MUNICIPAL SOLID WASTE MANAGEMENT:

Long-Term Public Health and Environmental Protection

Prepared by

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Prepared for

Workshop

Landfills and Groundwater Quality

NWWA National Outdoor Action Conference
Las Vegas, Nevada

May 15, 1991

FOREWORD

This report is based on the authors' over 25 years of experience in evaluating groundwater and surface water contamination by sanitary landfills and information from the literature. It has been provided to many individuals knowledgeable in the area of solid and hazardous waste management for their review and comment. Appropriate changes have been made in the paper based on the comments received. The authors wish to thank all of those who provided comments. Hopefully, this report will help to develop an approach that will ultimately result in formulating a solution for the national solid waste management crisis that exists in the US today that will protect public health, ground and surface water quality, and the environment.

This original version of this report was formulated while the authors held positions at the New Jersey Institute of Technology, Newark, New Jersey. At that time, Dr. Lee held the position of Distinguished Professor of Civil and Environmental Engineering. Dr. Jones held the position of Associate Professor of Civil and Environmental Engineering.

This report may be referenced as: Lee, G. F., and Jones, R. A., "Municipal Solid Waste Management: Long-Term Public Health and Environmental Protection," Workshop Lecture Notes, National Water Well Association National Outdoor Conference, Las Vegas, NV, May (1991).

This report presents information on the MSW characteristics and the state of knowledge on landfill containment system properties as of 1990. Since its development 15 years ago, considerable additional information has been developed on several of the topics presented in this report. Please consult Drs. G. Fred Lee and Anne Jones-Lee website, www.gfredlee.com for additional information on these topics. In particular is the report,

Lee, G. F. and Jones-Lee, A., "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste," Report of G. Fred Lee & Associates, El Macero, CA, November 2004; Last updated January (2021). https://www.gfredlee.com/Landfills/Landfill_Pollution_Impacts.pdf

ABSTRACT

Leachates from municipal and many industrial landfills contain a wide variety of chemical contaminants that can impair the use of groundwater for domestic water supply and many other purposes. In an effort to prevent groundwater pollution by landfill leachates, some state water quality management agencies and the US EPA have adopted regulations for "non-hazardous" landfills that require a combination of plastic sheeting membrane and compacted soil liners and caps to try to keep the buried wastes dry. This approach is based on the concept that as long as the wastes are dry, leachate will not be generated and groundwater quality deterioration will not occur. Requirements for leachate detection, collection, and removal systems are similarly being incorporated into the design of landfills to intercept leachate that may be generated. This "dry tomb" approach requires proper siting of landfills and their perpetual maintenance to protect groundwater quality.

This report includes discussion of the potential problems that sanitary and industrial "non-hazardous" landfills represent to groundwater quality, problems with the use of plastic sheeting and clay liners and caps for landfills, and areas in which many state and federal regulations covering postclosure maintenance of landfills could be improved. Specific guidance is provided on the approaches that water utilities and others should follow to protect groundwaters that are or could be used for domestic water supply purposes. Also, discussions are presented on the costs of more appropriate methods of municipal solid waste management that will protect public health, groundwater quality, and the environment.

Alternative approaches are suggested to the "dry tomb" approach involving fermentation/leaching to convert "non-hazardous" solid waste residues to materials that will not represent a significant threat to groundwater quality upon land burial.

BIOGRAPHICAL INFORMATION ON THE AUTHORS

G. Fred Lee is President of G. Fred Lee and Associates, an environmental consulting firm located in El Macero, California. R. Anne Jones is Vice President of G. Fred Lee and Associates. El Macero is located about 10 miles west of Sacramento, CA. Prior to July 1989, Dr. Lee held graduate level professorial positions for 30 years at universities, where at the time of his "retirement" from teaching/research, he held a Distinguished Professorship in Civil and Environmental Engineering. Until December 1989, Dr. Jones held the position of Associate Professor of Civil and Environmental Engineering at the New Jersey Institute of Technology.

Drs. Lee and Jones have worked as a team since the early 1970's in various areas of surface and groundwater quality and solid and hazardous waste management. Dr. Lee has conducted over 5 million dollars of research on various aspects of water supply water quality, water and waste water treatment, water pollution control for fresh and marine waters, and solid and hazardous waste management and has published over 450 professional papers and reports on this work. Dr. Jones has been involved in these activities during the past 15 years and has published over 175 professional papers and reports on them. Throughout their teaching and research careers they maintained a part time consulting activity working with governmental agencies and industry in the USA and other countries. They have served as advisors to the states of California, Wisconsin, Michigan, Colorado, and Texas on solid waste management.

Dr. Lee holds a Ph.D. degree in Environmental Engineering and Environmental Sciences from Harvard University, an M.S. degree in Public Health from the University of North Carolina, and a B.A. in Environmental Health Sciences from San Jose State University. Dr. Lee's primary areas of expertise are aquatic chemistry, environmental engineering, and public health. Dr. Lee is a registered professional engineer in Texas and is a Diplomate in the American Academy of Environmental Engineers.

Dr. Jones holds a Ph.D. and an M.S. in Environmental Sciences from the University of Texas at Dallas and a B.S. in Biology from Southern Methodist University. Her areas of expertise are aquatic biology, aquatic toxicology, and aquatic chemistry. Dr. Lee and Dr. Jones' paper, "Is Hazardous Waste Disposal in Clay Vaults Safe?" was judged by the Water Resources Division of the American Water Works Association as the best paper published in the Journal of the American Water Works Association in 1984.

Dr. Lee has been an American Chemical Society tour speaker on "Solid Waste Management Problems With Current Approaches" for the past five years on ACS lecture tours in many parts of the US, including tours in Indiana-Kentucky, Ohio-Michigan, Missouri-Illinois, New York-New Jersey, and is scheduled for tours in North Carolina-Virginia and Rocky Mountain states. Dr. Lee has presented two day short courses on Landfills and Groundwater Quality Protection for the American Society of Civil Engineers. American Water Resources Association, American Groundwater Association, and the University of California Berkeley, Davis, Santa Barbara, and Riverside Extensions.

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Introduction

Municipalities throughout the US and in many other countries are facing crises in solid waste disposal which are primarily caused by a lack of landfill capacity. This situation is often the result of the inability to site new landfills. While there has always been a problem in siting landfills due to opposition by residents of the area where the proposed landfill is to be located, today the local opposition has become sufficiently well organized to effectively prohibit siting new landfills in many parts of the US. The NIMBY (not in my back yard) syndrome is often characterized by those who do not face having a landfill developed in their area, as one in which the local opposition is "unjustified" in opposing the landfill. However, as discussed below, with few exceptions, NIMBY is justified for long-term public health and environmental reasons.

This report is based on the authors' experience in examining environmental contamination problems caused by sanitary landfills and the literature on this topic. It reviews the deficiencies of the current approaches being used in the US in developing new landfills and suggests an approach that would provide for true long-term public health and environmental protection from municipal and/or industrial landfills.

Need for Landfills

While it is possible through recycling and incineration of municipal solid wastes to significantly reduce the amounts of wastes that need to be landfilled, it is not possible to totally eliminate the land burial of municipal solid wastes. Typically, the US citizen produces about five pounds of municipal solid wastes per day or one ton per year. The US EPA (Forester, 1988) estimates that in 1960 the per capita generation of municipal solid wastes in the US was 2.7 pounds per person per day. They estimate that it will be on the order of 4 pounds per person per day in the year 2000. The American Public Works Association estimates that the current municipal solid waste generation by the US population is on the order of 7 pounds per person per day where, according to Forester (1988), from 80% to 90% of this solid waste is disposed of in sanitary landfills. In California, because climate allows production of year round yard waste, the authors have found that seven pounds per person per day is the typical amount of municipal solid waste generated in several parts of the state. The US EPA (1988a) has presented a summary of municipal solid waste management practices in the US which should be consulted for further information on this topic.

The US EPA (1988a) has reported that in 1986, paper and paper board materials represented about 36% of typical municipal solid wastes. Yard wastes amounted to about 20% of municipal solid wastes with glass, metal, plastic, rubber, and food each representing from 7% to 9% of the total of municipal solid wastes. It is typically being found that about 20% to 50% of municipal solid wastes can be readily recycled. In some areas of the US, such as New Jersey, mandatory recycling is now being practiced in which newspapers, aluminum cans, and bottles must be separated and placed at the curb in separate containers for pickup by the recycling agency. Even with normal optimum recycling that can be readily achieved, there still are about three to four pounds of municipal solid wastes per person per day that must be removed from the home and disposed of by incineration or land burial.

Approaches for Landfilling of Municipal Solid Wastes

In the past, this MSW disposal was typically done by land burial. For many years prior to the late 1950's, this land burial was accomplished by disposal in an open dump usually located in a low lands, typically wet area because the land in these areas was the cheapest land available. The open dumps frequently utilized burning of the residues in order to reduce volume. At many of these dumps, hogs were raised on the garbage. This practice was stopped by public health officials throughout the US because of the threat of trichinosis associated with the public consuming inadequately cooked pork. 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.

Odors arising from the decomposition of the wastes in the open dump and/or burning of the wastes, flies, rodents and other vermin, blowing papers, etc., led to the development of what is now called the sanitary landfill. Basically, a sanitary landfill is an open dump in which each day's wastes are covered with a few inches of soil (see Figure 1). When the landfill has reached its uppermost capacity, which in some parts of the country such as northern New Jersey represents hills several hundred feet high, a foot or more of soil was placed on top as a cover. Frequently, the cover was seeded with grasses and other vegetation. If operated properly, the sanitary landfill greatly reduced the odors, vermin, or many of the other obnoxious characteristics of the open municipal dump.

The sanitary landfill, however, did not eliminate one of the most significant problems associated with municipal dumps -- water contamination in the region of the landfill by leachate generated within the landfill. Leachate (garbage juice) arises primarily from rainfall and other precipitation entering the landfill. Leachate is also produced by liquids disposed of in the landfill such as liquid wastes, septic tank pumpage, etc. Many states have already or soon will ban the disposal of liquid wastes and wastes that contain large amounts of liquids in sanitary landfills in order to minimize leachate generation.

On August 30, 1988, the US EPA (US EPA 1988b) released its proposed regulations governing the land burial of municipal solid wastes and industrial non-hazardous solid wastes. These regulations were mandated by the federal congress as part of the 1984 revisions of Resources Conservation Recovery Act (RCRA). The US EPA, as part of implementing Subtitle D of the

1984 revised RCRA, will likely prohibit the disposal of wastes containing large amounts of free liquids in sanitary landfills.

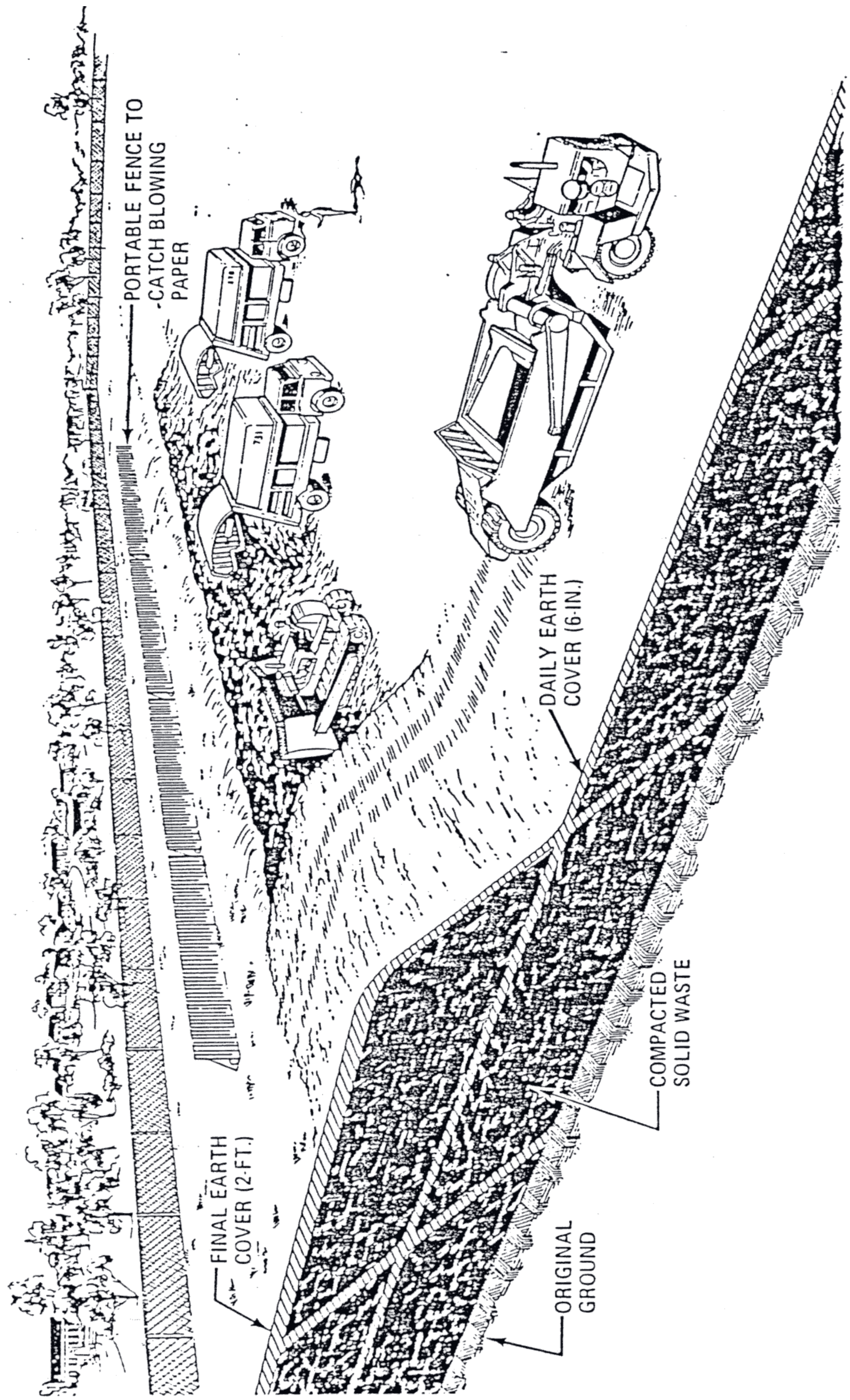
Increasing concern is being raised about the space that daily cover occupies in landfills. This can be as high as 20% of the landfill's volume. Typically, the daily cover is soil or sand derived from excavations at the landfill. In some instances, daily cover has to be purchased and represents a significant expense for the operations of the landfill. It has been suggested that a paste made from wetted newspapers could be used as an effective daily cover. Also, crushed glass from bottles that would normally be placed in the landfill could serve the same purpose. The use of newspapers or glass for this purpose would eliminate the need to purchase soil and also help reduce the significant market glut that is occurring due to recycle of these materials in municipal solid wastes.

Some states such as California have adopted daily cover regulations which would prohibit the use of crushed glass or newspaper as a substitute for soil. The California regulations attempt to achieve a certain amount of moisture diversion ability in the daily cover. It is felt that the daily cover should prevent precipitation of the open landfill cells from entering the wastes and thereby producing leachate. This approach is inappropriate in a modern landfill which has a leachate collection and removal system. In fact, it is far better to allow moisture into the waste where fermentation and leaching can occur with the leachate collected, removed, and treated. This practice is in the direction of minimizing future problems from leachate generation when moisture enters the waste after the landfill has been closed. During the active life of the landfill, there should be few problems with the liners and leachate collection and removal systems functioning as designed. It is after closure that normally the problems will develop.

Groundwater Pollution Issues by Municipal Landfill Leachate

As the moisture percolates through the landfill, it leaches (solubilizes) contaminants from the solid wastes and transports them to the groundwater in the vicinity of the landfill. For those landfills which are located with relatively impermeable strata below the landfill as well as those that are constructed above normal grade for the area of the landfill, the leachate may appear on the surface of the ground as it seeps to the surface of the soil. These seeps can lead to surface and groundwater contamination by contaminants leached from the solid wastes. Also, the leachate that enters groundwaters may lead to surface water contamination in those situations where contaminated groundwaters enter surface waters.

Table 1 presents a summary of the typical concentration ranges for a variety of contaminants found in leachate arising from sanitary landfills. The data that serves as a basis for this table was developed primarily from municipal landfills that were operated prior to the time when RCRA imposed restrictions on placing large quantities of highly hazardous chemicals in municipal landfills. RCRA, however, while limiting the amount of hazardous wastes that may be disposed of by commercial and industrial sources, does not preclude disposal of hazardous substances in sanitary landfills from household as well as many other sources. Chian and



PORTABLE FENCE TO
CATCH BLOWING
PAPER
DAILY EARTH
COVER (6-IN.)
FINAL EARTH
COVER (2-FT.)
COMPACTED
SOLID WASTE
ORIGINAL
GROUND

TABLE 1

Concentration Ranges for Components of Landfill Leachate

Parameter (in mg/l except when noted otherwise)	Concentration Range*	"Typical" Concentration Range**
BOD 5	4-57,700	1,000-30,000
COD	39-89,250	1,000-50,000
TOC	0-28,500	700-10,000
Total volatile acids (as acetic acid)	70-27,700	---
BOD 5/COD (ratio)	0.02-0.87	0.6-0.8
COD/TOC (ratio)	0.4-4.8	1-4
Total Kjeldahl nitrogen (as N)	7-1,970	10-500
Nitrate (as N)	0-51	0.1-10
Ammonia (as N)	0-1,966	---
Total Phosphate	0.2-130	0.5-50
Orthophosphate	0.2-130	---
Total alkalinity (as $CaCO_3$)	0-20,850	500-10,000
Total hardness (as $CaCO_3$)	0-22,800	500-10,000
Total solids	0-59,200	3,000-50,000
Total dissolved solids	584-44,900	1,000-20,000
Specific conductance (umhos/cm)	1,400-17,100	2,000-8,000
pH	3.7-8.8	5-7.5
Calcium	60-7,200	100-3,000
Magnesium	17-15,600	30-500
Sodium	0-7,700	200-1,500
Chloride	4.7-4,816	100-2,000
Sulfate	10-3,240	10-1,000
Chromium (total)	0.02-18	0.05-1
Cadmium	0.03-17	0.001-0.1
Copper	0.005-9.9	0.02-1
Lead	0.001-2.0	0.1-1
Nickel	0.02-79	0.1-1
Iron	4.0-2,820	10-1,000
Zinc	0.06-370	0.5-30
Methane gas(percent composition)	(up to 60%)	---
Carbon dioxide(percent composition)	(up to 40%)	---

---Indicates no data presented by cited author.
*Based on data of Pohland (1975), Pohland and Harper (1985), Keenen, et al. (1983), Chian and Dewalle (1977), and Mikucki, et al. (1981).
**Ranges in which 70% of the literature values reported by Lu, et al. (1984).
After: Lee et al. (1986)

DeWalle (1977), Lu, et al. (1984), Keenan, et al. (1983), US EPA (1990a) provide additional information on the composition of municipal landfill leachates. Their data is for municipal landfills that have accepted some industrial wastes which are now classified as hazardous wastes.

