

SANDIA REPORT

SAND2000-2303
Unlimited Release
Printed September 2000

Landfill Covers: Is it Time to Change Current Regulations?

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ABSTRACT

Landfills are used throughout the world to dispose of residential and commercial waste. These landfills are closed at the end of their usable life and generally must adhere to closure regulations set forth by the Resource Conservation and Recovery Act (RCRA). Closure activities include such things as installing groundwater monitoring devices, gas emission controls, final cover, and security or site access restrictions. This paper will discuss the final landfill cover and the regulations pertaining to these covers.

Overview of Regulations

Land disposal is governed under the Resource Conservation and Recovery Act (RCRA). The two principal types of landfills are regulated under RCRA Subtitles "C" and "D". A RCRA Subtitle "C" disposal facility contains hazardous solid waste while a RCRA Subtitle "D" disposal facility contains municipal non-hazardous solid waste. There are approximately 6000 Subtitle "C" Disposal Facilities, and about 250,000 Subtitle "D" Disposal Facilities in the United States. Department of Energy alone has over 3000 landfills covering thousands of acres.

RCRA Subtitle "C"

The RCRA Subtitle "C" regulations for final landfill covers are found in Title 40 Code of Federal Regulations (CFR) Parts 264 and 265. Specifically 40 CFR 264.310 Subpart G establishes the closure requirements for the landfill cover, and 40 CFR 264 Subpart N includes requirements for hazardous waste landfills. Most applicable to this paper are the regulatory requirements (40 CFR 264.310) for the design and performance of a final cover system, and the need for the cover to limit infiltration into the underlying wastes:

40CFR264.310 Closure and post-closure care.

- (a) At final closure of the landfill or upon closure of any cell, the owner or operator must cover the landfill or cell with a final cover designed and constructed to:
 - (1) provide long-term minimization of migration of liquids through the closed landfill;
 - (2) function with minimum maintenance;
 - (3) promote drainage and minimize erosion or abrasion of the cover;
 - (4) accommodate settling and subsidence so that the cover's integrity is maintained; and
 - (5) have permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.
- (b) After final closure, the owner or operator must comply with all post-closure requirements contained in 40CFR264.117 through 264.120 which include maintenance and monitoring throughout the post-closure care period. Section 264.117 specifies:

The owner or operator must:

- (1) maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events;
- (2) continue to operate the leachate collection and removal system (if such a system exists) until leachate is no longer detected;

- (3) maintain and monitor the leak detection system (if such a system exists) in accordance with 40CFR264.301(c)(3)(iv) and (4) and 40CFR264.303(c), and comply with all other applicable leak detection system requirements of this part;
- (4) maintain and monitor the ground-water monitoring system and comply with all other applicable requirements of subpart F of this part;
- (5) prevent run-on and run-off from eroding or otherwise damaging the final cover; and
- (6) protect and maintain surveyed benchmarks used in complying with 40CFR264.309.

These regulations are vague for design and construction of a final cover. The regulations state that a design should attempt to minimize percolation of water through the cover into the underlying waste thus minimizing the creation of leachate that can in turn leak from the landfill and potentially harm the surrounding environment. They also state that erosion of the final cover is to be kept to a minimum however the term minimum is not defined quantitatively. In an attempt to clarify the vagueness, the EPA authored a design guidance document for hazardous waste landfills. This design guidance document issued by the EPA in 1989 recommended that landfill closures for RCRA Subtitle "C" and/or Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) facilities incorporate the following layers (Figure 1) in a cover profile (EPA 1989):

1. Composite Barrier Layer. Consists of a low hydraulic conductivity geomembrane/soil layer. This is the first layer encountered above the landfill material. It consists of a 60-cm (24-in) layer of compacted natural or amended soil with a maximum saturated hydraulic conductivity of 1×10^{-7} cm/sec in intimate contact with an overlying 0.5-mm (20-mil) thick (minimum) geomembrane liner. The function of this composite barrier layer is to block moisture movement downward from the overlying drainage layer.
2. Drainage Layer. Consists of a minimum 30-cm (12-in) soil layer having a minimum hydraulic conductivity of 1×10^{-2} cm/sec, or a layer of geosynthetic material having the same characteristics. This layer exists directly above the composite barrier layer. This layer's design intent is to minimize the time the infiltrated water is in contact with the lower composite barrier layer and hence, lessens the potential for the water to reach the waste.
3. Topsoil Vegetation Layer. A top layer with vegetation (or an armored top surface) and a minimum of 60-cm (24-in) of soil graded at a slope between 3 and 5 percent. This layer should be capable of sustaining nonwoody plants, have an adequate water-holding capacity, and be sufficiently deep to allow for expected, long-term erosion losses. This is the upper most surface layer of the landfill cover.

