Municipal Landfill Post-Closure Care Funding: The "30-Year Post-Closure Care" Myth

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Introduction

On October 9, 1991, the US EPA promulgated RCRA Subtitle D regulations that prescribed composite-lined and covered landfills, a "dry tomb" approach, for municipal solid waste (MSW) management. While a number of states, including California, had already adopted similar approaches, the 1991 Subtitle D regulations represent the formal adoption of that significantly different approach for handling MSW on a nation-wide basis. Unlike the California regulations that specify post-closure care for as long as the wastes represent a threat however, the US EPA RCRA regulations and those of a number of other states specify a 30-yr period (as a definitive or minimum period) following landfill closure for which funding for care is to be provided. A review of the actual and expected performance of compacted soil layers and plastic sheeting of the types being used today as municipal landfill liners, as well as the character of "liner systems," shows that the "dry tomb" approach will not provide for protection of groundwater quality for as long as the wastes represent a threat; at best the approach only delays groundwater pollution (Lee and Jones, 1992a,b). This paper explores the myth that a MSW "dry tomb" landfill is no longer a threat after 30 years, and discusses the need for perpetual care of closed "dry tomb" landfills.

Need for Post-Closure Care

As discussed by Lee and Jones (1991a), municipal solid waste contains a wide variety of constituents (such as inorganic salts, heavy metals, non-degradable organics, and degradable organic residues) that produce a leachate ("garbage juice") upon contact with moisture. Leachate generated is of a character and sufficiently potent to pollute very large amounts of groundwater rendering it unusable for domestic water supply purposes. Such chemicals in and components of buried municipal solid wastes threaten the quality of groundwater hydraulically connected to the landfill area for as long as the wastes remains buried.

The containment systems that are being used as liners for "dry tomb" landfills will not permanently prevent the passage of leachate generated within the landfill to the groundwater aquifer system; the "containment systems" merely serve to postpone the leakage. While overall characterized as being of low permeability, flexible membrane (plastic sheeting) liners (FML's) typically have holes in them at the time the landfill is put in operation, holes that allow leachate to pass through the liner to the aquifer system of the area. Certain types of readily available hazardous organics can rapidly diffuse through intact (without holes) FML's. Further, FML's are subject to a wide variety of failure mechanisms, including the development of additional holes, cracks, and rips, and deterioration of the plastic sheeting. There is no question that the plastic

sheeting liners and liner systems, including those of multiple layers, will deteriorate over time and fail to provide an effective barrier to significant transport of leachate through them.

Compacted soil-clay layers used as liners, including those in single- and double-composite liner systems, are not impermeable and will ultimately be breached by landfill leachate. They are designed with definitive estimated transport properties and will allow passage of leachate even if constructed properly. Further, clay-soil liners are subject to a wide variety of cracking mechanisms and other factors that violate their integrity, factors that significantly reduce their ability to retard groundwater pollution by landfill leachate.

Thus, the inevitable deterioration of the liner system will cause the system to fail to function as a fail-safe barrier to leachate transport. Since landfill liner systems are typically buried beneath hundreds of feet of garbage, they cannot be inspected and repaired. Thus even if an effective liner system, including multiple layers of liners of various types and an associated leachate collection and removal system, were to be designed and constructed (i.e., not punctured during the active life of the landfill), groundwater pollution would still be expected to occur. Therefore, untreated wastes placed in a "dry tomb" landfill represent a threat to groundwater quality *ad infinitum*. The key to protection of groundwater quality under the influence of such landfills lies in diligent post-closure care of the cover and appropriate groundwater monitoring for as long as the wastes remain buried.

In 1988 as part of promulgating the then-proposed Subtitle D regulations, the US EPA stated,

"First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills." (US EPA Solid Waste Disposal Criteria, 1988a)

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

There have been no significant new technological, social, or economic developments since the US EPA published those statements that would invalidate the US EPA's recognition of the ultimate failure of the liner systems of the types being used today to "prevent" groundwater pollution by MSW leachate. In fact, as discussed by Lee and Jones (1992a), a number of professionals have reviewed the initial and long-term performance of such systems and have concluded that there is a wide variety of reasons for landfill liner systems to fail. Manufacturers of flexible membrane liners used in "dry tomb" landfills provide warranties against manufacturing defects typically for only a 20-yr period. Such warranties are pro-rated over that period and require the owner/operator to identify the site of imperfection and remove the wastes above the area to allow repair. No one knowledgeable in the topic asserts that liner systems of the type being developed today will provide permanent, effective barriers to leachate transport for as long as the wastes represent a threat, which is forever.

