Deficiencies in Subtitle D Landfill Liner Failure and Groundwater Pollution Monitoring

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Abstract

The US EPA (1991) MSW Subtitle D landfill regulations require a groundwater monitoring system based on vertical monitoring wells located at a point of compliance for monitoring that is no more than 150 meters from the down groundwater gradient edge of the landfill. The regulations specify that a detection monitoring program be implemented which has a high reliability of determining when leachate-polluted groundwaters reach the point of compliance. A critical review of the implementation of the Subtitle D landfill liner failure detection approach using the typical current groundwater monitoring approach shows that minimum Subtitle D landfills are being permitted with monitoring wells spaced one hundred to one thousand feet apart. The 1990 work of Dr. J. Cherry showed that plastic sheeting lined landfills such as a minimum Subtitle D landfill, will initially produce narrow plumes of groundwater pollution that arise through leachate leakage through the plastic sheeting liner that could readily pass by the typical point of compliance groundwater monitoring well array without being detected by the monitoring wells. This paper reviews the deficiencies in the Subtitle D groundwater monitoring approach in detecting groundwater pollution associated with the inevitable liner failure before widespread, off-site pollution occurs. Also presented is information on alternative monitoring approaches that have a high reliability of detecting liner failure before significant groundwater pollution occurs. The recommended monitoring system involves the use of a double composite liner with a leak detection system between the two liners where the lower composite liner functions as a pan lysimeter for the upper composite liner.

Introduction

In 1988, the US EPA-proposed RCRA Subtitle D municipal solid waste landfilling regulations recognized that a single composite liner for a landfill would not prevent groundwater pollution by landfill leachate for as long as the wastes in the landfill would be a threat. The US EPA Solid Waste Disposal Criteria (August 30, 1988a) stated,

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

The US EPA Criteria for Municipal Solid Waste Landfills (July 1988b) stated,

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

While in 1988, the US EPA developed the conclusion that a single composite liner would not protect groundwaters from impaired use for as long as the wastes in the landfill represent a threat, the general understanding by professionals of the significant shortcomings associated with the use of high density polyethylene liners or, for that matter, other plastic liner (flexible membrane liner–FML) systems were just beginning to be understood. Today, these deficiencies are well understood. Lee and Jones-Lee (1997,1998) have published a comprehensive review of the fundamentally flawed nature of minimum Subtitle D landfill containment systems to prevent groundwater pollution for as long as the wastes in a "dry tomb" type landfill will be a threat.

The wastes in a Subtitle D "dry tomb" type landfill will be a threat to pollute groundwaters, effectively forever. The flexible membrane layer in the composite liner has a finite period of time when it can be expected to function effectively to collect leachate. While no one can predict the length of this time before groundwater pollution will occur associated with a minimum Subtitle D single composite landfill liner system, there is increasing evidence that it could be as short as a few decades, even if high quality liner construction occurs and the placement of wastes in the landfill is done in such a way as to prevent penetrating the liner by waste constituents. This situation has been understood in

the landfill field for a number of years. There are eight states or parts of states that will not allow the construction of a single composite lined municipal solid waste (MSW) landfill.

Detection of Liner Failure

The US EPA, as part of developing Subtitle D landfill regulations, established monitoring requirements which were, in principle, designed to detect at the point of compliance for monitoring, the pollution of groundwaters by landfill leachate before off-site pollution occurs. The point of compliance for groundwater monitoring for Subtitle D landfills must be on the landfill owner's property and be no more than 150 meters from the downgradient edge of the waste management unit. It was the Agency's position at the time of the adoption of Subtitle D regulations that the inevitable failure of the single composite liner in preventing leachate from passing through it while the wastes in the landfill are still a threat would be detected by the groundwater monitoring system before off-site pollution occurred.

The Subtitle D monitoring approach requires that the landfill owner implement an extensive groundwater monitoring program once leachate-polluted groundwaters are detected at the point of compliance. Further, Subtitle D regulations require that once the extent of groundwater pollution has been defined, the landfill owner must initiate a groundwater remediation program to stop the spread of the pollution and start to clean up the polluted aquifer to the extent that it is possible. It is understood, however, that it will never be possible to clean up an MSW leachate-polluted aquifer system so the groundwaters associated with such a system would ever be considered safe for domestic consumption and many other purposes.

