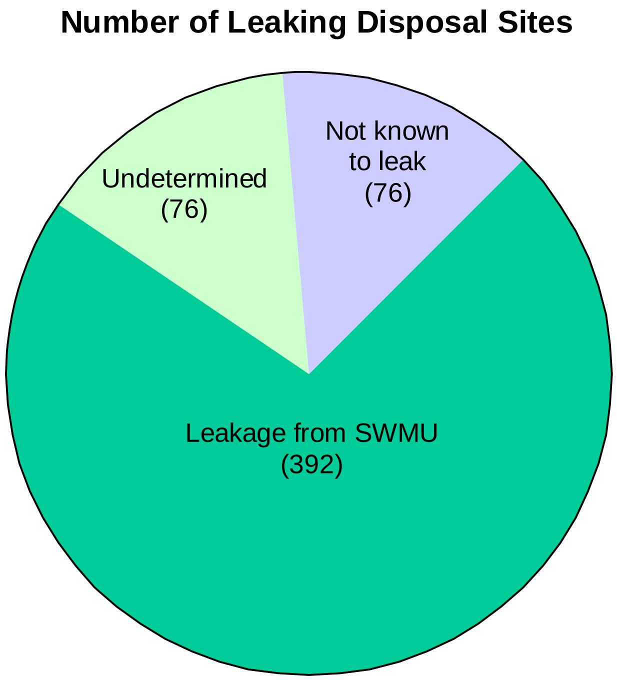
Appendix A

Problems with Prescriptive Cover Systems

A-1.0 STUDIES REVEALING PHYSICAL PROBLEMS WITH PRESCRIPTIVE COVERS

Prescriptive covers (resistive 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, Dwyer 2003). 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” covers, are not only inherently problematic but are very expensive (Dwyer 1998) and difficult to construct (Dwyer 1998). 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) and thus destined for failure, but these problems can be mitigated by capping the entire landfill with a properly designed cover. A study (Mulder and Haven 1995) titled the California Solid Waste Assessment Test Report found that 72–86% of existing landfills with compacted clay barrier layers are failing (Figure A-1.0-1). It also concluded that these clay barriers leak regardless of climate or site-specific geology.



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

Figure A-1.0-1. California Solid Waste Assessment Test Report findings (Mulder and Haven 1995)

A-2.0 PHYSICAL PROBLEMS

An investigation of a clay barrier in a Uranium Mill Tailings Disposal Site (Waugh and Smith 1997) concluded that these clay barrier layers' hydraulic conductivity will increase several orders of magnitude with time. Dwyer (2003) and Benson et al. (in press) had similar findings. 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 A-2.0-1). This revealed the incorrect assumption that the design of prescriptive covers is based on: that saturated 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.