Some proponents of "dry tomb" landfills assert that the inevitable failure of a MSW landfill's liner system is of no consequence to groundwater quality as long as the bottom of the landfill is sited above the permanent, natural high watertable (e.g., Eagle, 1992). Such assertions are based on the assumptions that under those conditions, the only way that leachate can be generated in the landfill after its closure is through moisture penetration of the cover, and that the integrity of the cover can be "maintained." They argue that since the cover is "accessible" to inspection, problems with the cover can be repaired once they are detected. That argument, however, does not reflect the realities of a landfill cover.

First, it is widely acknowledged that it is very difficult, if not impossible, to develop a truly impermeable cover for a landfill, much less maintain that integrity in perpetuity. Lee and Jones (1991b) presented a review of the literature on the expected performance of MSW landfill covers. Koerner and Daniel (1992) have also discussed numerous problems encountered in trying to develop low-permeability, much less "impermeable," covers for municipal solid waste landfills.

Second, even though the cover may present the appearance of being accessible to inspection and repair, the fact is that the key components of a cover are not. As discussed by Lee and Jones (1992a), the key to cover performance is the low-permeability layer; that layer is often below one or more feet of topsoil and a several-foot-thick drainage layer. As they discussed, cracks and holes can and do occur in the low-permeability layer of covers that cannot be detected by walking over the surface of the closed landfill. Therefore, there is little likelihood that society, through public or private entities, can keep all moisture out of a municipal solid waste landfill that can generate leachate for as long as the wastes represent a threat to groundwater quality (Lee and Jones, 1992a; Michaels, 1992a,b).

It is obvious that the ability to protect groundwater quality, *ad infinitum*, from "dry tomb" landfills by the nature and extent of post-closure care that can be assured, is severely limited. If adequate funds are made available for reliable groundwater and facility monitoring, maintenance, and necessary replacement of the "dry tomb" landfill cover in perpetuity, it should be theoretically possible to minimize the inevitable pollution of groundwater by "dry tomb" landfills. However, the approaches being used today for monitoring "dry tomb" landfills and area groundwater are largely ineffective in detecting leachate pollution of groundwater before widespread pollution occurs (Cherry, 1990; Lee and Jones, 1992c,d). As discussed below, the estimates of funding that will be needed for landfill maintenance, such as those estimates provided by the US EPA, typically grossly underestimate the true costs. There is virtually no mechanism in today's society to ensure continued and adequate maintenance of a landfill cover and groundwater monitoring for the hundreds and thousands of years (forever) for which it will be required. Therefore as long as the technologically flawed "dry tomb" landfilling approach to municipal solid waste management is practiced, adequate monies must be set aside up-front for the purpose of long-term maintenance and monitoring, and periodic cover replacement.

The Myth of a 30-yr Post-Closure Care Period

The Resource Conservation and Recovery Act (RCRA) specified that the owner/operator of a new "dry tomb" municipal solid waste landfill is required to provide post-closure care funding to

cover conventional care (groundwater monitoring, gas removal, leachate removal, superficial cover maintenance) for a 30-yr period after closure. By specifying a "30-yr post-closure care period" for landfill maintenance, the authors of the original version of RCRA created a myth that now threatens groundwater quality protection. The myth is that within 30 years after closure of a lined, "dry tomb" municipal or industrial "non-hazardous" solid waste landfill, the buried wastes will cease to represent a threat to groundwater quality and that therefore, the landfill owner/operator can be relieved of responsibility for monitoring, maintenance, and remediation. This myth has been advanced and cited as fact by landfill applicants, and even accepted by regulators in some states.

The groundwater quality and engineering technical and scientific community have recognized that 30 years is an infinitesimally small part of the total time period during which untreated wastes in a "dry tomb" municipal solid waste landfill will be a threat to groundwater quality. The authors of the 1984 re-authorization of RCRA also recognized that 30 years of post-closure care for landfills may not be adequate; they stated that the regional administrator "may extend" the post-closure care period beyond 30 years. That notwithstanding, regulatory agency boards and staffs, and consultants on behalf of public and private landfill applicants perpetuate the myth. They continue to claim that within 30 years after closure, lined and covered "dry tomb" landfills of the types designed and constructed today will be "stabilized" to a sufficient degree so that no further measures are needed to protect groundwater quality from the leachable chemical constituents in the solid wastes. Some landfill proponents go as far as to claim that after 30 years of post-closure care, the landfill could be converted to a botanical garden or some other highly beneficial use. Such claims are fallacious since any such use would significantly enhance the possibility that moisture would enter the landfill through the cover to generate leachate which could pollute groundwater.

An understanding of the nature of municipal solid wastes, the ability of components of those wastes to pollute groundwater, and the ability of FML's of the type being used today and of compacted soil-clay liners to prevent landfill leachate from polluting groundwaters for as long as the wastes represent a threat to groundwater quality shows that there is no possibility that a 30-yr post-closure care period will be sufficient for "dry tomb" municipal solid waste landfills.