Reliability of Groundwater Monitoring Under Subtitle D

The US EPA in developing its groundwater monitoring system for Subtitle D landfills did not critically analyze the ability of groundwater monitoring wells of the type that are typically used to monitor groundwater pollution at classical unlined sanitary landfills to be able to detect the leachate-polluted groundwaters that would occur when the flexible membrane liner in a composite liner for a Subtitle D landfill first starts to degrade/deteriorate. The classical unlined sanitary landfill can be reliably monitored by placing groundwater monitoring wells at about any location down groundwater gradient from the landfill since the classical sanitary landfills produce large plumes of polluted groundwaters. However, the plastic sheeting-lined landfills, such as the minimum Subtitle D landfills, will first start to leak leachate through the liner system in small areas compared to the total area of the landfill.

The US EPA (1991) in Subtitle D groundwater monitoring system requirements stated:

> *"The design must ensure that the concentration values listed in Table 1 of this section will not be exceeded in the uppermost aquifer at the relevant point of compliance..."*

and specify that

"(a) A ground-water monitoring system must be installed that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield ground-water samples from the uppermost aquifer (as defined in §258.2) that: (2) Represent the quality of ground water passing the relevant point of compliance..."

"(c) The sampling procedures and frequency must be protective of human health and the environment."

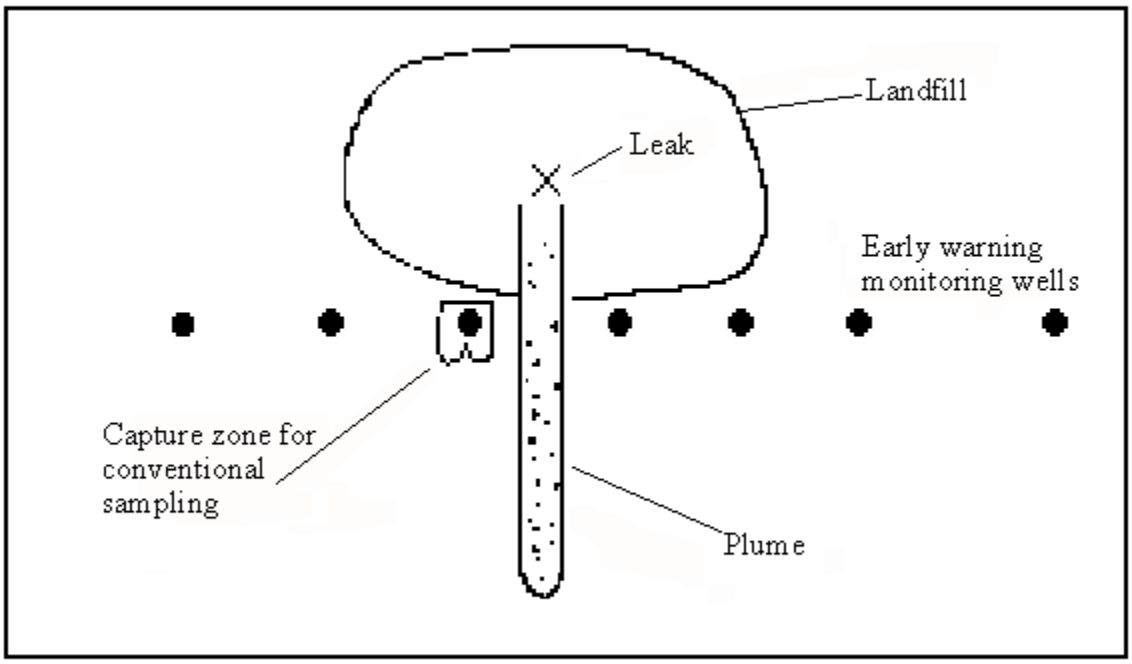
Further, the State of California Water Resources Control Board Chapter 15 regulations governing the landfilling of municipal solid wastes require that a sufficient number of monitoring wells be located so that they *"…provide for the best assurance of the **earliest possible** detection of a release from a waste management unit."* (emphasis added).

The Agency did not anticipate that the implementation of this requirement at the state and regional regulatory agency level would be based on mechanical application of the approach that had been used to monitor classical unlined sanitary landfills, i.e. a few downgradient monitoring wells spaced hundreds to a thousand or more feet apart. Dr. John Cherry (1990) was the first to point out that the approaches that were being adopted for monitoring plastic sheeting-lined landfills had a low probability of detecting landfill leachate-polluted groundwaters at the point of compliance before off-site pollution occurs. Cherry and his associates at the University of Waterloo, Ontario, Canada conducted a number of field experiments in which dyes were injected into a sand aquifer system at a specific source and the lateral spread of the dyed groundwater was assessed. It was found that the lateral spread of groundwater pollution plumes were limited near the source of pollution.

