How Well Can, and Should, Landfills be Monitored?

A summary of several landfill monitoring designs developed by *Flexible Liner Underground Technologies*

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Introduction

There is pretty good agreement that landfills of the past and current landfills are not well monitored. The rigorously calculated probability of a spatial intercept of a leak is in the 1-10% range. The lifetime of the sensors used is far less than the lifetime of the hazard, and the monitoring procedures are not to be carried out for very long or in many cases, there is no monitoring plan. Even the landfill owner/operators can appreciate a better method of monitoring, but the requirements of the regulations make it a financial disadvantage to install more than the minimum required.

This short paper describes several levels of monitoring that can perform far beyond current practice. The improvements which allow the better monitoring are to use large monitoring planes instead of point measurements, to construct the system to be reliable for even hundreds of years, and to avoid the cost of characterization, and the unsatisfactory nature, of the site geologic characteristics by building in the flow characteristics needed.

The ideal system is described first with cost estimates. Then approximations are described which cost less, but also perform less well.

The Ideal System

The ideal system would have at least the following characteristics:

1. Affordable - otherwise it won't be built.

2. Effective:
   a) Reliable function (can be tested in place).
   b) Can't be by-passed.
   c) Individual measurements are supported by other measurements.

3. Doesn't conflict with the landfill construction or degrade the containment system (e.g., doesn't penetrate the liners).

4. Inexpensive to operate (e.g., doesn't require hundreds of samples to be collected and analyzed).

5. Integrated with, and supportive of, the remediation procedure if a leak is detected.

6. Uses better measurement methods as they are developed (no permanently buried gauges).

7. Ageless (e.g., doesn't corrode, outlasts the landfill liner (30 years?)).

8. Low maintenance (otherwise it won't be available when needed).

9. Independent of a complete knowledge of the geologic site (when have all macropores been mapped?).

10. Provides data useful to leakage prevention procedures (e.g., warns of damage to the cap).

11. Allows an alarm of the earliest leakage before the remedy is hopeless.

12. Monitors each line of defense in the landfill containment design.

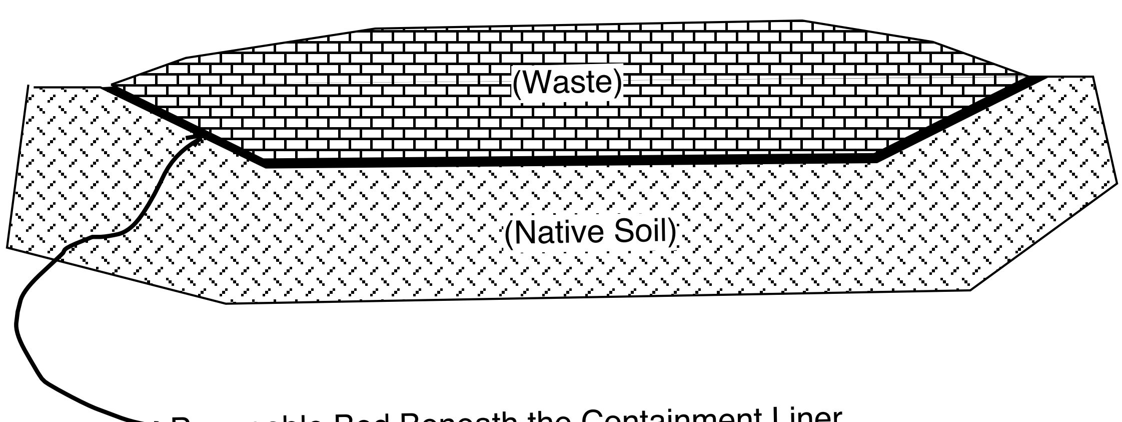
13. Provides data useful to improvements in future designs (i.e., information on why leaks occur or how construction materials perform).

(note: Items 10, 12 and 13 are dependent upon the containment system design and will not be discussed in this brief summary.)

These characteristics can be realized in the first design described hereafter. The subsequent designs are less expensive approximations to the fully effective design.

