill leachate, rendering them unsuitable for domestic uses. This could be significantly detrimental for property owners who depend on groundwater for their domestic supply.

While in most locations it is possible to provide a domestic water supply from other areas through piping of the water over considerable distances, the costs of such a water supply are typically much higher than those that are normally paid by urban dwellers. In a number of instances, the authors have observed that those in rural areas, whose waters are polluted by landfill leachate and have been provided with extensions of the municipal supply, are expected to pay a very high cost of this water compared to the cost that they had been paying for their water supply from their local aquifer prior to the time that it became polluted by landfill leachate. The reason that it was polluted, in most instances, was that those who generate the garbage in urban areas have paid significantly less for their garbage disposal than what they should have if disposal had taken place in such a manner that would protect groundwater quality under adjacent and nearby properties to the landfill.

It is readily possible to address the decreased property values through acquisition of adequate land buffer between the landfill and adjacent properties so that the decreased property values that occur during the active life of the landfill are borne by the landfill owner and not by the public who owns the lands near the landfill. It seems reasonable that the public who ultimately caused the groundwater pollution of the rural residents' water supply should have to pay the cost of providing them with an alternate water supply above the cost that the rural dweller would have spent to continue to use their local water supply.

Because of the decreased buffer lands needed during the post-closure period compared to the active life, it may be possible for the landfill owner to sell lands nearer the landfill once the landfill has closed and thereby recover some of the costs associated with maintenance of an adequate land buffer during the landfill's active life. Although, as discussed below, the adverse impacts of the closed landfill on the view may result in permanently depressed property values.

COMPOSTING

Composting is an aerobic process by which bacteria, in the presence of oxygen, convert readily oxidizable components in organic matter into CO_2 and a stable organic residue (compost). Compost can be a good soil conditioner, improving soil properties and to some extent enriching the nutrient content of the soil, to enhance plant production. Composting of municipal solid waste has been used for many years as an alternative to landfilling of some components of the wastes, especially the vegetable wastes and yard ("green") waste. This is typically done by placing the organic material in windrows in an open area, and occasionally stirring the windrows to introduce oxygen into the materials. There are several reasons that composting has not been used more extensively for MSW management. One of the more important reasons is that composting as it has been practiced tends to be highly odoriferous. Composting of even seemingly innocuous materials such as leaves can be highly odorous. In addition to odors, there is also concern about mold spores present in compost which are alleged to be adverse to the health of some individuals. Where such composting has been done without adequate buffer lands, the neighbors are adversely affected by it, sometimes filing sufficient complaints to cause the composting operation to have to be ceased. A notable example of a composting operation that has been recently ceased is the city of Portland, OR where the issue of odor control was one of the major reasons for termination of the MSW composting operations.

Another major reason that composting has not been used more extensively for municipal solid waste management is the disposition of the compost. In a number of areas where composting has been attempted, the demand for the compost - even when given away - is less than that which is readily produced. There are examples of where a municipal waste composting operation was terminated because of a lack of demand for the compost, including in Davis, CA. There, the compost ultimately had to be disposed of in landfill.

Increasing concern is being voiced about the quality of compost for use, particularly the impact of components of the compost on soil and water quality. Of particular significance in this regard are heavy metals in compost. In recent years there have been a number of discussions about the appropriateness of trying to compost what are called "municipal mixed wastes" because of the heavy metals in the waste. "Municipal mixed wastes" are the whole of the municipal solid wastes without significant segregation of its major components. Hammer (1991) has discussed the problems of mixed waste vs. green (yard) waste composting. Yard waste tends to have much lower heavy metal content and therefore produces a much "cleaner" compost. Some areas, such as Ontario, have established maximum contaminant levels in compost (Gies, 1992). Recently, Composting Frontiers (1993) have published a compilation of the contaminant levels allowed in MSW composts by various political jurisdictions in the US and some other countries. A review of this compilation shows that there is great variability in the currently allowed concentrations of heavy metals and some other constituents in compost. For example, lead is restricted in some compost to no more than 65 mg/kg dry weight, yet other political jurisdictions allow up to a 1000 mg/kg lead in compost. It is the authors experience that compost will come under increasing regulatory scrutiny where the concentrations of allowable heavy metals and other potentially hazardous chemicals will be decreased significantly from the higher values listed by Composting Frontiers.