While Cherry's original publication on this topic was in a conference proceedings that was not widely read by hydrogeologists who work in the landfill field, he discussed these issues at the American Society for Testing and Materials symposium, Current Practices in Ground Water and Vadose Zone Investigations, held in San Diego, CA in January 1991 where he indicated that the typical groundwater monitoring systems that are being used for lined landfills involving vertical monitoring wells spaced hundreds to a thousand or more feet apart at the point of compliance for groundwater monitoring have a low probability of detecting leachate-polluted groundwaters at this point before widespread, off-site groundwater pollution occurs by landfill leachate. Based on the work of Cherry and his associates, a two-foot long line source of leachate, such as would occur from a rip, tear or point of deterioration in an FML, would be expected in a sand aquifer system to spread laterally to about ten feet within 150 meters of the source.

[CLI wells are approximately 150 meters from the center of the LF, probabilistically between 50 and 100 meters horizontally and 7 meters below a leak. A 2 foot rip would produce a leachate plume 2-5 feet across if the plume moved in sand. However, it does not. Moving through clay the same leak would produce an irregular plume consisting of small veinlets and disseminations. The leak would take much longer to move the 50-100 meters laterally and the 7 meters vertically. Its geometric configuration would be unpredictable and would follow construction layering and natural fissure cracking. Upon entering a monitored sand body such as the Lower Radnor Till Sand, the leading edges of the veinlet-based plume would tend to coalesce and disperse into the sand body assuming a more conventional plume configuration but would not be detectable unless some part of it passes within the area of influence (about a foot) of the existing 200-300 foot wide-spaced well-point array.smj]

The typical leachate-polluted groundwater plumes developed initially from an FML-lined landfill liner failure would be finger-like with limited lateral spread near the landfill. This means that since the typical groundwater monitoring well used for monitoring groundwater pollution by landfill leachate where three borehole volumes are purged prior to sampling, that the monitoring well samples groundwater only within about a foot of the well. If the monitoring wells are spaced 200 feet apart, which is close for many groundwater monitoring systems for Subtitle D landfills, there are 198 feet between each well where leachate plumes generated by initial leakage through the landfill liner system can pass without being detected by the wells. Cherry developed Figure 1 to show this relationship.



After Cherry 1990

Figure 1

Therefore, the basic premise of the US EPA Subtitle D regulations that the inevitable failure of the single composite liner from preventing leachate from passing through it for as long as the wastes represent a threat would be detected with a high degree of reliability before widespread off-site groundwater pollution occurs is fundamentally flawed. The groundwater monitoring systems that are used today at Subtitle D landfills with monitoring wells spaced hundreds or more feet apart are highly unreliable in detecting the pollution of groundwaters by landfill leachate at off-site properties where there is an inadequate landfill owner-owned bufferland between the edge of the waste management unit and adjacent properties.

The US EPA in developing Subtitle D and most state landfilling regulations allow landfilling of waste essentially up to the property line. This means there is no bufferland space between where the initial leakage of leachate through the liner system occurs and off-site/adjacent property groundwaters are located that can be polluted by landfill leachate. The authors are involved in several classical sanitary landfill investigations where small area sources of constituents, such as the dumping of chloroform into the landfill for waste disposal, has occurred. These landfills have produced chloroform plumes that extend over a mile from the landfill. These plumes exist in sand and gravel aquifer systems which are not atypical of many aquifers where Subtitle D landfills are located.

The situation could be much worse in a fractured rock aquifer system, where as described by Haitjema (1991)

> *"An extreme example of Equation (1) (aquifer heterogeneity) is flow through fractured rock. The design of monitoring well systems in such an environment is a nightmare and usually not more than a blind gamble."*

* * *

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

While the initial work of Cherry, pointing out the deficiencies in groundwater monitoring of lined landfills was not widely recognized, today, as a result of subsequent publications by a number of individuals such as Parsons and Davis (1991), Lee and Jones-Lee (1994a) and others, the highly significant deficiencies in the typical groundwater monitoring approach that is proposed by landfill applicants and allowed by regulatory agencies is well understood. It has been the authors' experience that typically the regulatory agency personnel and boards have chosen to ignore this situation and proceed as though flexible membrane lined-landfills leachate leakage occurs throughout the entire bottom area of the landfill and a few groundwater monitoring wells spaced hundreds to a thousand or more feet apart can be expected to comply with Subtitle D requirements of ensuring that the concentrations of constituents in the US EPA "Table 1" are not exceeded in the uppermost aquifer at the point of compliance.

