Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview[1]

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Executive Summary

Classical unlined sanitary landfills are well-known to release large amounts of hazardous and otherwise deleterious chemicals to nearby groundwater and to the air, via leachate ("garbage juice") and landfill gas. It is known that such releases contain a wide variety of potential carcinogens and potentially toxic chemicals that represent a threat to public health. However, little quantitative information exists on the total hazard that landfills represent to those who live or otherwise use properties near the landfill. Epidemiological studies of the "exposed" populations near landfills and Superfund sites have not detected a clearly discernible increase in the incidence of cancer in those populations. This is to be expected because of the insensitivity of epidemiological methods for detecting small increases in cancer incidence in limited populations over the normal lifetime cancer risk for the US population of one cancer in three people. It would be rare that a sufficient number of individuals near Superfund site landfills would experience an average increased cancer risk of 1 in 1,000.

The leachate from MSW landfills is a highly concentrated "chemical soup," so concentrated that small amounts of leachate can pollute large amounts of groundwater rendering it unsuitable for use for domestic water supply. In addition to potential carcinogens and highly toxic chemicals, MSW leachate contains a variety of conventional pollutants that render a leachate-contaminated groundwater unusable or highly undesirable due to tastes and odors, reduced service life of appliances (e.g., dishwashers, hot water heaters, plumbing), fabric (clothes), etc. Furthermore, both gas and leachate from MSW landfills contain many organic chemicals that have not been characterized with respect to specific chemical content or their associated public health or other hazards. These "non-conventional pollutants" include more than 95% of the organics in MSW leachate.

There are more than 65,000 chemicals in US commerce today; about 1,000 new chemicals are being developed each year. Of those chemicals, only about 200 are regulated and measured in studies of MSW landfill leachate-contamination. Given the highly concentrated nature of MSW

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[1] References as:
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landfill leachate, that a large portion of the organics in MSW leachate are of unknown character and hazard, and that a comparatively few chemicals are regulated, it should not be assumed that the fact that a leachate-contaminated groundwater meets all drinking water MCL's (maximum contaminant levels) means that the water should be considered safe to consume. Furthermore, once a groundwater is contaminated by MSW landfill leachate of the type produced in today's Subtitle D landfills, it and the associated aquifer cannot be cleansed so as to render a water that can be considered reliable for consumption and certain other uses. The contaminated portion of the aquifer must be abandoned for future use as a domestic water supply source and for conjunctive use storage of surplus surface waters for use during drought periods. Therefore, it is prudent public health and water resource management policy to assume that any contamination of groundwater by MSW landfill leachate represents a significant threat to public health and the environment and should cause termination of the use of the water for domestic water supply purposes.

Landfill gas emissions also contain large amounts of obnoxious and otherwise deleterious chemicals that are highly detrimental to nearby property owners and users. The methane in landfill gas releases, while odorless, poses a threat of explosions in enclosed structures and contributes to the greenhouse gases that promote global warming. Both methane and C02 in landfill gas can also be highly detrimental to vegetation on the landfill cover and near the landfill. The obnoxious odors that are emitted from MSW landfills can persist for a mile or more from the landfill. Such odors provide a tracer for non-odorous as well as odorous hazardous chemicals in gaseous emissions. Because of the large amounts of non-conventional pollutants in landfill gas, the detection of landfill odors on offsite properties should warn of a significant public health threat. Odors and other adverse conditions created by landfill operations cause property values to decrease within a mile or so of the landfill.

New Subtitle D regulations prescribe a "dry tomb" landfilling approach in which untreated MSW is placed in plastic-sheeting- and compacted-soil-lined landfills in an attempt to isolate the wastes from water for as long as the wastes will be a threat. Evaluation of the character of the systems incorporated relative to physical, chemical, and biological processes as they occur in such systems, and the nature of the materials placed in them shows the "dry tomb" landfilling approach to be a flawed technology that will not protect the public health, or groundwater and air resources under and above the landfill and adjacent properties. At best, it will only postpone the leakage of leachate and gas to adversely affect public health and environmental quality.

MSW in a "dry tomb" landfill will be a threat to public health, groundwater resources, and the environment forever. The effectiveness of Subtitle D landfill liner systems in preventing leachate migration is compromised after installation, and will deteriorate over time allowing increasing amounts of leachate to pass through the liner into the groundwater system hydraulically connected to the bottom of the landfill.

The US EPA and states' Subtitle D groundwater monitoring approach of using vertical monitoring wells spaced hundreds to a thousand or more feet apart at the groundwater monitoring point of compliance is grossly inadequate for detecting incipient groundwater pollution from lined landfills. Unlike leakage from unlined landfills in homogeneous hydrological settings, the initial leakage from plastic sheeting-lined Subtitle D landfills will be through holes, tears, or imperfections in the sheeting. Such point-source leakage results in the emanation of "fingers" of leachate-contaminated groundwater which are a few feet wide at the point of compliance for groundwater monitoring. Vertical monitoring wells have effective zones of capture of leachate-contaminated groundwater of only about one foot around the wells. With the spacing of such wells allowed, the US EPA Subtitle D groundwater monitoring approach will not detect groundwater pollution, much less incipient landfill leakage, before widespread groundwater pollution has occurred.

The municipal solid waste stream of today and of the future potentially contains less industry-defined hazardous chemicals than the classical sanitary landfill. However, it does, and will continue to, contain large amounts of highly hazardous and otherwise deleterious chemicals that will render groundwaters contaminated by such leachate unusable for domestic water supply purposes.

RCRA set forth a minimum post-closure care period of 30 years; that period was also used by the US EPA in implementing Subtitle D regulations. However, 30 years is an imperceptibly small, and insignificant part of the total time that MSW in Subtitle D "dry tomb" landfills will be a threat to public health, groundwater resources, and the environment. Insufficient funds are being collected from waste generators and set aside to meet the inevitable and unending needs for post-closure care monitoring and maintenance, and groundwater and landfill remediation for Subtitle D landfills. The Subtitle D landfilling approach and requirements adopted by the US EPA are superficial and only serve as a stop-gap measure for managing MSW. They enable today's society to continue to enjoy solid waste "disposal" without the responsibility and expense of preventing them from causing future problems. This is being enjoyed at the expense of future generations' public health, groundwater resources, and welfare.

Contrary to claims made by the US EPA in implementing Subtitle D landfill regulations in October 1991, Subtitle D landfill requirements do not address the justifiable "NIMBY" concerns and problems associated with the active life of landfills or the post-closure care impacts on those who own or use properties within several miles of the landfills. In not recognizing the potential significance of non-conventional pollutants, the nature of processes within the landfills, the nature and limitations of the liner systems and monitoring approaches, and the perpetual threat of contaminants in landfills, the US EPA Subtitle D and state regulations do not protect public health or groundwater resources for as long as the wastes represent a threat. Since Subtitle D landfills only postpone groundwater pollution, and for many landfills, gas emission problems, Subtitle D landfills do not significantly alleviate the threat of landfill gas and leachate to those who own or use properties within the sphere of influence of the landfill. The "dry tomb" landfilling approach should be recognized as "temporary" storage for MSW that will ultimately require exhumation and treatment of the wastes unless groundwaters hydraulically connected to them are to be abandoned as water resources.

More protective alternatives to US EPA Subtitle D "dry tomb" landfills are available to address both the near-term and long-term threats that such landfills represent to public health, groundwater resources and the environment, as well as to the welfare of those within the sphere of influence of the landfill. The additional costs for such approaches are insignificant compared to the long-term costs that will have to be paid by future generations for today's waste management mistakes. One such alternative is a fermentation/leaching "wet-cell" approach. In brief, that approach includes the recycling of landfill leachate in a double-composite-lined landfill that contains shredded MSW followed by a decade or so of clean-water washing (leaching) of the solid waste to produce non-polluting residues. The lower composite "liner" serves not for last-resort containment, but rather as a lysimeter leak detection system for the upper-composite liner. Associated with that waste treatment/management concept is required the setting aside of sufficient funding in a dedicated trust fund derived from increased disposal fees to exhume the wastes when leakage through the upper-composite liner cannot be stopped. To address justifiable active-life NIMBY concerns and problems, it is necessary that the landfill be sited with an adequate landfill owner-owned land buffer of at least one mile about the outer reaches of the landfill. The landfill buffer would be used to dilute the adverse impacts of the landfill, such as odors, seagulls, etc. that occur with today's landfilling operations. The estimated initial cost of this approach is about 10 to 15 cents/person/day more than that paid for solid waste management in Subtitle D landfills. Expenditures of this amount will not only address justifiable NIMBY issues of today's landfills, but also significantly improve the protection of future generations from adverse impacts of gaseous and leachate emissions. Further information on each of these issues is provided in this report and in references contained therein.

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Introduction

During 1993 and 1994, the state of California Environmental Protection Agency conducted a Comparative Risk Project for the purpose of developing a relative ranking of the hazards associated with various types of chemicals and pathogens in the environment, and particular sources of hazardous chemicals and pathogens that may impact human health and the environment. One of the categories that was selected for consideration at the initiation of the Project was municipal and industrial "non-hazardous waste" landfills. However, after extensive review of the information that was available from the CA Integrated Waste Management Board and the CA State Water Resources Control Board (WRCB) and its regional water quality control boards (the California agencies that are responsible for regulating landfills), it was concluded that the database was insufficient to develop a comparative assessment of the risks of municipal and industrial non-hazardous waste landfills to public health and the environment.

Key areas in which information is needed to make this assessment include the emission rates of gaseous and liquid hazardous chemicals from a variety of municipal and non-hazardous industrial landfills located in various parts of the state, as well as on the population that is exposed to such emissions. Data are needed on the levels and fate of specific compounds, such as members of the VOC's (i.e., chlorinated hydrocarbons such as vinyl chloride, trichloroethylene, benzene, etc.), as well as methane in gaseous emissions, and on the releases of leachate from landfills to the groundwater systems in which the landfills are located. While there is a database on leachate-associated contaminant releases to groundwater and to a lesser extent to the atmosphere for hazardous waste landfills that are part of federal and state Superfund activities, such data are almost totally lacking for "non-hazardous waste" landfills. The situation in California in this regard is not significantly different from that in many other states. Federal and state regulatory agencies have, in general, devoted little attention to the quantification of the public health and environmental risks associated with municipal and industrial non-hazardous waste landfills. The magnitude of the hazard that such landfills represent to those who live or work on, or otherwise utilize, properties in the vicinity of landfills and thereby stand to be exposed to gaseous as well as leachate-derived landfill emissions are largely unknown.

It should not be concluded, however, that because of the inadequacy of the regulatory attention being given to quantification of the hazards of "non-hazardous waste" landfills that such landfills represent little or no threat to public health and the environment. In fact, the available evidence indicates just the opposite. This report summarizes the information that is available on the potential significance of non-hazardous waste landfills of the type that have been used in the past, as well as those that are being constructed today under the US EPA Subtitle D regulations that were adopted on October 9, 1993 and the state of California Landfilling Policy that was adopted on June 17, 1993. This report is designed to provide insights into the potential adverse public health and environmental impacts associated with non-hazardous waste landfills, as well as to provide a discussion of some of the key issues that should be included in programs designed to address significant air and water quality problems associated with non-hazardous waste landfills.