4. Optional layers include:

- (a) Gas Vent Layer. This layer should be at least 30-cm (12-in) thick and placed above the waste and below the composite barrier layer. The layer is generally composed of coarse-grained soil, similar to that used for the drainage layer. The gas venting consists of perforated, horizontal pipes which channel gases to a minimum number of vertical risers at a high point (in the cross section) to promote gas ventilation.
- (b) Biointrusion Layer. Consists of approximately 90-cm (3-ft) biotic barrier of cobbles placed directly beneath the top vegetation layer. This layer is designed to stop the penetration of some deep-rooted plants and the invasion of burrowing animals.

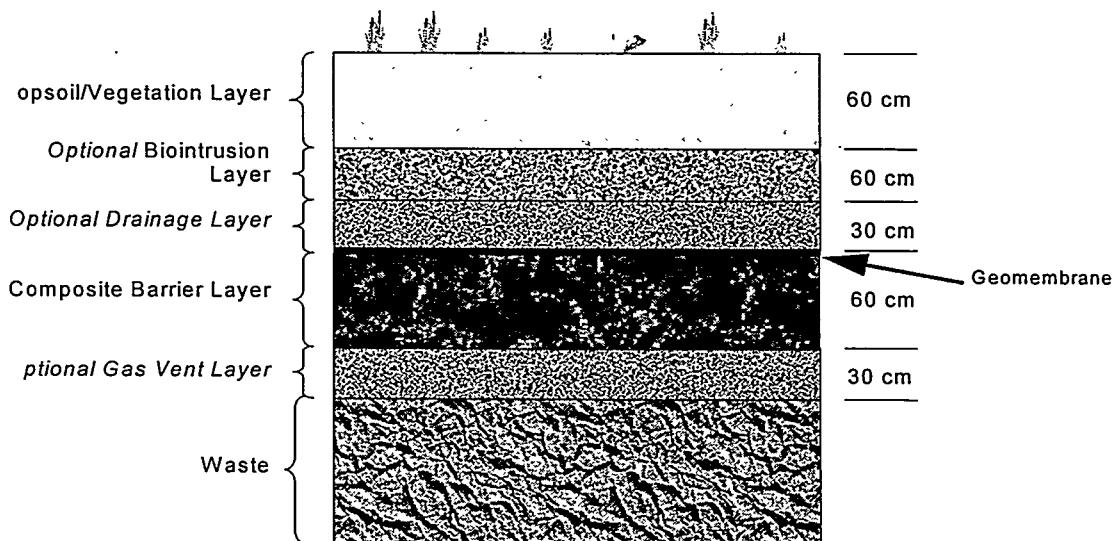


Figure 1. RCRA Subtitle 'C' Compacted Clay Cover

RCRA Subtitle "D"

The regulations for the final cover of a RCRA Subtitle "D" facility are much more specific than the Subtitle "C" facilities. These regulations are contained in 40 CFR 258. The owner/operator of the landfill must install a final cover system designed to effectively isolate the waste from the surrounding environment by minimizing the infiltration and erosion. Specifically the cover system must:

- 1) have a permeability or saturated hydraulic conductivity less than or equal to that of the bottom liner or natural subsoils present, or no greater than 1×10^{-5} cm/sec, whichever is less [40 CFR 258.60(a)(1)];
- 2) minimize infiltration through the closed Municipal Solid Waste Landfill (MSWL) by the use of an infiltration layer containing a minimum 45 cm (18-in) of earthen material [40 CFR 258.60(a)(2); and

- 3) minimize erosion of the final cover by the use of an erosion layer containing a minimum 15 cm (6-in) of earthen material that is capable of sustaining native plant growth [40CFR258.60(a)(3)].