Adequacy of Landfill Permit Review

The current landfill groundwater monitoring program development approach is basically the ostrich approach in which the professional consultants who recommend this type of monitoring and the regulatory agencies who approve such monitoring are carrying out their responsibilities in a technically inadequate manner. Both consultants to landfill applicants and regulatory agency staff are required to use high-quality science and engineering in carrying out the responsibilities with respect to the development of a landfill. To ignore, as is typically done, the grossly inadequate groundwater monitoring that is occurring at Subtitle D landfills will ultimately represent significant liabilities to the consultants and to the regulatory agencies. This consultant liability arises from the fact that the consultant is signing off on the landfill projects as complying with regulations when they only meet minimum prescriptive standards for design, but obviously do not conform to the US EPA Subtitle D requirements of protecting groundwaters from impaired use for as long as the wastes in municipal solid waste "dry tomb" landfills will be a threat–effectively, forever. The liner, cover and groundwater monitoring systems will not prevent leachate from

being generated in the landfill and leaving the landfill and detected at the point of compliance for groundwater monitoring for as long as the wastes will be a threat.

While some consultants for landfill applicants indicate that *"...groundwater monitoring programs are routinely designed to reflect the specific subsurface conditions and probable mechanisms of contaminant migration at each site,"* the authors have been involved in review of over 50 landfills located in various parts of the US and have yet to find a single case where the groundwater monitoring system that is used reflects the issues raised by Cherry (1990) that the initial leakage through a plastic sheeting-lined landfill will produce finger plumes of leachate of limited dimension at the point of compliance where groundwater monitoring occurs. Further, we have yet to find a single case where the fact that the groundwater monitoring wells at the point of compliance often have zones of capture of a foot or so around each well is considered in developing well spacing at the point of compliance. With monitoring wells spaced hundreds of feet apart, it is obvious that the groundwater monitoring systems being used for many Subtitle D landfills is a fundamentally flawed approach for assessing the inevitable groundwater pollution that will occur at essentially all minimum Subtitle D landfills sited at geologically unsuitable sites, i.e., lacking natural protection, when the flexible membrane liner systems being used fail to prevent leachate from passing through them for as long as the wastes in the landfill represent a threat.

Landfill applicants, through their consultants, should be required to conduct a site-specific evaluation of the potential characteristics of the leachate plumes generated through initial leakage through the FML when it reaches the point of compliance for groundwater monitoring. This requires a site-specific statistical/hydrogeological assessment of the dimensions of the leachate-polluted groundwater plume at the point of compliance relative to the zones of capture of the monitoring wells and the well spacing, for a failure of the landfill liner system that could occur at any location under the landfill footprint. This information should be part of the standard landfill design documentation that is made available to the regulatory agency and the public as part of reviewing the appropriateness of developing a particular landfill at a particular location.

Some landfill applicant consultants assert, in defense of their somewhat arbitrary approach for developing a groundwater monitoring system based on the typical approach that is being used today, that there has been no documentation that this approach has failed to detect landfill-liner leakage that results in groundwater pollution. Such assertions, however, fail to provide a discussion of the situation that exists today with respect to failure of minimum Subtitle D landfill liner systems and groundwater monitoring systems to function as required in Subtitle D requirements for as long as the wastes represent a threat. Lee and Jones-Lee (1996) have developed a review of this topic where they point out that minimum Subtitle D landfills have only been required since 1993. It would be highly unusual in this short period of time to have demonstrated proof that eventually during the infinite period of time that the wastes would be a threat at a minimum Subtitle D landfill, that the liner will fail and that the groundwater monitoring systems with monitoring wells spaced hundreds to a thousand or so feet apart at the point of compliance have failed to detected the liner failure.

In most cases, liner failure that would have occurred in the past four years would be due to grossly inadequate construction and waste placement. Further, the transport rates of leachate and leachate-polluted groundwaters are such that it would be unlikely that leachate that had passed through the failed liner system would have reached the point of compliance at this time, which can be located, under Subtitle D requirements, at 150 meters from the edge of the waste management unit. Because of the fundamentally flawed nature of the groundwater monitoring approach, involving the use of monitoring wells with limited zones of capture compared to well spacing, it would be a pure fluke that the initial liner leakage groundwater pollution plumes would be detected by a groundwater monitoring well at the point of compliance as required by US EPA and Chapter 15 requirements of detecting leachate-polluted groundwaters at the earliest possible time. Some have characterized minimum Subtitle D landfills as a "time bomb." If the approach advocated by some landfill applicant consultants is followed, there would be need to wait until the bomb goes off before action can be taken to address the obvious issues that the groundwater monitoring approach as being implemented today is fundamentally flawed and does not consider the issues raised by Cherry and others on the inadequacies of groundwater monitoring to detect pollution at minimum Subtitle D landfills.