Evolution of Landfilling Practices

Several hundred years ago, in many areas urban and rural dwellers deposited their solid wastes outside their places of residence. Eventually, because of problems of odor, rodents, etc., the garbage in urban areas began to be hauled for disposal to open dumps usually located in nearby, low-value land. Such disposal practices often included burning the garbage. At some locations, such as in California, food waste in the dumps was also used as food for hogs. Eventually the use of municipal solid waste as a source of food for hogs was stopped because of problems with the spread of trichinosis, a disease that is caused by an intestinal nematode (Trichinella spiralis). Hogs became infected with trichina cysts in the raw garbage; people became infected by eating insufficiently cooked pork (Benenson, 1985). While the trichina in pork are readily killed if the pork is sufficiently cooked, eating insufficiently cooked pork results in the release of the organism's cysts in the intestinal track of man or other animals; from there they enter the blood stream and eventually encyst in muscle tissue. Trichinosis is ordinarily not debilitating if the trichina encyst in large, nonsensitive muscles. However, it can cause severe debility and death if the trichina enter vital organs. According to Tchobanoglous *et al.* (1977), in the first half of the 20th century, 16% of the US population was infected with trichinosis from eating inadequately cooked pork. At one time, attempts were made to cook garbage destined for dumps in order to reduce the problem with trichinosis transmitted by hogs grazing on garbage. This proved to be an unsatisfactory solution and was abandoned in favor of discontinuing animal grazing on garbage. Michaels (1994) reported that the city of Philadelphia currently conducts a separate pick-up of food wastes, which are then fed to hogs in New Jersey. The wastes are reported to be cooked to reduce the potential for the spread of trichinosis. The authors attempted to learn more about this operation, but the New Jersey hog farmers who are involved in these activities did not respond to requests for information on the degree to which the garbage is cooked. The authors, therefore, cannot verify that the cooking is adequate to destroy the trichina cysts in uncooked pork scraps that are discarded in Philadelphia.

The open dumps that were used for solid waste disposal in California until the 1950's, often had severe problems of localized odors, vermin such as rodents and seagulls, potential disease vectors such as flies and rodents; they were also known to cause groundwater pollution in the vicinity of the dump. Beginning in the 1950's the US Public Health Service and a number of states including California began to manage municipal solid waste (which often included industrial waste, both what is now called "hazardous" and "non-hazardous" waste) in what became known as "sanitary landfills."

Sanitary landfills, typically located in low-value land, usually wetlands, were basically open dumps in which the daily garbage was covered with a few inches of soil. The purpose of the soil was to reduce the entrance of vermin, flies, and other nuisance organisms into the waste, and to reduce the rate of release of gases including odors from the landfill. Further, the daily cover tended to control, to some extent, blowing papers and other debris associated with the landfill. Sanitary landfilling as it was initially practiced and was practiced in many areas until recently, did not incorporate any significant provisions to prevent either air pollution from gaseous emissions or groundwater pollution from liquid emissions.

In recent years, the sanitary landfilling approach and associated regulations have been modified to often include "lining" beneath the landfill and other engineered features in an attempt to entomb the wastes to address the problems of landfill emissions. As discussed further below, however, the "modern" "dry tomb" landfills as being developed today at best only postpone problems caused by such emissions and do not remedy many of the other concerns about the adverse impacts of landfills on nearby property on owners and users.

Lee and Jones-Lee (1993a) discussed potential adverse effects of municipal solid waste (MSW) landfills and other waste management facilities on those who own or use properties near them. Table 1, developed from that review, summarizes those impact issues. As discussed by Lee and Jones-Lee, the emissions from MSW landfills, truck traffic, and other problems associated with the normal landfilling approach often results in significant local opposition to the siting of landfills. While those who oppose such facilities are often negatively characterized and dismissed as "NIMBY's" ("not in my backyard"), their concerns in these areas are justified. While essentially all of the potential adverse impacts of MSW landfills on nearby property owners and users can be mitigated by proper siting, landfill operation, closure of the landfill once it is filled, and maintenance for as long as the wastes represent a threat, adequate steps in these areas are rarely taken by those who develop landfills. A number of the problems associated with landfilling of municipal solid wastes are the direct result of gaseous and liquid (leachate) discharges from the landfill that are transported to or under adjacent properties impairing the use of those properties or associated water resources. Those who generate wastes that are placed in MSW landfills typically do not pay the full real costs that would be associated with management of their wastes so as not to cause adverse impacts on nearby property owners and users.

Lee et al. (1994) discussed common problems with the siting of landfills, and Lee and Jones-Lee (1993a, 1994a) discussed approaches that can be used to address the potential adverse effects of landfills to reliably assuage the justifiable concerns expressed by those who own or use properties near a landfill when they learn that a governmental agency has selected their area for a new landfill or for the continued operation of a landfill that had been scheduled to be closed. As discussed by Lee and Jones-Lee (1993a, 1994a) the key issue in the siting of landfills of the type being developed today to properly address many of their potential adverse effects is the provision for an adequate land buffer around the landfill. The landfilling practices of the past and still today do not recognize that the acquisition of sufficient lands about the landfill to dilute the adverse effects of gaseous emissions and some of those associated with operation of landfills should be part of the cost of landfilling of municipal solid waste.

Lee and Jones-Lee (1993a, 1994a) have reported that the sphere of influence of many MSW landfills depends on a variety of factors including the extent of groundwater pollution, odors, and garbage truck traffic that adversely impacts normal traffic flow etc. Hirshfeld *et al.* (1992) reported that property values near MSW landfills are adversely impacted by the landfill for distances of a mile or two from the area where waste deposition occurs. It is certainly not unreasonable to expect that any landfill that is sited without at least one mile and preferably two miles of landfill-owned bufferland between the outermost edge of where waste deposition occurs and adjacent property owners' land will be adverse to those who own or use this property.

Table 1

Adverse Impact Issues of MSW Landfills and Other Waste Management Units on Users/Owners of Nearby Properties

- Groundwater and Surface Water Quality; Leachate Migration & Disposal - *Public Health, Economics, Aquatic Life, Aesthetics*
- Migration of Methane and VOC's - *Public Health, Explosions, Toxicity to Plants*
- Illegal Roadside Dumping and Litter near Landfill - *Aesthetics, Public Health, Economics*
- Truck Traffic - *Congestion, Air Pollution, Aesthetics, Public Health*
- Noise - *Aesthetics, Public Health*
- Odors - Dumping & Landfill Gas - *Aesthetics, Public Health*
- Dust and Wind-Blown Litter - *Aesthetics, Public Health*
- Vectors, Insects, Rodents, Birds - *Public Health, Nuisance, Aircraft Hazard*
- Impaired View/Viewshed - *Aesthetics*
- Decreased Property Values - *Condemn Future Users of Nearby Properties*

Because of the inadequate resolution of such problems in the past, and the fallure to incorporate adequate provisions for their resolution in the future, it has become difficult if not impossible to site additional landfills of the type that have been operated in the past in many areas of the US. This situation is manifested as a national solid waste management crisis. There are few individuals who would not become a NIMBY if a landfill were proposed for their region; landfills of the past and still today are very poor neighbors to those who own or use properties within several miles of the landfill.

Landfill Emissions and Impacts

MSW landfills and many industrial non-hazardous waste landfills emit large amounts of landfill gas and leachate ("garbage juice") to the environment. Such emissions can have a significant adverse impacts on public health, public safety, groundwater quality, and aesthetic quality of the area near the landfill. A review of these emissions and their impacts is presented below.

Landfill Gas

On the order of 50% or so of municipal solid waste is potentially usable by bacteria as a source of energy through aerobic and/or anaerobic fermentation reactions. Composting of municipal solid waste is an aerobic process in which part of the degradable organic matter is converted to CO_2, water, and a "stabilized" organic residue (compost). Because of the high demand for oxygen by bacterial respiration in sanitary landfills compared with the available oxygen supply from the atmosphere, the waste in a landfill quickly becomes anoxic (without oxygen, O_2). When sufficient moisture is present, bacteria in the landfill can utilize some of the organic matter through anaerobic fermentation processes. These processes lead to the formation of landfill gas which is typically composed of about 50 to 60% methane and 30 to 40% CO_2. Landfill gas also typically contains on the order of 10% N_2 gas which arises from air that enters the landfill, and up to a few percent other gases. One pound of municipal solid waste can generate about 3 ft3 of CO_2 and 4 ft^3 of CH_4 over a several-year period.

The rate of landfill gas production depends primarily on the moisture content of the waste. In a typical sanitary landfill, it takes 30 to 50 years to "stabilize" the waste, i.e., to convert the fermentable organics in the waste to landfill gas. At the end of the stabilization period a significant part of the anaerobically fermentable organics have been converted to landfill gas. It has been repeatedly demonstrated that under optimum conditions (shredded waste and addition of moisture (leachate) to the waste), it is possible to reduce the waste stabilization time from 30 to 50 years to 5 to 10 years (Lee and Jones-Lee, 1993b).

Table 2 lists potential problems associated with landfill gas production and migration. The principal hazard of concern with landfill gas emissions is the potential for explosion of the methane. The lower explosive limit for methane is about 5 %; methane in concentrations above about 5 % in air is explosive. There have been numerous examples of explosions at landfills. There have also been numerous examples of underground migration of landfill gas to nearby properties and sufficient accumulation of landfill gas in buildings to become an explosive mixture which can be set off by a spark. The problems of explosive conditions developing from methane emissions from landfills have stimulated regulatory agencies to require that landfill owner/operators construct landfill gas collection systems that are envisioned, in concept, to collect sufficient landfill gas emissions so that landfill gas is not transported below the ground surface off-site to cause explosive conditions in nearby structures.

Table 2

Potential Problems Associated with Landfill Gas Production and Migration

Explosion - CH_4
Vegetation Distress - CO_2
Odors
Property Value Reduction
Physical Disruption of Cover
Toxic Gases - VOC's, Vinyl Chloride
Groundwater Pollution -
    CO_2 in Carbonate Geological Strata
    Increases TDS

Landfill gas can also have adverse impacts on vegetation that is developed on the landfill cover or near the landfill. Typically when the landfill stops receiving wastes, i.e., when it is closed, a cover is installed over the landfill and includes the development of vegetation (grasses) to reduce erosion of the cover. The emission of landfill gas can exclude oxygen from the root zone of vegetation, and thus lead to the death of the vegetation. Many landfill covers that have inadequate landfill gas collection systems have large, non-vegetated areas due to landfill gas emissions through the cover.

The principal problem caused by landfill gas emissions is odor. While methane and CO_2 are odorless, gas emitted from municipal solid waste contains large amounts of highly odorous compounds that are highly obnoxious to most people at low concentrations. Such odors are emitted during the dumping of the garbage, as well as through the cover of closed landfills that do not have adequate gas collection systems or have systems that do not destroy the odorous gases by incineration which is typically done by flaring of landfill gas. As discussed by Lee and Jones-Lee (1993a), highly odorous conditions from landfills can persist for a mile or more downwind from the landfill. In the US today, no attempt is made to control off-site migration of highly odorous gases emitted at the landfill face when dumping is taking place. Also, little attempt is made to control the highly odorous landfill gas emissions while the landfill is accepting waste, i.e., is open to the atmosphere, other than what can be accomplished by covering each day's garbage with a thin layer of soil. The daily soil cover often is only partially effective in controlling gaseous emissions from solid wastes that have been deposited at a landfill on the previous days of operation.

Several papers presented at the Sardinia '93 IV International Landfill Symposium discussed the European experience with landfill odors and the situations that promote long-distance transport of highly malodorous conditions, such as the presence of valleys and periods of near-surface inversions (Christensen *et al.*, 1993). Although often little is done in the US to control the malodorous conditions that frequently occur on properties near landfills, a number of European countries have adopted legislation to greatly curtail malodorous conditions from arising from landfills to adversely affect nearby property owners/users.