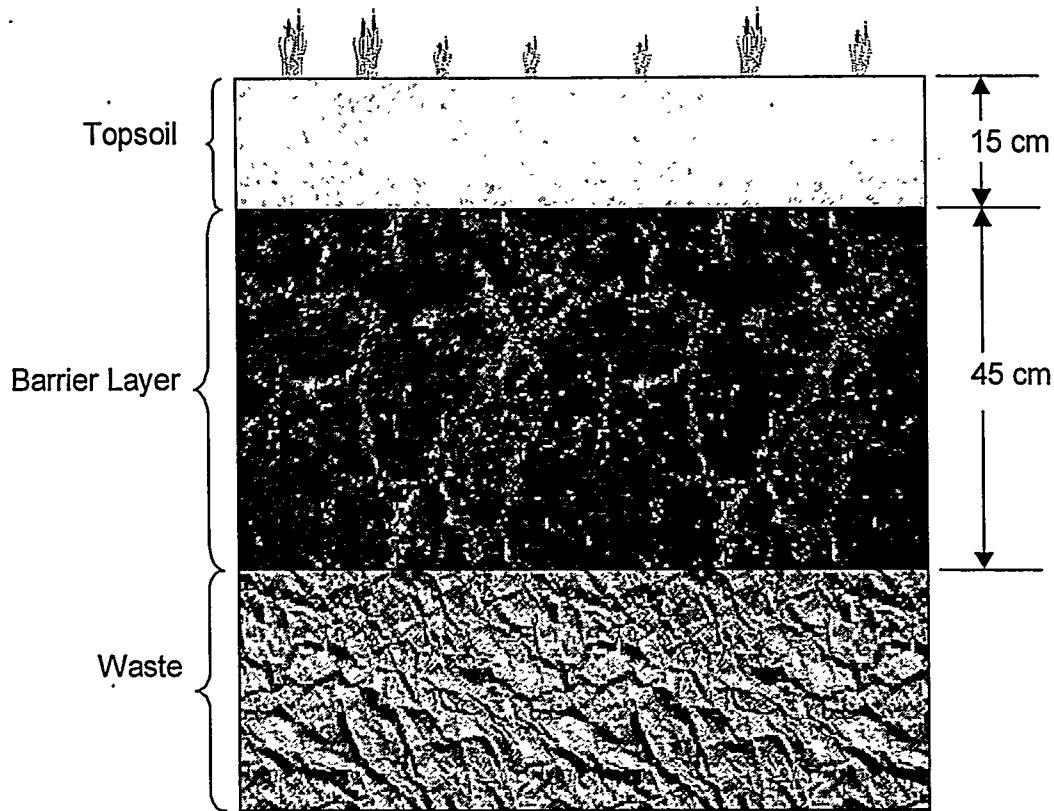


Figure 2. RCRA Subtitle 'D' Soil Cover

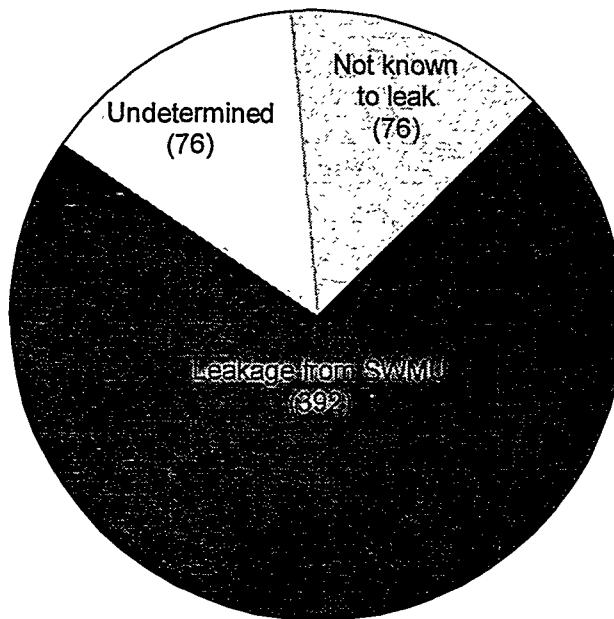
Studies Revealing Physical Problems with Covers

Traditional covers presently in use for RCRA Subtitle "C" and "D" regulated facilities as recommended by the EPA are used throughout the country with little regard for regional conditions. Experience in the western United States has shown these designs to be vulnerable to such things as desiccation cracking when installed in arid environments. An EPA design guidance document (EPA 1991) for final landfill covers states: "In arid regions, a barrier layer composed of clay (natural soil) and a geomembrane is not very effective. Since the soil is compacted 'wet of optimum', the layer will dry and crack". The clay barrier layer in the traditional Subtitle "C" Cover must be constructed to yield a maximum hydraulic conductivity of 1×10^{-7} cm/sec. To achieve this, the soil often requires an amendment (e.g. mixed with bentonite) and should be compacted 'wet of optimum'. Compacting this layer 'wet of optimum' in dry environments leads to drying and cracking of this layer. Desiccation, which can occur by several mechanisms, is an important failure mechanism for compacted soil hydraulic barriers, especially in arid

environments (Suter et al. 1993). The barrier layer in Subtitle "D" covers is also subject to desiccation cracking, as well as deterioration due to freeze/thaw cycles.