The myth must be recognized as such and dispelled, and the realities of long-term responsibilities associated with landfilling of wastes properly addressed, or landfill companies, agencies, and current society will profit from the legacy of groundwater pollution that will be left for the public of future generations to address.

Origins and Technical Flaws in the 30-yr Post-Closure Myth

After the "open dump" technology was abandoned and until recently, municipal solid wastes were buried in unlined "sanitary landfills" often located in low-lying or wetland areas. "Sanitary landfills" differed from "open dumps" largely in the placement of a soil layer over each day's waste deposits. "Closure" typically involved placing a few feet of highly permeable soil on top of the landfill. Significant moisture was allowed to enter sanitary landfills from atmospheric sources, run-on onto the landfill (if it was sited in a canyon or next to elevated lands), and groundwaters. Given the moist environment, fermentable organic wastes in such landfills would

undergo anaerobic fermentation ("stabilization") with the production of gas. Typically within 20 to 50 years following closure of a sanitary landfill, fermentation would diminish and the production of gas virtually cease. Thus, it was generalized that within about 30 years or so of sanitary landfill closure, the fermentable wastes would have been largely stabilized. The technical flaws in assuming that that process and time-period have anything to do with groundwater quality protection associated with "dry tomb" landfills of the type being permitted today are outlined below.

First, municipal solid wastes of the types being generated today are not benign materials as their categorization as "non-hazardous" wastes suggests. These municipal so-called "non-hazardous" wastes contain a wide variety of hazardous heavy metals such as lead, cadmium, and mercury; inorganic salts; non-degradable organics; as well as degradable organic residues, all of which can readily pollute groundwaters, rendering them unusable for domestic water supply purposes. Some landfill proponents claim that through recycling, collection of household "hazardous" wastes, and similar waste-stream modification activities, "hazardous" materials can be kept out of municipal landfills and thus eliminate threats of groundwater pollution from landfill leachate. This claim is fantasy. Even with the best of the recycling and household hazardous waste collection efforts today and envisioned for the future, municipal solid wastes will still contain a wide variety of constituents that when present in leachate can pollute groundwaters to a sufficient degree to render them unusable for domestic water supply purposes.

Second, contrary to what some presume, the "stabilization" of fermentable organics in a landfill does nothing to convert many of the chemical components of the wastes that can pollute groundwater to forms that do not represent threats to groundwater quality. For example, fermentation does not reduce the threat to groundwater quality posed by many Priority Pollutants, conventional pollutants, and non-conventional pollutants that are in and derived from the buried wastes. Those constituents will be a threat to groundwater quality for as long as wastes and/or their residues are present in the landfill. Thus, a 20 to 50 year "stabilization" period has no relationship to the period of time over which the buried wastes represent a threat to groundwater quality.

Third, the rate at which fermentable organics are "stabilized" in a classical "sanitary landfill" has no relevance to what occurs in "dry tomb" landfills of the type that are being designed and permitted today. Since developing the 30-yr post-closure maintenance concept, the US EPA and many states have adopted regulations that purport to create "dry tomb" landfills for municipal solid waste. The design objective for such landfills is to keep the waste in the landfill dry in order to prevent the formation of leachate. "Dry tomb" landfills include low-permeability covers to reduce the entrance of moisture into the landfill from the atmosphere; siting requirements typically provide that the wastes are to be separated from the groundwater. The rate and extent to which stabilization of fermentable organics occurs in a landfill is directly related to the amount of moisture present. Christensen and Kjeldsen (1989) have reported that on the order of 20% moisture is required within buried municipal solid waste in order for any significant methane formation (fermentation) to occur. While it is folly to presume that a "dry tomb" landfill of the type being developed today will in fact keep wastes dry forever, it is readily plausible that wastes placed in a "dry tomb" municipal solid waste landfill would dry out as a result of leachate removal and gas (water vapor) extraction at the time of closure. However, to the extent that "dry

tomb" landfills can in fact meet design objective of keeping the wastes dry, they also reduce the rate and extent to which fermentation takes place in the landfill. Significant "stabilization" would not be expected to occur in a "dry tomb" landfill until the landfill cover and/or groundwater barrier begins to allow moisture into the landfill. Thus, the 20 to 50 year "stabilization" period characteristic of unlined "sanitary" landfills has no relevance for modern-day "dry tomb" landfills.

Fourth, barring major design errors or carelessness in construction, "dry tomb" landfills of the type being designed today can be expected to maintain sufficient integrity to prevent widespread leachate contamination of groundwaters for some period of time after closure. It may not be until a few tens of years after closure that the failures in the containment systems begin to manifest themselves as leakage of leachate from the landfill to the underlying groundwater.