The system described in reference 1 (an older version of the design described here) was developed for the California requirements of vadose monitoring under all new landfills (Ref. 1). Figure 1 shows how the monitoring system is contained in a permeable layer built into the earth forming a thin bed beneath the containment system. The containment system is the lined landfill and associated leachate collection systems and clay layers. The details of the containment system are not important to the monitoring system. There may be no liner or containment system at all. The thin monitoring layer is made of three layers, each about a foot thick. The layers are of coarse, fine, and coarse materials (sands,silts and gravel) with about a 100-1000 fold difference in permeability between the coarse and fine layers. In addition, the fine layer should be capable of wicking leachate liquids to lateral distances of 30 or more feet. That requires a relatively fine grained layer of about a Darcy, or less, permeability. The synthetic materials are avoided in this design, because they are usually plastic and of uncertain lifetime. The geologic materials used are long lived with reasonably predictable flow properties.

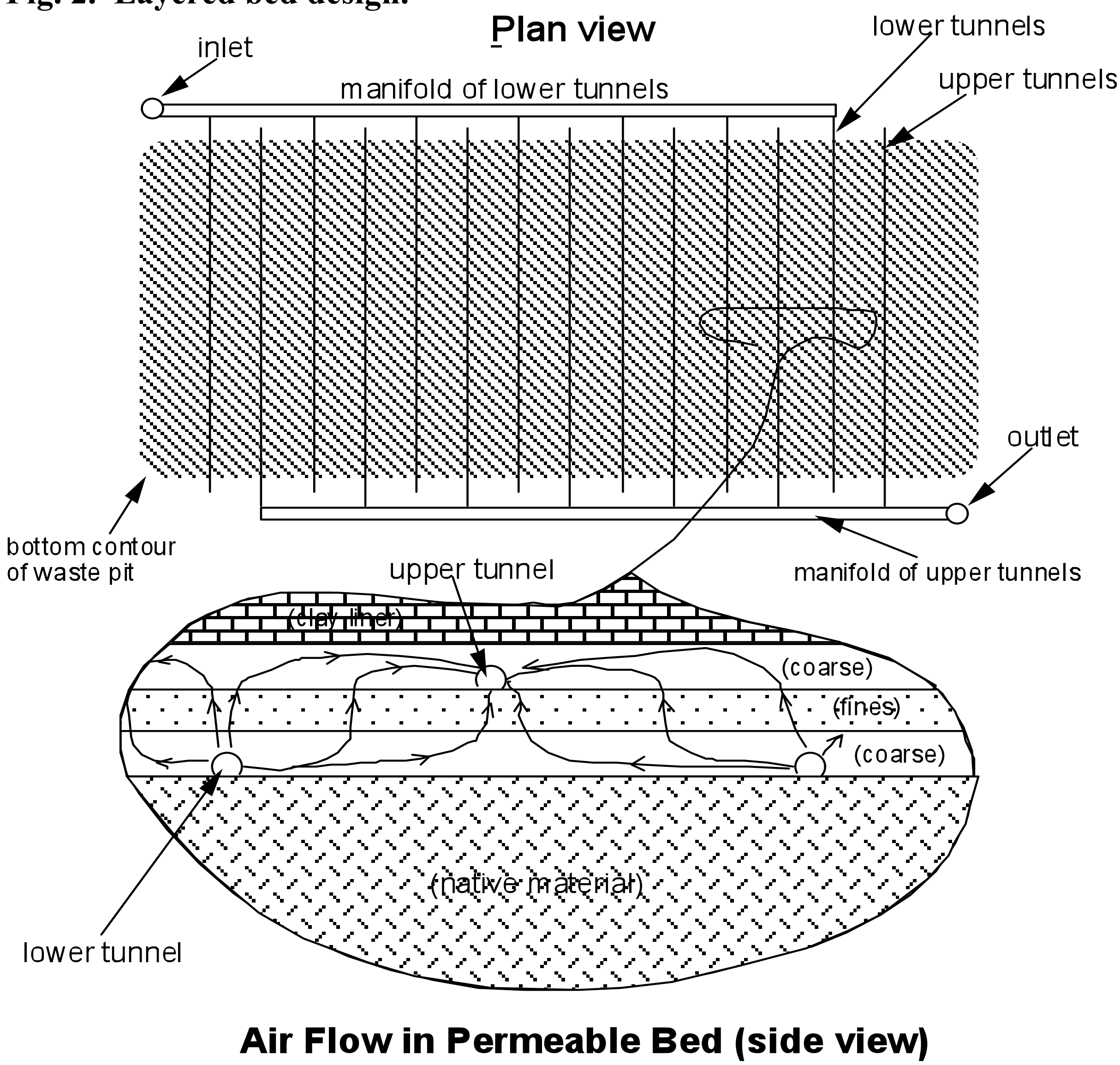
Figure 1. The ideal system geometry



The layered bed contains lateral arrays of pipes as shown in Figure 2. The lateral pipes are of a special kind in that they are perforated to allow easy air flow through the walls, and the wall material is such as to allow easy wicking of pore liquids from the surrounding material. A candidate material is a special vitrified clay pipe. Another requirement of the pipe is that moisture sensors such as neutron moisture logs, induction coupled resistance logs and other electrical and radiation monitoring devices can function within the interior of the pipe. Therefore, metals and plastics are not desirable. Of course, the piping would best not be very expensive and it must survive for 100-1000 years.

The lateral perforated piping system is connected to the surface by impermeable piping that connects the many laterals to a common manifold. The lateral pipe arrays are located on two levels. The upper layer sits on or in the upper surface of the fine grained layer. The lower layer sits on or in the native material below the lower coarse layer. The upper layer is the "outlet layer", and the lower layer is the "inlet layer". The manifolds are also named accordingly.

Fig. 2. Layered bed design.



The Function of the System

The entire underside of the containment system is monitored for leakage of vapor by drawing the pore vapor from the layered bed via the outlet manifold. A blower attached to the outlet manifold can draw the entire pore gas volume of the layered bed through a charcoal filter. The recharge air to the layered bed is supplied from the lower coarse layer by the inlet layer of pipes. (Remember that the pipes are perforated along their top surface to allow easy air flow through the pipe wall.) Since the layers are made of the proper permeability to allow predictable flow of the air, the volume of air drawn is a minimum and it should sweep any fugitive vapors through the filter on the outlet manifold. Detection of contamination in the manifold is easily determined by the measurement of only one sample, the filter, instead of the many sampling points of some systems.