Traditional covers, such as the Subtitle "C" Cover, are not only inherently problematic but are very expensive (Dwyer 1998b) and difficult to construct (Dwyer 1998c). A study (EPA 1988) of existing landfills revealed that RCRA landfill cover technologies may not be working as well as intended. Randomly selected landfills revealed that the vast majority are leaking. Many have serious problems including groundwater contamination and serious ecological impacts such as flora and fauna mortality. Virtually all parts of the nation have experienced water contamination due to leachate leaking from landfills to some degree (EPA 1988). Not all of these problems are the result of inadequate covers. Many older landfills were crudely installed (e.g., poor siting, inadequate or lack of liner) thus destined for failure, but these problems can be mitigated by capping the entire landfill with a properly designed cover. A more recent study (Mulder and Haven 1995), titled the California Solid Waste Assessment Test Report found that 72 to 86 percent of existing landfills with compacted clay barrier layers are failing (Figure 3). It also concluded that these clay barriers leak regardless of climate or site-specific geology.

Number of Leaking Disposal Sites



- Of 2242 total solid waste disposal sites, 544 sites were reviewed.
- 72 to 86% of the sites reviewed were found to have leaked.

Figure 3. California Solid Waste Assessment Test Report findings

Physical Problems

A study conducted by the University of North Dakota (Wentz 1989) concluded that regulations are by far the most important determining factor considered by environmental professionals when deciding what technology to use and/or what to include in an environmental remediation design. The unfortunate finding is that the best technology to be applied was the least important consideration. The deciding factors affecting which hazardous waste management technology is to be used are from most important to least important: 1) government regulations, 2) economics, 3) public relations, and 4) process/technology.

A recent and very thorough investigation of an existing closure of a Uranium Mill Tailings Disposal Site (Waugh 1997) concluded that clay barrier layer's hydraulic conductivity will increase several orders of magnitude with time. The study noted that root intrusion, insect and earthworm intrusion, density changes, and desiccation effects will all contribute to increase the saturated hydraulic conductivity of the clay barrier layer (Figure 4). This exposes the earlier theory that hydraulic conductivity at construction will hold for the life of the cover system. In the past, the changed hydraulic conductivity properties would have been deemed a failure of the cover – but in reality considering all environmental factors, the cover may still have prevented moisture from reaching the underlying waste. It has been shown that even with higher hydraulic conductivity values, flux rates can still decrease because of an increase in transpiration due to the root intrusion. The flux rate is the entire cover system's ability to prevent percolation. The lower the flux rate, the better the cover system is at limiting percolation and thus minimizing the potential of leachate generation.