It has been known for many years that landfill gas contains trace quantities of a variety of highly hazardous chemicals. More recently, Hodgson *et al.*(1992) reported on landfill gas emissions of VOC's (volatile organic compounds) from a group of California municipal landfills.

Table 3 presents a summary of the results of that study. Hodgson *et al.* stated,

"The Landfill Gas Testing Program of the State of California has demonstrated that landfills typically contain toxic VOC regardless of the type of waste they are designated to accept and that off-site migration of landfill gas is a fairly common occurrence."

At this time the Los Angeles County Sanitation Districts are in the process of expanding the Puente Hills Landfill, the second largest landfill in the US. That landfill, which accepts about 12,000 tons of garbage per day, is located in the City of Industry and immediately adjacent to the residential community of Hacienda Heights (population about 40,000) and other commercial and industrial activities. The Los Angeles County Sanitation Districts are proposing to expand the landfill toward the Hacienda Heights property boundary and to landfill waste within about 1,500 yards of adjacent properties which include an elementary school, numerous homes, and a variety

Table 3

Concentrations of Methane and Ten Toxic VOC in Landfill Gas Compared with Concentrations of Methane in Soil Gas at the Perimeter of the Landfill and with Concentrations of VOC in Soil Gas near the House

(From: Hodgson, A. *et al*., "Soil-Gas Contamination and Entry of Volatile Organic Compounds Into a House Near a Landfill," Air & Waste Mgt. 42:277-283 (1992))

Compound	Conc. range landfill gas[a] (ppbv)	Conc. range soil gas (ppbv)	Max. soil gas/max. landfill gas
Methane	180,00-	2-1000 ppmv	0.002
Dichloromethane	500,000ppmv	(Perimeter)	0.004
1,1,1-	2,500-51,000	<0.1-2000	0.001
Trichioroethane	<10-13,000	1.4-11	0.008
Tetrachloroethylene	620-18,000	23-150	----
Vinyl chloride	<500-19,000	NM[b]	----
1,2-Dichloroethane	<20-850	NM	----
1,2-Dibromoethane	<1	NM	----
Trichloromethane	<2-980	NM	----
Tetrachloromethane	<5	NM	----
Trichloroethylene	1,600-8,300	NM	----
Benzene	890-4,500	NM	

[a] Landfill gas and perimeter soil gas concentrations are from Reference 1.

[b] Either not measured or not present above limit of detection of ~0.1 ppbv at study site.

of commercial establishments. The Los Angeles County Sanitation Districts have operated the existing Puente Hills Landfill in such a way as to allow highly significant malodorous conditions to occur on adjacent properties, including within Hacienda Heights. There is little doubt that the landfilling of wastes in areas closer to the Hacienda Heights/Sanitation Districts property line will result in even more severe odors due to inadequately controlled landfill gas emissions of odorous and hazardous chemicals. According to the Districts' self-generated Environmental Impact Report (BIR) which was self-certified in December 1992, the expected lifetime cancer risk to individuals living in Hacienda Heights that would be caused by known hazardous chemicals in gaseous emissions from the expanded landfill would be on the order of 10^{-5} risk.

Lee and Jones-Lee (1993a) discussed the fact that measured, known hazardous chemicals represent a small part of the total gaseous emissions of potentially hazardous chemicals from landfills. There are certainly hazardous chemicals in landfill gas emissions that have not been identified or characterized with respect to their potential public health and environmental significance to plants and animals. They concluded that landfill odors should be used as a tracer of potential public health harm associated with both known and unknown gaseous emissions from municipal landfills. If landfill odors are detected on adjacent properties, there is the potential for significant public health harm associated with odorous and non-odorous chemicals in landfill gaseous emissions.

The public health implications of landfill odors go beyond their being a "nuisance" and their being used as tracers for potentially hazardous chemicals. It is well-recognized in the public health literature that malodorous conditions are detrimental to public health. In his "Critical Review: The Health Significance of Environmental Odor Pollution," Shusterman (1992) summarized the findings of a conference organized by the California Department of Health Services devoted to "The Health Effects of Environmental Odor Pollution," which was held at the University of California, Davis in January 1989. The abstract for his summary stated,

"ABSTRACT. Environmental odor pollution problems generate a significant fraction of the publicly initiated complaints received by air pollution control districts. Such complaints can trigger a variety of enforcement activities under existing state and local statutes. However, because of the frequently transient timing of exposures, odor sources often elude successful abatement. Furthermore, because of the predominantly subjective nature of associated health complaints, air pollution control authorities may predicate their enforcement activities upon a judgment of the public health impact of the odor source. Noxious environmental odors may trigger symptoms by a variety of physiologic mechanisms, including exacerbation of underlying medical conditions, innate odor aversions, aversive conditioning phenomena, stress-induced illness, and possible pheromonal reactions. whereas relatively consistent patterns of subjective symptoms have been reported among individuals who live near environmental odor sources, documentation of objective correlates to such symptoms would require as-yet unproven research tools. Therefore, given our current state of knowledge, any differential regulatory response to environmental odor pollution, which is based upon the distinction between community 'annoyance reactions' and 'health effects,' is a matter of legal - not scientific - interpretation."

In his discussion of the impacts of odors on public health, Shusterman (1992) reported that symptoms include headache, nausea, throat irritation, and sleep disturbance. He also reported that odors can exacerbate pre-existing medical conditions. One of the pre-existing medical conditions that may confer hypersusceptibility to odors is bronchial asthma; odorous conditions are known to trigger asthma attacks. They are also known to augment sensitivity to "morning sickness" or nausea during pregnancy.

The National Academy of Sciences National Research Council, Board on Toxicology and Environmental Health Hazards, Committee on Odors from Stationary and Mobil Sources (NRC, 1979) reported, *"Some effects of odors have been studied and are well known. Odors may affect well-being by eliciting unpleasant sensations, by triggering possibly harmful reflexes and other physiologic reactions, and by modifying olfactory function. Unfavorable responses include nausea, vomiting, and headache; induction of shallow breathing and coughing; upsetting of sleep, stomach, and appetite; irritation of eyes, nose, and throat, destruction of the sense of well-being and of enjoyment of food, home, and external environment, disturbance; annoyance; and depression. Exposure to some odorous substances may also lead to a decrease in heart rate, constriction of blood vessels of the skin and muscles, release of epinephrine, and even alterations in the size and condition of cells in the olfactory bulbs of the brain."*

That Committee report also stated,

"Irrespective of the physiologic mechanism of action, persons who live in malodorous environments report adverse somatic symptoms, such as 'odor-induced' nausea and headache."

In a discussion of the control of odors, including hazardous and toxic odors, Hesketh and Cross (1989) summarized the literature on the impacts of odors on communities. They stated,

"In communities close to odorous sources, there may not be excess disease or infirmity, but there certainly is not a state of complete mental, social or physical well-being. This follows from the recognition that prolonged exposure to foul odors usually generates undesirable reactions in people, which can vary from • unease, • discomfort, • depression, • headaches, • irritation, • anger, • nausea, • vomiting."

While it is difficult to identify landfill gas releases as a direct cause of cancer or other diseases, there is no doubt that the highly odorous conditions on properties near MSW landfills are strongly detrimental to public health. Therefore, sufficient controls should be provided so that malodorous conditions do not exist on properties adjacent to or near landfills. Until such time as MSW and other landfills are designed and operated so as to reliably and consistently prevent off-site migration of odors associated with garbage dumping and landfill gas releases, it will be necessary to incorporate sufficient landfill-owned land buffers about landfills for the dissipation (dilution) of odors and thus the avoidance of the public health impacts associated with them.

Another significant concern about landfill gas emissions from municipal and many industrial landfills is their contribution to greenhouse gases (principally methane). As part of the US EPA's landfill gas emissions program, Thornebe (1991) reviewed alr emissions from MSW landfills for background information for proposed standards and guidelines. Subsequently she reviewed the issues of landfill gas (methane) and its role in global climate change (Thornebe, 1994). She pointed out that landfills are considered to be a major source of the greenhouse gas, methane, and noted the need to control landfill gas emissions to reduce the methane input to the atmosphere.

Landfills are typically closed today by the construction of what is characterized as a "low-permeability" cover consisting of a clay layer approximately one foot thick over the top of the solid waste. Until June 1993, the California regional water quality control boards were allowing the closure of landfills with only one foot of soil compacted to achieve a maximum permeability of 1O~6 cm/sec at the time of closure. It has been recognized for many years that a landfill cover of that type will not be an effective barrier to the entrance of moisture into a landfill or to the escape of gases from the landfill. As discussed by Lee and Jones-Lee (1993c), clay and other types of covers for landfills quickly deteriorate from their design permeability characteristics to allow large amounts of water to infiltrate the landfill and gas to escape from the landfill through the cover. Desiccation cracks, differential settling of the wastes that leads to cracks, failure to maintain seals around gas vents and leachate removal pipes that protrude through the cover, plant roots and burrowing animal activities, etc. all serve as significant conduits for passage of water and gas through the cover. As discussed above, increased moisture entering landfills stimulates gas production and leads to even greater adverse impacts from the gaseous releases from the landfill. With the trend toward large, regional mega-landfills, the adverse impacts of landfill gas, including odors and hazardous chemicals, can be greater and more pervasive than those of smaller landfills because of the greater surface area through which gas is emitted.

Attempts are made in many areas of the US today to collect landfill gas through the installation of landfill gas collection systems in landfill covers and/or around landfill perimeters. It has been the authors' experience, however, that landfill gas collection systems are rarely highly effective in collecting landfill gases emitted from a landfill. Part of the problem lies in the inadequacies in design of the collection systems. Significant problems also arise from inadequacies in construction of the systems that lead to system failure and, most importantly, failure of the landfill owner/operator to maintain the landfill gas collection system in a highly effective mode of operation so that most of the landfill gas emissions will be collected for flaring or other processing. On behalf of the California Air Resources Control Board, Emerson (1990) presented suggested control measures to reduce landfill gas emissions. While the focus of his review was reduction of public health hazards from non-methane gases, it has applicability to methane as well.

Eden (1993) discussed the finding that the typical flaring of landfill gas can lead to the formation of dioxin in the flare. It is possible to control dioxin formation in landfill gas flares by changing the design to one that minimizes the conditions that lead to dioxin formation. It appears, however, that the flares conventionally used for landfill gas may be a source of atmospheric dioxins.

While it is not possible to quantitate the adverse impacts of landfill gases on owners and users of nearby properties, there is no doubt that these impacts are highly significant and contribute to the justified opposition to siting of landfills by those who own or use properties near them. Even with so-called state-of-the-art gas collection systems, there still will be periods during the active life of the landfill associated with the dumping of the garbage when highly offensive odors can migrate for distances of a mile or more downwind of the landfill.

Landfill Leachate

Sanitary landfills are notorious for causing adverse impacts on domestic water supply groundwater quality. The Resource Conservation Recovery Act (RCRA) evolved out of concern about impacts of municipal landfills on groundwater quality. It has been well-known since the 1950's that sanitary landfills and municipal dumps have had significant adverse effects on groundwater quality (Todd and McNulty, 1976). Further, it is also recognized that contamination by municipal solid waste landfill leachate renders groundwater unusable for domestic water supply purposes. By the 1970's it was becoming widely recognized that MSW landfill leachate contained a variety of potentially highly hazardous chemicals that represent a significant public health threat to those who consume waters contaminated by leachate. Of particular concern are the chlorinated solvents and other chemicals, such as benzene. Prior to the 1980's, industry and commercial establishments were allowed to place what are now considered to be highly hazardous chemicals in municipal landfills. With the implementation of RCRA, the legal disposal of large amounts of such chemicals in MSW landfills was prohibited. However, the illegal disposal from industrial/commercial sources is well-known to occur. Further, significant quantities of highly hazardous chemicals are legally disposed of today through the municipal solid waste stream from household, commercial, and industrial activities so that even today's landfills contain VOC's, heavy metals, and other chemicals that are potentially highly hazardous to public health.