It is estimated by the authors that on the order of about one gallon of hazardous chemicals per year is disposed of in sanitary landfills by each person. This means that a landfill serving 100,000 people would receive on the order of 100,000 gallons per year of what are normally considered hazardous chemicals that are disposed of in household solid wastes. Tables 2 and 3 lists some of the common household products which contain significant amounts of chemicals which cause industrial wastes to be classified as hazardous in accord with RCRA. Brown and Donnelly (1988) have recently summarized the information available on the hazardous nature of municipal solid waste leachates.

Another source of hazardous chemicals in sanitary landfills is commercial and some industrial solid wastes. The US EPA's definition of hazardous waste involving the use of the EP Toxicity Test as well as the recently-adopted TCLP test that was developed is somewhat arbitrary in classifying wastes as "hazardous" vs. "non-hazardous" and does not preclude placing substantial amounts of hazardous chemicals in sanitary landfills. Lee and Jones (1981) have discussed the problems with the use of the US EPA EP TOX test as a basis for classification of the hazardous nature of solid wastes. As discussed by Lee and Jones, the conditions employed in this test were arbitrarily chosen and do not necessarily represent the conditions that exist in municipal landfills much less the conditions that exist in industrial landfills. The same basic problems exist in the US EPA's TCLP test. The release of contaminants from a solid is dependent on a variety of physical, chemical, and biological factors. In order to properly classify a solid waste as "hazardous," the conditions used in the test must properly mimic the landfill conditions where the solid waste is proposed to be placed. Consideration must be given not only to initial conditions, but also to future conditions.

The authors have found that frequently proponents of municipal landfills will assert that municipal landfills will not accept hazardous wastes. The implication is that there will be no hazardous materials placed in the landfill. This is, as discussed above, certainly not the case. Unfortunately, the US EPA is still insisting with their highly inappropriate approach of allowing contaminants to be leached from a waste in the TCLP test at concentrations up to one hundred times the drinking water standards and still have the waste classified as non-hazardous. As discussed below, this is a highly inappropriate approach which should not be continued to be allowed, since it permits significant amounts of hazardous chemicals to be placed in municipal landfills. The classification of contaminated soils into "hazardous waste" versus "non-hazardous waste" allows significant amounts of highly-hazardous chemicals present at state of California superfund sites to be deposited in municipal landfills. There is a significant incentive for principal responsible parties (PRPs) for remediation of federal or state superfund sites to use municipal landfills for site remediation rather than hazardous waste landfills. The difference in disposal cost for the two types of landfills is often hundreds of dollars per ton. As an example of this type of situation, the California Department of Health Services (DHS) requires that lead at a state superfund site be remediated to less than 1,000 mg/kg. This value was arbitrarily established by DHS as the value at which a soil becomes a hazardous waste. The safe level for lead in soils to which children will be exposed has been determined by DHS to be 274 mg/kg. Therefore, PRPs which wish to remediate a property for residential use can take all soils from the site which contain lead above 274 mg/kg, but less than 1,000 mg/kg to a municipal landfill.

Another source of hazardous chemicals for sanitary landfills is the construction waste and demolition debris frequently disposed of in municipal landfills associated with residential and commercial development and redevelopment. Such wastes can contain a wide variety of chemicals which would significantly increase the hazard to public health and the environment that landfill leachate can represent. Even materials which are in themselves relatively non-hazardous such as wall board, principally gypsum, can, in the presence of other wastes such as vegetative matter (leaves, grasses, etc.) in the landfill environment, interact to produce a leachate which is highly obnoxious containing large amounts of hydrogen sulfide which imparts a rotten egg smell in groundwaters contaminated with the leachate. Ferguson (1980) conducted a limited study on the leachate characteristics of demolition wastes. He found that leachate from plaster had a pH > 12 which could cause plaster to be classified as a hazardous waste. The recent review by Brown and Donnelly (1988) on the hazardous nature of sanitary landfill leachate provides additional information on the potential hazards that sanitary landfill leachates represent to public health and the environment.

Some states such as California classify demolition debris as "inert wastes." These wastes may be placed in pits without any attempt to prevent groundwater pollution from them. Some landfill owner/operators use these wastes as fill below the lined landfill. While the state regulations specify that such wastes should not leach any contaminants which could impair the uses of groundwaters, the State has never developed a leaching test to evaluate whether demolition debris and so called "inert waste" are in fact inert-have no soluble components. Such wastes should be carefully evaluated using appropriately conducted leaching tests to determine whether chemicals can be leached to pollute the groundwaters.

Lee (1990) reports that while significant improvements have been made in reducing the public health hazard of municipal solid waste leachate through limiting the amounts of industrially derived highly hazardous chemicals that may be placed in municipal landfills, such landfill leachate must be considered as hazardous that should not be allowed to contaminate groundwaters. The US EPA (1988b) concluded that vinyl chloride which is derived from anaerobic degradation of TCE is sufficiently common in modern day municipal landfill leachates so that this chemical could be used as a basis for detecting landfill leakage. While as discussed below this approach is valid for many situations, there are situations where it is not reliable. Lee further indicates that improvements can be achieved in reducing the hazardous nature of municipal landfill leachates through community collection of household and commercial establishment hazardous materials. It is impractical-impossible to totally eliminate all hazardous substances from municipal landfill leachates. Heavy metals such as lead, and cadmium will always be present in municipal solid wastes and, therefore, a threat to groundwater quality.

Table 2

HOUSEHOLD PRODUCTS THAT CONTAIN HAZARDOUS WASTE COMPONENTS

* Drain and Oven Cleaners
* Wood and Metal Cleaners and Polishers
* Automobile Oil and Fuel Additives
* Grease and Rust Solvents
* Carburetor & Fuel Injector Cleaners
* Air Conditioning Refrigerants
* Batteries
* Paint and Paint Thinners
* Fluorescent Light Tubes and Ballasts
* Paint Strippers and Removers
* Adhesives
* Herbicides and Pesticides
* Fungicides/Wood Preservatives

Total about 1 gal/cap/yr of Hazardous Chemicals

TABLE 3

Organic Solvents in Household Cleaning Products

Solvent	Product(s)
Orthodichlorobenzene	Drain degreaser
Paradichlorobenzene	Drain degreaser Toilet bowl deodorizer
1,1,1 Trichloroethane	Septic tank drain field cleaner Drain opener Oven cleaner (aerosol) Cleaning fluid Furniture polish
Trichloroethylene	Cleaning fluid
Perchloroethylene	Laundry degreaser Home and auto parts cleaner
"Aliphatic, Aromatic"	Septic tank drain field cleaner Laundry degreaser Cleaning fluid Engine degreaser Car wash
"Petroleum distillates"	Septic tank drain field cleaner Drain opener Oil and grease dissolver Garage degreaser Cleaning fluid Engine degreaser Spray cleaner Floor cleaner Furniture polish Spot remover
Methylene chloride	Oven cleaner Graffiti remover Brush cleaner
"Harmful organics"	Floor stripper and cleaner
"Chlorinated solvents"	Laundry degreaser

After Malhiesen and Cadwallader, Public Works May (1988).

It is important to point out that even if little or no highly hazardous chemicals were placed in a sanitary landfill, groundwaters contaminated by leachate developed in such landfills would still render the groundwater unusable for domestic water supply purposes without extensive and expensive treatment. The "garbage juice" mixture of organics and inorganics produced in leaching municipal solid wastes can cause significant taste, odors, color, and other qualities which would force the abandonment of homeowners as well as municipal water supply wells that are contaminated by this leachate. While many of these contaminants are not, at this time, considered to be highly hazardous to human and animal health, the disposal of hazardous chemicals in sanitary landfills as permitted by RCRA today as well as state solid waste disposal regulations can readily lead to a leachate from a sanitary landfill which is not only obnoxious but also hazardous. It is, therefore, imperative that if the public health and welfare of current and future owners of lands adjacent to a sanitary landfill who use the groundwaters as a water supply source are to be protected, steps must be taken to prevent contamination of the groundwaters near the sanitary landfill by leachate generated in the landfill.

One of the areas of greatest concern with municipal landfill leachate contamination of groundwaters is the fact that typically only a small fraction (normally less than 5%) of the organic matter present in municipal landfill leachate is measured by specific compound analysis in groundwater monitoring programs near municipal landfills. The bulk of the organics in municipal landfill leachate are uncharacterized. Further, their human health hazards are unknown. It is prudent public health protection policy to assume that municipal landfill leachate is hazardous and should not be allowed to contaminate groundwaters that are or could be used for domestic water supply purposes.

One of the most significant problems with the US EPA proposed sanitary landfill regulations (US EPA 1988b) is that they focus on the prevention of cancer in individuals who consume groundwaters that are contaminated by landfill leachate. While this is one concern for potential impacts of leachates and must be included in any solid waste disposal regulations, it alone is not a sufficient basis for controlling the contamination of groundwaters and possible surface waters near solid waste disposal facilities. Municipal and industrial solid waste leachates contain a wide variety of conventional and non-conventional contaminants that can render an aquifer unusable as a domestic water supply source yet not pose a significant risk for increasing the number of cancers that will occur in a population who consume the water. These contaminants, in addition to those that may cause cancer, need proper regulatory attention.

Even with the focus on protection from cancer-causing chemicals, an important basic problem with the proposed regulations is that the US EPA has proposed to require measurement of only a small number of the wide variety of carcinogens that are or may be present in so-called "non-hazardous" wastes. Each year new chemicals are added to the list of carcinogens as more information is obtained. No one can be certain that next week a new "dioxin" will not be found that could be a contaminant in municipal or industrial "non-hazardous" solid wastes that has not or would not be measured by the US EPA's proposed regulations as set forth on August 30, 1988.

It is a well-established public health principle that public health protection cannot be provided by assuming, as the US EPA has, that keeping the level of currently known carcinogens below some arbitrarily established "trigger" level will unequivocally provide for public health protection. This is especially true for such complex mixtures of contaminants as those associated with municipal and some industrial solid waste leachates. It is for this reason that the appropriate solid waste management regulations should not allow any contamination of groundwaters under adjacent property owners' lands, independent of whether the contaminants measured are believed, at this time, to represent a potential public health or environmental threat. Contamination of any kind may be a signal that other contaminants that are in fact hazardous to health and the environment are being transported from the solid waste disposal site to off-site groundwaters. It is only with this approach can residents-owners of properties adjacent to landfills have some assurance that reasonable steps are taken to protect their health and welfare and the quality of their environment.

In addition to being deficient with respect to providing protection against cancer, the US EPA proposed regulations do not protect groundwaters against other types of water quality deterioration. There is a wide variety of contaminants in municipal solid waste leachates that, while not representing a public health threat, can render a groundwater unusable for domestic water supply purposes because of deterioration of the aesthetic characteristics of the water. The US EPA (1988b) Appendix II, list of contaminants that must be considered, falls short of the contaminants that should be considered. By tradition and by law, public health protection is more than just preventing the death of people from toxicants or carcinogens in their drinking water. It includes the quality of their water and environment as well. In more than 20 years of work on groundwater contamination associated with municipal landfills, the senior author has repeatedly seen situations in which the well of a resident near a landfill has been contaminated by leachate with the result that the well had to be abandoned as a domestic water supply source since the user of the well could not afford the highly expensive treatment needed to remove the leachate components from the groundwater.

The US EPA (1988e) in their economic analysis of municipal landfill pollution of groundwaters concluded that once a groundwater was contaminated by municipal landfill leachate, the groundwater would be unusable for domestic water supply purposes. The Agency further concluded that because of the virtual impossibility of cleaning up the groundwaters that municipal landfill leachate contaminated well water would cause the well to have to be abandoned for further use for domestic water supply purposes.

In water short areas, such as central and southern California, where conjunctive use of surface and groundwaters is being practiced in which "wet year" surplus surface water is artificially recharged into the groundwater aquifer, water utilities should aggressively pursue protection of aquifer quality. Municipal landfill leachate contains a wide variety of chemicals which can destroy a contaminated aquifer for conjunctive use storage.

It is therefore readily apparent that the pollution of groundwaters by municipal landfill leachate represents a significant threat to public health and groundwater quality. Those who promulgate sanitary landfill regulations should consider the risk that they, themselves, would be willing to accept in terms of drinking water that, based on their regulations, should be acceptable for drinking. For example, if anything like the US EPA's proposed regulations of August 30, 1988 is implemented at the federal and state levels, all individuals who contribute garbage or other solid wastes to a particular landfill which, at any time in the future, contaminates adjacent property owners' groundwaters, should be required to accept this leachate with all its known and unknown components as an additive to their treated domestic water at the home tap at a concentration twice what those who live near the landfill and use the groundwaters for domestic purposes could experience in their drinking water supply. For all governmental agency regulators who recommend and/or approve such regulations, the concentration of leachate in the drinking water delivered to their home tap should be five times what the residents who live near the landfill are expected to consume. The same applies to all elected officials who allow the US EPA and the states to proceed with this proposed approach.

If it is "safe" for a person living near a landfill to consume leachate-contaminated water, with or without currently-known carcinogens, then the municipal resident who developed the waste, the governmental agency officials who declared the leachate "safe" to consume, and the politicians who allowed the governmental agency officials to declare the leachate-contaminated groundwaters "safe" should be willing to accept at least twice to five times the degree of leachate contamination in the waters of their home. If the politicians, regulatory officials, and others who are consuming what the US EPA and/or the state consider to be "safe" leachate at five times that which the resident living near a landfill is expected to consume start dying of cancer or are otherwise adversely affected by the leachate, then those who generate the solid wastes and try to dispose of them at a cost less than the real cost of providing true long-term public health/welfare and environmental protection, will be able to convince those responsible for wastes generation, i.e., the urban residential dweller, industries, commercial establishments, etc., that they should remediate the contaminated groundwaters independent of whether a "trigger" concentration set forth by the US EPA and/or the states in the proposed water quality monitoring approach is exceeded.

Adopting this approach would put the public health, environmental, and aesthetic quality hazards of leachate-contaminated groundwaters on the community that generates the wastes rather than pass it on to those who are forced to accept waste disposal facilities in their area without adequate safeguards for true long-term public health/welfare and environmental quality protection. The objective of the US EPA sanitary landfilling regulations should be changed from prevention of cancer to maintenance of existing groundwater quality near solid waste disposal facilities. Protection of groundwater quality, as properly defined, means protection from impairment of all beneficial uses of the groundwater.

While each member of the US generates about one ton of municipal solid waste per year and about one ton of hazardous waste per year, at this time, the federal and state regulatory agencies are focusing almost exclusively on the hazardous waste management problem. Lee and Jones (1984) have discussed the problems of land disposal of hazardous wastes in clay vaults (clay lined pits). As they point out, the emphasis that is now being given to hazardous wastes should be expanded to include municipal solid wastes; since, in the long run, managing these wastes will become a much larger problem than those caused by hazardous wastes. In the future, it will likely be found that the solid non-hazardous waste problem represents a greater threat to public health, the environment, and the public's welfare than hazardous wastes.

Landfill Design Issues

Presented below is a discussion of the problems with the current approaches being used for the design of municipal and industrial non-hazardous waste landfills. Many of these problems are also applicable to hazardous waste landfills.

Landfill Liner and Cover Design.

The primary problem with many existing state regulations governing the land burial of municipal solid waste is that they fail to properly consider the long-term public health and environmental consequences-impacts of the landfill on the groundwater quality in the vicinity of the landfill. The approach being adopted by many states that have recently revised their sanitary landfill regulations is to require one or more liners for the bottom of the landfill. Usually a leachate collection and removal system will be installed above the uppermost liner on the bottom of the landfill, and a leachate detection system will be installed between the two liners in a double composite lined landfill. While some states are still requiring only a single liner, several are beginning to require a composite liner consisting of a flexible membrane material, FML, and a compacted soil-clay liner. The double composite lined system for sanitary landfills required in some states such as New York and New Jersey is similar in design to that required by the US EPA for RCRA approved Subtitle C hazardous waste landfills. As discussed by Lee and Jones (1990a), there is no justification for regulatory agencies to require less groundwater protection from sanitary landfills than from hazardous waste landfills. Leachate from both is hazardous and can render a groundwater unusable for domestic water supply purposes.