There are some who attempt to use various types of leaching tests, such as the US EPA TCLP, that are designed for hazardous waste characterization as a method of determining the pollutional characteristics of MSW compost. As discussed by Lee and Jones (1981), the EP Tox Test or TCLP test developed by the US EPA for limiting the size of the hazardous waste stream that must be managed as hazardous waste in the US, is not a valid test for determining whether a material like compost would represent a threat to public health and the environment when spread or worked into the soil. TCLP allows the leaching of heavy metals such as lead up to a hundred times the drinking water standard and still have the material classified as "non-hazardous." Obviously, soils to which compost has been added that leach lead well above the drinking water standards, but below the hazardous waste classification approach used by the US EPA, could be highly hazardous to children who would play in the soils yet not be a hazardous waste by US EPA definition.

Contaminants in compost can be hazardous through soil ingestion or through ingestion of plant material that has been grown in the soil. Lead in compost is of particular concern. Lead is a common contaminant of soils owing to its former use as an additive in gasoline. Therefore, care must be exercised to be sure the yard wastes do not contain lead at concentrations that are considered potentially adverse to children's health in the areas where the compost is applied. Lee and Jones-Lee (1992b) reviewed recent changes in the perception of the significance of lead in soils as it may affect public health. Some regulatory agencies are establishing soil lead limitations of 50 to 100 mg/kg to protect children from excessive exposure. These concentrations are below acceptable compost levels of lead such as many of those listed by Composting Frontiers (1993) and therefore, could be hazardous to children who would come in contact with soils to which compost has been added.

In addition to the concern about heavy metals in compost, increasing attention is being given to anthropogenic organics, such as herbicides and pesticides, that are present in composted yard waste. Gintautas et al. (1992) discussed the finding in municipal landfill leachate of a common herbicide, that is not routinely measured in municipal landfill-associated contaminant monitoring programs. Those authors stated,

> *"We conclude that the chlorinated 2-phenoxypropionic herbicides, particularly Mecoprop, are ubiquitous in municipal landfill leachates from the United States. These compounds may have been undetected or unidentified in previous studies due to analytical limitations."*
>
> *"Our studies suggest that the degradation of (chlorophenoxy)propionic acids in landfill leachates is sufficiently slow that transport into groundwater is possible."*

The finding of this oxyherbicide in municipal solid waste leachate by Gintautas et al. is of potential concern since it appears to be derived from yard waste deposited in landfills. This material will also likely be present in compost.

Another chemical that is going to receive greater attention in the future is arsenic. With increasing attention being given to the significance of arsenic as a carcinogen, and the potential lowering of the allowable concentrations of arsenic in drinking water through the US Environmental Protection Agency's current review of drinking water standards for arsenic, it is likely that arsenic levels considered safe in soil will be decreased significantly to around 20 mg/kg. There are many soils that contain arsenic in concentrations at or above that level. Further, arsenic has been used as a herbicide in some lawn weed control formulations. Care will have to be exercised to be certain that the compost developed from composting of yard wastes does not contain sufficient concentrations of arsenic to cause it to be considered hazardous to those who have contact with the soil.

As discussed elsewhere in this report, MSW contains many organic chemicals whose specific identity and potential public health impacts remain unknown; these are referred to as "non-conventional pollutants" (Jones-Lee and Lee, 1993). Their presence is known by the large proportion of the "total organic carbon" concentrations that is not accounted for in the individual organic chemicals that are determined in routine analyses. Compost would be expected to also contain some of these chemicals. Use of compost could introduce those chemicals and their potential hazards to off-site locations.

Yard waste compost is often rich in nitrogen compounds which can lead to nitrate pollution of ground waters in the areas where the compost is used. As discussed by Maynard (1993), care must be exercised in the application of compost to prevent groundwater pollution by nitrate that is derived from nitrogen in the compost.

The increase in backyard composting as part of implementing the 3 R's by homeowners and renters is a potential source of problems, especially in those areas where food wastes are added to the compost pile. Such practices can increase the rodent population in the area to the point where they can become a nuisance and a potential public health hazard as vectors of disease. This area is receiving increased attention in several areas of the US where a number of human deaths have occurred that are attributable to the hantavirus that is carried by rodents. Further, backyard compost piles can be a source of odor. It is likely that restrictions on backyard composting will be developed in some areas in order to better control vermin and odor problems.

Composting can be used to manage about 20 to 25% of the MSW from residential areas. From the information available, it should not be used for mixed wastes but should be restricted to clean yard waste. If large amounts of land are available, and especially if adequate buffer lands are available which are owned by the composting operation between the operation and adjacent properties where dilution of odors can take place, composting can be done relatively inexpensively in areas where a market can be developed for the compost. This market does not necessarily result in an income for the composting operation; it may be necessary to make the compost available at no cost in order to enhance its use.