In summary, the concept of a 30-yr maintenance period was developed on the basis of the characteristics of fermentation of degradable organics in "sanitary landfills." Because of the fundamental differences between that type of landfill and a lined "dry tomb" landfill of the type being developed today, and because the factors that govern the generation, transport, and water quality impacts of municipal landfill leachate, a "30-yr" period has no relevance or applicability to the period of time over which wastes in a "dry tomb" landfill represent a threat to groundwater quality or to the period of time during which the containment systems of such a landfill must be maintained in order to protect groundwater quality.

Regulatory Requirements and Their Implications

The regulations governing solid waste management and associated groundwater quality protection in almost all states require that the siting, operation, closure, and post-closure care of a municipal solid waste landfill be conducted in such a manner as to provide for protection of groundwater quality from the landfilled waste components. The regulations in some states, such California, require that new and expanded waste management units, such as municipal landfills, must be sited and developed in such a way so as to protect groundwater quality for as long as the wastes represent a threat to groundwater quality; they do not limit post-closure care requirements to some arbitrary period, such as 30 years. Rather, those regulations define the post-closure period to be that period of time during which the wastes in the landfill represent a threat to groundwater quality. While permitting regulations in other states may not explicitly state that the landfill containment system (covers and liners) shall be sufficient and suitably maintained to prevent groundwater pollution forever, many typically imply that to be the objective of the regulations.

The implications of such requirements for the implementation of the regulations creates the desire by landfill companies to limit the duration of their responsibility for landfill maintenance and minimize their financial obligations. Therefore, with distortion of the US EPA's RCRA guidelines that specify a 30-yr post-closure period, landfill applicants and their consultants continue to advance the myth that a 30-yr post-closure period will be adequate. This myth has even been incorporated into California's regulations; the regulations adopted in June 1990 by the California Integrated Waste Management Board to govern post-closure care funding require that the landfill owner/operator initially provide an assured funding mechanism to cover 30 years of

post-closure care. Those regulations also indicate that if a landfill is not producing leachate at the end of the 30-year post-closure care period, the owner/operator of the landfill may be relieved by the Board of all further post-closure care responsibilities, and further, that any funds remaining from those set aside to cover such care may be returned to the owner/operator of the landfill at that time. Until the regulatory agencies understand that there is no technical foundation for specifying a "30-yr post-closure care period" and that such a time period is meaningless in terms of the duration of the threat of groundwater pollution from "dry tomb" MSW landfills, the level of funding established for post-closure care will surely be inadequate to provide for the post-closure care that will in fact be needed to prevent or significantly limit groundwater pollution by the waste components in the landfill.

One of the most disconcerting aspects of the perpetuation of the 30-yr post-closure myth - beyond the threat to groundwater quality - is that some professionals working on behalf of proponents of proposed "dry tomb" landfills have or should have knowledge of the technical fallacies of a 30-yr post-closure specification, yet apparently choose to ignore them. They should know that there is no possibility that a 30-yr post-closure care period will be sufficient for the types of "dry tomb" MSW landfills being developed today. They should know that burial in a lined landfill will not detoxify or immobilize all of the waste components that can pollute groundwater and that there will be need for post-closure cover maintenance, leachate collection and removal, groundwater monitoring, and funds for groundwater quality remediation to halt pollution of the groundwaters by landfill leachate when it begins, for as long as the wastes remain buried. Nevertheless, it is repeatedly observed at public agency hearings to consider permits for proposed landfills, that consultants to proponents of landfills perpetuate the myth that 30 years of post-closure care is all that will be needed for the proposed landfill.

Unfortunately, there are consultants to landfill proponents who lack specific academic and professional education in requisite topic areas including the composition of municipal solid wastes; physical, chemical, and biological processes that occur within "dry tomb" municipal solid waste landfills; the ability of thin plastic sheets and compacted soil layers to prevent chemical contaminants in landfills from being transported to groundwaters in the vicinity of the landfill for as long as the wastes represent a threat to groundwater quality; and domestic water supply water quality and public health implications of waste components in municipal landfill leachate. While educational backgrounds and experience in geology and geotechnical engineering are important to investigating the characteristics of a proposed site for a landfill and the design of the structural components of the landfill, education or expertise in those areas provides little or none of the background needed to adequately address the pollution aspects of a closed landfill. Unfortunately, at this time, some regulatory agency staff and boards do not recognize the significance of the deficiencies in educational backgrounds and professional expertise among many so-called experts that are practicing in the field today and accept landfill proponents' claims that the wastes in a MSW landfill will not be a threat to groundwater quality 30 years after the landfill is closed.

It is time that the professionals in the solid waste and groundwater quality management field dispel the myth that 30 years of post-closure care is all that is needed for new, existing, or proposed municipal "dry tomb" landfills. The professionals working in this field should become pro-active in developing solid waste management systems that will provide a high degree of

reliability for protecting public health, groundwater quality, and the environment for as long as the waste components represent a threat to man, water resources, and the environment.