Brown and Nelson (1990) discussed toxic constituents in MSW landfill leachates and pointed out that many of the products used in the home and commerce are potentially highly hazardous to public health and the environment. They also presented typical concentration ranges of potentially hazardous organic chemicals and metals in such leachate. For those contaminants having drinking water standards, they compared the median concentrations to those standards. They found that a wide variety of constituents in MSW leachate have concentrations were above existing drinking water standards. Brown and Donnelly (1988) estimated the risk associated with organic constituents in "hazardous waste" landfill leachate and municipal solid waste landfill leachate. They concluded that MSW landfill leachates were only slightly less hazardous than the leachates from "hazardous waste" landfills.

More recently, Jones-Lee and Lee (1993) summarized the characteristics of municipal landfill leachate and discussed their implications for municipal solid waste management for the protection of groundwater quality. Table 4 presents a summary of the types of constituents of concern in municipal landfill leachate that can be hazardous or otherwise deleterious to the quality of groundwater used for domestic water supply purposes. These include "conventional pollutants," "priority pollutants" (certain "hazardous" chemicals), and "non-conventional pollutants." Table 5 identifies and presents concentrations ranges and "average" concentrations for some of the hazardous and "conventional" pollutants characteristic of conventional municipal solid waste leachate of the early to mid-1980's. It indicates the presence of many known chemicals in concentrations that can readily render a groundwater unusable for domestic water supply purposes.

Included in the "conventional pollutant" classification are high concentrations of biochemical oxygen demand (BOD), total dissolved solids (TDS), NaCl, hardness, H_2S (hydrogen sulfide), ammonia, iron, manganese, etc. The biochemical oxygen demand of municipal landfill leachate on the order of 10,000 mg/L of BOD_5 means that municipal landfill leachate has a tremendous potential to remove the dissolved oxygen from groundwaters, converting them to anoxic/anaerobic conditions. Typical groundwaters have about 10 mg/L dissolved oxygen; there is little opportunity to resupply the O_2 since it has to come largely from infiltration of precipitation and air migration through the soil. The rendering of a groundwater anoxic/anaerobic can have significant implications for the transport and transformation of constituents in MSW landfill leachate or that may be in the groundwater from other sources as a result of chemical/biochemical reactions that lead to the formation/solubilization of *contaminants that are ordinarily not present in oxygenated groundwaters. These include iron, manganese, hydrogen sulfide, various heavy metals, and vinyl chloride. The vinyl chloride that is typically present in MSW landfill leachate arises from anaerobic bacterial dehalogenation of chlorinated solvents such as TCE and PCE.*

Table 4
Leachate from Municipal Solid Wastes
"Garbage Juice"

- Highly Concentrated SOUP of Chemicals - *Even Low Concentrations Can Have Adverse Impacts on Domestic Water Supply Water Quality*

Conventional Pollutants

- Oxygen Demand - TOC, COD
- Odorous Chemicals
- TDS
- Sodium
- Ammonia
- Hardness
- Iron
- Manganese
- H_2S
- Alkalinity

Priority Pollutants

- Heavy Metals – Pb, Cd, Hg, Cu, etc.
- Organics – Solvents, Vinyl Chloride, etc.

Non-Conventional Pollutants

- 95% of Organics in Leachate
  Not Characterized
  Hazards Unknown
  Transformations Unknown

Jones-Lee and Lee (1993) also discussed the potential importance of what are called "non-conventional" contaminants or pollutants in municipal landfill leachate. MSW landfill leachate contains large amounts of organic carbon that includes a broad array of hazardous, otherwise deleterious, and non-hazardous chemicals that are not characterized for their potential hazards and are not identified or looked for in chemical analysis regimens. Only a few percent of the total organic carbon present in municipal landfill leachate is normally characterized in any groundwater pollution study. The potential hazards to public health and environmental quality associated with most of the organic chemicals contained in leachate are unknown.

Table 5
Concentration Ranges for Components of Municipal Landfill Leachate

Parameter	"Typical" Concentration Range	"Average"*
BOD	1,000 - 30,000	10,500
COD	1,000 - 50,000	15,000
TOC	700 - 10,000	3,500
Total volatile acids (as acetic acid)	70 - 28,000	NA
Tota Kjeldahl Nitrogen (as N)	10 - 500	500
Nitrate (as N)	0.1 - 10	4
Ammonia (as N)	100 - 400	300
Total Phosphate (PO_4)	0.5 - 50	30
Orthophosphate (PO_4)	1.0 - 60	22
Total alkalinity (as $CaCO_3$)	500 - 10,000	3,600
Total hardness (as $CaCO_3$)	500 - 10,000	4,200
Total solids	3,000 - 50,000	16,000
Total dissolved solids	1,000 - 20,000	11,000
Specific conductance (mhos/cm)	2,000 - 8,000	6,700
pH	5 - 7.5	63
Calcium	100 - 3,000	1,000
Magnesium	30 - 500	700
Sodium	200 - 1,500	700
Chloride	100 - 2,000	980
Sulphate	10 - 1,000	380
Chromium (total)	0.05 - 1	0.9
Cadmium	0.001 - 0.1	0.05
Copper	0.02 - 1	0.5
Lead	0.1 - 1	0.5

Nickel	0.1 - 1	1.2
Iron	10 - 1,000	430
Zinc	0.5 - 30	21
Methane gas	60%	
Carbon dioxide	40%	

All values mg/L except as noted
NA - not available
After: Lee et al. (1986) *From CH2M Hill based on 83 landfills (1989)

There are approximately 60,000 chemicals used in everyday commerce in the United States. Fewer than 200 of them (Priority Pollutants and others) are normally analyzed for in any groundwater pollution study of landfill leachate. Every few years a new highly hazardous chemical is found in the environment. A few years ago dioxin, one of the most hazardous chemicals known to man, was unknown in the environment. Dioxin has now been found to be ubiquitous in the environment and to be derived from a wide variety of sources. It is certainly inappropriate to conclude that the last "dioxin" has been found and that there will be no new "dioxins" ever found in municipal landfill leachate in the future.

In 1992 Gintautas et al. found in municipal landfill leachate a phenoxyalkanoic acid herbicide derived from its use in home gardens. Gintautas et al. (1992) 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."

Jones-Lee and Lee (1993) discussed the impossibility of eliminating hazardous and otherwise deleterious chemicals from the municipal solid waste stream. Even if all illegal dumping of hazardous waste in municipal landfills were stopped, household hazardous waste derived from products used in everyday activities would still represent a significant source of chemicals for landfill leachate that are potentially highly hazardous to public health. While some areas attempt to address this problem by instituting programs to collect household hazardous waste, such programs will not eliminate hazardous and otherwise deleterious chemicals from MSW landfills. Further, the landfill operators load checking programs which are purported to be designed to keep hazardous waste out of landfill are largely cosmetic and ineffective in preventing large amounts of hazardous chemicals from being present in municipal solid wastes that are deposited today in MSW landfills. Most of the organics present in MSW landfill leachate that are not identified or characterized yet could represent public health hazards to those who would drink leachate-contaminated groundwater. Furthermore, many of the conventional pollutants can be deleterious to the quality of groundwater for use for domestic water supply purposes and therefore, even without hazardous chemicals in leachate, the pollution of groundwater by such leachate would render the groundwater unusable for domestic purposes.

While it is common for landfill proponents today to assert that no "hazardous waste" will be placed in a proposed municipal landfill, such claims are highly misleading. It is clear from the discussion above that such claims do not mean that no highly hazardous or otherwise deleterious chemicals would be placed in the landfill. Furthermore, as discussed by Jones-Lee and Lee (1993) the US EPA's and many states' approaches for classification of waste as "hazardous" and "non-hazardous" is arbitrary and allows hazardous chemicals (chemicals which cause hazardous waste to be classified as such) to be present in municipal solid waste at concentrations just under the arbitrarily-developed "hazardous waste" designation concentration limit. The fact is that municipal solid waste leachate will always be highly hazardous to the use of leachate-contaminated groundwater for domestic water supply purposes.

One of the most significant problems with federal and state regulatory approaches governing landfilling of municipal solid wastes is that the regulatory agencies allow pollution of groundwaters by landfill leachate up to drinking water standards. It is presumed that as long as drinking water standards (MCL's - Maximum Contaminant Levels) are met, the groundwater is safe to drink. That presumption, however, ignores the fact that there are not MCL's for all of the potentially hazardous chemicals that could be present in MSW landfill leachate. Ignored is the presence of unidentified, hazardous chemicals in the group of non-conventional pollutants known to be present in MSW landfill leachate. It is unjustified to presume that all highly hazardous chemicals have been identified and characterized and that garbage juice (leachate) is hazardous only if the concentrations of a few chemicals that are regulated are above drinking water standards. While such an approach is bureaucratically simple to administer, it is not technically valid. As discussed by Jones-Lee and Lee (1993), it is prudent public health policy to assume that any contamination of groundwaters by MSW landfill leachate represents a hazardous situation to the public health of those who consume the waters, even if the concentrations of all regulated contaminants measured in the groundwater are below the drinking water standards.

It is important that the impact of leachate on groundwater quality be examined from a domestic water supply perspective rather than from a waste discharger's perspective as is typically done today. The MSW discharger's perspective is typically minimizing costs to just achieve regulatory compliance. Just meeting existing regulatory requirements for landfill characteristics or MCL's for drinking water, however, has not been and cannot be considered necessarily adequate to protect public health and groundwater resources from pollution by landfill leachate. Further, once polluted by MSW landfill leachate, a groundwater and associated aquifer cannot be restored so as to ever provide again a reliable domestic water supply. Jones-Lee and Lee (1993) and

Rowe (1991a) have discussed the impossibility of ever removing all leachate-derived chemicals from an aquifer.

It is important to understand that all chemicals can be toxic - adverse to human health. The toxicity of a chemical is determined by the concentration of toxic-available forms that are absorbed into the body and the duration of exposure to that chemical. Table salt, sugar, etc. are toxic when taken in sufficient concentrations for a sufficient time. The primary chemicals of concern in evaluating the impacts of landfills are those chemical contaminants that are toxic to humans at concentrations that are typically found in MSW leachate-contaminated groundwaters, that increase the potential of an individual who consumes the leachate-contaminated groundwater to contract cancer, or that lead to birth defects and/or mutations. Also of major concern are those chemicals that are aesthetically unpleasant or adverse to the economic welfare of those who use leachate contaminated groundwaters for domestic purposes such as shortening the useful life of appliances, plumbing and clothing and other washed cloth.

The municipal water supply literature repeatedly documents the importance of controlling the malodorous character of waters. One of the primary reasons the public uses such large amounts of bottled water today for drinking purposes is undesirable odors in municipal drinking waters. Californians are spending more than $1 billion annually for bottled water and special household water treatment devices because of undesirable tastes and odors in municipal supplies as well as concerns about chemical contaminants. Many of the adverse physiological and psychological responses discussed above in association with odorous conditions in landfill gaseous emissions are also applicable to malodorous conditions in drinking water contaminated by landfill leachate. Thus, the contamination of groundwater by landfill leachate is a threat to public health not only because of toxic chemicals that cause disease, but also because of obnoxious chemicals that cause adverse physiological and psychological responses.