SOLID WASTE TREATMENT AS A LIQUID WASTE

Consideration is being given to a variety of approaches for MSW treatment to remove components of the waste that are hazardous or otherwise deleterious to public health and welfare, and groundwater and environmental quality. As discussed above, incineration is a waste treatment process that can, if properly sited and operated, be an effective method of reducing the potential environmental problems associated with landfilling of MSW. The fermentation/leaching wet cell approach described above is a method of waste treatment, as is the aerobic composting of yard waste. It also would be possible, through waste stream source separation, to treat some of the components of municipal solid waste using procedures similar to those that are conventionally used in municipal and industrial waste water treatment. The readily soluble components of MSW are amenable to treatment by physical, biological, and chemical treatment processes of the type that are frequently used today for domestic and industrial waste waters. The solid organic components of MSW could be treated in much the same way as municipal and industrial waste water solids by anaerobic fermentation. The liquids that result from such treatment can be treated by processes that are conventionally used for municipal and industrial waste waters.

The reason that these approaches have not been explored to a significant extent is that they are more costly than simply depositing the raw solid wastes in a landfill. While each person generates about a ton of MSW per year, they generate about 250,000 tons of waste water per year. Those waste waters are treated to a considerable degree, by conventional technology, at a cost of a few cents/person/day. That treatment, however, does not necessarily remove all of the components of MSW that are of particular concern in groundwater pollution, such as the total salts. Typically, total salts in waste waters are managed by dilution of the waste water effluent with low-salt receiving waters or, for some, by discharge into marine waters. Increasing attention is being given, however, to the total salt load to waterbodies, since the ability to dilute below potentially significant levels has been, and continues to be, utilized to the maximum extent possible without adverse impacts to the receiving water quality. It therefore appears that there is little likelihood that conventional wastewater treatment technology will be used for MSW treatment. This technology will not likely produce a liquid or solid residue that is not significantly adverse to the environment and, for some components, public health.

Also of concern is the fact that domestic wastewater treatment facilities are notorious for being poor neighbors owing to some of the same types of problems as those faced by property owners and users in the vicinity of an MSW landfill. Domestic wastewater treatment works frequently have significant odor problems, especially associated with sludge management. A close analogy to the treatment of municipal solid wastes by conventional municipal wastewater treatment processes is found with the treatment of food processing wastes, such as cannery wastes of various types of fruits and vegetables. While cannery wastes typically contain large amounts of solids relative to a small volume of liquid, they are treated by conventional wastewater treatment processes. However, there are frequently problems associated with such treatment including severe odor problems, treatment and disposal of the liquid fraction, and management of the treated residues (sludge).

Therefore, not only could wastewater treatment facilities that employ conventional wastewater treatment processes likely be more expensive than storage and/or treatment of the waste such as by fermentation/leaching "wet-cell" approaches in landfills, but also they can cause significant problems associated with the treatment operations that have to be considered in the evaluation of the use of such approaches in developing a municipal solid waste management program for a region.

ABOVE-GROUND MSW LANDFILLING

Above-ground landfilling has been discussed in the literature for a number of years (see Environmental Institute for Waste Management Studies, 1989; Brown, 1983; Brown and Anderson, 1983; Brown and Nelson, 1993). Brown and Nelson (1993) indicated that ideally only treated, biologically stabilized residues of MSW would be placed in the above-ground storage facilities. Since those waste materials represent only on the order of 15 to 20% of the total volume of municipal solid wastes, they argued that such facilities could be substantially smaller than conventional landfills.

Brown and Nelson's proposed approach for the above-ground landfill cover is similar to that used for below-ground landfills. That would incorporate a waterproof cap that would include a plastic sheeting "liner;" above the liner would be a gravel drain and a layer of soil to support vegetation. They indicated that if raw, untreated wastes were placed into the above-ground storage unit, it would be desirable to stabilize the wastes prior to placement of the cap, stabilization that could be accomplished through the addition of water to the wastes in much the same approach as the "fermentation/leaching wet-cell" approach described elsewhere in this report. They expected that in 3 to 5 years after addition of moisture, the permanent cap could be used to cover the stored wastes.