Perpetuation of the myth has resulted in and will further regulations that virtually ensure that there will not be adequate funds available when needed to halt widespread groundwater pollution by landfills, and manage the source of the contaminants in perpetuity. Rather than planning for a 30-year post-closure care period, the owner/operators of landfills and those responsible for regulating them should plan for a non-terminating post-closure care period and a mechanism that will ensure that adequate funds are available to maintain and when necessary replace the cover, to remove leachate, to properly monitor groundwaters for leachate contamination, and, most importantly, to exhume the wastes and properly treat them when the liner systems are breached.

Post-Closure Care Funding Realities

The level of funding needed for a conventional 30-yr post-closure maintenance period is orders of magnitude below that which will actually be needed for post-closure maintenance for as long as the wastes represent a threat to groundwater quality (forever, as long as the wastes remain in the landfill). However, post-closure maintenance for as long as the wastes remain a threat to groundwater quality is part of the total cost for the "dry tomb" method of waste "management" and a cost that should be borne by those who generate the wastes. Those costs should not be passed on to future generations either in the form of economic responsibilities for maintenance or in the form of lost water resources and public health and environmental quality problems. It is therefore evident that a perpetual care fund of substantial magnitude will be required at every "dry tomb" landfill that is sited such that leachate from the landfill can enter an aquifer that is or could be used for domestic purposes.

The US Congress General Accounting Office (GAO, 1990) released a report entitled *"Hazardous Waste Funding of Postclosure Liabilities Remains Uncertain."* The 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 post-closure operations to prevent groundwater pollution by landfills. The GAO (1990) stated as one of its conclusions,

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

While the GAO report focused on RCRA hazardous wastes, its findings are equally applicable to municipal solid wastes and in many instances industrial "non-hazardous" solid wastes. In fact, the situation for municipal solid wastes is even more uncertain because of the prevalence of the mistaken belief that leakage from municipal (so-called "nonhazardous waste") landfills does not represent a highly significant threat to groundwater quality.

In an article entitled, *"Financial Assurance - Will the Check Bounce?"* Hickman (1992) discussed the problems of providing financial assurance for municipal solid waste landfills. He stated,

"Municipal solid waste management (MSWM) system owners/operators are now being challenged to exercise financial prudence, plan for the future, and provide their own safety nets. Owners/operators are being required to assure that if landfills cause a problem, money will be there to fix the problem, and that the check won't bounce when it comes time to pay the bill. Financial assurance has emerged as a major part of owning and operating both present and future landfills."

Hickman (1992) noted the difficulty for public agencies and private companies to keep funds available as a "safety net" for future needs of a closed landfill. He stated,

"A surplus of cash allows a company to declare an extra dividend; the stockholders expect it. Surplus funds in a government bank account allows elected officials to engage in all sorts of interesting dances with the electorate."

The authors agree with the positions articulated by the GAO and Hickman, that at both the federal and state levels, inadequate attention has been given to how the provisions of the respective regulations, requiring post-closure care for as long as needed to protect groundwater quality, can be implemented. Since post-closure care is the key to groundwater quality protection from "dry tomb" landfills of the type being developed today, a high priority should be given to developing reliable mechanisms for ensuring adequate funding for the needed perpetual post-closure care. Hickman (1992) indicated that while there is a variety of financial instruments that have been used to provide post-closure care funding for landfills, dedicated trust funds are, in his assessment, the most reliable method of assuring that funds will be available when needed.

Magnitude of Post-Closure Care Funding Needed

One of the issues that needs to be addressed is the magnitude of funding that may be needed for contingencies associated with the post-closure care of a "dry tomb" municipal solid waste landfill, such as clean up of polluted groundwater. In its October 1991 final rule governing solid waste disposal criteria, the US EPA made several estimates of the costs of adopting "dry tomb" landfilling (composite-lined and covered landfills) as a standard for municipal solid wastes. The US EPA indicate that the typical disposal fee (tipping fee) for unlined sanitary landfills is on the order of $30 to $40/ton. At $36.50/ton, the classical sanitary landfilling of wastes in unlined landfills costs a waste contributor about 10/person/day. The US EPA's projected "best estimate scenario" for the additional cost associated with requiring a composite-lined landfill with groundwater monitoring and other conventional post-closure care was $2 to $4/household/year. That translates to an approximately 0.3/person/day increase in cost for "dry tomb" landfills. However, in developing its estimate, the US EPA made a number of inappropriate assumptions that render its cost estimates unrealistically low. For example, the US EPA assumed that only 30 years of post-closure care would be needed to protect public health, groundwater, and environmental quality. As discussed above, that assumption is inappropriate.