WRCB Chapter 15 governing landfilling of municipal solid waste in the State, requires protection of groundwater from all use-impairment including those that might be classified as a "nuisance. The Porter-Cologne Act (WRCB, 1989) defines nuisance as follows:

"Nuisance" means anything which: (1) is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property, and (2) affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal, and (3) occurs during or as a result of the treatment or disposal of wastes.

Many of the adverse impacts of MSW landfills on nearby property owners/users that are not considered to be direct human health threats or classical disease impacts, are clearly nuisances that should be controllable through the Porter-Cologne Act. Unfortunately, however, the regulatory agencies responsible for protection of health, welfare, and interests of those who are adversely affected by solid waste management in landfills and for that matter for other waste management units rarely take action against landfill owner/operators to prevent the waste management practices that only cause a nuisance from adversely affecting those within the sphere of influence of the landfill. This situation may be changed as a result of the new citizen suit provisions of the US EPA's Subtitle D regulations.

While most of the water quality concerns about MSW landfill leachate rest in its potential impact on groundwater quality for domestic water supply use, there are situations in which MSW landfill leachate enters surface waters where it can pose threats to aquatic life and other beneficial uses. There are principally two ways in which leachate can contaminate surface waters. One is the discharge of leachate-contaminated groundwater to surface waters through springs or subsurface discharge, and the other is the discharge of leach ate collected in a leachate collection and removal system, usually after some treatment, to surface waters. Typically MSW landfill leachate treatment is accomplished today by dilution at a POTW (publicly owned treatment works - municipal wastewater treatment plant). Because of its highly concentrated nature, MSW landfill leachate, even in small amounts, can upset the operations of such plants and readily lead to violations of discharge limitations for them. It is becoming increasing recognized that conventional POTW treatment of MSW landfill leachate may not be adequate to protect the aquatic life-related designated beneficial uses of surface waters into which they are discharged. Specific, extensive additional treatment is often needed to achieve such protection.

Aquatic life is more sensitive than people to adverse impacts from many chemicals, and leachate contains high concentrations of a wide variety chemicals that are potentially toxic to, otherwise deleterious to, or bioaccumulate in aquatic life and other wildlife. In the past, the significance of the accumulation of chemicals such as chlorinated hydrocarbon pesticides, PCB's, and mercury, in tissue of aquatic organisms was assessed based on Food and Drug Administration (FDA) Action Levels that consider not only health impacts but also economic factors. With the shift toward cancer risk-based standards for evaluating the accumulations of chemical contaminants in aquatic life tissue, the allowable tissue concentrations are being reduced. As part of the US Great Lakes Initiative, the US EPA recently proposed wildlife-based bioaccumulation criteria which for some chemicals are several orders of magnitude lower than those of the FDA and US EPA.

Therefore, great care must be exercised in allowing MSW landfill leachate to enter surface waters, even after the leachate receives treatment of the type typically practiced today, in order to prevent toxicity to aquatic life and/or the bioaccumulation of potentially hazardous chemicals in aquatic life tissue to cause adverse impacts to man and other animals that use aquatic life as a source of food.

In addition to containing hazardous and otherwise deleterious chemicals, municipal solid waste streams have contained, and still contain, notable amounts of human and animal fecal material. Domestic wastewater treatment plant sludge and septic tank pumpage have been disposed of in MSW landfills. Approximately 2% of current MSW is disposable diapers, a portion of which contain fecal material. Further, manure from pets and other animals is deposited in MSW landfills. Human and animal fecal material contains bacteria, viruses, and protozoans which if ingested, can readily cause a variety of enteric diseases in people. There is little information on the long-term survival of human enteric pathogens in MSW landfills. The bacteria and enteroviruses would not be expected to persist in a landfill for long periods of time. However, cyst-forming protozoans could represent a long-term threat to the health of those who have contact with MSW and its leachate, and leachate-contaminated waters.

In their report on the "Public Health Significance of Waterborne Pathogens in Domestic Water Supplies and Reclaimed Water" Lee and Jones-Lee (1993d) summarized the current information on human disease associated with waterborne pathogens. Organisms that cause classical enteric diseases such as typhoid fever, dysenteries of various types, and cholera, are present in human feces and their threat has long been the focus of concern. During recent years, emphasis on human pathogens in fecal material has been broadened to include greater consideration of enteroviruses and cyst-forming protozoans. In the spring of 1993, Cryptosporidia, cyst-forming protozoans, in the city of Milwaukee, WI's municipal water supply killed an estimated 80 people and were reported to have caused illness in more than 400,000 people. That outbreak raised new concerns about the need for more effective control of human pathogens in domestic water supplies. It is well-recognized that domestic water treatment as commonly practiced cannot be relied upon to produce a treated water that is free of human enteric pathogens. Further, the approaches used for assessing the microbiological safety of domestic water supplies, based on the quantification of coliforms, are not reliable for assessing the risk of disease from enteric viruses and cyst-forming protozoans in water supplies; coliforms are readily killed by the chlorination that typically takes place in water treatment while enterovirus and cyst-forming protozoans are more resistant to destruction by such chlorination.

Lee and Jones-Lee (1993e) discussed the current information on the transport of waterborne enteric pathogens through groundwater systems. They reported that inadequately disinfected domestic wastewaters recharged into aquifers can represent a significant source of human pathogens for domestic water supplies. While bacteria and cyst-forming protozoans are typically not transported for long distances in homogeneous sand and other fine-grained aquifers, enteroviruses can be transported for considerable distances in such systems. Transport of all of those pathogens would be greater in aquifer systems containing fractured rock or limestone. From the information in the literature it appears that for protection of groundwater supplies from enteroviruses in wastewater recharged into fine-grained aquifer systems, there should be on the order of one year's travel time allowed between the recharge of the wastewater and the withdrawal of the groundwater for domestic use. Considerably greater distances/time would have to be allowed in fractured rock or limestone aquifers.

Similarly, it is possible that domestic groundwater supplies located near an MSW landfill could be contaminated with enteroviruses and, in fractured rock or limestone regions, with cyst-forming protozoans. An intact, well-functioning Subtitle D composite liner would be expected to provide protection of the surrounding substrata and aquifer from contamination by pathogens in landfill leachate. While pathogens could pass through holes that are present in the flexible membrane liner component of a composite liner, the 2-ft thick compacted clay component of it would likely be effective in reducing the transport of pathogens from the landfill to the substratum. However, it is recognized that the compacted clay components of Subtitle D-type composite liners are subject to structural failures due to inadequate development of liner bases, resulting in cracks in the clay layers. Cracking or other such breeches of the clay layer of a composite liner would be expected to allow the passage of pathogens out of a landfill and into the surrounding substrata. In general, it would be expected that the likelihood of humans' acquiring disease from waterborne pathogens in MSW landfill leachate transported via groundwater is small; the public health concerns associated with other components of leachate-contaminated groundwater would likely be greater.

Another important aspect of the public health significance of human pathogens in MSW is the ability of disease vectors such as flies, seagulls, rodents, and other animals commonly present at a landfill, to carry the pathogens from the landfill. While such vectors should be highly effectively controlled at the open dumping face of a landfill, the control of vectors at MSW landfills is typically only partially effective. Therefore, those living or working on, or otherwise using lands within the transport distance of vectors, could acquire enteric disease from the landfill. In general, it is likely that such disease would occur as isolated cases and not necessarily traced to the landfill source because of the vector mode of transport.

Fugitive Dust Emissions

Blowing dust can be a problem for property owners/users near landfills, especially at those landfills having heavily used dirt roads. Dust and other particulate emissions to the atmosphere, such as those from diesel trucks, are of concern to those who own or use properties downwind of dust-generating areas, not only for aesthetic and economic reasons but also for reasons of public health. It is becoming commonly recognized that PM_{10} particles (particulate matter less than 10 microns in diameter) in dust are a significant health hazard, especially for sensitive populations such as those who suffer from asthma. Active-life operations and post-closure conditions of landfills should not be allowed to create additional atmospheric particulates (dust) on properties adjacent to or near a landfill.

In the past regulatory agencies have allowed landfill owners to spread landfill leachate on roadways to suppress dust. This practice can readily lead to significant surface water pollution by a wide variety of chemical contaminants and pathogenic organisms in the leachate when precipitation events lead to runoff from the areas that have received the leachate. In some areas, the use of leachate for dust control is no longer allowed because of the potential for environmental pollution by contaminants in the leachate. A landfill owner/operator should have responsibility to maintain an appropriate vegetative cover on a closed landfill ad infinitum as part of their responsibility to prevent migration of airborne particulates downwind of the landfill property.

Superfund Sites and Public Health

With more than 20 billion dollars' having been spent on Superfund site investigations and remediation, and several hundred billion dollars more scheduled to be spent on industrial and military sites, it might be assumed that a well-defined link has been established between the release of chemicals from Superfund sites and illness of those who live on, work on, or otherwise utilize areas near such sites. Since many of those sites are former municipal landfills, examination of the Superfund site data might be expected to provide some insight into the public health hazards of municipal landfills. However, a critical review of how Superfund sites have been designated and investigated and the information generated shows that in general the federal and state Superfund programs provide little information on the public health impacts of MSW landfills and other Superfund sites.

The US EPA and state Superfund programs are primarily focused on the perceived increased risk of those who are exposed to gaseous and especially liquid releases from the site, to acquire cancer. At this time there has been no demonstrated cause and effect relationship developed between the releases of chemical contaminants from Superfund and other similar types of sites that contain large amounts of potentially hazardous chemicals, some of which have migrated off-site, and adverse health effects on those who live on, work on, or otherwise use properties near the site. In fact, there is considerable discussion in the technical literature as well as in the popular press about the cost-effectiveness of the Superfund program in the prevention of deaths due to exposure to the chemicals that are regulated by that program. As noted elsewhere in this report, federal and state Superfund programs focus largely on the Priority Pollutants which are primarily chemicals which, in very high doses, have been found to cause tumors in rodents.

An International Congress on the Health Effects of Hazardous Waste was held in May 1993 in Atlanta, Georgia. That Congress included consideration of the evidence for direct health effects associated with Superfund sites. While the proceedings of that conference have not yet been published, one of its organizers, John S. Andrews, Jr., M.D., indicated that while it appears that there may be increased infirmity among those who live near Superfund sites, the available evidence is not such that a direct link can be made between chemical releases from such sites and public health impacts (Andrews, 1994). What appears to be an increase in infirmity could be related to socio-economic status and/or ethnic heritage since in general those residing near Superfund sites tend to be economically disadvantaged and of a non-Caucasian heritage. The sensitivity of epidemiological methodology in investigating the cause of illness in a limited population is such that very large dramatic impacts must occur in the population being investigated in order to enable those impacts to be clearly discerned from the illness that otherwise occurs in the general population. This does not mean that there are not adverse health effects on individuals in the populations living near Superfund sites. It does mean, however, that such illness cannot be distinguished from the general background illness that occurs in the US today.