The US EPA's August 30, 1988 proposed design of municipal and industrial "non-hazardous" solid waste disposal facilities is similar to that proposed under Subtitle C of RCRA for hazardous waste facilities. As discussed above, this is justified. It is important to note, however, that it is now well-known and, in fact, it has been known for many years that the US EPA Subtitle C regulations governing land burial of hazardous wastes do not provide unequivocal long-term protection of public health or environmental quality for those who could be affected by the failure of the landfill liners to contain the wastes. The most significant difficulty is with the arbitrary approach that has been adopted of selecting a 30-year postclosure period as the period during which the owner/operator would be responsible for the postclosure activities such as leachate removal, cap maintenance, monitoring of groundwaters, remediation of the site, etc. While in its Subtitle C regulations the US EPA indicates that the regional administrator may require a longer period of time for postclosure activities, there is no assurance that such activities will in fact be carried out and, even if mandated, that there will be funds available for this purpose. The appropriation of funds is controlled through local and state legislators and the congress which are influenced less by rural residents who could be affected by a landfill's failure to contain the wastes (since landfills are typically located in rural areas) than by urban dwellers.

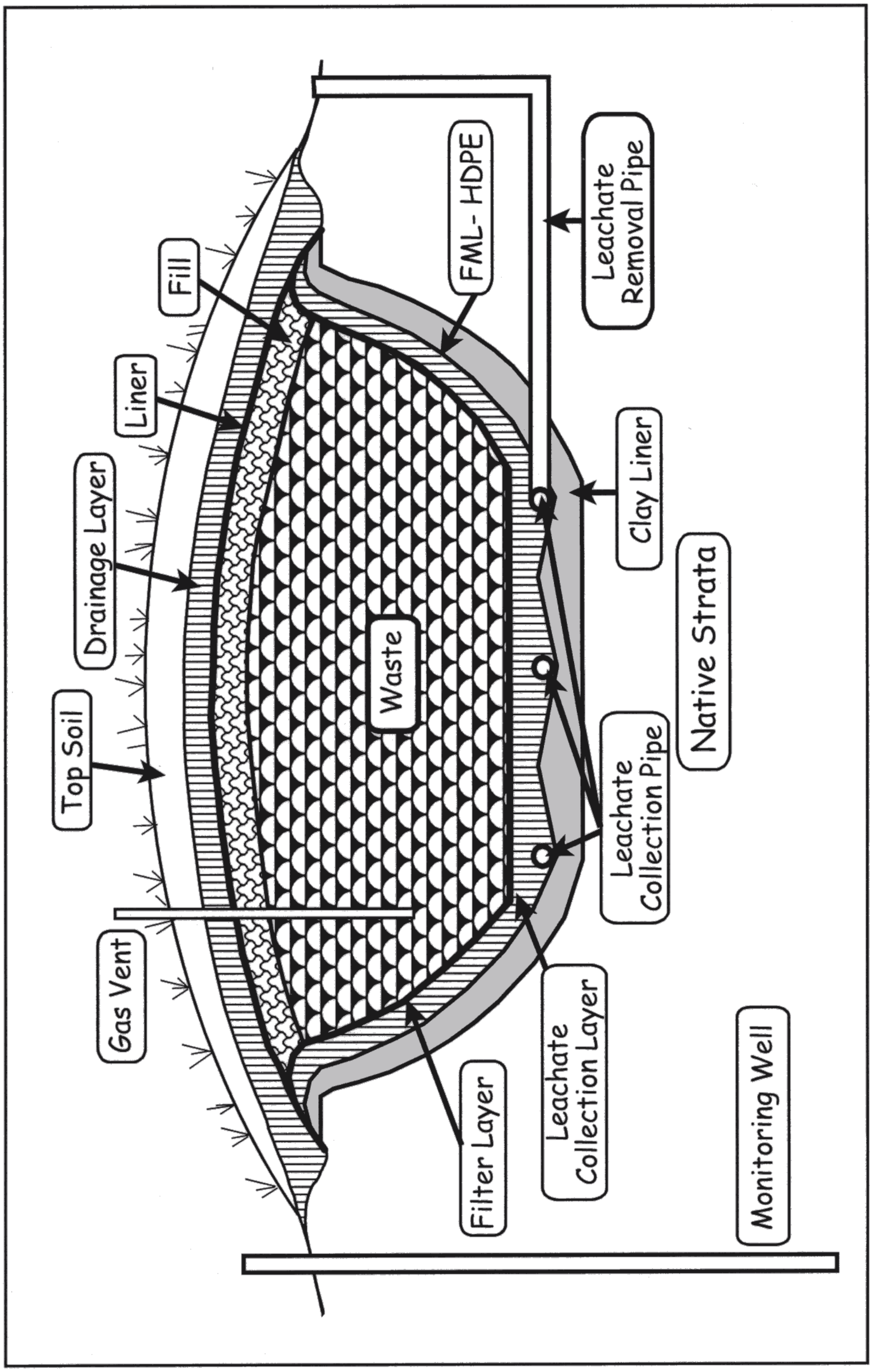
It is easy to envision a scenario in which if a landfill has not been demonstrated to contaminate groundwaters within 30 to 40 years after closure, regulatory agencies would receive considerable pressure to de-emphasize postclosure activities on the part of the owner/operator as a means of saving funds for both the agency and the owner/operator. It is important to emphasize that when the owner/operator saves funds, this is, to some extent, saving funds for the public who generated the wastes.

The June 1990 regulations of the Integrated Waste Management Board (1990) for the state of California governing closure of landfills allow a landfill owner/operator to be relieved of responsibility for further postclosure activities if the landfill is not generating leachate at the end of a 30-year postclosure period. As discussed below, unless there was extremely sloppy construction of the landfill liner system and significant failures of the cap to keep moisture out of the landfill at the end of a 30-year postclosure period, there is a high probability that a landfill would not be generating leachate at that time and the owner/operator could therefore be judged to be eligible for relief from postclosure activities. Granting this relief would be highly inappropriate since the waste in the landfill would still be a significant threat to groundwater quality.

It is well-recognized today by those who are familiar with the design of landfills under Subtitle C and those proposed under Subtitle D that if properly constructed, landfills would not likely contaminate groundwaters during the mandated postclosure care period. As discussed below, the current design in which significant attempts are made to keep the wastes dry simply postpones the date when the problems will likely occur. This approach, in essence, allows cheaper garbage disposal now for the generator of the wastes in favor of passing the rest of the costs on to future generations; not only would future generations have to pay for the remediation of these sites, but also those who would be using the lands adjacent to the site would experience public health/welfare and environmental quality degradation.

Figure 2 shows a design of a landfill cap and liner system utilizing the "dry tomb" approach with a single composite liner. Typically under the solid waste is a porous layer consisting of a foot or two of sand. Under the sand will be a flexible membrane liner (FML) or a compacted soil or clay liner or some combination of the two types of liners. The liner will be sloped to a sump which is designed to allow any moisture (leachate) that is present in the porous layer under the waste to be transmitted to the sump where it can be removed by pumping. This system is known as the leachate collection and removal system (LCRS).

Figure 2 Single Composite Liner Landfill Containment System


Gas Vent
Top Soil
Drainage Layer
Liner
Fill
FML- HDPE
Leachate Removal Pipe
Waste
Clay Liner
Native Strata
Leachate Collection Pipe
Leachate Collection Layer
Filter Layer
Monitoring Well

The landfill cap which is installed at the time of closure (termination of waste acceptance) typically consists of a vegetated topsoil layer underlaid by a porous layer. The porous layer, typically sand, is underlaid by an "impermeable" layer. This impermeable layer may consist of a compacted soil-clay layer, an FML or a combination of the two. The "impermeable" layer is sloped so that moisture that passes through the vegetated soil layer will, in principle, be transported off of the cover to the sides of the landfill by the "impermeable" layer. Typically soil is placed between the top of the waste and the "impermeable" layer. However, this soil layer (typically called base-to-final cover) is not compacted to a sufficient degree to represent a significant impediment to moisture transport through it. The uppermost soil layer is vegetated in order to reduce water and wind erosion of the cap. Some regulatory agencies allow 1 foot of topsoil as the uppermost layer in a landfill cover. According to Duell (1987), this is insufficient topsoil to provide an adequate moisture reserve to support plant growth during periods of drought. He recommends no less than 2 feet of topsoil in a landfill cover.

The "dry tomb" landfill system shown in Figure 2 is basically designed to keep the waste "dry" by limiting the amount of moisture that enters the waste through the cap. Typically landfills are located a few feet or so above the highest expected water table so that groundwaters cannot enter the waste through the bottom liner. In principle, any moisture that enters the "dry tomb" landfill while the landfill is still open (i.e. accepting wastes) and after it is closed-capped would be removed by pumping the LCRS sump thereby preventing any buildup of head of moisture (leachate) on the liner. Normally, the sumps are designed to allow no more than about one foot of head to accumulate in the sump before it is pumped.

Sometimes it is mistakenly asserted by proponents of landfills that in order for leachate to be generated in a landfill the field capacity of the waste must be exceeded. Field capacity is a measure of the moisture-holding ability of the solid such as waste. When it is exceeded, excess moisture will readily drain from the waste. This statement about the need to exceed field capacity to generate leachate is incorrect. Waste like other solids exhibit unsaturated transport of liquid which, while the wastes appear dry, can and does transport large amounts of contaminants to the bottom of the landfill. At the bottom of the landfill, sufficient moisture can accumulate as a result of unsaturated transport from above to exceed the field capacity of the media (waste or sand in the leachate collection and removal system) to result in leachate being present in sufficient amounts to readily pollute groundwaters if the liner and leachate collection and removal system is not functioning properly.

Some landfill caps and liners are designed with a combination of FML and compacted soil layer in intimate contact with each other. This is called a "composite liner" which in principle is much more effective in reducing moisture transport through it than either a compacted soil layer or an FML alone. Some states are requiring a double composite liner system for municipal landfills consisting of two composite liners one on top of the other in which a leachate detection system (LDS) is installed between the two composite liners. The LDS typically consists of a porous layer which in principle would allow any moisture that passes through the uppermost composite liner to be transported to a sump where it can be removed. The presence of moisture in the LDS is an indication that the uppermost composite liner has failed to function properly or that moisture is entering this system by failure of the seals that occur at the land surface where the system is anchored.

Landfill caps normally have a number of pipes protruding through them which serve as gas vents-collection systems for the landfill gas (methane and carbon dioxide) that is produced in municipal solid waste landfills. There may also be pipes protruding through the cap for the LCRS as well as the LDS. All of these pipes tend to become potentially significant points where moisture can enter the landfill because of the difficulty in sealing the landfill cap "impermeable" layer to the pipe.

It has become well-known (Daniel, 1990) that soil or clay layers of the type that are used as part of landfill liners, including composite liners and composite caps used to close landfills, can readily transmit large amounts of moisture. For example, a 1-ft-thick soil layer with a permeability of 1 x 10^{-7} cm/sec that is saturated with water and has a few mm of water above the surface of the layer, i.e., 1 ft of head, can pass 50,000 gallons of water per acre of area per year. If the permeability of the 1-ft-thick soil layer is 1 x 10^{-6} cm/sec (which is allowed in landfill caps and liners in California today), the potential moisture transport with 1.5 ft of head is 500,000 gallons per acre per year. These transmission rates do not require that 1.5 ft of head exists above the compacted soil layer. For a 1-ft-thick soil layer, all that is needed is a few mm of water above a saturated layer to have 1 ft of head. Under these conditions the clay layer can transmit water at these rates so long as a few mm of water are available above the layer. It is obvious that such soil layers are permeable and can allow significant infiltration of surface water into the landfill through the cap and leachate leakage out of the landfill to the groundwaters.

While landfill companies and their geotechnical consultants frequently assert that a composite liner will not leak or that any leakage will be found to be insignificant, they are basing this assertion on an assumption that a true high quality composite liner can be constructed. Such a liner requires intimate contact between the FML and the underlying compacted soil layer. If intimate contact is not achieved, then the two layers will not function as a composite liner but as somewhat independent liners. Under these conditions, which are likely to be the case at most landfills, the composite liner will leak at a much higher rate than what the landfill's applicants' consultants claim. Brown and Thomas (1988) have reported on the leakage rates of composite liners where they have found that even under laboratory conditions, it is impossible to achieve true composite liner characteristics. Jayawickrama, et al. (1988) discuss the leakage rates of FML's that are not backed by compacted soil layers. It is clear from their work that unbacked FML's can leak at a very high rate dependant on the size and number of the holes and the liquid head on the FML.

A key to the ability of the composite liner systems that are used in landfills prevent groundwater pollution is the integrity of the flexible membrane liner. Typically today, HDPE FML's are used because of their resistance to chemical attack. FML's under optimum manufacture and construction are known to leak from 5 to 20 gallons/acre/day under one ft of head due to holes in the liner. Over time, FML's deteriorate due to such phenomena as stress cracking and polymer chain scission. Polymer chain scission is a free radical-caused disintegration of the FML that naturally occurs in landfill liners. While there are attempts to estimate the useful life of HDPE liners in municipal landfills through the use of accelerated testing of liner stability involving elevated temperature testing and extrapolation through the use of the Arrhenius equation, such approaches are not based on a technically reliable foundation and should not be judged as having any significant validity. At this time, no reliable information is available on how long HDPE FML's liners will last before they disintegrate. They will likely last 30 years or more but will not likely last 100 to 200 years. During this period there will be increased rates of leakage from that found at the time of construction.

An important indication of the useful life of landfill flexible membrane liners is provided by the warranties that liner companies provide on the liner. Typically, these companies warranty the liner on a pro-rated basis for no more than 20 years. These warranties are somewhat misleading in that typically, the liner companies will repair the liner during this period of time if the owner/operator of the landfill will remove all wastes from above the area where the liner has failed. Obviously, this makes the warranty for liners used in landfills essentially worthless.

A geotechnical engineer has testified at a landfill hearing on behalf of an applicant that there was no need to be concerned about the ultimate decomposition of the FML's (which he acknowledged would occur) because the waste in the landfill would decompose faster than the FML's. This is a totally inappropriate assessment of the situation and shows a lack of understanding of the physical, chemical, and biological processes that take place within landfills and liners. As discussed elsewhere, there are many components of municipal solid waste such as heavy metals, non-degradable organics, inorganic salts, etc., which never decompose, and therefore, will always maintain a threat to groundwater quality. Further, even the decomposable parts of municipal solid waste, i.e. those parts that are converted to methane and carbon-dioxide, still have organic residues that can readily pollute groundwater. In addition, based on what is known now on the decomposition of FML liners versus the decomposition of waste, the waste decomposition requires moisture while the liner decomposition does not necessarily require moisture. It is therefore highly possible that the FML can disintegrate to a considerable degree where the decomposable parts of the waste may have shown little or no decomposition.

An important aspect of determining the leakage rate of FML liners for solid waste disposal sites is the number of holes in the FML at the time of installation. Some geotechnical firms are promoting the idea that normally an FML liner will have about two 1 cm diameter holes per acre. Often reference is given to a US EPA sponsored report for this number of holes per acre. Actually reviewing this report (Bonaparte, et al., 1987), however, shows that this is not a value based on field measurements but was an assumed value for the purposes of the report. A growing consensus is developing in the field which indicates that the two 1 cm diameter holes per acre significantly under estimates the number of holes that actually occur in FML's.

An area of concern with respect to HDPE liners is the recent finding of stress cracking near seams. Peggs and Carlson (1988) have reported on cracks several inches in length in HDPE liners. These cracks have developed in time after installation of the liner. They are located near seams and seem to be due to tension stress in the areas of the FML which have been heated during seaming. At this time, the magnitude of this type of problem in landfill liners is unknown. However, it is of concern to regulatory agencies and the HDPE liner companies. Peggs and Carlson (1988) and Koerner, R. M. (1989) have indicated that while the potential significance of this problem under field conditions is unknown since the HDPE liners are typically covered with wastes, it is reasonable to suspect that this is a problem of concern that needs to be addressed.

Soil or clay layers used as liners are constructed with added water so that they are near what is called optimum moisture density. Under these conditions, the layer has the least permeability. However, in a dry climate a cap will dry out and the compacted soil will crack due to desiccation. These desiccation cracks do not reheal completely upon addition of moisture and, therefore, with the next precipitation event will serve as conduits for moisture transport through the clay layer. There is little doubt that during the summer in dry climates, desiccation cracks should develop which will significantly increase its permeability from that in the original design. It is also known that as little as a few inches of differential settling under a compacted soil liner over a 20-ft diameter area will lead to cracks in the soil layer. Typically, many feet of settling of municipal solid waste would be expected in a landfill. There can be little doubt that cracking of the soil layer of the cover will occur due to differential settling of the wastes. These cracks will become channels for increased transport of water through the cover during rainfall events. It is also well-known that burrowing animals and plant roots can develop channels through landfill covers that allow significant moisture to enter the landfill.

The prevention of the above-mentioned problems of desiccation cracking and cracks caused by differential settling as well as plant roots and burrowing animals cannot be repaired by filling in the cracks. Since the compacted soil layer (liner) is covered by a drainage layer and a porous soil layer in which vegetation is to be developed for the purpose of minimizing erosion, it is possible that the compacted layer cracks would not be visible from the surface. If these cracks were found on the surface, their repair would require that the compacted soil layer (liner) would have to be removed and replaced. This would be expensive and it is doubtful that landfill owners/operators would be diligent in finding cracks that develop in the cap and in properly repairing them.