It is reasonable to expect that a groundwater monitoring system would have a high probability of detecting leachate-polluted groundwaters at the point of compliance, for any plausible landfill liner leak that could occur for as long as

the wastes in the landfill will be a threat that could lead to the pollution of off-site groundwaters impairing their use for domestic or other purposes. Certainly, a situation where a substantial part of the leachate associated with liner leakage can pass by the point of compliance for groundwater monitoring without being detected by the monitoring wells does not comply with either Subtitle D or Chapter 15 requirements of adequate and reliable groundwater monitoring.

The current approach for development and implementation of groundwater monitoring systems for minimum Subtitle D landfills focuses considerable resources on collection and analysis of chemicals in vertical monitoring wells at the point of compliance as well as upgradient from the landfill. Comprehensive statistical procedures have been developed to determine when an increase in a waste-derived constituent above background has occurred. While such approaches are appropriate, they fail to address the fundamental issue of the overall reliability of the groundwater monitoring system being used. The issue that should be first addressed is whether the groundwater monitoring well array is a reliable array for a particular site to detect leachate-polluted groundwaters at the point of compliance with a high degree of reliability when the leachate pollution of groundwaters at this point first occurs. The approach that is used today of ignoring this essential step in developing groundwater monitoring programs for lined landfills is highly inadequate and technically invalid.

The problems with landfill applicants and their consultants failing to provide adequate and reliable information on the ability of a proposed landfill groundwater monitoring system to comply with regulatory requirements is part of a significant problem than exists today in the regulation/permitting of landfills. Typically, landfill applicants and their consultants follow the approach of doing the least possible in order to get the landfill permitted. Lee and Jones-Lee (1995a) have discussed the significant, well-known problems that exist today where landfill applicants and their consultants fail to provide full disclosure of the potential problems associated with a proposed landfill in protecting public health, groundwater resources, the environment and the interest of those within the sphere of influence of the landfill for as long as the wastes in the landfill will be a threat.

The codes of ethics for the National Society for Professional Engineers and the American Society of Civil Engineers require that any registered engineer provide full disclosure with respect to public health and environmental protection of their proposed projects. The typical approach used today by landfill applicants and their consultants follows the legal-adversary system used in the courts, where only the merits of a proposed project are discussed, without informing the public or regulatory agencies of the significant deficiencies in the proposed project in complying with Subtitle D requirements of protecting groundwaters from pollution by landfill leachate for as long as the waste in the landfill will be a threat. It is well known that many consultants who work for landfill applicants and, for that matter, many other project proponents that have the potential to be adverse to the environment, must, if they want to continue to obtain business, only report on the positive aspects of a particular project and fail to report on the well-known significant negative aspects. It is also well known in the field that any consultants who normally work with landfill applicants who fully discuss in a public arena, such as a landfill permitting hearing, the long-term problems associated with the proposed landfill will do this only once, since they will not obtain further work with landfill applicants.

Lee and Jones-Lee (1995a) recommend that an independent, interactive full public peer review of technical issues, such as the adequacy of a groundwater monitoring system for a proposed landfill be conducted in which the landfill applicants and their consultants are required to provide detailed information/documentation on their evaluation of the reliability of the groundwater monitoring system that they propose to use in detecting, at the earliest possible time, leachate polluted groundwater at the point of compliance. Adoption of this peer review process would eventually lead to a situation where engineering consultants would not have to violate the NSPE and ASCE codes of ethics for protection of public health and the environment in order to gain additional work with landfill applicants.

Recommended Approach

There is need to immediately terminate the facade that exists today in the permitting of Subtitle D landfills with respect to the reliability of the groundwater monitoring systems that are being allowed in detecting leachate-polluted

groundwaters before they cause off-site groundwater pollution. It will be necessary to immediately change how groundwater monitoring programs are developed for lined landfills. The current seat-of-the-pants approach for designing monitoring systems in which a few monitoring wells are arbitrarily installed along the point of compliance must be terminated. Regulatory agencies must start requiring that landfill applicants, through their consultants, develop an estimate of the reliability of the groundwater monitoring system proposed for a landfill in detecting leachate-polluted groundwaters at the point of compliance. These estimates should be based on a site-specific evaluation of the initial size and lateral spread of the leachate pollution plumes that could be produced from leaks at any location through the landfill liner system, including near the downgradient edge of the waste management unit. Development of this type of information will show that the typical groundwater monitoring system being permitted today for minimum Subtitle D landfills cannot comply with Subtitle D groundwater monitoring requirements.