Plumb (1989) conducted a review of the groundwater data that have been collected from groundwater monitoring near Superfund sites across the country. He found that more than 50% of the many thousands of samples that had been collected at the time of his study contained trichloroethylene (TCE). The average concentration of TCE found in groundwater samples was about 2,000 μg/L, indicating that there is widespread contamination of groundwaters near Superfund sites by TCE. TCE is a Priority Pollutant that has been found to cause tumors in some rodents exposed to high concentrations. The US EPA drinking water standard (MCL) for TCE is 5 μg/L. Based on the US EPA's current approach for assessing the upperbound cancer risk associated with consuming water containing a contaminant at the MCL, 5 μg/L TCE represents an upperbound increased cancer risk of one additional cancer in 1,000,000 people who consume 2 liters per day of water containing that concentration of TCE for their lifetimes (70 years).

If it is assumed that the increased cancer risk associated with drinking water containing 5 μg/L TCE is one in one million (it will certainly be less and likely significantly less than that), then a groundwater that contains 5,000 μg/L of TCE would represent an increased cancer risk of about one additional cancer in 1,000 people who consume 2 liters of the water per day over their 70-year lifetimes. Given that the background lifetime cancer risk from all other sources of carcinogens (few of which are associated with environmental and anthropogenic chemicals) is one in three people, it is not surprising that there is no correlation between increased cancer risk near Superfund sites and the presence of TCE or other rodent carcinogens or some known human carcinogens such as vinyl chloride that are being regulated under the federal and state Superfund programs. It should be noted, however, that water containing 5,000 μg/L TCE along with the other chemicals present at Superfund sites would likely be so highly contaminated with a wide variety of chemicals that it would be repulsive to consume and would be lost for use as a domestic water supply, even to individuals with their own water supply wells. As discussed by Lee and Jones (1992a), the high background cancer rates in the US population due to non-anthropogenic carcinogen sources mask increases in cancer risk due to consumption of domestic water supplies, even those containing contaminants with a projected upperbound cancer risk of one in 1,000.

The failure to link increased cancers with consumption of waters contaminated by Superfund site-derived chemicals cannot be interpreted to mean that MSW landfill leachate-contaminated groundwaters are safe to consume. As discussed above, there are many adverse impacts other than cancer that can be caused by such contamination.

DiZio et al. (1994) of the Human and Ecological Risk Section of the Office of Scientific Affairs, Department of Toxic Substances Control, California Environmental Protection Agency (Cal EPA), conducted a study of the expected public health risk associated with managing hazardous substances (wastes) in California as part of the Cal EPA Comparative Risk Project. Included in that study was the estimation of the populations potentially exposed to a variety of potentially hazardous chemicals in water, soil, and air at a variety of locations that contained elevated concentrations of potentially hazardous chemicals. Insufficient information was available to enable DiZio et al. to develop quantitative risk assessments for human population exposure to hazardous chemical releases from Superfund sites. DiZio et al. encountered the same problems in the ability to estimate the impacts of emissions from California Superfund sites and existing hazardous waste management facilities that were discussed above for municipal and industrial non-hazardous waste landfills. The DiZio et al. study concluded:

" • Ground water contamination by release of hazardous substances onto land from hazardous waste sites and hazardous waste facilities has the potential for widespread public exposure.

• Soils contamination which occurs in areas where direct public contact exists or is probable is associated with high human health risks.

• Permitted facilities are numerous and are potential sources of continuing low levels of exposure to large populations. The volume of hazardous waste generated annually (1.9 million tons) carries the potential for high human health risks to large populations if regulatory oversight programs are not in place.

• Additional efforts are necessary to evaluate the potential human health threats posed by accidental sudden releases of hazardous substances into the environment."

The authors of that report noted that because of the significant regulatory programs that are in effect, the actual hazards to the public today associated with hazardous chemicals (wastes) at inactive hazardous wastes sites (a number of which were former landfills) and at hazardous waste management facilities, are small. Regulatory requirements dictate that those hazards be "de minimus." Those authors expressed concern that without adequate regulatory programs the contamination of groundwaters by potentially hazardous chemicals could lead to widespread public exposure to these chemicals through their domestic water supplies.

The ultimate expenditure of several hundred billion dollars nationally in Superfund site investigation and remediation can be expected to have an insignificant impact on the cancer risk to the general population as well as to those who live on, work on, or otherwise utilize properties near Superfund sites. This is because of the high background levels of cancer in the US population due to other causes including natural carcinogens in food, as well as to the insensitivity of epidemiological methods in detecting small changes in cancer incidence in the limited populations that are impacted by Superfund sites. It is important to note that with a few well known exceptions, no more than a few hundred people would likely be exposed to significantly elevated concentrations of chemicals from Superfund sites for a significant part of their lifetimes. That conclusion should not be interpreted to mean that the Superfund program should not be carried out. Without such a program the releases of potentially hazardous and otherwise deleterious chemicals from Superfund sites would continue with a concomitant loss of groundwater resources for use by future generations. While no attempt should be made to justify the Superfund expenditures based on achieving a perceptible change in the cancer risk for the US population, such a program is justified based on the need to protect groundwater resources, especially for use by future generations.

In evaluating the potential hazard of municipal solid waste landfills, including those that have become Superfund sites, it is important to put in context the rate of movement of groundwaters contaminated by chemicals from the site. Typically, groundwaters move at the rate of about 0.1 to 1 ft/day, or 30 to 300 ft/yr. This means it can take a considerable period of time after the first off-site releases occurs at a Superfund site for widespread contamination of groundwaters by these releases to occur. The slow rate of movement coupled with the relative recency (post-World War II) of the emergence of the chemical industry in the US limits the groundwaters that have been polluted by Superfund sites thus far to those typically fairly close to the site. Without remediation programs, however, there will be continued spread of the potentially highly toxic chemicals and otherwise deleterious chemicals from those sites, with ever-increasing loss of groundwater resources. As with MSW-leachate-contaminated groundwaters, there is little possibility that aquifers polluted by chemicals present at many Superfund sites can be cleaned up to render reliable water supplies. The remediation programs at most Superfund sites must therefore be directed toward preventing further spread of the contaminants, which typically includes reducing the magnitude of the source of the contaminants and cleaning up the contaminated areas of the aquifer to the maximum extent practicable.

It, therefore, may be concluded that the Superfund program nationally or in California has not provided definitive information on the potential hazards associated with living on, working on, or otherwise utilizing properties within the sphere of influence of Superfund sites. This is due to a considerable extent to the focus of a Superfund program on a limited number of rodent carcinogens.

Public health assessments typically consider all forms of infirmity including classical illness associated with pathogenic organisms, acute and chronic illness arising from exposure to chemicals at concentrations above their toxic thresholds, as well as cancers, mutations, and birth defects. These are the types of infirmities that are being considered by the Human Health Committee of the Cal EPA Comparative Risk Project. It is recognized in the public health field, however, that of equal importance is the infirmity associated with insults to the body senses including tastes, odors, hearing, sight, and touch. To many individuals facing such situations, infirmity arising from obnoxious odors, unsightly situations, excessive noise, etc. is just as important as classical disease. Such insults are however often classified as "nuisance" and are not recognized for the damage they do to an individual's psyche - "the body politic." While an occasional exposure to unpleasant or obnoxious situations seems to have limited adverse health impacts for most individuals, repeated exposure to such situations can be highly debilitating and adversely impact many aspects of an individual's activity. While MSW landfills can and do adversely impact personal health due to excessive concentrations of highly toxic chemicals, carcinogens, mutagens, teratogens, far more infirmity is caused by the repeated exposure to the highly obnoxious conditions that occur from improperly sited, managed, and maintained landfills during their active lifetimes, and after closure. For example, the odors from municipal landfills can readily cause an exposed individual to experience anxiety and depression; they certainly place an additional burden on the individual and diminish his/her sense of well-being. This, in turn, can lead to an altered sense of well-being that is manifested throughout the individual's dally activities. An evaluation of the adverse impacts of a landfill that is restricted to "body count" of deaths from exposure to highly hazardous chemicals released from an MSW or other landfill falls to recognize the full magnitude of the adverse impacts of landfills on those in the sphere of influence of the landfill.

Lined Landfill vs Classical Unlined Sanitary Landfills

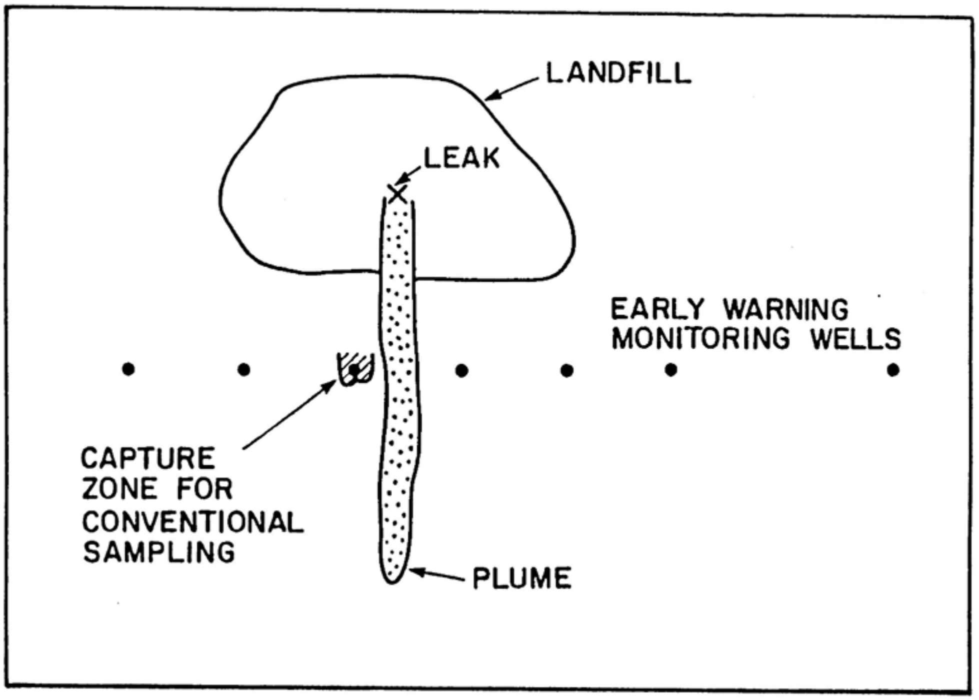
Landfill applicants and some regulatory agencies often assert that today's "modern," high-tech, lined landfills will be less hazardous to public health and the environment than the unlined classical sanitary landfills that were used prior to the 1990's in many areas. The facts are, however, that today's lined landfills represent about the same hazard to overall groundwater quality as many municipal landfills that received waste at the time when there were limited restrictions on the amounts of industrial hazardous waste that could be placed in a municipal landfill. While certainly some of the municipal landfills that received large amounts of highly hazardous chemicals of industrial origin contained higher concentrations of many of the constituents of the greatest concern today in Superfund site investigations, it is important to note that the Superfund program is not directed toward protecting groundwater quality from all use impairments, but rather is focused largely on the control of a few known chemicals that have been found to cause tumors in rodents at very high concentrations compared to normal ambient concentrations that occur in groundwaters even at Superfund sites.

Superfund site remediation programs in general cannot be relied upon to "clean up" groundwater to the point that it could be safely used for domestic water supply, because of the presence of non-conventional contaminants in MSW leachate. As discussed elsewhere in this report, the contamination of a groundwater with MSW landfill leachate destroys the use of that groundwater for domestic purposes. It also destroys the ability to use that part of the aquifer for conjunctive use storage of surplus surface waters that occur in wet years within the aquifer by enhanced groundwater recharge. While the leachate that is produced in municipal solid waste landfills today may be somewhat less of a threat to domestic water supply water quality from the perspective of certain "rodent" carcinogens that are being regulated as part of RCRA, it is not significantly different from the leachate produced in the past from the perspective of its ability to destroy the use of a groundwater and associated aquifer areas for domestic water supply purposes.