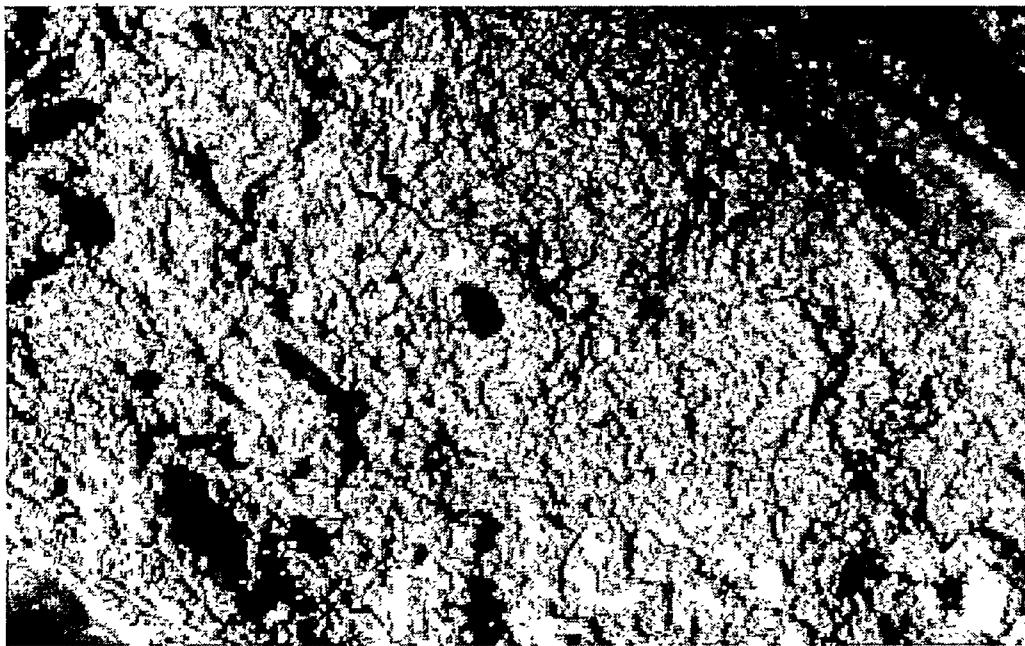


Figure 4. Root and Earthworm Intrusion into Clay Barrier Layer

Covers that are only designed to meet the regulations are prone to a variety of physical problems. Federal regulations call for barrier layers to be designed to meet a minimum thickness and saturated hydraulic conductivity value. Hence, soils generally high in clay content are placed and compacted to relatively high densities and water contents in order to achieve these low saturated hydraulic conductivity values. For example, the constructed volumetric water content of the preferred soil is approximately 20%. After installation, the soil dries to a state similar to that in the soils adjoining the landfill. Soil water contents in the Albuquerque area can be as low as 5%. Consequently, over time the soils will have about 15% volumetric reduction. Soil high in clay will have a high cohesion resulting in detrimental desiccation cracking as shown in Figure 5. Cracking provides preferential pathways for water migration downward into the underlying waste and defeats the purpose of trying to install a relatively impermeable (low saturated hydraulic conductivity) barrier layer.



Figure 5. Desiccation Cracking in Clay Barrier Layer

In addition to the required high soil densities required by regulations for the barrier layers, relatively high cohesion's also lead to serious problems from cracking due to differential settlement (Figure 6). The underlying waste settles with time due to consolidation and biodegradation. Because the waste materials are inconsistent and randomly placed, the settlement occurs differentially. Potential cracks in the cover allow for surface runoff to enter the waste thus substantially increasing leachate generation and increasing the risk for leakage from the landfill into the underlying and surrounding soils harming the surrounding community.



Figure 6. Longitudinal Cracking due to Differential Settlement

Vegetation or erosion layers are also often designed to meet only the minimum federal requirements. Vegetation is critical to stabilize the soil protecting it from erosion, and, perhaps most importantly, removing the moisture the soil layers have stored from past precipitation events. These thin layers as dictated by regulations or design guidance documents are often not adequate to sustain a healthy and diverse plant community. Often they do not have adequate water storage capacity or adequate soil nutrients. Figure 7 shows a Subtitle "C" landfill cover installed with a thin erosion vegetation layer underlain by a drainage layer meeting applicable regulations. The vegetation above the landfill is sparse with deep-rooted shrubs while the soil adjacent to the landfill has a much higher leaf area index with a better, more stable plant community composed primarily of native grasses. Without a stable plant community the landfill cover soil is much more susceptible to surface erosion, will see less moisture removal due to transpiration, and will see barrier layer intrusion from deep rooting shrubs searching for water at greater depths during dry periods.