Brown and Nelson stated that above-ground waste storage units have been constructed in Alabama, New Jersey, and Wisconsin and that, by some estimates, construction costs of above-ground storage of wastes are about the same as those for below-ground storage. Brown and Nelson listed a number of advantages of above-ground landfills, including,

- leachate can be removed by gravitational drainage;
- once a unit is closed, the primary leachate collection system serves as a leak detection system as well as a leachate removal system;
- since the unit is above ground, methane released from the unit would be collected and/or dissipated to the air;
- through the use of separate cells for various types of waste, it could be possible to segregate waste types into cells that could facilitate recovery at some time in the future;
- the cost of future remedial action in the above-ground landfill would be small compared to that which will be encountered with below-ground landfills; and
- site selection for above-ground landfills is much less dependent on the geology, hydrogeology, soil, and climate of the region than that for conventional below-ground landfills.

One of the principal reasons for considering the above-ground storage of MSW is that failures of the containment system can be more readily detected. Leachate generated in an in-ground landfill that passes through the liner containment system is not readily detected by the monitoring approaches used today for single-composite-lined landfills. In contrast, leakage from a single-composite-lined, above-ground landfill can be readily detected and, as discussed by Brown and Nelson (1993), readily collected and treated.

It may be anticipated that wastes deposited in an above-ground storage facility would have been pre-treated to "stabilize" them. The issue of treatment of the wastes before placement in an above-ground landfill is one that needs to be specifically addressed in detail. There could be significant potential adverse environmental impacts at the point at which the waste treatment takes place, including many of those impacts of concern to the people who own or use properties near any other solid waste treatment facility. It is also questionable whether the wastes would be sufficiently pre-treated so as to remove all components that could threaten public health or environmental/groundwater quality at any time in the future. If the wastes were so sufficiently treated, they could be stored as safely in an in-ground facility as in an above-ground facility, without the added visual impairments. Therefore, like the situation for in-ground landfills, the key to long-term environmental protection from MSW components in an above-ground landfill is the ability to provide appropriate maintenance for the above-ground landfill's containment system for as long as the wastes remain in the facility. Above-ground landfills would most likely be considered when there is a desire to put an MSW landfill in an area that has groundwater resources that are particularly vulnerable to MSW leachate-pollution. Therefore, *ad infinitum* maintenance and monitoring of an above-ground storage facility must be considered essential.

While some of the groundwater quality protection concerns can be alleviated by above-ground landfills, operation of above-ground facilities can result in many of the other problems discussed in this report associated with landfills whose bases are below the surface of the ground. Truck traffic, noise, odors, damaged viewshed, other degradation of aesthetics, above-head seagulls, decreased property value, vermin, etc. are all problems that can occur with above-ground landfills during their active lifetimes.

One of the advantages that Brown and Nelson discussed for above-ground landfills is that they could be used to segregate wastes into compartments that would facilitate recovery of certain types of waste components at some time in the future when such recovery becomes economically feasible. The same approach could be used for in-ground landfills.

Overall, while above-ground landfills offer the potential for more reliable storage of MSW residues than below-ground landfills from the perspective of nearterm management of both leachate and landfill gas, their use as part of a waste management program for a region must be carefully evaluated to ensure that the significant potential adverse impacts are properly evaluated and addressed/mitigated in the siting, construction, operation, closure, and post-closure care of the facility.

ENVIRONMENTAL IMPACT OF THE 3 R'S

The development of a solid waste management approach in a region requires that consideration be given to the impacts of waste reduction, recycling, and reuse (the "3 R's"). While it is generally accepted today that reduction in municipal waste streams can be effected through the 3 R's, the magnitude of that reduction is still somewhat uncertain. Steuteville and Goldstein (1993) recently presented the results of a nationwide survey conducted in the USA on the approaches used in various regions for managing MSW and the extent of recycling and composting that is being practiced. They reported that in the southern, midwestern, western, and Great Lakes states, about 70 to 80% of MSW is landfilled, while in New England only about 35% is landfilled. Incineration is used for about 1 to 3% for solid waste management in the midwestern and western states, 11 to 12% in the southern and Great Lakes states, and 41% in the New England states. Solid waste recycling ranges from about 4% in some US states to about 35% in New Jersey, Minnesota, and the state of Washington. The US national average for recycling was 17% in 1992, up from about 9% in 1989. The national average incineration rate has increased from about 9% in 1989 to about 11% in 1992, while landfilling of MSW has decreased from about 80% in 1989 to 72% in 1992. Recycling of MSW is a major cause of the reduction in the landfilling rate in the USA over the past few years.