It is also argued by landfill proponents that the modern, "high-tech" liner systems of today's landfills provides a mechanism whereby leachate generated from the buried, untreated wastes will not reach groundwater to pollute it. The fact is, however, as discussed subsequently that the lining of landfills as being practiced today, with plastic sheeting and a compacted soil layer, at best only somewhat postpones leachate-pollution of groundwater hydraulically connected to the landfill area. Furthermore, for many types of landfills, especially the Subtitle D single-composite-lined landfill, the liners create conditions that make the detection of incipient groundwater pollution very difficult.

As discussed by Lee and Jones-Lee (1994b) and Lee and Jones (1992b), the groundwater monitoring programs being used today for lined landfills were developed based on the presumption that landfill leachate develops and moves from the landfill as a broad plume across the landfill, as may be expected for an unlined landfill in a uniform porous medium. Where leachate moves in that manner, the conventional monitoring approach of several vertical monitoring wells located down-groundwater-gradient from the landfill, could be expected to detect leachate-polluted groundwaters since essentially all of the landfill bottom area would be polluting the groundwater. However, the initial leakage of leachate from lined landfills will not be over the entire landfill bottom, but will be through holes, rips, or tears in the plastic-sheeting liner. Leachate emanates from those point sources of leachate-leakage as narrow, finger-like plumes a few feet wide at the point of compliance for groundwater monitoring (Cherry, 1990). This is illustrated in Figure 1. With vertical groundwater monitoring wells' being spaced hundreds to a thousand or 50 feet apart at the point of compliance, and with each monitoring well's having an effective zone of capture of only about 1 ft about it, the likelihood of the groundwater monitoring wells' being able to detect the initial leachate-pollution of groundwater before widespread pollution occurs is extremely remote. As discussed by Lee and Jones-Lee (1993f,g) the US EPA's Subtitle D groundwater monitoring program which is essentially the same as the state of California WRCB groundwater monitoring program is conceptually flawed and offers little protection of groundwater resources from pollution by landfill leachate. Lee and Jones-Lee (1993h, 1994b) discussed alternative monitoring approaches for detection of leachate-leakage from lined landfills that offer the real potential to detect the passage of leachate through a Subtitle D-type composite liner shortly after it occurs, and thereby provide an early warning of potential groundwater pollution before it occurs.

Figure 1. Pattern of Landfill Leakage - Groundwater Contamination from Lined Landfills (after Cherry, 1990)



In its proposal of Subtitle D regulations for municipal solid waste landfills, the 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."

The US EPA 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."

Such statements were omitted from the October 1991 (US EPA, 1991) final promulgation of these regulations. Instead, the Agency now claims that Subtitle D landfills, with a single composite liner, should be protective of public health even at poor locations.

This appearance of reversal in the US EPA's position was surprising because no new information had been developed between 1988 and 1991 that would justify a claim that the inevitable failure of a plastic sheeting and soil liner system will not occur at any time during which the wastes in the landfill remain a threat to groundwater quality. In fact, that period of time brought forth increasing evidence to support the 1988 position of the Agency of the eventual failure of the liner system to contain the waste components within the landfill. A review of the basis for the change in the US EPA's position shows that the Agency made a number of overly optimistic, inappropriate assumptions about the characteristics of leachate emissions from landfills and the magnitude of the exposed population to these emissions, and did not address the issue of the groundwater's needing to be protected for as long as the wastes in the landfill represent a threat, i.e., essentially forever. The Agency did not conclude in its 1991 statement that there was any fundamental improvement in the longer-term groundwater quality protection properties of the liner systems that are being used for "dry tomb" landfills. According to Clay (1991), then the Assistant Administrator for Solid Wastes and Emergency Response for the Agency, the landfill liner systems described in Subtitle D will eventually fall to prevent leachate from migrating out of the landfill. In order to get the regulations implemented after the very long delay that had occurred after they were first proposed, it was necessary to set up a highly optimistic release and exposure scenario that in reality significantly underestimated the real exposures that could take place from the Subtitle D landfills.

For example, in making the claim that its single-composite-liner approach was protective of public health, even at sites unsuitable for landfills, the US EPA assumed that only those individuals who live within one mile of a landfill would be adversely affected over the next 300 years. It was also assumed that only 1.6 people would live or otherwise be impacted within one mile of the landfill during that 300-year period. Furthermore, the only "public health" concern considered was the added risk of those 1.6 people's acquiring cancer. For the purposes of that evaluation and claims that its approach would be "protective," the destruction of a region's groundwater resources for domestic water supply use by chemicals that are typically present in MSW landfill leachate but that do not cause cancer was not considered to be of significance. The Agency focused only on cancer production. It is evident that the basis for the claim that a single-composite-liner of the type allowed by Subtitle D landfills will be "protective" of groundwater resources has no technical foundation, and that it is simply a political statement with little relevance to the real world that will exist near many landfills.

One of the most significant problems with the US EPA's approach toward addressing the environmental and public health hazards associated with the "dry tomb" landfilling approach for management of solid waste and solid waste residues, is its failure to focus on the broader context of water quality impairment. The public, whose water supply is being or stands to be impacted by a landfill, is concerned with all aspects of use-impairment of the water for domestic purposes. In addition to potential impacts from non-carcinogenic hazardous chemicals, problems of tastes and odors, staining, shortened life of hot water heaters, dishwashers and clothes, and increased corrosion of water supply distribution systems and home plumbing and fixtures are all important to the public. To evaluate the impact of landfill leachate on groundwater use for domestic purposes based solely on whether the water contains contaminants on a limited list of chemicals most of which are rodent carcinogens reflects a serious lack of attention to many domestic water supply water quality issues.

There is an urgent need to change federal regulations such as RCRA, and state regulations so that they more properly reflect the real potential water quality impacts of landfills other than those associated with a few identified carcinogens on a somewhat arbitrarily developed list of Priority Pollutants. As noted above, there are more than 60,000 chemicals in commerce today. Certainly well-over 1,000 of these are routinely deposited in municipal solid waste landfills. To limit the public health and water quality concern for chemical contaminants in MSW landfill leachate to a few Priority Pollutants and largely ignore the broader context of domestic water supply water quality as is now being done by the US EPA in implementing its Subtitle D regulations, is short-sighted and not in the best interest of protection of public health and welfare, and water resources. Without implementation of more appropriate groundwater quality and resource protection provisions associated with municipal solid waste management, future generations will look back on this generation as being exceedingly selfish in its zeal to have the least expensive solid waste management at the expense of properly managing these wastes so that they are not a threat to the future generations' health, and economic and social welfare.

The state of California Water Resources Control Board's Chapter 15 requires that landfills be developed so as to prevent impairment of groundwater use for as long as the wastes in the landfill represent a threat. That is the overall groundwater protection performance standard for landfill containment systems set forth in those regulations. While that performance standard has been in effect since 1984, it has not, in general, been implemented at the regional water quality control board level. The State's regional boards have been allowing the construction of landfills in areas hydraulically connected to high-value groundwaters, that only have the minimum landfill liner design characteristics such as one foot of soil compacted to a permeability at the time of construction of less than 10^{-6} cm/sec. It has been clear since Chapter 15 was adopted in 1984 that such a liner would do no more than delay groundwater pollution by, at best, a couple of years. It is important to note, however, that Chapter 15 does not stipulate that the minimum liner design included in the regulations would be sufficient to achieve the groundwater protection performance standards set forth in those regulations.

As part of adopting its Landfilling Policy on June 17,1993, the State WRCB reaffirmed the groundwater protection performance standard for landfill containment systems of preventing use-impairment of groundwaters from all causes, not from just from a few "rodent" carcinogens on the US EPA's October 1991 Appendix 1 list, for as long as the wastes represent a threat. Nevertheless, regional water quality control boards today are proposing to allow the construction of landfills in the State that incorporate only the US EPA's minimum Subtitle D single composite liner system or similar types of liners. It is clear from the technical information readily available today that such liner systems cannot protect groundwater from use-impairment in perpetuity (for as long as the wastes represent a threat) as required in the WRCB Landfilling Policy.

Lee and Jones-Lee (1994c) discussed issues of the long-term liability associated with the management of municipal and industrial hazardous and "non-hazardous" wastes in "dry tomb" landfills. They pointed out that that liability will lead to public and private interests' ultimately becoming responsible parties and having to pay for the clean-up of contaminated groundwaters from today's Subtitle C (hazardous waste) and Subtitle D (municipal solid waste) "dry tomb" landfills. The magnitude of the liability of responsible parties will be determined to a considerable extent by the characteristics of the site at which the landfill is located. Those landfills that are hydraulically connected and in close proximity to high-value groundwaters will represent the greatest liability for future generations who reside in the area from which the solid wastes deposited in the landfill have been derived since those populations will ultimately likely have to pay for groundwater remediation. Further, at many locations, funds will be needed for waste exhumation, recycling of usable components, treatment of the wastes, and reburial of non-recyclable treated residues.

Overall, the new modern, high-tech landfills are not significantly more protective of groundwater resources than the classical unlined sanitary landfills. Basically the new lined landfills only postpone groundwater pollution. Lee and Jones-Lee (1993b,f,i) provided a detailed discussion of the significant problems with the US EPA's and the state of California's approach of relying on "dry tomb " landfills with plastic sheeting and soil layers to try to isolate untreated municipal solid wastes from water for as long as the wastes represent a threat. MSW in a "dry tomb" landfill will be a threat forever, not just 30 years as is typically assumed today (Lee and Jones-Lee, 1992, 1993j).

Lee and Jones (1990) and Lee and Jones-Lee (1993b,h) discussed alternative approaches for landfilling of municipal solid waste that offer the potential to protect groundwater resources from use-impairment by landfill leachate. Those approaches typically employ treatment of the waste to remove components that represent long-term threats to groundwater quality. The "fermentation/leaching wet cell" waste treatment approach described by Lee and Jones-Lee is initially slightly more expensive than the current Subtitle D "dry tomb" landfilling approach; it would add an estimated bc/day to an individual's solid waste management costs. In the long term, however, the fermentation/leaching wet cell approach will be less expensive since it will prevent future generations from having to spend massive amounts of money for Superfund-type groundwater remediation that would have to be carried out at dry tomb landfills because of their failure to prevent groundwater pollution by landfill leachate for as long as the wastes in the MSW landfill represent a threat.

In the fermentation/leaching "wet cell" approach described by Lee and Jones (1990) and Lee and Jones-Lee (1993b,h), the wastes are shredded to promote contact of moisture added to the landfill with the solid wastes. During the first five or 50 years of treatment, leachate generated in the landfill would be recirculated back into the landfill to enhance landfill gas formation through fermentation reactions. After gas production has essentially ceased, clean water would be added to the landfill, on a single-pass basis, to leach the fermented wastes of leachable components; the leachate generated from that step would be removed from the landfill in the leachate collection and removal system and treated to remove contaminants as necessary to allow the treated waters to be discharged to surface water. It is projected that the clean-water washing (leaching) of the fermented waste would take 10 to 15 years, the actual time depending on the character of the leachate being produced which is dependent on the design of the landfill and the mode of operation of the leaching. By the end of the leaching period, those components in the MSW that were readily leachable and hence represented the major threat to the groundwater resources in the vicinity of the landfill, will have been removed. The period of time necessary for the fermentation/leaching treatment would be expected to be within the period of time during which a double-composite landfill liner system could be expected to be able to function as effectively as it can to collect leachate. Therefore, the fermentation/leaching "wet cell" approach should not require major redesign of landfills from what is typically done today in a number of states that now require double-composite-lined landfills for MSW management

Impact of Solid Waste Diversion on Leachate Impacts

Several years ago as part of the AB 939 legislation, the state of California Integrated Waste Management Board adopted regulations that required that counties divert 25 % of the solid waste stream destined for landfilling by 1995; by the year 2000, that diversion is to be 50% of the solid waste stream. Substantial penalties will be imposed on municipalities that fail to meet the waste diversion requirements. Similar requirements are being developed for other states; while few other states have mandated a 50% diversion of solid waste, many are requiring at least 25% diversion. These diversion requirements are stimulating considerable interest in alternative approaches for managing municipal solid waste, including waste reduction, recycling, and reuse.