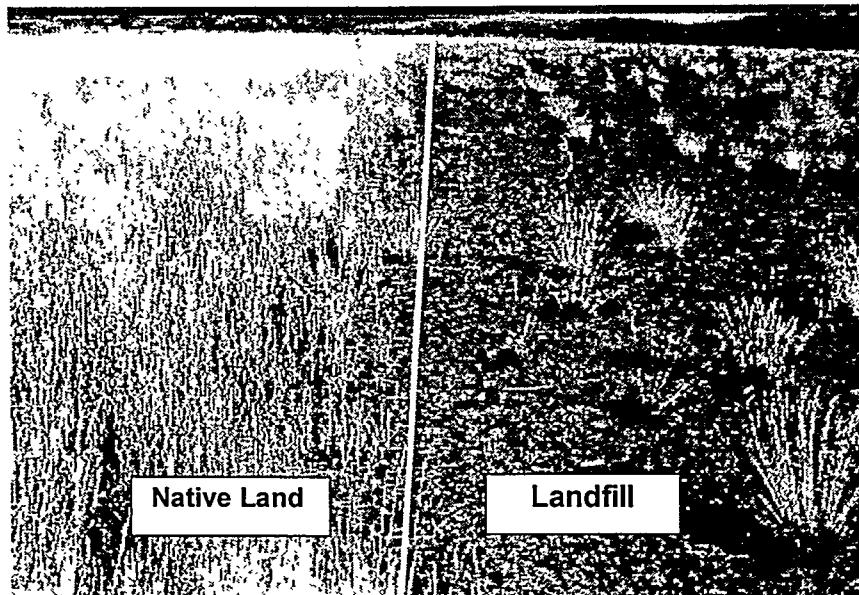


Figure 7. Surface Vegetation of Undisturbed Rangeland versus Landfill

Another potential problem associated with the erosion layer relates to surface runoff. The surface runoff and all flow control measures are designed in accordance with 40 CFR 258 to meet the 25-year storm event. Buried waste can be harmful to the surrounding environment even after it has been buried for 25 years. This is particularly true in dry environments where parts of the landfill may have remained dry over the 25-year period and experienced little biodegradation. Figures 8 and 9 show how erosion created by a single thunderstorm has failed a drainage control facility at a landfill. Landfill waste was found several miles downstream of the landfill site.

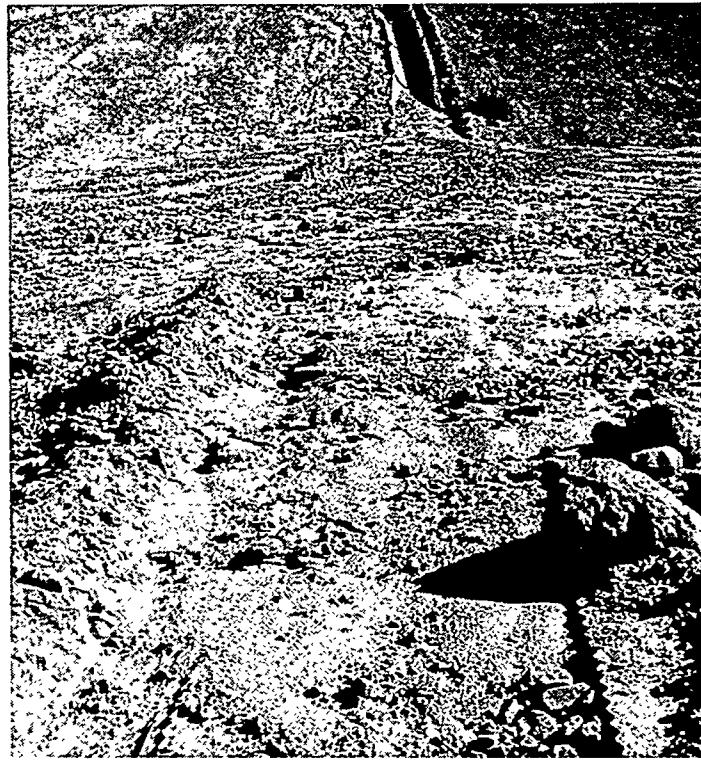


Figure 8. Failed Surface Flow Control Device on Landfill – Flow Perpendicular to Collection System

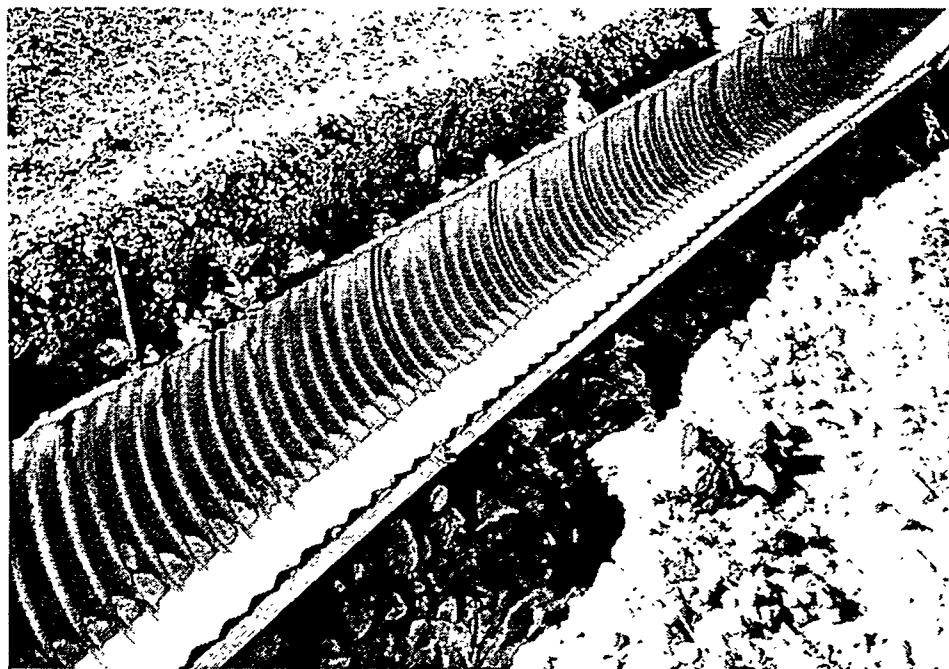


Figure 9. Failed Surface Water Collection Device on Landfill – Flow Parallel to Collection System