Another potentially significant problem with some types of clay liners used in landfills occurs with expandable layer clays such as montmorillonite. The degree of swelling of these types of clays depends on the cation at the clay exchange sites. The sodium form of the clay is the expanded-swollen form while the calcium or magnesium form at the exchange site is the more compact form. This has important implications for some situations where if a sodium montmorillonite clay is used for a liner which comes in contact with a hard water, i.e. high calcium and magnesium relative to sodium, under these conditions, the calcium and magnesium will replace the sodium causing the compacted clay to shrink and develop cracks. It is possible that given the range of concentrations of sodium, calcium, and magnesium in municipal solid waste leachate that the above described situation could readily occur causing failure of the compacted clay liner to perform as designed. This failure could occur in composite liners where under holes in the FML cracks in the clay would occur due to calcium and magnesium replacing sodium in the clay in this region. This could readily cause the composite liner characteristics to be destroyed and the liner to be essentially ineffective in prevention of leachate contamination of groundwater.

A key to preventing groundwater pollution by landfill leachate is the ability of the leachate collection and removal system to transport leachate to sumps where it can be removed. As discussed above in the typical landfill liner design, an FML underlies a porous layer which is designed to allow leachate generated in the wastes to move down to the FML and then horizontally to the sump. If, however, the leachate encounters holes in the FML, it will pass through these holes rather than being transported to the sump. Even under ideal initial construction conditions, it is clear that ultimately there will be some leakage through the composite liner at the landfill at the time of construction, and that over time this leakage will become progressively worse where ultimately the leachate collection and removal system will not function since all of the leachate is passing through the composite liner rather than being transported to the sump.

There are many questions raised about the proper design of leachate collection and removal systems that are located above the uppermost liner and the leachate detection system between the primary and secondary liners in a double composite liner system as well as those that involve only a single composite liner with leachate detection below the liner. In the past, a foot of sand was generally used to transmit the leachate that leaked through the uppermost liner system to a sump where it could be removed by pumping. Today, increasing use of geonets is being made. Koerner (US EPA, 1988c) has raised questions about the long-term stability of the plastics used in geonets especially in contact with municipal domestic waste leachates. There is also concern about the tendency of geonets to become fouled/blocked especially with municipal solid waste leachates. Also, in the US EPA (1988c) design manual, questions are being raised about whether sand provides sufficient leachate transmission properties to transport the leachate to the sump at a sufficient rate under large leachate input. There are some who feel that pea gravel may be more appropriate for this purpose.

Koerner, R. M. (1989) has reported on a significant potential for municipal sanitary landfill leachate to support biological growths which lead to plugging of the geonets. This is an area of considerable concern since it could mean that the leachate collection and removal systems that are typically being developed today will not function as designed because of plugging.

One of the problems with composite liners is that the underlying soil layer which was packed at near optimum moisture content eventually dries out and desiccation cracks occur. These cracks then become conduits for leachate at any place where a desiccation crack is near a hole in the overlying FML.

Sometimes landfills are designed today with an FML that is not backed with low permeability soils or clay. It is well-known that an FML not in contact with a low permeability soil layer is not an effective barrier to moisture or leachate transport. At the time of construction there can be appreciable leakage that will increase over time and ultimately this FML will deteriorate to the point where it is non-functional as a leachate transport barrier.

One of the areas of concern that is frequently not adequately addressed in the analysis of the design of landfills is the stability of the sub-base to the liner system. Sometimes so-called inert wastes or other materials are used as the sub-base fill for the liner system. It is difficult, if not impossible, to compact inert wastes so that they provide a good base for a liner. If a good base is not achieved, then differential settling under the liner can occur and the same kinds of problems as discussed above for the impact of differential settling on the integrity of the cap (cracking of the soil layer) will occur in the liner.

Confusion exists in the landfill literature concerning the generation of leachate in more arid climates. Some engineers on behalf of landfill proponents claim that since the net annual water balance in the area is negative, evaporation exceeds precipitation, and no leachate will be generated. This approach is technically invalid. Appreciable leachate can be generated in arid climates under the conditions of short-term, high intensity precipitation where water moves down through the landfill in a short period of time to a depth where it will not be evaporated. The short-term net water balance should be used, not the annual water balance in evaluating the potential for leachate generation in a landfill.

The California Water Resources Control Board (1990) conducted the Solid Waste Assessment Test (SWAT) study of groundwater pollution by California landfills. It was found that the pollution of groundwater was not dependent on the precipitation in the area of the landfill. While some proponents of landfills assert that in dry climates, such as in Central and Southern California will not pollute groundwaters with leachate, it is important to point out that typically dry climates have wet years that are as wet as the areas of the country where landfill leachate is readily produced in landfills. It may be that in climates with an average of less than 15 inches of precipitation per year, in dry years there would be very little moisture transported into the landfill through the cap. However, in wet years, appreciable moisture transport could take place. It should be noted that the issue is not the annual precipitation, but the precipitation pattern, where high intensity, short-term precipitation events will transport less moisture into the landfill through the cap than long-term, low level precipitation events. This is a result of the fact that for properly constructed and maintained caps, the high intensity precipitation will largely run off before it has the opportunity to pass through the cap. It is therefore very important that the maintenance of the cap focus on the impermeable layer(s) and especially prevent depressions from occurring where pools of moisture could stand during and after a precipitation event.

Geotechnical consultants for landfill proponents frequently use the US EPA's HELP model to try to convince regulatory agencies that little or no leachate generation will occur in the landfill. While this model has some applicability to predicting moisture transport through a compacted clay layer, such as a recently constructed cap for a landfill, it is not a reliable tool to predict the amount of moisture that will enter a landfill from the typical cap that will exist at a landfill after a few years of differential settling and the other processes that occur in landfills and their caps which allow moisture to readily enter the landfill. Further, the HELP model is of no value in reliably predicting moisture transport through a cap which consists of an FML. In order to use the model for caps containing FML's, the user must assume the number and characteristics of the holes that exist in the FML. This value is not known with a high degree of reliability at the time of construction of the cap and is totally unknown as the cap FML ages. Therefore, great caution must be exercised in using the results of HELP model calculations as a reliable indicator of leachate generation within a capped landfill.

Chapter 15 of the California regulations governing land disposal of wastes allows landfill owner/operators to construct municipal landfills which have only one foot of compacted soil with a maximum permeability of 1×10^{-6} cm/sec as the impermeable layer in the cap and/or landfill liner. The HELP model shows that a cap or liner with this permeability is largely ineffective in preventing moisture from entering the landfill and leachate from leaving the landfill. The permeability of compacted clay layers used in landfill caps and liners should not be less than 1×10^{-7} cm/sec.

Some states still allow the construction of a landfill where the bottom of the wastes could be below the water table under the condition where an FML or other material water barrier is placed below the landfill liner system. Such an approach should not be permitted since it is only a matter of time until the FML deteriorates and allows groundwater to enter the wastes under high water table conditions (Lee, 1989).

A similar problem exists with landfills located in areas where springs exist. These springs show the presence of groundwaters at or near the surface of the land. Some landfill owner/operators and their consultants propose to construct groundwater diversion systems (concrete structures) under the landfill for the purpose of conveying the spring water out from under the landfill and thereby preventing it from entering the landfill. This approach should not be allowed since it is only a matter of time until the concrete or other spring water diversion structures develop cracks and would fail to prevent spring water from entering the landfill.

Similar problems exist with a landfill located below the water table where pumping of groundwater is proposed to artificially lower the water table near the landfill. In order for this system to work, the pumps must function properly as long as the wastes represent a threat to groundwater quality. This is difficult to achieve.

The groundwater monitoring system that landfill companies and agencies typically propose to use for landfills normally will not have a sufficient number of wells that are located in such a way as to have a high probability of detecting leakage from the liner system. Basically, the monitoring systems that are designed for landfills today would be suitable for unlined landfills where there will be generalized leakage across the landfill. Lined landfills will leak from specific points near holes in the FML. There will be little spread of the leachate as it migrates to the groundwater and in the groundwater as it proceeds down-gradient from the point of leakage. This could easily result in a situation in which the groundwater monitoring wells will not detect the leakage that has occurred since the leakage plume will pass between wells. Under these conditions, the only way that a leak will be found is when the plume eventually reaches a well on adjacent properties. Very large areas of groundwater pollution could therefore occur. For additional discussion of problems with current groundwater monitoring near landfills, consult Lee and Jones (1983a, 1983b).

There is also considerable concern about the adequacy of the typical analysis of the stability of various structures such as the leachate collection and removal system, the gas collection system, groundwater monitoring systems, liners especially the compacted clay liner overlying inert wastes, to seismic activity. The analysis of the ability of the various structures to withstand an earthquake of greater than magnitude 6 is typically unknown.

It is clear that compacted soil layers and flexible membrane liners, whether used alone or as a composite liner, are not technically credible units for preventing groundwater pollution by landfills. They leak at the time of construction and deteriorate in time, ultimately leading to failure of the system to prevent groundwater pollution. In California and some of the states, the regulations governing land disposal of waste require prevention of groundwater pollution by leachate developed in the waste disposal unit (landfill). If the natural strata provides for groundwater quality protection or if there is no groundwater in the area, then unlined landfills may be constructed. If, however, the natural strata does not provide this protection, then "engineered alternatives" (liners, leachate collection and removal systems) may be constructed. It is readily apparent that even though the basic design of the landfill conforms to the engineered requirements for landfills located in geologically unsuitable areas, this approach is seriously flawed with respect to providing groundwater quality protection. It is only a matter of time until groundwater pollution will occur at a landfill situated in an area where the natural strata do not protect groundwater quality. There is, therefore, an need to take a significantly different approach for the design of landfills that are to be constructed in areas where leachate leakage from the landfill could pollute groundwaters that are or could be used for domestic water supply purposes.

The US EPA Federal Register (Solid Waste Disposal Criteria, August 30, 1988, US EPA 1988b) states:

"*First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills.*"

In the US EPA "Criteria for Municipal Solid Waste Landfills," (July 1988d):

"*Once the unit is closed, the bottom liner of the landfill will deteriorate over time and, consequently, will not prevent leachate transport out of the unit.*"

As discussed above and by the US EPA (1988b,c,d), there are many ways that landfills of the type being designed, constructed, operated, closed, and maintained today can fail to prevent groundwater contamination. It is in the best interest of society to assume that all landfill liners and caps leak at the time of installation. Further, in time, FML's will deteriorate with the result of massive failure of the system.

Landfill Gas Problems

The anaerobic fermentation of wastes leads to the formation of methane and carbon dioxide in about equal amounts. It is important to emphasize that a significant part of municipal solid wastes are not fermentable. Further, as discussed below, this fermentation is dependent on having moisture present which provides a suitable environment for the bacteria that carry out this process to develop. Landfill gas is of concern from several points of view. First and foremost is explosions. Gas migrating from municipal landfills has caused explosions in buildings many thousands of feet from the landfill.

Another problem with gas migration is the impact of the carbon dioxide on vegetation. When the roots of plants are in the presence of high concentrations of carbon dioxide the plants will show distress and may die. There is also a problem of odors associated with landfill gas migration which can cause property value reduction. Also, gas production can cause disruption of the landfill cover such as by build up under an FML.

Landfill gas migration can cause significant pollution of groundwaters in aquifer systems that contain limestone. The carbon dioxide in the landfill gas can dissolve the calcium and magnesium carbonates increasing the total dissolved solids and hardness of the water. This process can take place to a sufficient degree to render the groundwater unusable for domestic purposes without treatment. Further, the landfill gas typically contains a variety of highly hazardous chemicals such as vinyl chloride (a known human carcinogen) which is derived from the conversion of TCE to vinyl chloride which occurs in anaerobic situations within landfills or groundwaters impacted by landfill gas or leachate. Vinyl chloride is a common constituent of concern of both landfill gas migration to release to the atmosphere and in groundwater pollution by landfill leachate. As noted elsewhere, the US EPA (1988b) has determined that vinyl chloride is such a common constituent of landfill leachate as to allow it to be used as a chemical of principal concern and one that should be monitored for in groundwaters near landfills.

It is important to emphasize that landfill gas migration does not necessarily occur down groundwater gradient from the landfill. Appreciable migration can occur up gradient in the unsaturated part of the aquifer under the landfill. The authors have observed situations where up gradient groundwaters are contaminated by landfill gas migration which tends to mask the real up gradient concentrations of constituents in groundwaters that serve as a background against which landfill pollution is judged. It is very important that up gradient monitoring wells be a sufficient distance from the landfill to adequately monitor the up gradient waters that can be impacted by leachate and landfill gas migration.

Suggested Landfill Design

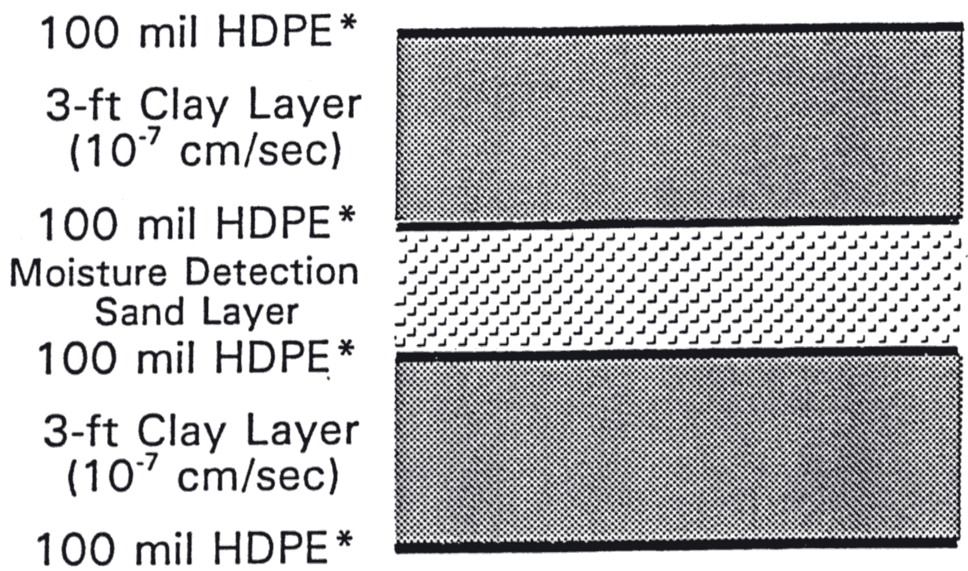
Municipal and industrial landfills employing the "dry tomb" approach of the type typically designed today should not be used where the groundwaters underlying these landfills are or could be used for domestic water supply purposes. Any use of landfills of this type under these conditions should only be done with the understanding of the true risks involved and with the recognition by everyone involved that such a facility would be only for temporary storage of the wastes, not permanent storage. Attempts to plan for permanent storage of municipal solid wastes in "dry tomb" landfills create situations in which long-term protection of public health and groundwater quality cannot be ensured; the wastes will be hazardous and detrimental to groundwater quality <u>forever</u>; liner and other systems will eventually fail, and perpetual financial assurance cannot be guaranteed. It would be far better to design all waste storage facilities to be above-ground facilities to facilitate rapid detection and remediation of any failure of the containment system (liners).

It is suggested that the design of landfills that are located in areas where groundwater pollution is possible utilize a double composite, double FML sandwiched liner and cap system. The bottom liner should be placed at a level at least 10 ft above the highest anticipated water table level. The lower liner should be placed on natural strata or properly-compacted fill that will eliminate the possibility of differential settling that leads to liner failure. Each of the composite liners should consist of two 100-mil-thick HDPE or equivalent material and at least 3 ft of well-graded, compacted clay with a field-tested permeability of less than 1×10^{-7} cm/sec between the two FML's. Figure 3 presents a diagram of the sandwiched liner and cap. This sandwiching of clay with FML's on each side will significantly reduce and quite likely eliminate the desiccation cracking that occurs in compacted clays used in liners in which one side is open to the system.

Every possible effort should be made to ensure that there is intimate contact between the FML's and the sandwiched compacted clay. The FML should be subjected to at least two independent checks for leaks at the time of installation. Great care should be exercised to ensure that the liners are not damaged by construction equipment or by the deposition of waste above them.

Between the two composite, sandwiched liners a leachate detection system should be installed which would have a high probability of detecting the passing of leachate through the uppermost liner. When such failure is detected, i.e., at the first indication of leachate present in

Figure 3. Double-Composite "Sandwich" Cap or Liner



* or VLDPE (more flexible)

the leachate detection system sump, the useful life of the landfill as a storage area for municipal solid waste will be considered to have been exhausted. The waste should then be removed from the landfill, treated in such a way as to minimize future potential for adverse public health and environmental impacts, or deposited in an appropriately-sited "dry tomb" landfill which cannot adversely affect groundwater quality.

Above the upper liner would be a leachate collection and removal system to remove leachate during the active life of the landfill and after landfill closure. This system should consist of a coarse pea gravel to avoid problems of biological growth plugging. No geonets, fabrics, or other materials that can plug due to biological growth should be present between the wastes and the sumps used to remove leachate. Once the landfill is closed, there should be no additional leachate generation. However, the leachate collection and removal system should still be inspected frequently and any leachate found removed. The presence of leachate would be indicative of problems with the cap that need immediate attention.

It is important to point out that even if properly constructed, the above described liner system will not necessarily prevent groundwater pollution. FML's, even when fully intact and non-degraded, are permeable to organics. Haxo (1988) has shown that organics can dissolve into the liner (be absorbed by the liner) on one side and then desorb out of the liner on the down gradient side. This process means that some of the most hazardous chemicals in landfills such as the low molecular weight chlorinated solvents such as TCE are transported through an intact FML and, thereby, led to groundwater contamination on the down gradient side (underneath side).