The waste diversions that are currently being implemented and that are contemplated will not significantly change the potential impact that future Subtitle D "dry tomb"-type, lined landfills will have on groundwater resources. While leachate composition would be expected to change because of diversion of certain types of waste (especially yard ("green") wastes which can comprise on the order of 20 to 25% of the total MSW waste stream to a landfill), the residual contaminants present in an MSW landfill, even with this diversion, will still produce a highly potent leachate; small amounts of that leachate can still readily render a large amount of groundwater unusable for domestic water supply purposes.

Substantial amounts of the types of material that are targeted for diversion contribute very little to the pollutional tendencies of the MSW waste stream. Glass bottles and aluminum cans are inert in a landfill and only take up space. The removal of such materials from the waste stream and the use of the additional landfill space for waste disposal would be expected to make the leachate more concentrated.

Considerable effort and money are being expended today for the collection of "household hazardous wastes" in the name of prevention of pollution from landfills. Much of what is done in this regard, however, will have little or no impact on the characteristics of MSW landfill leachate. An analysis of the magnitude of the diverted materials compared with the characteristics of leachate shows that a very small part of the total amount of hazardous chemicals that arise from activities in the home, much less from other sources of hazardous materials in a landfill, is being collected in the household hazardous waste collection programs. Further, some of the materials that are recommended for diversion from MSW landfill waste streams in such programs, while potentially hazardous to landfill workers under certain circumstances, do not add significantly to the public health and environmental hazards posed by MSW landfill leachate. (Appropriate and more cost-effective handling of waste materials that pose a threat to landfill worker safety but not to the character of landfill leach ate is another issue which is beyond the scope of this discussion.)

For example, the diversion of bleach and ammonia from landfills at household hazardous waste collection stations is of no value in improving the characteristics of MSW landfill leachate. In a landfill environment, chlorine bleach will be converted to chloride; the additional chloride derived from this conversion will be insignificant compared with the amounts in MSW derived from other sources. A similar situation occurs for ammonia. MSW landfill leachate contains very high concentrations of ammonia from a wide variety of sources, most of which are associated with the decomposition of organic nitrogen, including animal and plant protein material present in MSW. The amount of ammonia that is contributed from partially full bottles of ammonia discarded with household trash is insignificant compared to other sources of ammonia in landfills.

Recently the Recycling Program of the Public Works Department of the city of Davis, CA released a "Garbage Guide" similar to guides being developed by cities and counties across the country. In that guide it was indicated that it costs the city of Davis about $3.00 to dispose of each partially full aerosol can of oven cleaner which had cost $2.79 to purchase at the supermarket, because of the residual chemicals in the can (City of Davis, 1994). However, an examination of what is accomplished by diverting partially full spray cans of oven cleaner from the landfill shows that such diversions will have no impact on the hazardous and deleterious nature of the municipal landfill leachate. While hazardous to the user of the concentrated product in the can, the high-pH chemicals in common oven cleaners do not represent exceptional hazards when added to landfill leachate; the high buffer capacity of MSW landfill leachate will neutralize the high-pH oven cleaner. Similarly, many of the other items targeted by the city of Davis for waste diversion owing to presumed "adverse impact on the environment" will not contribute significantly to the adverse impacts of MSW landfill leachate on public health and the environment when deposited in the MSW waste stream. There is need for a comprehensive, critical, re-evaluation of the true pollution prevention that will be accomplished by the household hazardous waste collection programs that are underway in cities across the country, and the development of appropriate, more cost-effective management of materials that pose a potential threat to landfill worker safety. While the public is led to believe that it is helping to solve the solid waste crises by participating in such activities, the real environmental quality and public health problems associated with solid waste management, such as those precipitated by the inappropriate siting of landfills and allowance of landfilling that does not protect groundwater resources, will remain even if there were significant and widespread participation in household hazardous waste collection programs.

The specific changes in the character of MSW landfill leachate that will occur as a result of waste diversion programs will be site-specific. However, it is clear that waste diversion programs will not significantly reduce the ability and tendency of landfill leachate to render groundwaters and associated aquifer areas unsuitable for domestic water supply.

One of the most significant benefits of diversion of solid waste from MSW landfills is that it will save landfill space. A 50% diversion of solid wastes will represent a 50% reduction in the rate of filling of the landfill if no new sources of wastes are introduced into the waste stream to the landfill. While the landfill will ultimately still pollute the area groundwaters with leachate, a significant reduction in rate of filling of the landfill will mean that the siting of new landfills may be delayed. This in itself will reduce the rate at which additional groundwaters are polluted. If landfilling approaches are implemented in the interim that offer true, long-term protection of groundwater quality, the value to groundwater quality protection provided by waste diversion Will be even more significant. It is important, however, not to be deluded into believing that municipal solid waste diversion will significantly reduce the pollutional character of MSW landfill leachate.

In establishing and evaluating the potential benefits of a program of waste diversion from a landfill, it is important to carefully consider other public health, nuisance, and environmental quality problems that may be associated with operations in which the diverted wastes are transformed, reused, or otherwise managed. As discussed by Lee and Jones-Lee (1993a) all methods of MSW management, including all forms of recycling, have the potential to cause significant adverse impacts on public health and welfare, and the environment. Each method of management of municipal solid waste must be critically evaluated before it is undertaken to be sure that it is a significant step in the right direction toward overall protection of public health and welfare, groundwater and surface water resources, and the environment.

Landfill Gas Emissions from Dry Tomb Landfills

The pattern of gas emission from dry tomb landfills will be significantly different from that of a classical sanitary landfill. At a classical sanitary landfill, gas emissions begin shortly after operation and continue for 30 to 50 years depending on the amount of moisture that enters the landfill through its cover. However, once the low-permeability cover is placed on a dry tomb landfill, the gas emissions will likely decrease significantly, and remain low as long as the low-permeability characteristics of the cover are maintained. It may be expected that those characteristics would likely be maintained for about 30 years after landfill closure, i.e., for the minimum post-closure care period mandated by Subtitle D. If the post-closure care period passes without the detection of problems, Subtitle D provides a mechanism whereby a landfill owner/operator can be relieved for further responsibility for post-closure monitoring and maintenance of the landfill. Once the low-permeability characteristics of the cover are no longer adequately maintained and increasing amounts of water enter the landfill, landfill gas emission rates will increase generally proportional to the amount of moisture that enters the landfill.

Assuming an active landfill life of about 20 years and 30 years of post-closure maintenance, gas emissions from a dry tomb landfill would be expected to resume at an increased rate about 50 years after the opening of the landfill. By contrast, landfill gas production would be expected to be ceasing at a classical sanitary landfill by about 50 years after initiation of operation. By the time gas production resumes at an increased rate at a dry tomb landfill, the gas collection system installed at the time of landfill closure will likely have deteriorated significantly. By that time also there would likely be limited funds available for maintenance and operation of that system. Since even in a deteriorated state the low-permeability cover will likely restrict the entrance of moisture into a dry tomb landfill compared to what would occur in a classical sanitary landfill, the period of time over which gas production occurs in a dry tomb landfill will likely be significantly longer than that which occurs in a classical sanitary landfill.

Another factor that complicates the estimation of the rate of and duration of gas production in a dry tomb landfill compared with what occurs in the classical sanitary landfills upon which fermentation information has been generated, is the fact that much of the solid waste received at an MSW landfill is contained in plastic bags. While many of such bags are somewhat open due to the handling of the waste during collection and deposition, the waste in them would not be as accessible to water; rates of gas production would depend, also, therefore, on the rate of deterioration of the plastic garbage bags in the landfill environment.

Assessment of the Public Health, Water Quality, and
Environmental Impacts of Landfills in California

The estimation of the potential adverse impacts of solid waste management facilities, including landfills, on public health and the environment for those who utilize properties within their spheres of influence, requires evaluation of

- the mass rate of release of both waterborne and airborne pollutants,
- the areal extent contamination, and persistence and transformation of the pollutants and their transformation products,
- the concentrations and concentration gradients of those pollutants that adversely impact the alr, water and land resources,
- the number of people and especially any sensitive populations that could be influenced by the release of pollutants from the landfill,
- the duration of exposure,
- the total period of time over which pollutant release will occur,
- synergistic and antagonistic impacts of other pollutant releases or adverse health conditions that might cause an exposed population to be more susceptible to pollutants derived from the landfill,
- the characteristics of the landfill, such as the depth of solid waste and degree of compaction that took place,
- the characteristics of the wastes accepted by the landfill owner/operator during the landfill's active life,
- the size of the landfill as defined by the total amount of solid waste disposed of and the areal extent of the landfill.

Each of these characteristics will influence the potential adverse impacts that a particular landfill represents to those within the sphere of influence of the landfill. Rowe (1991b) conducted modeling efforts to predict the significance of some of these parameters on contaminant release rates for a number of different potential situations for various types of landfills. With appropriate adjustments, these predictions can potentially be translated into potential public health and environmental impacts.

In conducting such modeling, it is important to not use an increase in concentration of a particular chemical such as chloride to some arbitrary level as an indicator of the amount of leachate-pollution of groundwater that is allowable. A wide variety of highly hazardous and otherwise deleterious chemicals that are present in MSW landfill leachate are typically present at comparatively greater concentrations than chloride or many of the commonly measured MSW constituents.

While it is not possible at this time to assess the relative environmental significance of landfills as sources of environmental pollution compared with many other sources, there can be little doubt that MSW landfills, industrial non-hazardous waste landfills, as well as hazardous waste landfills have significant adverse impacts on public health and the environment. When considered in the broadest public health protection context (the body politic), gaseous and liquid releases from landfills are highly deleterious to the aesthetic and economic well-being and welfare of those within the landfill's sphere of influence.

Acknowledgement

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Short-Course on
Landfills and Groundwater Quality Protection Issues

Municipal solid waste (sanitary) landfills represent significant causes of groundwater pollution. The "new generation," state-of-the-art, lined "dry tomb" landfills being constructed today can, at best, only postpone pollution. Drs. G. Fred Lee and Anne Jones-Lee have developed a two-day short-course that addresses issues of landfills and groundwater quality protection. In addition to presenting a discussion of problems with current approaches for managing municipal solid wastes, they identify alternative methods for solid waste management that address deficiencies in the current approaches.

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- National Ground Water Association - Las Vegas, NV
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- University of California, Los Angeles University Extension Los Angeles, CA
- American Water Resources Association - Reno, NV
- University of California, Santa Barbara University Extension - Ventura, CA
- University of California, Berkeley University Extension - San Francisco, CA

In 1993, this course has been sponsored by the following groups at the locations indicated:

- American Society of Civil Engineers - New York City, NY; Atlanta, GA; Chicago, IL and Seattle, WA
- American Water Resources Association - Tucson, AZ
- University of California, Riverside University Extension - Riverside, CA

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