At the time of trying to promulgate the Subtitle D regulations, the Office of Manpower and Budget (OMB) exercised considerable financial constraint on the proposed regulations, reportedly asserting that an insufficient number of cancers will be prevented in the US as a result of adopting the proposed municipal solid waste landfill regulations to justify their adoption. This situation arises out of the inappropriate way in which RCRA was initially established where it focused on the control of hazardous chemicals that have the potential of causing cancer rather than on all chemicals that can impair the use of groundwater for domestic purposes; this issue was discussed by Lee and Jones (1991a). The result has been that the US EPA has underestimated the cost of post-closure care for "dry tomb" landfills in order to make it appear that the additional cost will not represent a significant financial burden to the US population. While the Subtitle D regulations implemented with a 30-yr post-closure care period may not result in a significant financial burden to this generation, they will represent a significant burden to future generations who will not only have to take care of their own waste, but also will have to pay the cost of this generation's failure to properly manage its municipal solid waste.

As discussed by Lee and Jones (1991b) while the magnitude of funds needed to properly maintain the cover of a landfill are not well-known, Carden (1981) conducted a review of the potential costs of landfill cover maintenance. The long-term costs of post-closure maintenance depends on the rate of inflation; at 5%/yr inflation, the estimated cost for 200 years of cover maintenance for one landfill is $28 billion. At 10% inflation, that cost would be $154 trillion for one landfill. However, a "dry tomb" municipal landfill of the type claimed to be able to be safely sited at any location will not stop being a threat to groundwater quality after 200 years; the threat will continue forever. Therefore, the cost of cover maintenance will continue in perpetuity and is thus far greater than that estimated even by Carden.

The authors have reviewed the costs that could be associated with the pollution of groundwater that has been caused by an 80-ac, unlined municipal landfill in the San Gabriel Basin of southern California. They found that the cost for pumping and treating the currently contaminated groundwater so that it may be disposed of, and the cost for purchase of replacement water for that which had to be disposed of, is on the order of several hundred million dollars. Furthermore, the conjunctive-use storage capacity of that aquifer has been lost. Conjunctive-use storage is a process by which surplus surface water available in wet years is recharged into aquifers for storage and use in dry periods. Once an aquifer has been contaminated by municipal landfill leachate, it cannot be used reliably for such purpose.

The US EPA (1988a, 1991) concluded that once a groundwater well is polluted by municipal landfill leachate, that well has to be abandoned and a new well drilled at another, unpolluted location. Rather than groundwater protection, this is a "musical wells" approach that may be able to be followed - even for a number of generations - in some areas where large amounts of groundwater are available compared to needs. However, demands on groundwater for domestic water supply are increasing. In many parts of the United States, groundwater is too valuable a resource to be used-sacrificed as part of inadequate solid waste management. Further, water authorities across the country have found that the likelihood of constructing additional surface water storage facilities for drought periods is very small. This is forcing many water authorities to employ conjunctive-use storage in groundwater aquifers in order to meet the water resource needs.

In the state of California, the landfilling of municipal solid wastes is governed by a set of regulations known as Chapter 15 (WRCB, 1984). The state of California Water Resources Control Board, which administers those regulations, adopted a revised version of Article 5 of Chapter 15 (WRCB, 1991), which became effective July 1, 1991; that Article includes revised financial assurance requirements. Basically, it requires that the owner/operator of a landfill provide financial assurance for initiating and completing corrective action for a "reasonably foreseeable release" from the waste management unit (landfill). The financial assurance requirements are being tied to the reliability of the groundwater monitoring program that the owner/operator proposes to undertake for the waste management unit. Those owner/operators who propose to carry out an "extraordinary" groundwater monitoring program for the landfill would be required to provide less financial assurance than those who propose to carry out a conventional monitoring program of vertical monitoring wells spaced hundreds of feet apart along the down-groundwater gradient edge (point of compliance) of the landfill. This is the point at which the groundwaters are assessed for leachate pollution.

The Chapter 15 regulations are explicit in requiring that waste management units such as landfills be sited and developed in a manner so that they do not impair the uses of groundwater for domestic or other purposes as a result of any contaminant from the landfill, whether it is categorized as "hazardous" or not; they require that the protection of beneficial uses of groundwater be ensured for as long as the wastes represent a threat, which for municipal solid wastes landfills is becoming to be understood to mean forever. Therefore, if the California Chapter 15 regulations are implemented as written, the financial assurance instruments for MSW landfills will have to be of sufficient magnitude to cover not only routine monitoring and maintenance, but also corrective action associated with groundwater pollution. Further, those instruments will have to be effective for as long as the wastes remain buried in the landfill.