Trichloroethylene (TCE) is a chemical of special concern in municipal landfills. It is a common degreasing solvent that at one time was widely used for industrial purposes. It has been also widely used by commercial establishments and homeowners. Even today, anyone can go to the local hardware store and purchase gallon cans of TCE. A half full one gallon can of TCE discarded in a homeowner's trash can pollute many million gallons of groundwater above the drinking water standards (MCLs). Of even greater significance is the fact that in the landfill environment and in groundwaters contaminated by leachate or gas, TCE is converted by bacterial processes to vinyl chloride. Vinyl chloride has the lowest of all of the US EPA VOC MCLs. While TCE is a suspected human carcinogen with a drinking water MCL of 5 ug/L, vinyl chloride, a known human carcinogen, has a US EPA MCL of 2 ug/L. The California Department of Health Services (DHS) has adopted a drinking water MCL for vinyl chloride of 0.5 ug/L. While the US EPA VOC MCLs are based on an upper bound additional cancer risk of one additional cancer in a hundred thousand people who consume 2 liters of water per day over their lifetime (70 years) containing this concentration of the MCL, the DHS MCLs are based on an additional cancer risk of one in a million people who consume 2 liters a day over their lifetime that contain the constituent of concern at the MCL concentration.

The authors have frequently observed that landfill owner/operator consultants responsible for the groundwater quality monitoring program at municipal landfills and for that matter regulatory agencies which approve the monitoring programs do not use sufficiently sensitive analytical procedures do detect vinyl chloride at the DHS MCL concentration of 0.5 ug/L. This is a serious deficiency with many groundwater monitoring programs associated with existing and closed municipal landfills. At this time, the pollution of groundwaters by vinyl chloride has not been adequately assessed. It could be a much larger problem than is known today.

Daniel, et al. (1988) has discussed the migration of chemicals through packed clay liners due to molecular diffusion. He points out that when the permeability of the packed clay layer is less than about 10^{-8} cm/sec, molecular diffusion becomes the dominant transport mechanism for contaminants transport through the liner. The Haxo and Daniel work demonstrates that all liners of the type being constructed today will allow the transport of contaminants-leak independent of the quality of construction. Poor quality construction and inadequate protection of the liner during placement of the wastes will enhance the amount of leakage that will occur.

A cap should be constructed to include a 100-mil-thick flexible membrane liner overlying 3 ft of compacted clay having a field-tested permeability of 1 x 10^{-7} cm/sec or less. Below this clay should be another 100-mil-thick flexible membrane liner, creating a sandwiching of the clay between two FML's. The FML's and the clay should be in intimate contact. Some recent research has indicated that certain types of clays, such as montmorillonite, may be superior in a sandwiched FML liner system over other clays. Further work needs to be done to verify this preliminary finding.

Above the FML-sandwiched-clay cap would be a layer which would consist of a moisture detection system, such as a layer of sand. Above this system would be another sandwiched composite liner of the type described above. Above this double composite liner, FML-sandwiched clay layer system should be a drainage layer consisting of 2 ft of sand that would allow moisture that reaches the top FML to move laterally off of the cap liner. On top of the drainage layer should be 2 ft of top soil planted with vegetation to minimize erosion of the cap. It may be necessary to fertilize the cover and water it during periods of drought. It would be essential to control the types of vegetation to prevent growth of deep-rooted plants. There would be need for frequent inspections of the cap to detect problems in the integrity due to erosion, burrowing of animals, plant roots, etc., that would allow moisture to enter the landfill. Also, particular attention should be given to frequent inspection of areas near pipes that protrude through the cap to insure that the cap liner system is properly sealed around the pipe. If at any time moisture is detected in the moisture detection system between the two composite cap liners, then the upper cap will be considered as having failed and it should be replaced with a completely new system.

Increasing attention is beginning to be given to the possibility of adding polymers or other chemicals to the clay liners in landfills to improve their ability to prevent the passage of moisture-leachate through the liner. This is an area that needs research and one that shows promise in enhancing the ability of the clay part of the composite liner system to minimize the potential for groundwater contamination.

Comprehensive unsaturated and saturated monitoring systems would have to be constructed, operated, and maintained for as long as the wastes are stored at the site. The monitoring system should be designed to have a high probability (greater than 95 percent) of detecting leachate migration. Those systems would serve as a back-up contaminant detection system. However, contaminants would be detected by these systems only if the leachate detection system and lower liner have failed.

If the system is designed to meet the characteristics discussed, it is likely that storage at the facility could last for decades or a hundred or more years. It must be considered temporary, however, because it will, someday, fail to contain leachate. Unlike the "dry tomb" landfills being developed today, this system would plan for that eventual failure in a way so as to virtually preclude the possibility of groundwater contamination when that failure occurs.

The key to successful temporary storage of municipal solid wastes, especially at inherently unsuitable sites, is a fail-safe system of financial assurance, for as long as wastes remain at the site, that will provide the funds necessary to exhume the wastes when the primary (upper) liner system fails to contain the landfill leachate. As discussed below, it is felt that such a system could best be developed by the collection of a dedicated disposal fee from the public who contributes wastes to the landfill, proportional to the amount of waste deposited in the landfill. The accumulated funds must be sufficient to fund maintenance of the cap to minimize water entry into the landfill, including cap replacement; the conduct of other postclosure maintenance such as the removal of leachate found in the leachate collection and removal system; the monitoring of the saturated and unsaturated groundwater beneath and around the landfill; the exhumation of the wastes when the upper liner fails to contain leachate; and the removal of the wastes to permanent treatment and/or storage. It is essential that the amount of money collected be sufficient and the management of those monies be done in such a way as to ensure that funds available at any time would keep up with inflation and increased costs of waste exhumation and proper treatment and disposal of residues.

These funds must be in a dedicated financial instrument that could not be used for any purpose other than the management of the wastes deposited at the landfill as specified above. The owner/operator of the facility would not be entitled to receive any what might appear to be excess funds or any unused funds even after the cessation of use of the temporary storage facility. If it appears that funds available will be insufficient for the required maintenance, the people in the service area would have to be taxed to generate the monies needed. If, after termination of the use of the facility and all clean-up, monies remained in the fund, the excess monies would be transferred to a general fund to be used to clean up solid waste sites developed prior to development of this procedure. In this way, this generation would be passing on some level of funding necessary to address solid waste management problems in addition to the legacy of solid waste landfills that will eventually pollute groundwater.

The US EPA landfill cover design seminar of August 1990 and the associated seminar manual (US EPA, 1990b) serve as a basis for some of the information presented in this section. The US EPA landfill design manual (1988c) should be consulted for recent information on various factors that should also be considered in the design of landfills. While the focus of this manual is Subtitle C-hazardous waste landfills, it is equally applicable to Subtitle D-"non-hazardous" waste landfills. Since the landfill design field is rapidly evolving, those concerned with designing landfills that will minimize groundwater pollution should contact the authors for the latest information in these topic areas.

Duration of Postclosure Care

It is sometimes advocated by proponents of sanitary landfills and their consultants that sanitary landfills will not generate leachate 15 to 20 years after the wastes have been placed in the cell. This approach is based on the erroneous conclusion that what happens in a typical sanitary landfill of the type that has been constructed in the past where there is little or no attempt to restrict moisture entering the landfill through the cover by construction of an impervious cap will happen in landfills where impervious caps are constructed and maintained. The cover in the classical sanitary landfill was typically constructed from readily available soils which normally had high permeability to water. Under these conditions, the wastes within the landfill undergo anaerobic fermentation with the production of methane and carbon dioxide gases. In a typical sanitary landfill, the period of active gas formation is from 20 to about 40 years. When gas formation stops, the landfill is said to be "stabilized."

As discussed by Lee, et al. (1985, 1986), there is confusion today by some of those working in the municipal solid waste management field in which individuals attempt to relate the cessation of gas formation within the landfill with the termination of leachate generation. This is inappropriate. Actually, little is known at this time about how long a municipal solid waste or, for that matter, any type of solid waste landfill will generate leachate which can cause significant groundwater contamination near the landfill site. Freeze and Cherry (1979) state: "*It has been observed, for example, that some landfills from the days of the Roman Empire are still producing leachate.*" The leachate production period of time is certainly in excess of 50 years and likely on the order of several hundred to thousands of years before a leachate is generated from municipal solid wastes that would be considered suitable for human consumption as a water supply. Basically, for this situation to occur, the solid waste must be leached to a sufficient extent so that the rate of release of contaminants from the wastes in the leachate is sufficiently slow so that their concentration in the leachate is below that which would impair the use of the leachate as a domestic water supply. This period of time is dependent upon the amount of water that contacts the waste. The more wet the wastes, provided that the leachate is removed, the shorter the time that potentially adverse leaching will occur.

The above discussion on the times typically associated with landfill stabilization-gas formation and leachate generation is associated with the typical sanitary landfill that has been constructed until, recently, where there was little to no attempt to restrict the water entering the landfill. Today, many regulatory agencies are adopting the above described approach for closure-capping of landfills in which a significant attempt is being made to keep the wastes dry. It is well established that the rate of gas formation in a sanitary landfill is controlled to a considerable extent by the amount of moisture present in the wastes. It was found several years ago (see Pohland 1975) that the addition of moisture to a sanitary landfill such as associated with leachate recycle, could greatly speed up gas formation. Lee, et al. (1985), Pohland and Harper (1985), and Lee, et al. (1986), have recently published reviews on this topic. It is thought that the typical period for landfill stabilization of 20 to 40 years with respect to gas formation can be reduced to 5 to 10 years if significant amounts of additional moisture such as leachate is recycled through the landfill. Lee, et al. (1985, 1986) point out that some states prohibit leachate recycle in sanitary landfills because of the potential for increased groundwater contamination by the recycled leachate. This is justified since typically the liner systems that are being used for landfills today do not provide for adequate groundwater quality protection from landfill leachate. It would, however, be possible, in fact it is recommended (see Lee and Jones, 1990b), that leachate recycle be practiced to enhance the rate of stabilization of the wastes. They recommend that this be done in the double composite lined cells of the type described above.

While not investigated, it is reasonable to propose that the period of time in which municipal solid wastes would generate a leachate which would serve as a threat to groundwater pollution, would be a function of the amount of moisture added to the landfill. It is reasonable to conclude that the wastes in today's modern sanitary landfill in which there is an intact relatively impervious cap, would remain in a relatively unstabilized-unleached state until such time as sufficient moisture enters the landfill to allow fermentation-leaching to proceed. The relationships between gas formation and leachate generation for classical and modern day dry tomb sanitary landfills are shown in Figure 4. There is no doubt that the modern sanitary landfill will require perpetual care to keep it as dry as possible and to remove any leachate which collects within the landfill. At this time, with the possible exception of one state, i.e. California, to the knowledge of the authors, no regulatory agency is requiring that the owners/operators or others associated with a sanitary landfill will provide for postclosure maintenance, monitoring, and remediation to assure that a sanitary landfill will not cause groundwater contamination at some time in the future. Most states require only a few years (5 to 10) of postclosure monitoring and maintenance for sanitary landfills. The US EPA only requires a period of 30 years of postclosure monitoring and maintenance for hazardous waste landfills. The RCRA regulations indicate that the US EPA Regional Administrator may require additional postclosure care by the operator. There is no assurance, however, for either hazardous waste landfills or sanitary landfills that the long-term maintenance needed to prevent groundwater contamination by a landfill will, in fact, be provided.

In a typical sanitary landfill situation if constructed with at least a single composite liner and cap, the landfill will not likely cause any problems during the time that the owner/operator would be obligated to provide for remediation of the site. During the required postclosure monitoring, maintenance, and remediation period, the landfill would typically remain fairly dry and generate little leachate. However, at some time in the future when there is inadequate attention given to maintenance of the cap, there almost certainly will be introduction of significant amounts of water into the landfill. At that point, the normal fermentation-leaching process will occur, gas production will begin again, and leachate generation will also become an active process. At that time, there will not likely be any monitoring of the landfill, maintenance of the leachate collection-removal system, and removal of leachate as it accumulates. Increasing head of leachate will build up within the landfill, and the potential will exist for groundwater contamination. By then, it is possible that significant aging-deterioration of the FML will have occurred, cracks may have developed in the FML as well as the clay liner, and ultimately, the liners will be breached resulting in groundwater contamination by the landfill leachate.

Figure 4. Comparison of Pattern of Landfill Gas Generation over Time at Classical Sanitary Landfill and "Dry Tomb" Landfill

As discussed by Johnson and Dudderarl (undated), there are a wide variety of factors that can lead to landfill cap failure. The US EPA landfill design manual (US EPA 1988c) also lists these factors. Figure 5 presents a summary of many of the areas of concern which influence the ability of a landfill cover-cap to prevent moisture from entering the landfill. It is clear that unless a very aggressive, effective cap maintenance program is carried out forever for the hazardous as well as solid waste landfills that are being designed today, it is only a matter of time until cap failure leads to significant infiltration of percolation, leachate generation, and then contamination of the groundwaters in the region.

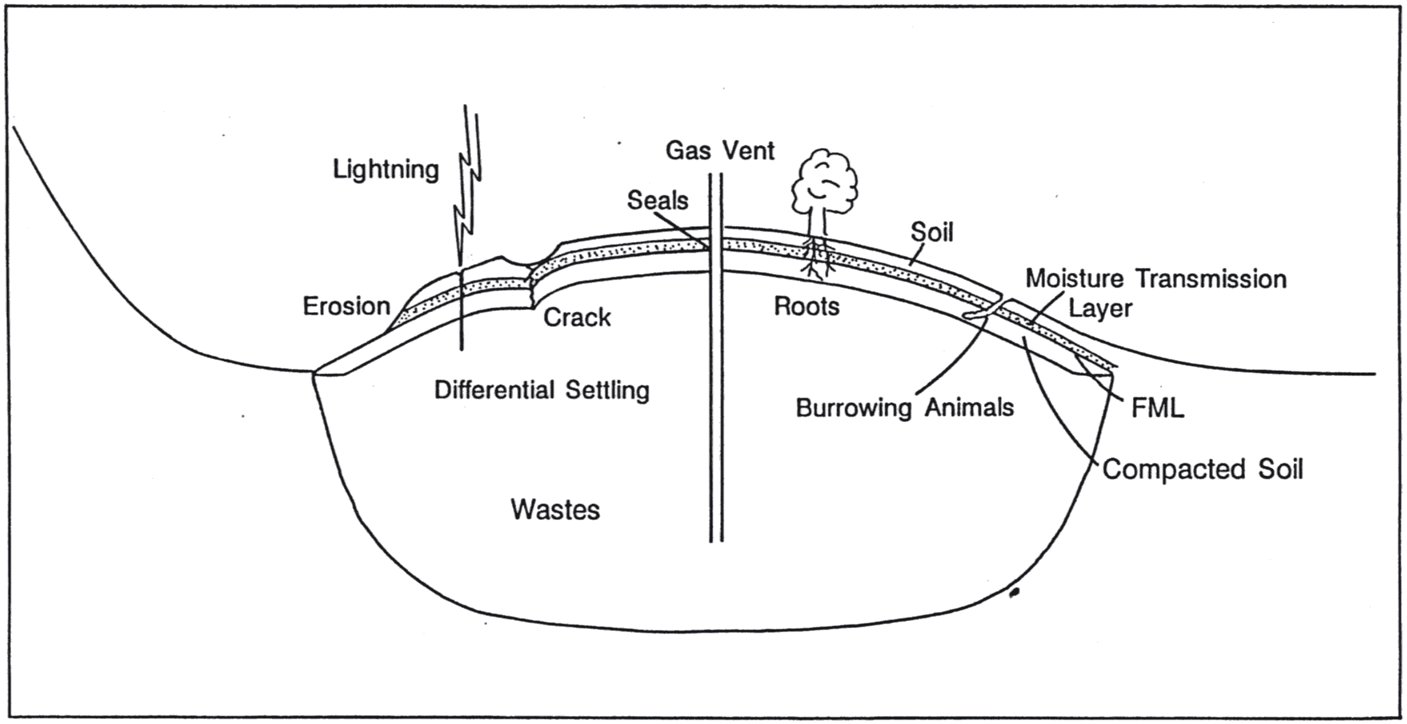
Several years ago, the State of California Water Resources Control Board adopted regulations which specify that the owner/operator of the landfill is responsible for the maintenance, monitoring, and remediation of the landfill as long as the landfill represents a threat to groundwater quality. This is the approach that should be used in all regulations governing solid and hazardous waste management. It is inappropriate for regulatory agencies to establish a fixed period over which monitoring, maintenance, etc., is required. Instead, the burden of proof on when it is safe to no longer monitor and maintain the landfill should be on the landfill owner/operator. Adopting this approach will put the burden of potential damage on the owner/operator rather than the nearby residents of the landfill. It should not be up to them to experience groundwater contamination in their wells and then attempt to get the regulatory agencies to eliminate this contamination as is typically occurring today. Instead, the regulatory agencies should require that the owner/operator of the landfill take the necessary steps to assure that the adjacent property owners' health and welfare are protected forever from any potential damage by that landfill. Failure to adopt this approach clearly represents a condemnation of adjacent property owners' land values without paying them for the damage that will be done to them.

Landfills, whether hazardous or sanitary, will require a significant amount of long-term, likely forever, monitoring and maintenance. First and foremost, the landfill cap must be maintained. Of particular concern is presence of appropriate vegetation, erosion, and differential settling within the landfill. The vegetation that caps the landfill must be maintained. It may have to be watered during periods of drought, fertilized, and most importantly, managed to prevent deep rooted plants from developing. If bare spots develop within the vegetation, they will have to be reseeded; if erosion occurs, it will have to be regraded; and if cracks develop, as evidenced by differential settling of the cap, then both the clay and the FML will have to be examined and repaired. This management is not for just a few years as is typically required in regulations governing landfill operation; it will have to be managed forever, i.e., until the waste within the site no longer represents a threat to groundwater contamination. As discussed above, since municipal landfills contain a variety of highly hazardous heavy metals, non-degradable organics, salts, and other constituents, postclosure care operations and especially the cap maintenance for dry tomb landfills located in areas where the groundwaters are or could be used for domestic water supply purposes will have to be done forever if groundwater quality is to be protected.