The state of Michigan addressed this problem several years ago and adopted a double composite liner for municipal solid waste landfills in which there is a leak detection system between the two composite liners. The lower composite liner is not a containment liner, but is the base of the leak detection system for the upper composite liner. As discussed by Lee and Jones-Lee (a), this approach can be an effective approach for preventing groundwater pollution by Subtitle D landfills provided that the landfill owner is required to take the necessary action to stop leachate leaking through the upper composite liner when it occurs. Because of the impossibility of repairing the liner, this action would likely involve repairing the landfill cover. Since Subtitle D landfill covers are not designed to prevent moisture from entering the wastes and since their ability to control moisture input to the landfill will deteriorate significantly over time where this deterioration cannot be observed through visual inspection of the landfill surface, the approach that should be followed is to install a leak detectible cover over the landfill that the landfill owner operates and maintains in perpetuity, i.e. for as long as the wastes in the landfill will be a threat. Lee and Jones-Lee (1995b) have discussed the issue that should be considered in developing long term protection of groundwater quality associated with the closure of a Subtitle D landfill. The key to developing groundwater quality protection associated with the use of a leak detectible cover is the development, from disposal fees, of a dedicated trust fund of sufficient magnitude to operate and maintain the leak detectible cover for as long as the wastes represent a threat to groundwater quality. Lee and Jones-Lee (1994a,b) recommend that if a landfill owner is unable or unwilling to stop leachate from occurring in the leak detection layer between the two composite liners, then the landfill owner must exhume (mine) the wastes and properly manage them at a geologically suitable site where there are either no groundwaters or natural protection of the groundwaters that could be polluted by landfill leachate is present.

The additional costs of these systems compared to the conventional minimum Subtitle D MSW landfilling is estimated to be from 10 to 20 cents per person per day more for solid waste management than is being paid under minimum Subtitle D landfilling. This is a small cost compared to the large Superfund-like costs that will ultimately have to be borne by future generations in groundwater clean-up at minimum Subtitle D landfills, potential damage to public health of those within the sphere of influence of the landfill and the lost groundwater resources that will occur because of leachate pollution.

Summary

Today’s minimum Subtitle D groundwater monitoring systems are fundamentally flawed in complying with Subtitle D requirements of protecting groundwaters from impaired use by MSW landfill leachate for as long as the wastes in a "dry tomb" landfill will be a threat. The typical groundwater monitoring well array being allowed at Subtitle D landfills today has a low probability of detecting landfill leachate-polluted groundwaters at the point of compliance before trespass of leachate-polluted groundwaters occurs under adjacent properties. There is immediate need to require, as part of permitting a Subtitle D landfill, that the landfill applicant critically analyze the expected reliability of the groundwater monitoring system in complying with regulatory requirements of preventing groundwater pollution beyond the point of compliance. Such an analysis would show, for many Subtitle D landfills, that vertical monitoring wells spaced more than about ten feet apart for most hydrogeologic settings at the point of compliance cannot comply with Subtitle D groundwater monitoring requirements.

Alternative, more reliable groundwater monitoring approaches are available, such as those adopted by the state of Michigan, in which a double composite liner is used where the lower composite liner is a leak detection system for the upper composite liner. This approach, if properly funded and implemented in perpetuity, could significantly improve the monitoring of landfill liner failure over that being achieved today. The cost of this approach is from 10 to 20 cents per person per day more for waste disposal than is being paid now for minimum Subtitle D landfilling. Payment of these costs now will be highly cost-effective in terms of protecting groundwater resources for use by future generations and preventing Subtitle D Superfund site clean-up costs that will evolve from most of the Subtitle D landfills that are being developed today.

Additional Information

Additional information on these topic areas is available from the authors' web site (http://members.aol.com/gfredlee/gfl.htm). The papers by the authors listed in the Literature Cited, are available from this web site.

Acknowledgment

This paper is adapted from a review of these topics by the authors that was published in the California Groundwater Resources Association newsletter, HydroVisions.

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