If a leachate leak is suspected, or on a periodic basis, the piping system can be surveyed for evidence of water saturation changes, radiation, or resistance changes by towing logging tools through the pipes with the SEAMIST system (Ref. 3). The same SEAMIST system can be used to wick pore liquid samples through the permeable pipe walls for analysis of the contaminant concentrations. The logging and the wicking allow determination of the location of the leak, the size of the leak, and even the leak rate (via sequential measurements). The reason that the detection can be so reliable in the piping is because the fine grained layer will cause the leak to spread laterally allowing much easier detection before breaking through into the medium below. The logging would be done first in the upper pipe array, and later if needed in the lower array of pipes.

Since the SEAMIST system can also discretely draw gas samples in the pipes, the location of any vapor leaks can also be determined.

The Response to a Leak

The location, composition and leak rate are important data for determination of the appropriate remedy. The vapor leak is easily captured by the air flow control. The sampling flow procedure develops vertical upward flow in the fine grained layer. That same flow can prohibit any downward migration of a known vapor leak by controlling the individual pipe flow. For that purpose, the pipe connections to the manifold are individually fitted with valves. That also helps in the determination of the location of the leak in that each pipe or groups of pipes can be sampled separately.

The leachate leak can be controlled in several ways. The brute force method is to remove the source and/or repair the leak. The more attractive method is to stop the leak in the permeable monitoring bed using the access of the piping. The leak can be dehydrated so as to not flow by controlling the air flow and possibly even heating the air flow. The next level of remediation might be to install tubing to freeze the leak via development of a permafrost layer. The third possibility is to inject a sealant in the upper coarse bed by using tubing emplaced in the upper pipe arrays and monitoring the operation in the adjacent pipes. Finally, the success of the leachate arrest can still be monitored in the lower array of pipes in the lower coarse bed.

Reliability

The reliability of the approach described above is dependent upon several features of the design. No instruments are permanently emplaced. All are removable and recalibratible. The permanent emplacement is of the access only. The flows are much more predictable than in any naturally occurring medium, and the flows are of the nature desired by design. The flow predictions are for short distances and short times. That is a much more reliable application of the predictive models than when applied to large unmeasured geologic media and long transport times.