While it is too early to judge how effective this somewhat unusual approach of tying the magnitude of financial assurance to the potential costs of clean-up of groundwater will be, it is certainly a major step in the right direction toward improving the ability to ensure that the owners/operators of landfills will meet their financial responsibility for groundwater quality protection once the profit-making phase of the landfill development has ceased.

Funding of Financial Assurance

Figure 1 presents a conceptual illustration of the income and expenditure associated with operating a "dry tomb" landfill of the type being developed today. 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 rapidly recover the initial investment, and the landfill becomes highly profitable. In one case with which the authors are familiar, a landfill company purchased an area (gravel pit) for the purpose of developing a 200-ac landfill, for $60 million. It was estimated by representatives of that firm that the company would generate $12 million per year in **profit** during the approximately 20-yr 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. To the extent that the information provided by

the landfill company was reliable and reflects actual experience, this example demonstrates the potentially very high profitability of municipal solid waste landfills.

At the time the landfill is closed, the landfill company or, for public landfills, the agency, will have the expenses of closing (capping) the landfill. Correll (1992) indicated that conventional landfill closure costs for a landfill in the state of Washington is from $84,000 to $172,000/acre. These cost estimates do not include funds for contingencies and other than superficial maintenance of the cover.

For a period of many years after closure the landfill company will have the expenses of monitoring the groundwater, maintaining the cover, removing leachate, etc., i.e. conventional post-closure care. These types of expenditures will have to continue indefinitely until groundwater pollution caused by failure of the liner system to prevent leachate migration from the landfill

is detected. With the types of monitoring programs typically accepted today for lined "dry tomb" MSW landfills, by the time groundwater pollution is detected it will have affected potentially large volumes of groundwater. At that time, there will be very significant expenses associated with groundwater clean-up and other remedial measures, including possibly exhuming the wastes, properly treating them, and appropriately burying residues so that they do not represent a threat to groundwater quality. Furthermore, since once groundwater is contaminated by MSW-derived contaminants it cannot be considered a reliable water supply source, expenses associated with developing alternative water supplies or storage capacity, or the loss of that resource, must be included in the "costs" of the landfill.

In order to remain in business, private landfill companies must generate a net profit from the landfills they develop. A net profit cannot be generated from a "dry tomb" landfill located where groundwater can be adversely affected, however, if post-closure care consumes the profits from the landfill operation. Unless adequate funds are available for perpetual post-closure care, the landfill company's post-closure care operations will stop after 30 or so years when the landfill represents a significant financial drain on the company's resources, or the public will have to start paying for the remaining costs *ad infinitum*.

In reporting a stock-offering by Waste Management International (the largest solid waste management company in the US) in *Barron's*, Cochran (1992) stated,

"Legal liability in this [solid waste management] *field is significant and uninsurable. Illustrating the risks, WMX* [Waste Management Inc.] *has agreed to pay WMII* [Waste Management International] *$285 million over 50 years for 'certain environmental costs and liabilities which may be suffered by the Company' because of past practices, and which are 'both probable of incurrence and capable of reasonable estimation.' The amount for known problems exceeds WMII's total earnings for its corporate history.*

"In this field, liability never ends, even though operations may cease: 'The Company may be required to undertake corrective measures at operating or closed...facilities, the costs of which could be substantial.' As a result, income could vary significantly from year to year. As for the

most recent acquisitions, 'it is probable that environmental liabilities exist which may be significant.'"

There are significant questions about the ability of private waste management companies as well as public entities (such as county boards of supervisors) to provide financial assurance to meet post-closure care maintenance and contingencies.

The only way to provide definitive assurance that "dry tomb" MSW landfills will not ultimately pollute groundwaters is to not locate them where there are groundwaters that can be adversely affected. In the view of the authors, if landfills are sited in areas of vulnerable groundwater those who contribute wastes to the landfill should be required to contribute the necessary funds to a trust that will be used for perpetual post-closure care. In this way those who are trying to get by with paying less than the true cost of appropriate municipal solid waste management by landfill siting and waste treatment inadequacies, will pay for the post-closure care operations for their wastes, rather than passing those costs on to future generations. It is suggested that the owners/operators of each existing landfill sited in an area of vulnerable groundwater, be required to compute the per capita annual fees that need to be assessed those contributing waste to the landfill to establish an adequate trust fund for perpetual post-closure care. Such computations should be required of all future landfill applicants. The magnitude of the fees should generate sufficient funds to cover worst-case scenario contingencies as they are realized today, including the need to exhume the wastes and properly treat them before re-burial of the treated residues.