Basically, the approach being adopted by regulatory agencies across the US of trying to keep the landfill dry, but not ultimately succeeding in doing so because of a lack of adequate maintenance of the site and improper monitoring and maintenance once the waste becomes wet again, represents an attempt by today's society to pay less for municipal solid waste management than is really necessary to provide for long-term public health and environmental protection. This is being done at the expense of landfill adjacent property owners' health and welfare. While there are some public officials and their appointees as well as some in the public, in general, who bemoan the NIMBY approach of adjacent property owners, it is clear that NIMBY is justified based on the approaches being used today for management of both solid and hazardous waste by land burial. There is no truly long-term public health and environmental protection being provided by existing regulations. Until this is done, those who oppose landfills being sited in their area are justified based on the fact that society today has not made adequate provisions for public health and environmental protection and their interests.

It is evident from the above discussion that little is known today about the long-term stability of landfill liners and caps. It is clear that the current approach will perpetuate the public health/welfare and environmental quality compromises associated with providing less than adequate postclosure care while continuing the deception of less expensive solid waste disposal. By not mandating true long-term public health and environmental quality protection during the postclosure care period, the US EPA is saving the urban/residential area dweller a few cents per person per day associated with their solid waste disposal. As discussed below, the US EPA should propose revised regulations as part of implementing Subtitle D of the 1984 RCRA that

Figure 5. Factors Affecting Long-Term Integrity of Landfill Cap



promote a conservative public health protection approach of requiring that those who propose to dispose of wastes in a certain manner do more than what is obviously the minimum necessary to give the appearance of assuring that these wastes will not have an adverse effect on public health/welfare and the environment. If an error is to be made in the expenditure of funds associated with waste management, it should be made on the side of protecting those who could be adversely affected by providing more protection than is currently understood to be really needed, rather than on the side of the waste generator by providing less protection than is obviously really needed.

It is important to emphasize that the garbage-solid waste management crisis that exists in the US is fundamentally controlled by economics. This crisis could be solved in a short period of time if those who generated the wastes in their homes and commercial establishments and who create the demand for the goods that generate the wastes from industries, businesses, etc., would pay the true cost of these goods, services, etc., that includes proper waste management. The US and, for that matter, the world's population has put the burden for waste management on the environment and those individuals who reside or otherwise use the areas wherein the wastes are disposed. In the short term, this is the least expensive way to proceed and is how this society developed its current solid waste management crisis. The revisions of the US EPA's August 30, 1988 Federal Register must be significantly changed from perpetuating this approach to developing unequivocal long-term protection of public health/welfare and of the environment even to the extent of providing more protection than is really needed through the postclosure care period. The period of postclosure care must be mandated to be as long as the wastes represent any threat to public health and welfare of any nearby residents-users of adjacent lands and to environmental quality.

The leachate collection and monitoring systems will have to be inspected periodically, and any leachate that is found above the FML liner will have to be removed. If significant leachate begins to be found, then the source of the liquid that generates this leachate must be identified and prevented from continued entry into the landfill. If contamination of the leachate detection system between the two liners composite liners occurs in a double composite lined landfill, then it is clear that the FML liner has been breached, and steps should be taken to prevent groundwater contamination. This will likely require exhumation of the wastes since once the primary FML is breached, it is only a matter of time until groundwater contamination occurs.

Monitoring of the solid and/or hazardous waste disposal site must continue forever. There is no justification for developing regulations which would enable an owner/operator to ever be relieved from his/her responsibility of monitoring the groundwaters near the solid waste disposal site for the purpose of detecting groundwater contamination before it reaches an adjacent property owner's wells. This monitoring should not follow the typical approach as required in some state's sanitary landfill monitoring regulations of measuring only a few so-called indicator parameters such as specific conductance, pH, COD, etc., but must include many of the more hazardous components of greatest concern, such as the chlorinated hydrocarbons, as well as some of the more mobile highly toxic heavy metals such as lead and cadmium.

There are some who question whether landfill owners/operators today should be concerned with what may happen 50, 100 or several hundred years from now. Many in society would agree that today's society does not have the right to dispose of its solid wastes in a less expensive manner than is really necessary to protect future generations' health and welfare. This society should not perpetuate the situation that exists today where past societies disposed of their solid wastes from municipal and industrial sources by land burial with little or no regard for long-term public health protection. It is important to point out that the problems with sanitary landfills contaminating groundwaters have been known for over 30-50 years. As discussed by Todd and McNulty (1974), there are numerous examples in the literature of sanitary landfills-municipal dumps contamination of groundwaters that predate 1950. It has taken over 30 years for society to begin to address the problems of groundwater contamination associated with sanitary landfills in a meaningful way. As of yet, to the knowledge of the authors, no state regulations have been developed to provide for true long-term public health and environmental protection. The states have been attempting to provide for stop-gap relatively short-term protection and thereby pass these problems on to future generations.

There will likely be many who object to the increased cost of solid waste management associated with providing for perpetual care for the landfill disposal sites. These costs should be paid by the generators of the waste associated with disposal of the waste by land burial. Regulatory agencies should require the owner/operator of the landfill to establish a trust fund in a sufficient amount so that there is no question that there will be sufficient funds available <u>forever</u> to maintain the cap, remove leachate as it is collected, continue to monitor the site and, if breaching of the FML occurs, to remediate the site including <u>exhuming</u> the wastes to prevent groundwater contamination.

A basic problem that exists today is that society has become accustomed to paying little or almost nothing for solid waste management. In some parts of the US today, individuals are still only paying a few cents per person per day to dispose of their solid wastes. Under these conditions, the wastes disappear from the front or rear of their home and little or no regard is given to their ultimate fate or impacts on others in society. It is now clear that this society is going to have to significantly increase the amount of funds that are spent for solid waste management. Even with the projected increases, however, it still will not, in most instances, represent a significant part of any household budget. These costs are discussed below. Failure to properly address these problems now will result in future “Superfund” like activities where much greater expenditure of funds will have to be made to clean up contaminated sites from both hazardous and solid waste disposal than would be needed to properly dispose of them initially.

Groundwater Monitoring - Problems with Current Approaches

In the early 1980's the US EPA, as part of developing RCRA regulations, proposed what was called the "fail-safe" approach for landfilling of wastes. This approach involved providing a liner, leachate collection and removal system, low permeability cap and a groundwater quality monitoring system. The key component of the "fail-safe" system was groundwater quality monitoring. The typical groundwater monitoring program for landfills that was developed at that time and is still being used today is one upgradient well and three downgradient wells. Then and today it is advocated that whenever a statistically significant increase in contaminants occurs in the downgradient wells as compared to the upgradient wells that landfill leakage is occurring. It is proposed that at that time corrective action can be taken to prevent widespread pollution of the aquifer by landfill leachate. It was further proposed in the early 1980's that only a few indicator parameters, such as TOC, TOX, TDS, and pH, need to be monitored to detect landfill leakage. As discussed by Lee and Jones (1983b), the US EPA's so-called "fail-safe" monitoring approach was based on an inappropriate assessment of the ability of the measurement of the one upgradient and three downgradient wells to detect landfill pollution of groundwater.

Over the years it has become increasingly recognized that the typical landfill groundwater monitoring program for new lined landfills is grossly inadequate in detecting landfill leakage. Recently, ASTM Committee D18.21 conducted a "Symposium on Groundwater and Vadose Zone Investigations" that was held January 30-February 1, 1991 in San Diego, California. The proceedings of that symposium will be published within the next year. Several speakers at that symposium discussed the highly significant deficiencies in the ability of the currently used groundwater monitoring programs in detecting landfill leakage. In the opinion of the authors, the current one upgradient, three downgradient monitoring well system would, rather than being considered a "fail-safe" system, be lucky to detect leakage. This situation is readily understood when consideration is given to the typical placement of downgradient monitoring wells. In order for a well to detect leakage from a landfill the leakage plume must intercept the zone of water capture for the well. In a typical monitoring well, the zone of capture of water after purging the well with the typical three well volumes is no more than a few inches from the well.

It is also now well known, primarily from the studies of J. Cherry and his associates at the University of Waterloo's Centre for Groundwater Research, that in a sand aquifer system that is highly homogeneous in its characteristics, the vertical and horizontal dispersion of the leachate plume in the groundwater is limited. Injection of point sources of contaminants which would resemble leakage through a hole in a liner move downgradient in the groundwater as "fingers" rather than cones. The typical picture often portrayed for leaks is that of a fan or cone with rapid horizontal spread of the leachate plume as it moves downgradient. It is now clear that this characterization is not reliable for the kinds of aquifers (sand) of greatest concern. The dispersion that occurs is primarily longitudinal. This situation puts in great doubt the ability of three downgradient wells to detect a leak in a liner from a landfill before widespread contamination of the aquifer has occurred. In order to detect such a leak before this contamination occurs, an array of downgradient monitoring wells must be established that will detect relatively thin (from both a vertical and horizontal perspective) "fingers" of leachate contaminated groundwater. With typical monitoring well zones of capture being no more than a few inches from the well, it is clear that hundreds of downgradient monitoring wells, not three wells, are needed to have any significant probability of detecting the leak from a modern day landfill.

The situation in detecting leaks in the unsaturated (vadose) zone is the same if not worse. It has been known for some years that movement of moisture-contaminants in the vadose zone is typically via small channels (macropores) rather than by sheet flow. In work that the authors were involved in several years ago at Texas Tech University, it was found that vacuum cup lysimeters placed only a few inches apart would show drastically different vadose zone transport of moisture and contaminants. Further, the contaminant transport was typically a short term pulse event which would not be detected by the typical vadose zone detection equipment being used today in landfill monitoring. The typical vadose zone monitoring system would likely intercept leakage from a very small part of the landfill liner system.

The situation for monitoring landfill leakage in fractured rock is also difficult to do with any significant degree of reliability. Dependent on the degree of fracturing, it is highly likely that leachate can readily pass by a monitoring well system and not be detected because the monitoring well did not intercept the fracture carrying the leachate. Even with highly fractured systems, insufficient zones of capture occur in the fractures intercepted by the well to detect leakage. It is also known that in some instances these fractures (fracture traces) can provide conduits for leachate contaminated groundwater that allow rapid transport of leachate down the trace compared to the general movement of groundwater in the region. These fracture traces can be effective conduits for leachate over considerable distances approaching or exceeding kilometers in length.

A factor that must be considered in sampling groundwaters contaminated by municipal landfill leachate is that the leachate typically contains sufficient salts so that it will, upon entering the groundwater, tend to sink due to its greater density. This means that, dependent upon the horizontal velocity of the groundwater and the characteristics of the aquifer, the leachate plume may be somewhat below the water table where it will occur as a relatively narrow "finger" in a sand aquifer system. This situation necessitates an array of monitoring wells screened to various depths at each monitoring well location to achieve a significant probability of detecting incipient leakage-pollution of groundwater by a landfill. The typical three depth monitoring well array (near surface, mid, and near bottom) used in groundwater monitoring systems cannot be relied upon for many saturated aquifers of tens of feet thick to detect landfill leakage near the landfill. Many more depths are necessary to detect such leakage.

It is sometimes argued by proponents of landfills who wish to reduce monitoring costs that a single well screened the full depth of the aquifer saturated zone can be used to detect landfill leakage. This approach is technically invalid since the leakage can readily be diluted by the well volume to the point where the concentrations of the contaminants in the leakage are below the detection limits of the analytical procedures used. Fully screened saturated zone monitoring wells are not reliable systems for detecting landfill leakage and should not be allowed. Instead, comprehensive arrays of monitoring wells designed to sample discrete, fairly narrow depths of groundwater in the aquifer should be used.

The indicator parameters, such as pH, TOC, TOX, TDS, etc., do not provide adequate sensitivity to detect landfill leakage. Typically, but not always, the VOC's, such as TCE and its transformation product vinyl chloride, are better indicators of leakage than the indicator parameters that are often used. It is clear that a monitoring program must include routine measurement of a wide variety of chemicals that are known or suspected to be present in the landfill that can be measured at low concentrations.

Another problem with the typical landfill groundwater monitoring program, of the type being used today, is the failure to properly purge the well as part of sampling. Several papers at the recent ASTM conference demonstrated the inappropriateness of using indicator parameters, such as pH, specific conductance, and temperature, as a measure of adequate purging prior to sampling. For VOC's, and especially vinyl chloride, the stagnant water in the monitoring well will likely have significantly different concentrations of these chemicals compared to the aquifers.

The typical groundwater quality monitoring program assumes that the release of contaminants from a landfill is a steady stream once the liners are breached. In arid climates with a moderate degree of cap integrity, the release of leachate from the landfill will more likely occur through holes in the liner in discrete, short term pulses. The typical quarterly groundwater monitoring program will likely be inadequate to detect such pulses.

From an overall point of view, it is clear that the groundwater quality monitoring programs being constructed today have a typically low probability of detecting leakage before significant aquifer pollution occurs. These monitoring systems provide little or no public health and groundwater quality protection. It is evident that to provide a high degree of groundwater quality protection from municipal and many industrial landfills that drastically different groundwater monitoring systems need to be used where arrays of hundreds of wells must be sampled frequently to achieve even a moderate probability of detecting leaks before widespread groundwater pollution occurs. With each monitoring well typically costing between five to ten thousand dollars there is little likelihood of ever being able to develop groundwater monitoring programs that provide for a high degree of detection of groundwater pollution at the edge of the landfill or other waste management unit. Under such conditions, it is essential that landfills of the "dry tomb" type being used today are only used where the inevitable leakage from such landfills will not pollute groundwater that is or could be used for domestic or many other water supply purposes.

Groundwater Monitoring - Suggested Approach

Presented below is a summary of a suggested approach for establishing a groundwater monitoring program for landfills.

1. Conduct comprehensive, in-depth investigations of the geology and hydrogeology of the landfill area with particular reference to plausible transport of contaminants from the landfill to domestic or other water supply aquifers. It is essential that a good understanding of the flow paths and rates be developed before the groundwater monitoring program is developed. The typical approach of arbitrarily placing one well upgradient and three wells downgradient of the landfill should not be allowed.

2. Define the monitoring objectives, i.e., 95% detection of incipient contamination of groundwater by leachate from any point of leakage in the landfill.

3. Determine well spacing to capture groundwaters contaminated by leachate at the objectives of the monitoring program considering both horizontal and vertical transport of leachate contaminated groundwaters.

4. Determine the frequency of sampling by assuming the time of traversing the zone of capture of the monitoring wells based on groundwater velocities in the vicinity of the wells.

5. Collect and set aside funds from disposal fees that will be needed to operate and maintain (including well replacement) the groundwater monitoring system forever.

6. Utilize individuals who are highly knowledgeable in groundwater monitoring data review associated with the particular type of landfill being monitored, i.e., municipal solid waste landfill, to review the groundwater quality data as it is collected.

Financial Assurance for Funding of Postclosure Care

Recently the Federal Congressional General Accounting Office (GAO, 1990) has released a report entitled "Hazardous Waste Funding of Postclosure Liabilities Remains Uncertain." GAO has determined that the current provisions of RCRA do not necessarily establish reasonable assurance that any entity will provide the funding necessary to conduct landfill postclosure operations to prevent groundwater pollution by landfills. While this report is focused on hazardous wastes, it is equally applicable to municipal solid wastes and in many instances industrial, non-hazardous wastes. In fact, the situation for municipal solid wastes is even more uncertain since there is the mistaken belief that leakage from municipal landfills is not highly significant with respect to groundwater quality. Lee (1990) has recently discussed why municipal solid waste contamination of groundwater is of more importance than just Priority Pollutants. The author agrees with the GAO position that at both the federal and state levels, inadequate attention has been given to how the provisions of the respective regulations requiring postclosure care as long as needed to protect groundwater quality. Since postclosure care is the key to groundwater quality protection, a high priority should be given to developing reliable mechanisms for adequately funding postclosure care.

Figure 6 presents a generalized portrayal of the income and expenses associated with operating a "dry tomb" landfill. At the time of construction of the landfill, the owner of the landfill has significant expenses associated with establishment of the landfill. Once the landfill starts to accept wastes, however, the landfill owner can recover the initial investment and the landfill becomes highly profitable. In one case that the author is familiar with, a landfill company purchased an area (gravel pit) that could become a 200-acre landfill at a cost of $60 million. It was estimated by representatives of that firm that the company would make $12 million per year profit during the approximately 20-year active life of the landfill. This means that the company would recover its initial investment in about five years. For the next 15 years of the expected active life of the landfill, the company would make a total profit of about $180 million. This example demonstrates the high profitability of municipal solid waste landfills.

At the time of closing of the landfill, the landfill company will have the expenses of closing (capping) the landfill. For a period of postclosure care, the company will have the expense of monitoring the groundwater, maintaining the cap, removal of any leachate, etc. This type of expense continues indefinitely until groundwater pollution occurs at the landfill due to failure of the liner system to prevent leachate migration from the landfill. At that time, there will be significant expenses associated with groundwater clean-up and other remedial measures, including possibly exhuming the wastes, properly treating them, and appropriate burying of any residues so that they do not represent a threat to groundwater quality.

It is clear that private landfill companies have to be relying on the premise that any landfill will result in a net profit to them. The only way that this can occur, however, is for them not to continue to fund postclosure care operations. Either these operations will stop after 30 or so years, or the public will have to start paying for their costs. States such as California have requirements that the owner/operator of the landfill is responsible for postclosure care funding as long as the wastes in the landfill represent a threat to groundwater quality. Since many of the heavy metals and a wide variety of non-degradable organics that are present in municipal solid wastes will be a threat to groundwater quality forever, it is clear that the companies that own municipal landfills obviously cannot plan to fulfill this obligation even though they agreed to do so as part of obtaining a permit for the landfill operations.