It has become apparent that at least a 25% diversion can readily be accomplished through recycling and reuse of newspaper, aluminum and steel cans, and glass bottles. In suburban areas, the typical MSW waste stream can be reduced by another 25 to 35% by diverting yard (green) waste from landfills for aerobic or anaerobic composting. Additional MSW waste stream diversions can be accomplished through recycling and reuse of commercial and industrial paper and other products, and through reuse of considerable parts of the construction waste and demolition debris associated with the development and redevelopment of properties. It therefore appears that conventional MSW waste streams can be reduced on the order of 50% today. This means that landfills of half the size/intensity of operation can be constructed and still provide for longterm solid waste management capacity for an area.

At this time, only two of the 3 R's (i.e., recycling and reuse) are being effectively implemented. Waste stream reduction is still in its infancy. While some efforts are being made to change packaging to reduce the amount of solid waste that must be managed, it will likely be a number of years before such efforts have a significant impact on the magnitude of the waste stream that must be managed by landfilling or other approaches. When significant waste stream reduction occurs due to repackaging will likely be controlled by when effective legislation mandating efficient minimum packaging is adopted and implemented.

There are some who suggest that through aggressive pursuit of the 3 R's it would be possible to reduce the municipal solid waste stream by 90% or so. In our opinion, it is highly unlikely that that degree of reduction can be achieved in the next 10 to 15 years, although it may be possible to achieve a 75% reduction if very aggressive 3 R's programs are instituted, including significant reduction in the packaging of materials.

Significant problems are beginning to surface with the cost-effective management of "3 R"-diverted wastes. In order to effectively recycle and reuse waste, it is necessary to find markets or uses for the diverted waste and/or their transformation products. Communities across North America that have landfill or other waste management capacity are finding that practicing the 3 R's is more expensive than directly depositing the waste in existing landfills. In the mid-1980's, newspapers collected in the New York/New Jersey area could be sold for $30 to $40 per ton. Today, across the US, it is necessary to pay on the order of $30 to $40 per ton for someone to take the newspapers that are collected as part of recycling. There are significant gluts in the market for recycled/reused materials. There are many who maintain that if the 3 R's are to be effective in reducing the magnitude of the MSW waste stream, a fourth "R" will have to be added, namely, "repurchase." It is essential that the current glut of many of the recycled materials from waste stream diversions be reduced significantly in the near future if 3 R's approaches are to become effective in MSW management. It will likely be that the subsidizing of markets for 3 R materials will have to be part of the costs of MSW diversion and management.

There is a general misconception about the significance of the 3 R's to environmental impacts of solid waste management. It is sometimes advanced by those who advocate aggressive 3 R activities that such practice will reduce water pollution by MSW. That concept is not necessarily correct. The purpose of the 3 R's is to reduce the magnitude of the waste stream in order to extend the existing landfill capacity and to conserve resources. Examination of the pollutional characteristics of the materials being diverted in 3 R programs today shows that in general the materials that cause landfill leachate to be a significant threat to groundwater quality are not being diverted to any significant extent. Further, the removal of the inert items from the waste such as aluminum cans, glass, and plastic bottles, and to some extent newspaper, results in a more concentrated waste that has a greater potential to pollute groundwater. The 3 R's programs as practiced today do not reduce the potential for landfill leachate pollution of groundwater; indeed, the change is in the direction of making leachate pollution more significant.

While not part of traditional 3 R activities to reduce MSW volume, there is considerable effort in many areas to divert "hazardous" chemicals from the MSW waste stream. In many areas landfill operators are required to periodically inspect the waste loads for readily discernible "hazardous wastes," and when found, remove them from the waste stream. While such efforts are in the direction of reducing the hazardous nature of MSW, their effectiveness is typically inconsequential in affecting the hazardous and deleterious components of municipal solid waste leachate and their impact on groundwater quality. As discussed by Jones-Lee and Lee (1993), today's municipal solid waste stream contains a wide variety of hazardous and otherwise deleterious chemicals; even with the removal of what are classified by regulations to be "hazardous waste" from the waste stream, MSW landfill leachate is still highly hazardous and deleterious to groundwater quality. It will not be possible through waste stream diversion activities to cause a municipal landfill leachate to be innocuous; even small amounts of MSW landfill leachate will still be a very significant threat to groundwater quality after the best of the household hazardous waste collection programs is implemented. This is the result of the fact that there are a wide variety of sources of hazardous chemicals in the MSW waste stream that are not controllable. See Jones-Lee and Lee (1993) for a discussion of these issues.