The SEAMIST system has been proven to function in the kinds of passages required for this design in many situations. The degree of data gathering is dependent upon the desire of the investigators. The large integral measurements with the vapor sampling are sufficient unless a problem is indicated. Thereafter, the measurements can be carried to a spatial resolution not possible with current system. The instruments used are not only those available today but also those developed in the future. The system components are of very durable materials which have been in use for hundreds of years. It is reasonable to expect the lifetime of the proposed monitoring system to be ten to a hundred fold longer than that of current systems (e.g.. leachate collection systems or suction lysimeters).

A major advantage of the system is the detection of leakage immediately below the containment system and not in the ground water where the remedy is very uncertain. A presentation to the Groundwater Resources Association (Ref. 4) describes the reliability assessment model used to evaluate this design. Reference 5 is a report of the full fault tree model used for a mixed waste landfill monitoring design evaluation.

Old Landfills and Compromises on the Full Design for New Landfills.

New landfills

If for some reason such as cost the above design is not possible, the same approach can be applied in several less expensive ways to new landfills. In some unlined landfills, the approach has been to install the parallel piping array in trenches cut into the surface of the native medium at the bottom of the waste pit (Figure 3). The single layer of piping does not allow the arrest and spreading of the leachate in the fine layer as above, but the piping can be used for linear measurements using the full range of logging tools and for drawing local gas samples. The piping can be connected to two manifolds as shown in Figure 4 to allow the sweeping flow of vapor extraction using alternating pipes as sources and sinks. If the pit is lined, the sweeping flow has greater value in that any vapor detected is fugitive.