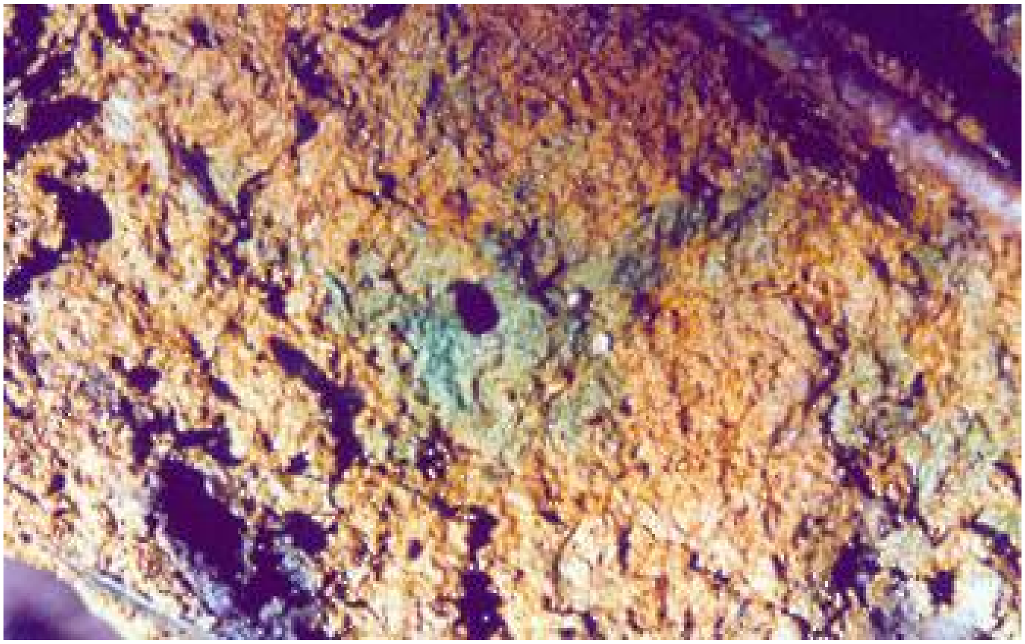


Figure A-2.0-1. Root and earthworm intrusion into clay barrier layer

Prescriptive 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 a preferred soil is approximately 20%. After installation, the soil dries to a state similar to that in the soils adjoining the landfill or in their undisturbed state. Soil-water contents in the dry climates 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 A-2.0-2. 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 A-2.0-2. Desiccation cracking in clay barrier layer

In addition to the required high soil densities required by regulations for the barrier layers, relatively high cohesions also lead to serious problems from cracking due to differential settlement (Figure A-2.0-3). The underlying waste settles with time due to consolidation and biodegradation. Because the waste materials are often inconsistent and randomly placed, the settlement occurs differentially. Potential cracks in the cover allow for surface runoff to enter the waste, thus increasing leachate generation and increasing the risk for leakage from the landfill into the underlying and surrounding soils, harming the surrounding community.

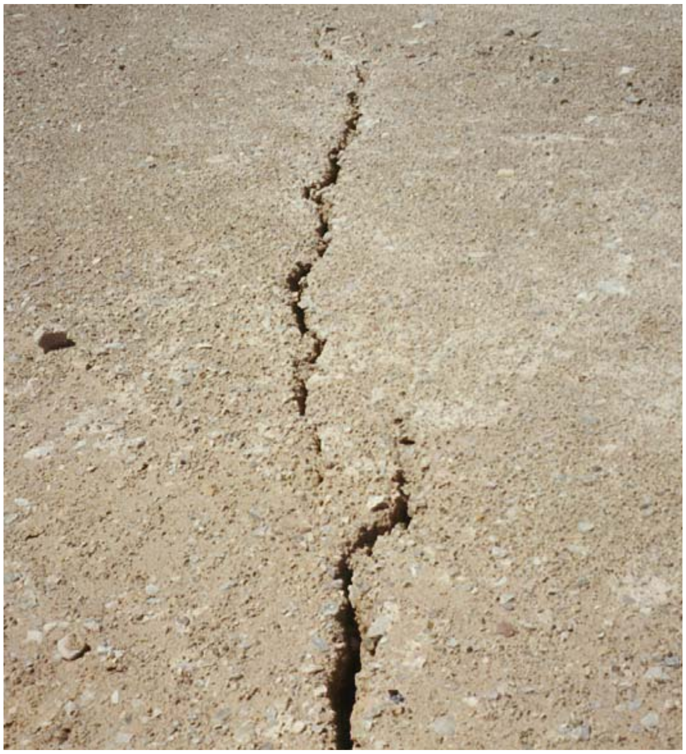


Figure A-2.0-3. Longitudinal cracking due to differential settlement

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 A-2.04 shows two different cover systems installed side-by-side (Dwyer 2003). The two cover surfaces looked identical after their first year because it was a relatively wet year. However, after a severe drought the vegetation on the cover to the left was unable to survive because that cover did not have an adequate water-holding capacity in its upper fine soil layer. The cover on the left is a multiple-layered cover with a very thin (30-cm) surface soil layer, while the cover on the right is an ET cover with a thicker (107-cm) soil layer capable of enough water-holding capacity to better enable a stand of native vegetation to survive a drought. 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 A-2.0-4. Surface vegetation of undisturbed rangeland versus landfill (Dwyer 2003)

A-3.0 THEORETICAL PROBLEMS WITH PRESCRIPTIVE COVER REGULATIONS

A problem with current landfill cover regulations centers on the fact that they are essentially “resistive” barriers designed to block the vertical infiltration of water from moving into the underlying waste. The soil characteristic chosen to determine the effectiveness of the “resistive” 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 prescriptive landfill covers is that flow occurs under saturated conditions. On the contrary, flow generally occurs under unsaturated conditions.

Darcy’s Law can be used to represent the fundamental equation of flow for both scenarios:

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

where:
Q = flow rate
K_{sat} = saturated hydraulic conductivity
i = hydraulic gradient = *f*(gravity and positive pressure)
A = area

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

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.