It is suggested that one way to provide for true long-term public health, groundwater quality, and environmental protection is to require that those who contribute wastes to a landfill also contribute funds to a trust that will be used for postclosure care. In this way those who are trying to get by, by paying less than the true cost of appropriate municipal solid waste management, will pay for the postclosure care operations for their wastes, rather than passing these costs on to future generations. It is suggested that every person who contributes wastes to a landfill should pay a $20 per year fee to fund postclosure care.

The trust fund would provide the funds needed by the private owner/operator of the landfill to maintain and when necessary replace the cap, operate and maintain the gas collection removal and management system, remove and treat the leachate, monitor groundwater, and when leachate has passed through the uppermost composite liner of a dual composite liner system, mine the wastes from the landfill and provide for proper waste treatment and disposal of the residues in a manner that will not represent a threat to groundwater quality. It is important to note that these kinds of activities will be required for as long as the wastes are present in the landfill since municipal solid wastes contain a wide variety of inorganic and organic contaminants that will always represent a significant threat to groundwater quality. It is also important to note that the trust fund should never be made available to the landfill owner/operator.

The statements of some landfill owner/operators and geotechnical engineers in support of landfill permit applications that municipal solid waste landfills do not represent long-term threats to groundwater quality are completely fallacious. As discussed by Lee (1990), municipal solid waste landfills contain highly hazardous heavy metals, such as lead, cadmium, mercury, and a variety of salts, and a large group of non-conventional contaminants typically measured as COD or TOC (unidentified organic matter). The conventional and non-conventional contaminants can destroy a groundwater system for use for domestic water supply purposes based solely on aesthetic-human welfare considerations. Further, it is highly likely that non-Priority Pollutant hazardous organic chemicals are present in municipal landfill leachate that represent a significant threat to the public health of those who consume groundwater contaminated by municipal landfill leachate. Such contamination not only destroys the groundwater for domestic use, but also destroys that part of the aquifer contaminated by landfill leachate for future use. It is therefore clear that municipal solid waste landfills should not be located in areas where the groundwaters are or could be used for domestic water supply purposes because of the threat that they represent to domestic water supply water quality.

The magnitude of the annual individual contributions to the trust fund (initially estimated to be $20 per person per year) will likely have to be adjusted as more information is gained on the true long-term costs of proper municipal solid waste management. $20 per person per year represents about 6 cents per person per day. Certainly the US society can afford to pay this amount in order to provide true long-term public health and environmental protection associated with municipal solid waste management by landfilling using the "dry tomb" approach.

The above-mentioned approach is one approach that will work to ensure that funds will be available when needed for municipal landfill monitoring, maintenance, and remediation. It is likely that other approaches can be developed. It is important, however, that an approach be developed as part of establishing US EPA Subtitle D regulations and state regulations designed to implement Subtitle D regulations to ensure that true financial assurance is available to protect the groundwaters of the state against landfill pollution from municipal and, for that matter, industrial, non-hazardous waste "dry tomb" landfills.

Approach for Evaluation of Public Health and

Environmental Impact of Proposed Landfills

The approach that should be followed in evaluating the possible public health and environmental impacts of a proposed landfill includes a careful detailed analysis of site characteristics, engineering, operations, closure, and most importantly postclosure care plans for the landfill. While it is possible to engineer a solid waste management facility which will not have an adverse effect on public health and the environment at essentially any location, it is in the best interest of the public residing near such facilities as well as those whose domestic water supplies could be effected by landfill leachate contamination to select sites in which the natural geology-hydrogeology provides significant additional safeguards against groundwater contamination.

Site Characteristics

The site characteristics that are of the greatest concern for proposed landfills include depth to water table, net recharge of groundwater, aquifer media, topography of the site both before and after the landfill is constructed, vadose zone media, hydraulic conductivity of the aquifer, presence of nearby ecologically sensitive areas such as wetlands, and the distance to existing and possible future wells. The worst possible case would be a shallow groundwater in a silica sand or gravel aquifer on a ground watershed divide with near surface fractured bedrock or cavernous limestone or other geological characteristics which would result in the rapid transport of the leachate from under the landfill to adjacent property owners' lands once the liners of the landfill have been breached.

In the past, sand and gravel pits have frequently been sites for sanitary landfills. With few exceptions, these sites are poor locations for landfills because of the highly porous nature of the strata in the region. Some states, such as California, have passed legislation that prohibit locating landfills in sand and gravel quarries. Lee (1989) has recently discussed the problems of expanding a sanitary landfill located in a sand and gravel quarry in the San Gabriel Valley of California.

The National Water Well Association, on behalf of the US EPA, has provided guidance on those geological-hydrogeological conditions which most readily lead to groundwater contamination (Aller, et al. 1987). They have developed the DRASTIC system for the classification of geology-hydrogeology of an area. While the DRASTIC approach is designed to address groundwater contamination problems associated with the presence of contaminants on the soil surface such as the agricultural use of pesticides, with minor modifications it provides useful information in siting landfills and other facilities that could contaminant groundwaters in a region. Aller, et al., should be consulted for further information on this topic.

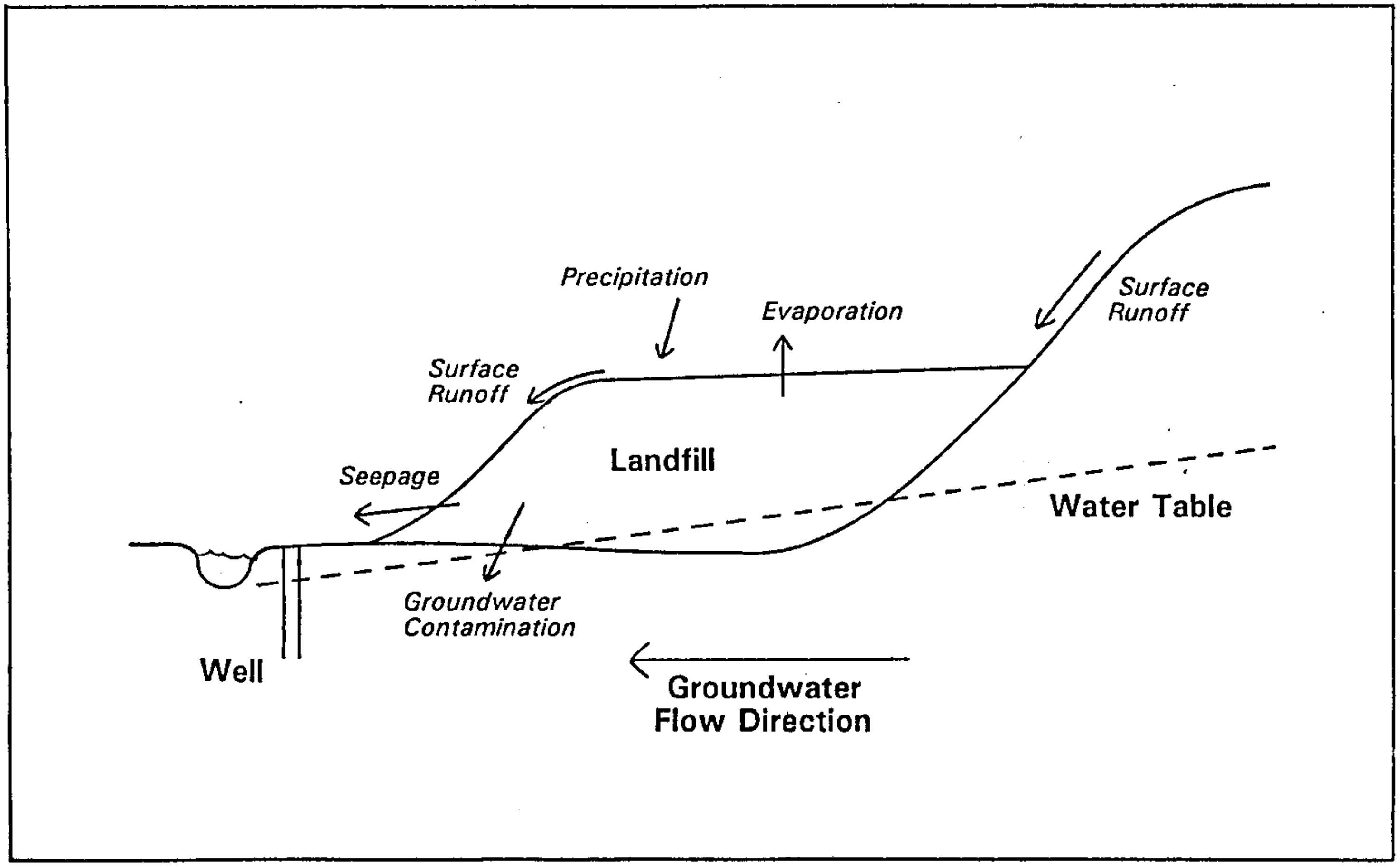
For additional discussion of the changes that need to be made in managing the land burial of municipal solid wastes, consult Heath and Lehr (1987). They have discussed this topic from a groundwater quality protection point of view in which they advocate that the unsaturated zone beneath the landfill be at least 10 feet thicker than the depth of the waste pit. This unsaturated zone should contain a significant amount of silt and clay and the groundwater flow regime in the region of the landfill should be toward the land surface, i.e., the landfill should be located close to a groundwater discharge zone. They provide a number of other suggested approaches that would tend to minimize groundwater contamination by sanitary landfills. These suggestions should be considered in siting new landfills.

In many parts of the country, garbage dumps and sanitary landfills have been located in low lying wet areas. These areas were selected because usually they were among the cheapest land available. With the development of wetlands protection regulations at the federal and state levels, locating landfills in wetlands areas is no longer possible. There are situations where landfills are sited today next to or adjacent to wetlands. As discussed below, this situation can also be detrimental to the wetlands.

In mountainous areas of the US there is an increasing tendency to site landfills in mountain canyons. Lee and Jones (1990c) have recently presented a discussion of the problems of siting landfills in canyons. Figure 7 presents the typical situation that is encountered with canyon landfills. Canyons are the headwaters for the surface and groundwater resources of an area and have higher precipitation than valley areas. Frequently canyons have shallow groundwaters and springs which make the siting of a landfill in the area which requires a 5-foot separation between the groundwater table and the waste impossible. As discussed above, some geotechnical consultants will advocate that groundwater diversion structures can be constructed which will keep the shallow groundwater out of the landfill. This approach is very dangerous and should not be allowed since ultimately such structures will prevent groundwater from entering the landfill and create leachate that can leave the landfill in another area and pollute groundwaters of the region.

Canyon landfills typically tend to have a significant potential for surface water run-on to the landfill from adjacent higher grounds. This increases the amount of moisture that has to be dealt with on the surface of the landfill to prevent entry into the landfill. Surface water run-on diversion structures will have to be maintained forever to prevent additional leachate formation over what can occur due to precipitation on the surface of the landfill. Also, many canyons are geologically less stable than valley areas and are more subject to seismic activity and landslides. Further, many canyons have fractured bedrock near the surface of the land. This makes the construction of a groundwater monitoring program that will have a high reliability in detecting landfill leakage difficult. Canyon areas also have greater recreational and wildlife values than many valley areas. In general, Lee concludes that canyons may be highly unsuitable sites for landfills.

Figure 7. Characteristic Canyon Landfill



Impact of a Landfill on Area Hydrology

The construction of a large landfill will significantly impact the groundwater recharge in the area covered by the landfill. This altered recharge could significantly alter the groundwater hydrology in the region. It could change the direction of groundwater flow by changing watershed divides and the water table which could alter the velocity of groundwater movement. This, in turn, could have a significant adverse effect on adjacent properties utilizing groundwater as a water supply as well as on adjacent areas where groundwater becomes an important part of the surface water hydrology such as in wetlands. Some consulting firms attempt to mediate this impact by constructing groundwater recharge areas in which surface water running off the cap from the closed landfill is deliberately recharged to the groundwaters at the edge of the landfill. Such systems will require perpetual maintenance to assure that the landfill does not adversely affect the groundwater flow regimes in the region. Of particular concern is the potential for plugging of the recharged galleries by eroded materials in the surface run off.

It is important to emphasize that if a landfill is located near a wetlands area, that significant damage to the wetlands systems could occur by the landfill altering the groundwater flow regimes that discharge in the wetlands. It is inappropriate, as sometimes advocated by landfill proponents, to claim that since the recharge system provides the same amount of annual average recharge to the groundwater as occurred prior to the construction of the landfill, that the construction of the landfill will not have an adverse effect on the wetlands. Wetlands ecosystems are sensitive to seasonal flow regimes. Therefore, great caution must be exercised in constructing landfills in areas where the landfill could significantly impact the amounts of groundwaters delivered to a wetlands at any time during the year. It will be virtually impossible to construct landfills in such areas without having an impact on the wetlands system.

Suggested Approach for Management of Municipal Solid Wastes

The suggested approach that should be considered for adoption by municipalities and others for management of municipal solid wastes involves the development of at least state and preferably federal legislation which will unequivocally provide for long-term public health and environmental protection associated with the land burial of the wastes or their residue. As discussed above, the current regulations governing the land burial of solid wastes and, for that matter, hazardous wastes as well as those proposed by the US EPA do not provide the adjacent-nearby property owners with reasonable assurance that groundwaters under their property will not, at some time in the future, become contaminated by leachate derived from the landfill. They, therefore, in general, are justified in adopting the NIMBY approach in opposing a new or expanded landfill in their area based on groundwater quality protection alone.

It is important to note that even if this issue is resolved through appropriate legislation providing for groundwater protection, there are still a number of other issues that must be addressed to assure that the residents near a new sanitary landfill will not be adversely impacted. Such issues as increased truck traffic, indiscriminant dumping of solid wastes by individuals in the area, odors, noise, decreased property values and the overall aesthetic characteristics of the landfill, etc., are all potentially significant reasons to oppose constructing a landfill in their area. As long as society sites, operates, and maintains landfills with a general philosophy of spending the least possible amount of money to just get by, the residents near a landfill will almost certainly be damaged by its presence. If this society is going to solve the solid waste management crisis that is occurring today in many parts of the US and could throughout essentially all of the US in the near future, it will have to take a drastically different approach toward siting, operating and maintaining sanitary and other landfills.

Every state should aggressively pursue developing enforceable regulations that will assure forever that residents of properties adjacent to and near the landfill will not, in any way, be adversely impacted by the landfill. Obviously, the legislation that must be adopted in every state and, most importantly, be vigorously enforced by the state regulatory agencies must provide for long-term -- for as long as the wastes represent a threat to groundwater quality - forever -- monitoring, maintenance of the cap and leachate collection system, removal of leachate, etc., as well as remediation of the landfill should readily detectable amounts of leachate be found in the leachate detection system between the two liners. In addition, the access roads to landfills should be of such character and quality to be able to handle the increased truck traffic without endangering or otherwise adversely affecting others who utilize these roads.

Sufficient buffer property should be purchased and maintained so that those living adjacent to the landfill would have limited opportunity to know that there is a landfill in their area because of adverse impacts on them. The common indiscriminant dumping of bags of garbage and other wastes near landfills should be prevented by aggressive policing of the area and law enforcement which would place heavy fines on those found dumping their wastes near the landfill. The landfill operators must be required to inspect the adjacent properties and roadways leading to the landfill every few hours whereby they pickup any solid wastes that have fallen off of trucks or have been illegally placed in the area by indiscriminant dumping. Under no circumstances should residents near a landfill experience solid wastes in the roads or on their properties that remain there more than a few hours.

All of the above will significantly increase the cost to the general public of solid waste management-disposal. However, anyone who complains about this increased cost should be prepared to accept the municipality's solid wastes on properties adjacent to them. There is no inherent right of today's society which guarantees that this society should be able to dispose of its solid wastes by placing them in a can or plastic bag at a cost of a few cents per person per day. This is how the garbage-solid waste crisis developed in the US. Society in general was not concerned about the impacts of their solid waste on others as long as the waste disappeared from their property once or twice a week and it did not cost them more than a few dollars a month to have this occur. This is basically a residence-near-the-landfill be damned attitude. Most society takes the attitude that they are happy that no one is proposing to site a landfill in their area. They would vigorously oppose such a landfill if anyone made such a proposal. They, however, are not willing to voluntarily support increasing their solid waste disposal fees in order to protect the health, environment, and welfare of those residing near an area where a landfill is located. This approach has led to the current solid waste crisis in the US and in other countries. The cost to properly manage their solid wastes so that they do not cause adverse public health, environmental, and welfare impacts on the residents near the solid waste disposal site will increase significantly from the few cents per person per day that is typically being paid today. However, the increased costs represent a small part of the total daily budget that a typical household utilizes for non-essential items. Residents near proposed landfills are entitled to this type of protection. Until such protection is provided, they are justified in preventing landfills from being located in their area.

The legislation that needs to be adopted in every state and at the federal level as well should not only provide for the nearby to the landfill residents' health and welfare but in many areas, possibly universally, provide for significant financial compensation of these residents as a result of their allowing a landfill to be placed in their area. This approach is being used in other countries to facilitate siting of what is considered by many of the public to be facilities which could be adverse to their health and welfare. By providing for true long-term public health, environmental and welfare protection through the above suggested approach, and through significant financial compensation of residents near landfills, it should be possible to significantly reduce the magnitude of the current solid waste and, for that matter, hazardous waste management problems that exist in the US today.