Figure 3. Monitoring Passages in Trenches Below Unlined Waste Pit

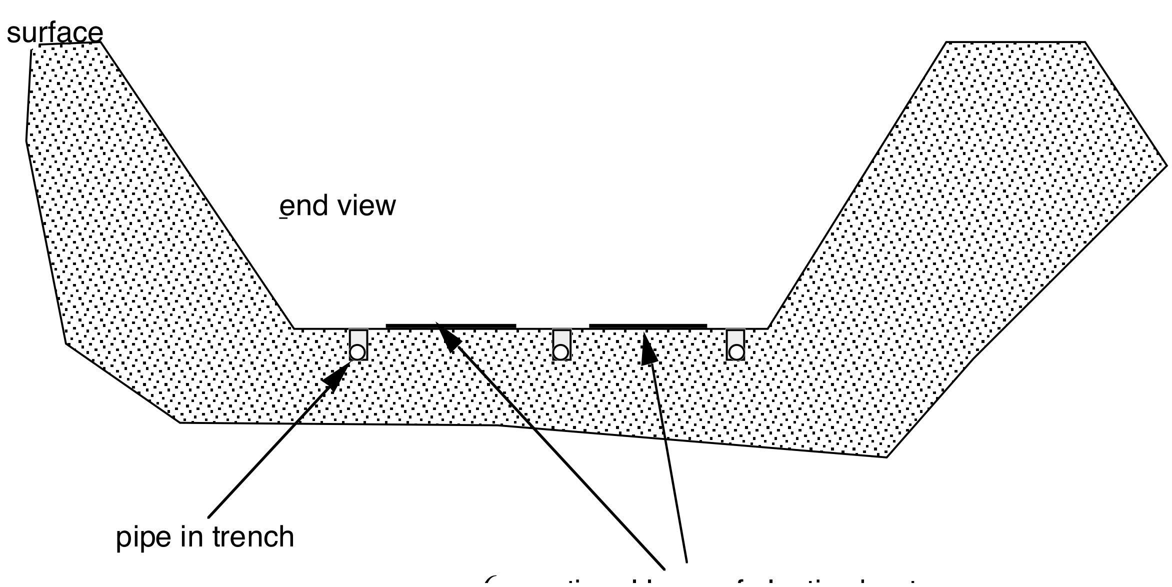
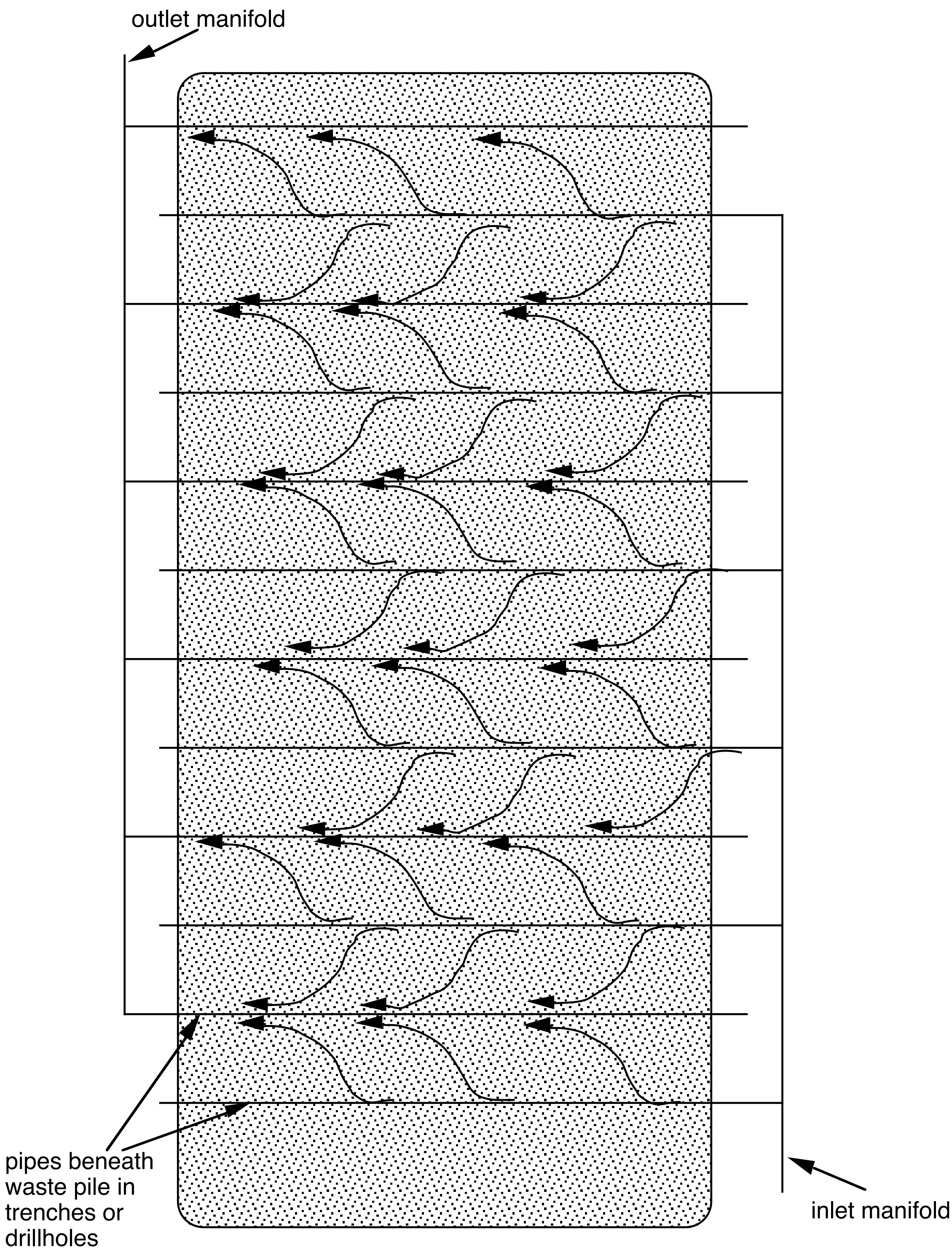