There are also significant questions about the cost-effectiveness of household hazardous waste collection programs. Many cities are finding that such programs are becoming a highly significant economic burden to the city since some of the materials collected have to be handled as "hazardous waste", which costs on the order of 10 - 50 times more for disposal than deposition in an MSW landfill. Another problem with the household hazardous waste collection programs is that some of the materials that are collected, while hazardous to individuals, such as bleach, represent little or no hazard in a landfill. This contributes unnecessarily to the increased costs of the handling of such materials.

The development of an effective 3 R's program typically requires that solid waste handling facilities be developed to separate and process the waste stream components. The materials recovery facilities (MRF's) can have significant adverse impacts on those who utilize the lands near the facilities. The principal problems are the truck traffic and associated air pollution, congestion, noise, and the odors from the garbage. MRF's should be located where there is sufficient land buffer owned by the MRF facility owner around them so that the adverse impacts of the operations that are not controlled within the facilities are diluted and dissipated in the buffer lands before they reach adjacent properties. It is especially important that all MRF's that handle putrescible wastes have adequate air handling and treatment capacity to collect all odorous emissions from the garbage trucks and wastes, and treat them so that they do not result in adverse odors on adjacent properties.

While practicing the 3 R's in an aggressive manner will reduce the amount of wastes that need to be landfilled, this does not necessarily lead to a decrease in the adverse impacts of landfills on nearby property owners/users. As discussed above, the impacts of landfills depend to a considerable extent on the rate of waste receipt, i.e., garbage truckloads per day. A landfill in a service area where the 3 R's are practiced to the maximum extent readily possible today, i.e., 50 to 60% waste stream diversion, would still likely be highly adverse to those who own or use properties near the landfill. The only difference would be how fast the landfill capacity (air space) would be used. Obviously if 50% of the conventional waste stream is being diverted from the landfill, there would be a potential to double the active life of the landfill. However, with the trend toward regional mega-landfills and the long-haul of MSW via truck and rail, it can be anticipated that any landfill sited today would be filled relatively rapidly, even with aggressive 3 R practices. Because of the difficulties in siting landfills in many areas, any landfill that is sited today can become a resource for a region.

While not normally considered by advocates of the 3 R's, there are significant costs and environmental impacts associated with practicing recycling and reuse. One of the principal components of MSW that can be readily diverted from the waste-stream is yard waste. While such waste can readily be aerobically composted, as discussed elsewhere in this report, composting can have significant adverse impacts on nearby property owners/users owing to truck traffic, noise, vermin, and odors. Unless great care is taken, a number of the problems that are associated with MSW landfills will be carried over to the location where composting takes place, should the composting facility be at another location.

Recently, the National Solid Waste Management Association released a report discussing the cost of recycling of MSW components (NSWMA, 1992). That report points out that, on the average, it costs about $50/ton to process recyclables at a materials recovery facility. The average market value of these materials is on the order of $30/ton. Therefore, the waste generators (the public) will have to subsidize the 3 R's by an average of about $20/ton, or about 5/person/day. However, since tipping fees for "dry-tomb" landfills typically run on the order of $50 to $75/ton today in areas where tipping fees are set to cover landfill costs, the diversion of components of the waste stream through the 3 R's not only saves airspace (capacity) in the landfill, but also saves the public money even though the materials cannot be sold for a profit. However, as discussed above, it is essential that substantial markets be developed for the diverted waste components if 3 R activities are to continue to be an effective method of MSW diversion from landfills. Without markets/uses for recovered and recycled materials, they will have to be landfilled.

NSWMA (1992) also presented information on the cost of recycling of major waste stream components. These costs are summarized in Table 2. As shown, it costs about $188/ton to recycle HDPE plastic, about $143/ton to recycle aluminum cans, and about $34/ton to recycle newspapers. The recycling of many of these materials is not without potential significant adverse environmental impacts at the point of recycling. The authors have recently had the opportunity to review the siting of a proposed newspaper recycling operation in the Sacramento, California area. There are significant questions about whether that facility can be sited in that area because of its environmental impacts. Recycling newspapers produces substantial amounts of wastes that can adversely impact air and water quality, and can add to the solid waste stream that must be disposed of in a landfill.