Adopting the US EPA August 30, 1988 proposed regulations will perpetuate the public health/welfare and environmental quality compromises associated with providing less than adequate postclosure care while continuing the deception of less expensive solid waste disposal. By not mandating true long-term public health and environmental quality protection during the postclosure care period, the US EPA is saving the urban/residential area dweller a few cents per person per day associated with their solid waste disposal. The US EPA should propose revised regulations that promote a conservative public health protection approach of requiring that those who propose to dispose of wastes in a certain manner do more than what is obviously the minimum necessary to give the appearance of assuring that these wastes will not have an adverse effect on public health/welfare and the environment. If an error is to be made in the expenditure of funds associated with waste management, it should be made on the side of protecting those who could be adversely affected by providing more protection than is currently understood to be really needed, rather than on the side of the waste generator by providing less protection than is really needed.

Alternative Approaches to Dry Tomb Landfilling of MSW

In many of the more rural parts of the US, the local society will be highly reluctant to adopt mass burn incineration of the municipal solid wastes. The public will likely feel that they should continue to land bury their wastes in sanitary landfills. As discussed above, land burial using improved current approaches (dry tombs) which provide for reasonable long-term safeguards against groundwater and surface water contamination will create a situation in which there will always be a significant potential for groundwater pollution by the landfill. Presented below is a discussion of an alternative approach (fermentation-leaching) toward landfilling of municipal waste which would, if adopted, produce a residue in the landfill that would not represent a long-term threat to public health and the environment.

The basic problem with today's current approach for landfilling of municipal wastes is that unless great care is taken with proper maintenance, monitoring and, where necessary, remediation of the landfill site, groundwater contamination will likely occur at some time in the future. Basically, the current approach creates a tomb which is stable because water is prevented from entering the system. If water enters the system, then fermentation and leaching will occur with the possibility of the associated concomitant problems developing. The authors suggest that consideration should be given to an alternative approach for landfilling of municipal solid wastes in which rather than trying to keep the wastes dry forever and not really succeeding in doing so, a waste disposal area should become a reactor in which aggressive attempts are made to actively ferment and leach the wastes.

Basically, the double composite lined disposal pit described above could be used in which the wastes are placed in the pit in such a manner as to allow intimate mixing with water added to the pit via precipitation, leachate recycle and, where necessary, supplemental addition. It is well known that the moisture content within the landfill is the key to the rate of "stabilization" of the wastes. Stabilization is defined as the anaerobic fermentation in which methane and carbon dioxide are produced. By following approaches similar to those typically used for stabilization of municipal waste water sludges, it should be feasible to ferment and leach municipal solid wastes to near maximum extent possible within a few years.

Harper and Pohland (1988) have also been critical of the US EPA's proposed approach for municipal solid waste management and also advocate a fermentation-leaching approach rather than the postclosure dry tomb approach for land burial of municipal solid wastes. The treatment-leaching approach is in accord with the overall philosophy that congress-the public mandated as part of the revised RCRA.

Several changes will have to be made in landfill design and operation if this rapid stabilization and leaching is to be readily achieved. First, the daily cover used in many sanitary landfills does not necessarily led to an even distribution of moisture within the landfill. This means that some parts of the landfill will be stabilized at a slower rate than other parts. The placement of the wastes, addition of water, and the daily cover used should be such that all parts of a landfill cell are wet to the optimum degree necessary to bring about rapid fermentation of the wastes within the cell to the maximum extent possible. This will likely require that the wastes be shredded before placement in the cell. The work of Ham (1975) has shown that shredding of municipal solid wastes in Madison, Wisconsin significantly improved the waste stabilization with respect to methane-carbon dioxide production. The cost of shredding municipal solid waste represents a few cents per person per day increase in solid waste disposal. It would significantly improve waste handling, fermentation, and leaching.

It may be necessary in some landfills to utilize a header system at various depths to insure that all parts of the landfill are receiving an optimum amount of moisture. Also, some changes will have to be made in the way in which cells are constructed within the landfill to insure that maximum methane generation rates are achieved. Much of the moisture needed to stabilize the wastes in many parts of the US can be derived from precipitation on the landfill surface and through leachate recycle. It is important that the leachate head on the uppermost bottom liner not be allowed to build up within the landfill so that it creates a significant additional potential for passage through the uppermost FML sandwiched composite liner into the leachate detection system below this liner.

Once the waste has been stabilized and leached, it can be removed from the pit. The residue can be sorted-classified by particle size-density and the "soil" like residue can be used as humus as a soil conditioner provided that it does not contain excessive concentrations of heavy metals or other contaminants that could significantly contaminate groundwaters or crops grown on the soil. The non-usable residue can be buried in a permanent landfill. Note, while these residues would have been extensively leached, there would be need to use a lined landfill where the residues are fixed with cement-silicates or another reagent.

This approach is similar to the approach that is being used by some municipalities for landfill mining. Such mining is being done to provide additional landfill space (Bogsted, 1989). The important difference is that the stabilization process would be greatly accelerated and, most importantly, the wastes would be extensively leached. The excess leachate would have to be treated as a waste water and then discharged to surface waters.

Basically, this suggested approach is that of an actively managed landfill rather than the traditional passive approach used today in which no attempt is made to control moisture addition to the landfill or the "dry" tomb approach being advocated by the US EPA (1988b) and some states. By actively managing the fermentation and leaching, many of the problems being encountered today with sanitary landfills should be eliminated or at least greatly minimized.

The second and actually most important aspect of the suggested alternative approach for land burial of municipal solid waste is the leaching of the wastes by the moisture-water added to it. While methane-carbon dioxide production is of concern in sanitary landfills because of the potential for explosion upon ignition when the methane exceeds a few percent of the landfill gas-air mixture as well as for groundwater pollution, the methane generation-migration problems that occur within sanitary landfills are typically readily controllable through an operating gas collection system. The long range problems of leachate contamination of groundwaters in conventional sanitary landfills are much more difficult to control. While not generally considered to be an important aspect of leachate recycle in sanitary landfill operations, it is evident that such recycle will lead to leaching of the wastes of those components that are readily leachable under the conditions that exist within the landfill. It has been known as discussed by Lee, et al. (1986), that leachate recycle within sanitary landfills tends to produce a leachate with improved quality characteristics. Additional research needs to be done, however, to understand how the composition of the recirculating leachate-water added to the landfill effects the leaching of the wastes.

The objectives of adding moisture to the landfill should be the enhanced leaching of the waste with respect to producing a solid residue that when contacted with a mildly acidic precipitation, will produce a leachate that would not be adverse to the use of groundwaters contaminated with this leachate for domestic water supply or other purposes. Essentially nothing is known today about the optimum conditions needed to most cost- effectively bring about this situation. There is no doubt, however, that it can be achieved and that when achieved, the solid waste residues within the landfill will have been sufficiently stabilized-leached so that it will no longer be necessary to maintain the caps, remove leachate from the landfill, and monitor the leachate collection system and the groundwaters near the landfill. This area should be a high priority for research associated with alternative methods of land disposal of municipal solid wastes.

The proposed approach is somewhat "similar" to composting of municipal solid wastes except that it would be done anaerobically rather than aerobically. While composting of municipal solid waste and domestic waste water sludges has been tried by many municipalities and frequently abandoned because of problems, today, highly mechanized composting with proper odor control is beginning to be used with greater frequency by municipalities. The objective of composting is to produce a "stabilized" residue that will not be "offensive" to the public. An important difference between composting as practiced today and the proposed anaerobic pit fermentation and leaching is that the composted residue has not been leached. The composted waste will likely leach contaminants that can have an adverse affect on surface and groundwater quality. Care must be exercised in the use of municipal solid wastes and waste water sludge compost residues to be certain that it does not cause environmental quality problems. Recently, Epstein and Epstein (1989) have discussed the public health issues associated with composting of solid waste.

It is suggested that it may be more economical and environmentally sound to practice anaerobic fermentation leaching (composting) of, at least, yard waste in the double composite lined, reusable, fermentation leaching cells of the type described above. The passive anaerobic fermentation and leaching of yard waste in reusable cells has some advantage over highly mechanized aerobic composting of the type that is being adopted today. First, the odor problems associated with the aerobic process can be readily controlled in the anaerobic cells. Second, the anaerobic process produces methane which can be collected and used as an energy source. Third, the fermented residues produced will be leached so that any soluble components present in them should have been removed. This would make the humus (soil like residues) have less potential for service and groundwater pollution than the aerobically produced compost. One of the primary disadvantages of the anaerobic process is that it will require a larger land area than the aerobic process. There will be some situations where such land is not available.

In some parts of the country, such as California, regulations have been developed which mandate that a certain percent of municipal solid waste stream be recycled by a specified date. In order to achieve the percent recycle specified, it will be necessary for municipalities-counties to recycle yard waste as well as bottles, cans, newspapers, and some plastics. It appears that the regulatory agencies will allow yard waste composting to be counted towards achieving the mandated recycle requirements. It is suggested that the anaerobic fermentation and leaching of yard wastes in reusable cells discussed above should also be counted toward achieving the degree of municipal solid waste recycle mandated by the regulations. So long as this approach is practiced in reusable cells where once the waste has been stabilized and leached and the residues removed from the cell, it will accomplish exactly the same objectives as the aerobic recycling, of not permanently utilizing landfill space for recyclable constituents in the municipal solid waste stream.

Because of the great difficulty in siting new landfills, including fermentation and leaching cells, it has been suggested by Lee and Jones (1990d) that this process could readily be accomplished at existing landfills where previously buried solid waste would be mined and processed to recover recyclable materials. This approach would not only facilitate the siting of fermentation and leaching of solid wastes; it would also mine solid wastes that have a potential for polluting groundwaters. Additional information on fermentation and leaching of wastes and the mining of landfills has been published by Lee and Jones (1990a, 1990b, 1990d).

An increasing consensus is developing that if society constructed its landfills above ground, that many of the problems with groundwater contamination being experienced today would be eliminated or at least greatly minimized. Brown at Texas A&M University has been a strong proponent of above ground landfills for both municipal solid wastes and hazardous wastes. Cadwallader (1989) has recently discussed the merits of above ground waste containment facilities. Moffett and Walters (1989) have discussed the design of elevated concrete buildings for landfills. According to Moffett and Walters, the cost of such landfills is not significantly different than the cost for below ground landfills. The authors feel that above ground landfills which are used to ferment and leach wastes in the procedures described above, have considerable merit and should be adopted. This approach can virtually eliminate the potential for surface and groundwater contamination from the "landfill" during the fermentation and leaching phases and for storage of any residues present after fermentation and leaching.

Conclusions

Significant problems exist across the US in disposal of municipal solid wastes. These problems are primarily associated with the fact that municipal sanitary landfills are being closed at a high rate and that municipalities are finding it virtually impossible to site new sanitary landfills. The public near proposed landfills, while frequently accused of developing the NIMBY syndrome of unjustifiably opposing any waste disposal facility in their area, in the opinion of the authors, can justify opposition to the landfill due to the fact that current regulations adopted at the state level and proposed by the US EPA do not provide for long-term protection of public health and the environment. Until state and federal regulations are modified to provide for such protection and until a mechanism for funding is developed of the type described above to assure that public health, environmental protection, and the welfare/interests of the public will be provided for, no new landfills should be sited. It is apparent that such protection and welfare can be provided at a cost that can be readily paid by the public of less than one and certainly no more than two soft drinks per day, i.e., on the order of one dollar per day.

There is an urgent need for additional solid waste management capacity in many parts of the US; however, the current design, operation, closure, and postclosure activities for sanitary landfills does not provide for adequate public health and environmental protection of the groundwater resources near the landfill. While in the past, sanitary landfills have almost without exception contaminated groundwaters in the vicinity of the landfill, if the public residing or utilizing the land near the landfills is ever to accept, without justifiable opposition, a landfill in their area, significant changes must be made in the approach used for landfilling of municipal solid wastes. First, if the regulatory agencies wish to persist with trying to keep the solid wastes dry, then the landfill must be lined, capped, and maintained for as long as the wastes represent a potential for groundwater contamination in such a manner as to prevent such contamination. It is expected that the duration of required postclosure landfill maintenance activities will be forever since municipal solid wastes contain a variety of highly toxic heavy metals, non-degradable organics and salts that will be available to be leached from the waste exposure to moisture.

It is suggested that municipalities in areas where there is limited space for new sanitary landfills should adopt recycling of wastes to the maximum extent readily achievable (about 50%) and then mass burn incineration of the remaining solid wastes. This approach should include the most readily available, highest efficiency air pollution control on the incinerator air emissions. The ash from these incinerators should be fixed with cement based reagents and placed in monofils which are properly lined, capped, operated, and maintained during operation and in postclosure to assure that at no time in the future will the contaminants in the ash lead to groundwater contamination.

The recycling of wastes should include newspapers and other papers, aluminum cans, glass and plastic bottles, and yard wastes. The yard wastes should be composted in the yard or at a centrally located facility under conditions that are not offensive to neighbors of the facility and do not significantly contaminate surface and groundwaters of the region.

For those communities with large amounts of land readily available where adequate safeguards can be provided to protect public health, the environment, and the welfare of those residing near the landfill, the landfilling of municipal solid wastes may be practiced. It is suggested that such wastes be shredded prior to disposal and that adequate lining of the disposal pit be installed to assure that there is virtually no possibility of groundwater contamination by leachate generated within the wastes. It is suggested that rather than trying to keep the wastes dry, the landfill should be designed and operated to add the optimum amount of moisture to the wastes which would lead to reasonably rapid fermentation-stabilization of the wastes and, most importantly, the leaching of all contaminants associated with the wastes which could cause groundwaters contaminated by this leachate to be rendered unsuitable for use for domestic water supply or other purposes. It is advocated that the landfill be constructed above ground.

Adoption of this approach, when coupled with other suggested approaches and safeguards presented in this report, should lead to a situation in which the public residing near a sanitary landfill (municipal solid waste disposal area) would not have any justification for adopting the NIMBY approach. Unfortunately today, the adoption of this approach is justified. Regulatory agencies and other members of the public are still trying to adopt solid waste disposal practices which do not provide for truly long-term public health, environmental protection and nearby residents' welfare. By trying to save a few tens-of-cents (less than two soft drinks per day) per person per day in the costs associated with disposal, the state and federal legislators, regulatory agencies, and local community officials have created the regional and soon to be national municipal solid waste disposal crisis. This crisis will not be resolved until a more technically-valid public health and environmentally appropriate approach is adopted by all levels of government.

Because of the stigma which, in turn, effects property values of those who reside near solid waste handling, management, and disposal operations-facilities, it is suggested that it will be necessary to make a significant payment to all residents who reside near solid waste and, for that matter, hazardous waste management facilities in order to compensate them for the damage done to their welfare by inappropriate approaches that have been followed by past and, for that matter, today's society. A few hundred dollars to a thousand dollars per month per resident living in the area impacted by the sanitary landfill could change a NIMBY situation to one in which there would be an interest in having a landfill located in their area provided that adequate appropriate public health, environmental, and welfare protection is provided to these residents.

There are some who advocate that even though the US EPA current proposed approach for management of solid and hazardous wastes will not provide for true long-term public health and environmental protection, it is justified since new methods could be found in the future to manage these wastes which would be cheaper than the approaches advocated in this report. The authors do not accept this premise as a valid approach. The public living next to or otherwise using the lands adjacent to an existing or proposed landfill will not accept that cheaper than readily achievable disposal-management approaches should be used today based on the hope that "cheaper" management technologies could be developed in the future. As discussed, the cost of managing the wastes correctly today is not excessively burdensome on the public. They should be adopted now! If cheaper methods are found in the future, they can be adopted at that time. Meanwhile, a significant step will have been taken toward solving the garbage crisis that exists in the US today.

The US today is at a significant turning point with respect to solid waste management. A significant solid waste management crisis exists in many parts of the US. The federal and state legislatures and the regulatory agencies are still attempting to follow past practices of adopting solid waste management procedures which provide for the minimum public health and environmental protection needed to just get by. As long as this attitude persists, the current solid waste management crisis will persist. Today's society must immediately adopt a significantly different approach for municipal solid waste management. This report has provided guidelines on an approach that should be considered.

It is important to emphasize that the garbage-solid waste management crisis that exists in the US is fundamentally controlled by economics. This crisis could be solved in a short period of time if those who generated the wastes in their homes and commercial establishments and who create the demand for the goods that generate the wastes from industries, businesses, etc., would pay the true cost of these goods, services, etc., that includes proper waste management. The US and, for that matter, the world's population has put the burden for waste management on the environment and those individuals who reside or otherwise use the areas wherein the wastes are disposed. In the short term, this is the least expensive way to proceed and is how this society developed its current solid waste management crisis. The provisions of the US EPA's proposed approach for municipal solid waste management as set forth in the August 30, 1988 Federal Register must be significantly changed from perpetuating this approach to developing unequivocal long-term protection of public health/welfare and of the environment even to the extent of providing more protection than is really needed through the postclosure care period.

The period of postclosure care must be mandated to be as long as the wastes represent any threat to public health and welfare of any nearby residents-users of adjacent lands and to environmental quality. While the authors agree with Lehr (1989) that "today's landfills are light years away from yesterday's dumps," they find that today's landfills still do not provide for true long-term public health and environmental protection. Adoption of the approaches advocated in this report would be a significant step toward eliminating this deficiency and addressing the valid concerns expressed by NIMBY's. The cost of properly addressing these concerns will represent a small increase in the cost of solid and hazardous waste management which is readily affordable by the public. Further, it is today's society's obligation to properly manage its wastes so that they do not represent a threat to the health and welfare of future generations. Connor (1988) has discussed the approach that should be used in addressing the NIMBY syndrome. First and foremost is the need to ensure that true long-term public health and environmental protection will be achieved through the proposed approach for solid waste management. This is typically not being done today. Hopefully, regulations will soon be developed and implemented which would achieve this objective.

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