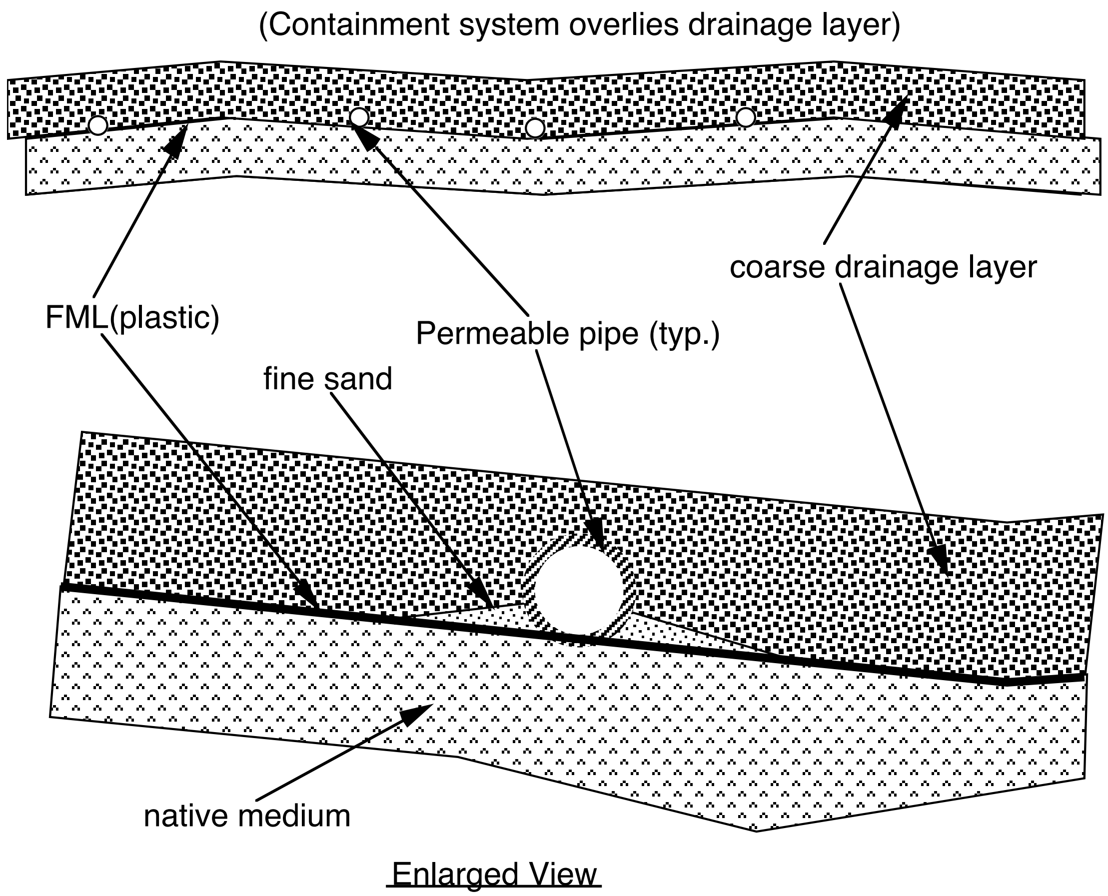
Figure 4. Lateral flow of single layer pipe system
(arrows show flow from inlet to outlet)



Another design uses the piping access as a means of locating leaks on the liner surface of a pan lysimeter as shown in Figure 5. Because of the known slope of the impermeable layer, the intercept of a wet spot allows one to presume that the leak is upgradient from the intercept on the impermeable layer. This allows much better location of a leak than the simple detection of leachate in the sump of the pan.

These approximations to the full design (called the "ideal") all require construction of the monitoring system as part of the landfill construction. Hereafter are described what can be done for old landfill without any monitoring system.

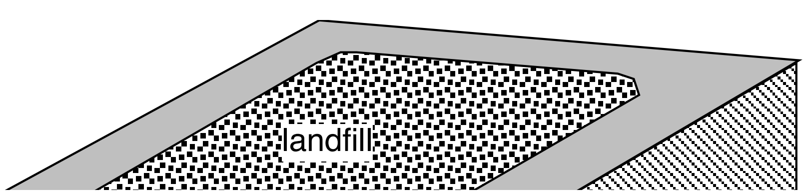
Figure 5. Pan lysimeter monitoring passages



Monitoring of old landfills

Reference 6 describes the several methods of monitoring under old landfills. The first improvement is to install a horizontal well to augment the intercept of leachate in the ground water (see Figure 6). The discrete sampling ability of SEAMIST along the horizontal well overcomes the dilution problem of pumping the full well screen (perhaps 300-600' long).

By moving the horizontal wells to several locations beneath the landfill (Figure 7, still in the ground water), the monitoring allows an earlier



intercept and the location of the leak for more explicit remedy. If the vadose zone is relatively thick (>30'), the wells can be located in the vadose zone beneath the old landfill. This allows the same sweeping lateral flow for vapor leak monitoring (see Figure 4) and the use of a variety of logging tools for leak detection. The natural state of the geology beneath the landfill should be considered in the placement and spacing of the horizontal wells.