There is considerable opposition to the siting of this facility in the Sacramento area because of concerns about deteriorated air quality associated with the incineration of some of the waste components, the high concentrations of salts and some specific components in the wastewater discharges from the facility, and the significant shortening of the useful life of the local landfill by the large amounts of industrial "non-hazardous" wastes that are derived from the newspaper recycling operations. While the air and water quality impacts can be controlled through increased treatment of air and water beyond those normally required, the costs for the additional treatment would have to be added to the cost of the paper recycling. These costs could become sufficient so that the recycling operations at that location would not be competitive with those at other locations where there might be less stringent air and water quality regulations, or where the adverse impacts of the emissions that typically occur at newspaper recycling facilities can be more readily assimilated without adverse impact on the air and water quality of the area.

Table 2
Costs of Recycling

Item	Cost of Recycling ($/ton)
Plastic, HDPE	188
Polyethylene terephthalate	84
Cans, Aluminum	143
Glass, Amber	112
Green	87
Clear	73
Cans, Steel	68
Glass, Mixed Color	50
Cardboard, Corrugated	43
Paper, Mixed	37
Newspaper	34

The loss of landfill capacity is of significance to the local residents, since the tipping fee at the landfill is only about $30/ton. There can be no doubt that when that landfill becomes full, the county that operates it will either have to expand it or develop another landfill, both of which options will likely result in significantly higher tipping fees for area residents.

The overall issues and concerns with the recycling of the other materials listed in Table 2 are not significantly different from those associated with newspaper recycling. The recycling of those components typically involves physical and chemical processing of the wastes, which generates a waste stream that must be managed. Thus, while the aggressive practicing of the 3 R's can reduce some of the adverse impacts of some landfills on nearby property owners/users, it does shift some of those impacts to other locations and can readily be significantly adverse to property owners/users in those areas.

One of the areas that is receiving increased attention associated with waste management is the common practice of siting landfills, chemical processing plants, etc. in areas where the nearby population is economically disadvantaged, and often minority-dominated areas. Less attention may be paid to enforcement of regulations in those areas. Regulatory agencies are becoming increasingly concerned about this situation, termed in some areas as "environmental racism." Such areas may be targeted for the facilities used to practice 3 R activities.

Aggressive practicing of the 3 R's will reduce the rate of utilization of existing solid waste management capacity storage space and thereby reduce the amount of additional landfill capacity that must be developed. Since the "dry tomb" landfills of the type being developed today have a great potential to eventually pollute groundwaters, every new landfill that can be avoided will reduce the number of foci of new water pollution from landfills. It is also clear that today's society is just in the infancy of beginning to utilize, evaluate and manage 3 R-related activities. Significant changes will likely occur over the next decade or so in what is recycled and reused, the cost of the 3 R's, and where such processing takes place.

FARMLAND PRESERVATION

In some areas, farmlands are in sufficiently short supply that there is justified concern about siting mega-landfills in the area because they will prevent the continued use of the lands for farming purposes. The potential loss of farmlands should be a consideration in the evaluation of potential sites for large landfills.

COSTS OF MSW MANAGEMENT

Throughout the discussion presented in this report, the costs of managing municipal solid waste in such a manner as to protect groundwater resources, public health, the environment, and nearby property owners/users' use and enjoyment of their properties have been presented on a cents/person/day basis. Landfill owners/operators, whether public or private, typically present the costs of improving the protection of public health and the environment from landfills in terms of the total cost. These costs often amount to millions to tens or hundreds of millions of dollars that will have to be spent by those who generate the wastes in additional disposal fees to provide the additional "protection" that is needed to mitigate adverse impacts of the landfill or other waste management unit on those who own or use properties near the unit. While their cost estimates may be appropriate, there are few, if any, who can understand what such costs mean to the public; the magnitude of these costs appears enormous when presented as a lump sum.

A more appropriate way to present the costs of additional environmental protection provisions would be to present them in terms of the increased cost that an individual would have to pay for waste disposal on a per day basis, and to discuss the costs of not spending that money on those controls. By dividing the total cost of a landfill protection activity by the total number of people who are contributing waste to the landfill and by the total time over which the protection is to be amortized, such as during the active life of the landfill, it is possible to gain a much greater understanding of those costs relative to an individual's disposable income (the amount of money an individual typically spends each day on non-essential items, such as soft drinks). It is found that many people do not consider the purchase of one or two soft drinks per day to be a significant financial burden, but when they are asked to pay an additional 50 to $1.00/day for the protection of groundwater resources and the public health and welfare of those who own or use properties in the vicinity of the landfill where their wastes are deposited, they complain about the increased costs. This situation arises from the fact that the public has been accustomed to paying a few cents per day to have its garbage "disappear" from property, homes, and commercial and industrial establishments. However, those costs, in increased proportion, have been passed on to those who own property, reside on or otherwise use lands in the vicinity of the landfill, in terms of public health hazards, environmental degradation, loss of groundwater resources, and impaired use and enjoyment of these lands.