It is suggested that private landfill owner/operators should provide financial assurance and be responsible for the first 75 years of post-closure care. That period is fairly arbitrarily selected but it would carry the landfill past the typical 20-yr warranty for liners and into a period where early leakage may be detected. Mandating such an extended period would also provide substantially greater incentive for the landfill owner/operators to properly site landfills, and design, construct, operate, close, and maintain them sufficiently well to prevent groundwater contamination at least during that period. The trust fund would provide the funds needed by the owner/operator of the landfill to maintain and when necessary replace the cover, 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 would be essential for the landfills to have a leakage detection system beneath the uppermost liner system to signal the failure of the liner system and the need to terminate the storage of wastes in the "dry tomb". The determination of what constitutes significant rates of leakage through the uppermost liner system should be based on a site-specific evaluation of the rate of leakage could cause groundwater pollution and the assumption that that was the only liner. (For further discussion of recommended approaches, see Lee and Jones, 1991b, 1992a.)

If groundwater contamination occurs during the 75-yr post-closure period, the wastes should have to be removed from the landfill and the groundwaters should have to be cleaned up to as close to background as possible. If the landfill owner/operator is allowed, instead, to opt for a quick-fix such as improving the ability of the landfill cover to reduce moisture penetration into the wastes, then the owner/operator should be required to clean up the groundwater and provide

the cover augmentation at its own expense, not at the expense of the trust fund. The trust fund would be maintained for use by future generations to address the inevitable problems of further groundwater pollution by the "dry tomb" landfill.

The magnitude of the trust fund contributions, as additional disposal fees, would have to be developed on a site-specific basis; they would depend on the characteristics of the landfill and the region in which the landfill is sited. Basically, this approach acknowledges that a "dry tomb" landfill provides only a temporary storage system management approach for municipal solid wastes and recognizes that the "containment" system will ultimately fail to prevent groundwater pollution in the vicinity of the landfill. While this temporary storage may last a hundred or so years before failure of the liner system to prevent significant leachate migration through it, it will eventually fail.

The trust fund should never be made available to the landfill owner/operator, whether public or private, for any purpose other than meeting the maintenance needs of the landfill.

The magnitude of the annual individual contributions to the trust fund will likely have to be adjusted as more information is gained on the true long-term costs of proper municipal solid waste management. Certainly today's society should take the responsibility to pay the cost of providing long-term protection of public health and environmental quality from its municipal solid wastes.

Benefits of Recognition of True Cost of "Dry Tomb" Landfilling

One of the potential benefits of funding anticipated long-term financial needs of a landfill as part of the disposal fees paid by those who generate the wastes that are placed in the landfill is that it will call to the attention and understanding of the public the true cost of its generation of municipal solid waste and its management by "dry tomb" landfilling. At this time, there is little incentive to adopt alternative approaches to "dry tomb" MSW storage because the public who generates the waste is lead to believe that the "dry tomb" landfilling approach is much cheaper than alternative approaches that incorporate treatment of the wastes to remove components that represent long-term threats to public health, groundwater quality, and the environment, and that it is "safe." While treatment of municipal solid wastes by fermentation-leaching, or other processes (Lee and Jones, 1990) is initially more expensive than not treating (direct "dry tomb" landfilling), in the long-term, if carried out properly, such treatment will be highly cost-effective in managing municipal solid waste to prevent significant public health, groundwater quality, and environmental problems.

The approach suggested above has the potential 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 very important, however, that some 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 against pollution from municipal and, for that matter, industrial, non-hazardous waste.

While the focus of this paper has been post-closure care and its funding for new-generation, lined, "dry tomb" landfills, it has applicability to the proper closure, maintenance, and post-closure care funding for existing unlined "sanitary" landfills. Lee and Jones (1991c) discussed approaches that should be considered for the closure of existing sanitary landfills in order to avoid further groundwater pollution.

Conclusions and Recommendations

There is growing recognition that the "dry tomb" landfilling approach that was officially promulgated by the US EPA on October 9, 1991 as the standard approach for managing municipal solid waste is a flawed technology that, at best, only postpones pollution of groundwater hydraulically connected to the area of the landfill. It is apparent that, at least for a while, the people of the United States are saddled with a technologically inappropriate approach for "managing" municipal solid waste which while superficially appearing to be less expensive will ultimately prove to be more expensive and detrimental than properly treating the wastes. Until the "dry tomb" landfilling approach is abandoned and more appropriate technologies are adopted for responsible MSW management, it is essential that adequate and reliable financial assurance instruments be provided for the post-closure care that will be needed. A dedicated trust fund or other financial instrument is needed to provide periodic cover replacement, extensive groundwater remediation, and waste exhumation, treatment, and disposal of treated residues, and to meet all plausible, worst-case failure scenarios for the "dry tomb" landfill. The monies for the trust fund should be collected as part of disposal fees charged those who generate the wastes. Today's "dry tombs" should not become burdens on future generations who will otherwise have to pay the post-closure care and groundwater remediation costs, the costs associated with lost groundwater resources, and adverse impacts on public health and welfare.

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