Theoretical Problems with Cover Regulations

The primary problem with current landfill cover regulations centers on the fact that they are essentially resistive barriers which attempt to block the vertical infiltration of water from moving into the underlying waste. The soil characteristic chosen to determine the effectiveness of the barrier layer is saturated hydraulic conductivity. For Subtitle "D" facilities, this value is to be no higher than 1×10^{-5} cm/sec, while the Subtitle "C" barrier layer is to be constructed to a value less than or equal to 1×10^{-7} cm/sec.

A flawed assumption with the use of traditional RCRA landfill covers is that flow occurs under saturated conditions. On the contrary, flow generally occurs under unsaturated conditions. This is particularly the case in dry environments. Darcy's Law can be used to represent the fundamental equation of flow for both scenarios:

Saturated systems:
$$Q = K_{\text{sat}} i A$$

where: Q = flow rate

K_{sat} = saturated hydraulic conductivity

i = hydraulic gradient = f (gravity and positive pressure)

A = area

Unsaturated systems:
$$Q = K_{\text{unsat}} i A$$

where: Q = flow rate

K_{unsat} = unsaturated hydraulic conductivity

i = hydraulic gradient = f (gravity and matric potential)

A = area

Moisture is driven by total potential difference toward equilibrium. Water moves toward regions of higher water potential and is consequently governed by gravity *and* matric potential for unsaturated flow. Under saturated conditions, the soil's matric potential is zero.

$$\Psi_{\text{Total}} = \Psi_{\text{grav}} + \Psi_{\text{matric}} + \Psi_s + \Psi_a$$

where: Ψ_{Total} = total soil water potential

Ψ_{grav} = gravitational potential

Ψ_{matric} = matric potential or soil suction

Ψ_s = solute potential

Ψ_a = air pressure potential

but Ψ_s and Ψ_a are generally considered to be zero for landfill cover applications, therefore the relationship can be simplified to:

$$\Psi_{\text{Total}} = \Psi_{\text{grav}} + \Psi_{\text{matric}}$$

However, in the field, water movement patterns are complicated by a number of things such as: climatic conditions, plants, structural voids, secondary pathways, non-homogenous soils, and hysteresis. Both saturated and unsaturated soil conditions must be taken into account when designing landfill covers.

What Regulations Should NOT Say

The first thing regulators should not require is that a design be used throughout the country without regard to site specifics. In dry environments where potential evapotranspiration (PET) far outweighs precipitation and unsaturated flow dominates, barrier layers that depend on their effectiveness due to a low saturated hydraulic conductivity should *not* be included. PET is essentially the climatic 'demand' for water. The number can be calculated using Penman's equation (Jensen *et al.* 1990). The total calculated PET for Albuquerque (Albuquerque Airport per the National Weather Service) from 1991 through May 1999 was 690.2 inches while the actual precipitation during this period was only 66.54 inches. This equates to greater than a 10:1 PET to precipitation ratio. There is generally a much greater demand for water by the atmosphere and plants than can be supplied to the soil in an arid climate. A monthly breakout of PET versus precipitation for 1998 is graphically shown in Figure 10.