It is suggested that all costs of increased environmental and other protection associated with mitigating the adverse impacts of landfills and other waste management units be presented in terms of the costs to the waste generators on a per day basis so that they and others can understand the true magnitude of these costs.

One of the issues that has to be considered in developing a solid waste management program for a particular area is the additional cost of the various mitigating approaches discussed in this report to those who generate the waste. These costs include the acquisition of additional land buffers, appropriate compensation for reduced property values, truck traffic, altered viewshed, etc., and include the additional costs of landfill liner and cover systems to provide for true groundwater quality protection for as long as the wastes represent a threat. While many of these cost are highly site specific, Lee and Jones-Lee (1993f) have recently discussed the costs associated with providing true groundwater quality protection at a Subtitle D landfill. They conclude that for about 10 cents/person/day more than is being paid for Subtitle D landfilling of MSW that a double composite lined landfill in which the lower composite liner is a leak detection system for the upper composite liner can be constructed. This amount of funds would also provide for a leak detection system in the landfill cover and a dedicated trust fund that would provide adequate funding to properly maintain the cover *ad infinitum* and a several hundred million dollar contingency fund to, if necessary, exhume the waste, and treat them to produce nonpolluting residues.

Lee and Jones-Lee (1993f) estimate that the typical cost for Subtitle D landfilling, including collection of the MSW, is on the order of 30 to 50 cent/person/day. Therefore, the additional 10 cents/person/day to change the landfilling approach from one associated with the Subtitle D landfill utilizing a single composite liner and groundwater monitoring to detect liner leakage which at best only postpones when groundwater pollution occurs, to a double composite lined landfill system of the type described by Lee and Jones-Lee (1993g) does not represent a significant increase in the typical cost paid by urban dwellers for MSW management.

CONCLUSIONS

All approaches for municipal solid waste management have potentially significant adverse impacts on public health, the environment, and those who own and/or use property near a proposed landfill or other waste management unit. It is highly inappropriate today for those responsible for developing waste management approaches for an area to focus on the development of landfill capacity to manage the municipal solid waste of an area without appropriate attention to those impacts and their reliable mitigation in the landfill siting and evaluation process. Because of the importance of the 3 R's in influencing not only the magnitude of the waste-stream, but also its characteristics, it is essential that careful consideration be given to the influence of waste-stream reduction and waste reuse and recycling in developing a longterm waste management program for an area. Further, those responsible for development of a waste management program in an area should work with the governmental agencies, the legislative and regulatory bodies, and the public in a highly developed, organized and coordinated program to significantly reduce the magnitude and improve the character of the MSW waste-stream that must be managed.

Once the character of the waste-stream has been carefully evaluated and managed to the extent possible, those responsible for developing a waste management program in an area should critically review all of the options and potential adverse impacts of each management option on those who own property or use lands within the potential zone of impact of each waste management option. With respect to landfilling of wastes, there must be a decision made as part of the development of the waste management program as to whether landfills that could be constructed as part of the program will continue to be highly detrimental to the public health, environment, groundwater resources, social and economic welfare of those within the zone of impact of the landfill.

As part of developing an appropriate solid waste management program for an area, consideration must be given to properly addressing and controlling the mitigatable impacts of all waste management units, including landfills, and properly compensating those who are potentially adversely impacted by the proposed waste management unit/landfill as the result of siting the unit in their area. The approach that has been used in the past in which those responsible for developing a municipal solid waste program in an area focus on cost minimization to the exclusion of proper consideration of addressing and mitigating adverse impacts should not be allowed to continue. Those who generate the waste, principally those in urban areas, should have to pay the true cost of waste management in order to protect the public health, environment, groundwater resources, welfare and economic interests of those in rural areas who host the waste management unit.

Rather than the confrontational posturing that is adopted today for siting landfills - where the landfill or other waste management unit is thrust upon the rural resident - a cooperative approach in which those who host such a facility are protected and compensated should be favored. This approach will increase the cost of solid waste management to those who generate the waste but who do not want the waste management unit in their back yard. These additional costs, however, will not, based on the author's experience, represent a significant detriment to those who generate the waste. The adoption of the approaches advocated in this report would be a major step toward technically valid, cost-effective management of MSW that would protect the health and welfare of those who could be adversely affected by the waste management program.

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