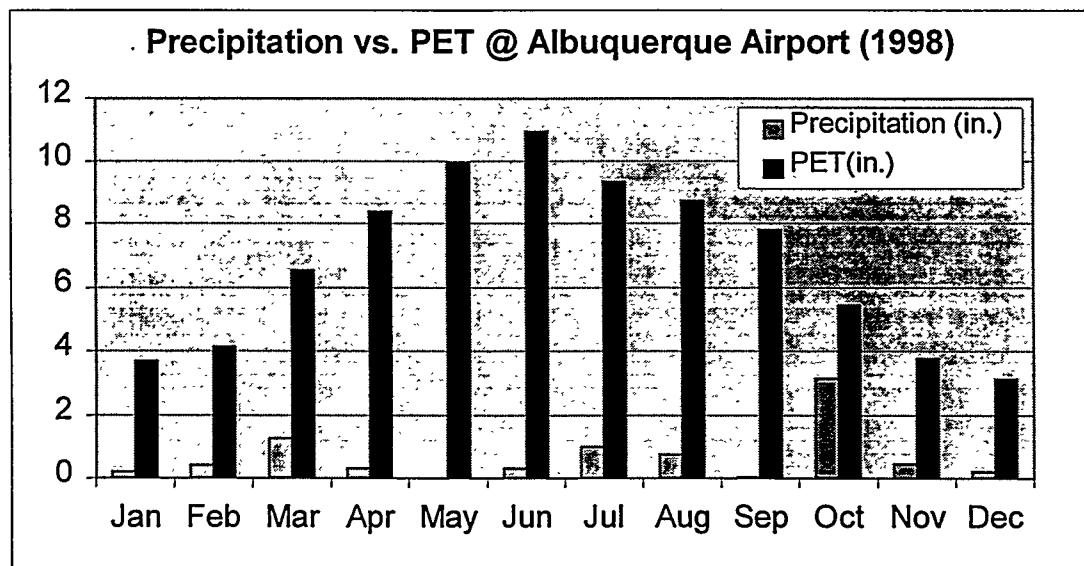


Figure 10. Actual Precipitation vs. PET in Albuquerque, NM for 1998

Designing soil landfill covers using PET vs. precipitation as a basis in dry environments have been shown to be more effective at a substantial cost savings than RCRA prescriptive covers (Dwyer 1998a).

What Regulations Should Say

Regulators need to address ecological processes for site specific cases. Engineering landfill covers which act as a system taking into account parameters which occur naturally in and on the site. Arid regions may incorporate many of the same engineered barriers used in moist climates however must take into account factors that are site specific, i.e. PET, site soils, and natural occurring vegetation. The objective in constructing an effective landfill is to design the cover so that subsequent ecological change will enhance and preserve the encapsulating system.

Conventional engineering approaches for designing landfill covers often fail to fully consider ecological processes. Natural ecosystems effective at capturing and or redistributing materials in the environment have evolved over millions of years and need to be taken into account when designing a cover system. Consequently, when contaminants are introduced into the environment, ecosystem processes begin to influence the distribution and transport of these materials, just as they influence the distribution and transport of nutrients that occur naturally in ecosystems (Hakonson et al. 1992). As the ecological status of the cover changes, so will performance factors such as water infiltration, water retention, evapotranspiration (ET), soil erosion, gas diffusion, and bioturbation.

Cover designs should incorporate the use of natural analogs in an effort to disclose what properties are effective in a given environment and/or what processes may lead to possible modes of failure. Analog studies involve the use of logical analogy to investigate natural and archaeological occurrences of materials, conditions, or processes that are similar to those known or predicted to occur in some part of the engineered cover system (Waugh 1994). The studies provide clues from past environments as to possible long-term changes in engineered covers and what can be expected in the future.

The ultimate goal is to design a maintenance-free landfill cover. Some degree of maintenance or post-construction refinement may be necessary until the cover reaches a state of equilibrium with its inherent environment. A cover should be stabilized with vegetation comprising plant communities that closely emulate a selected local "climax" (Reith 1993). A "climax" community, in ecological terms is the type of plant community one finds in an area that has long been undisturbed and is in equilibrium with all other environmental parameters (e.g., climate, soil, and landscape properties, fauna and other flora). Central to the concept of "climax" is the community's relative stability in the existing environment (Whittaker 1975). A diverse mixture of native plants on the cover will maximize water removal through ET (Link 1994). The cover will then be more resilient to natural and man-induced catastrophes and fluctuations in environments. Similarly, biological diversity in cover vegetation will be important to community stability and resilience given variable and unpredictable changes in the environment resulting from pest outbreaks, disturbances (overgrazing, fires, etc.) and climatic fluctuations. Local native species that have been selected over thousands of years are best adapted to disturbances and climatic changes (Waugh 1994). In contrast, plantings of non-native species common on waste sites are genetically and structurally monotonous

(Harper 1987) and are therefore more vulnerable to disturbances. Pedogenic processes will gradually change the physical and hydraulic properties of earthen material used to construct covers (Hillel 1980). In addition, plant communities inhabiting the cover will also change in response to these changes in soil properties.

In order for an engineered cover encapsulating waste to be deemed harmless it must be designed as an evolving component of a larger dynamic ecosystem. Cover components initially designed for a specific purpose such as a barrier or drainage layer will not function independent of one another and should therefore be designed as a system (linked assemblage of components) rather than as individual components. Inevitable changes in physical and biological conditions should be taken into account to help ensure the long-term effectiveness of the cover system. For resistant waste forms with long resident time, man-made materials of unknown durability should not be relied upon to effectively maintain waste isolation.

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