If the medium is highly layered with tight clay beds, the landfill can be monitored in the vadose zone and in the aquifer, both, in each well using vertical wells surrounding the landfill. Again, the natural beds, their dip, and composition should be considered in the placement of the wells. SEAMIST allows the discrete monitoring and logging of vertical wells just as well as horizontal wells. Because SEAMIST plugs the entire well, the sampling interval in vertical wells can penetrate the entire aquifer without hazard of vertical flow in the well (see Fig. 6). It may be best to install many vertical wells and a couple of horizontal wells. The horizontal wells should be completed in a manner to allow their use in the remedy if needed. The horizontal wells can be of the single entrance type or the entrance and exit type. The double ended wells allow the use of a number of logging techniques. The SEAMIST progressive packer (Ref. 7) can be used in a double ended well for mapping of the contaminant and the permeability along the well length.

The horizontal permeability profile of a vertical well can be measured quickly and easily with the Withdrawn Liner method described in Reference 8. This is especially useful in the design of the monitoring procedure.

The SEAMIST system emplaced in a horizontal hole allows both vapor and ground water sampling at discrete intervals of a length selected for the application. The ground water sampling system also allows the measurement of the elevation of the water table along the line of the hole. The measurement is not dependent upon the hole survey. This can be very useful if the monitoring hole is converted to a pump and treat hole at the location of the leak.

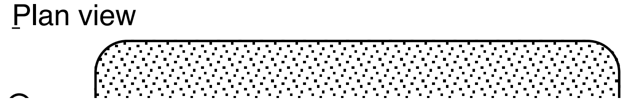
The Cost

A spread sheet has been developed for the explicit pricing of the components of the "ideal" design as a function of the landfill dimensions. The largest factor in the cost (~70%) is the removal and replacement of the layered bed materials. The cost is very dependent upon the local construction market, but the approximate cost of the system is about $100,000 per acre in 20 acre increments. That assumes a 50' spacing of the lateral pipes. The spacing selected is largely a function of the spatial resolution desired. However, if the spacing is too large, the wicking layer may not be able to function reliably, and the spatial intercept probability and the overall reliability will be less. With 30' spacing, the intercept probability can be greater than 90%. The SEAMIST sampling liner and canister is $6000/100ft depending upon the landfill dimensions and lengths required.

The cost of the system in trenches is about $10,000 per acre in 10 acre sections. None of these prices include any civil engineering design time to integrate the system into the landfill. But those costs are not usually large compared to the hardware, since the landfill design must be done anyway.

Figure 7. Discrete mapping of contamination in horizontal holes using SEAMIST

Plan view



The SEAMIST system for monitoring the pipes is $24,000 for a 400 ft. length with a canister to install the liner and a variety of logging tools. Air blowers and other auxiliary equipment are of a common kind and do not need to be dedicated to the system.

The life expectancy of a SEAMIST system depends very much upon how it is used. 100 to 200 installations is a reasonable expectation.

Since the cost of horizontal holes is highly dependent upon the site characteristics and the method of drilling, there is no point in pricing them here, but they range from $50-400 per foot. The SEAMIST system can be deployed in 4" id. holes, but a 6" hole is preferred.

Experience

The system of trenches beneath unlined pits is currently in use at Los Alamos National Laboratory to monitor the potential migration of low level radioactive waste into the underlying tuff formation.

The system has been adapted for use under a mixed waste repository, but that repository has not been built.

SEAMIST has been deployed for gas sampling to 400' in a 4 in. horizontal hole beneath a landfill at Sandia National Laboratories at only 2.8 psi. The SEAMIST system can be deployed in both dry and water filled holes (Ref. 9).

The main detraction from the greater use of the system is that it is not required by the regulators, and the cost is greater than no monitoring system or a couple of suction lysimeters. Current practice does allow an overall probability of detection after 50 years of 0-5% (Ref. 4). The actual probability of detection has been developed for some systems using the fault tree analysis of the kind used for reactors and airplanes (Ref. 5). To our knowledge, that kind of probability assessment has not been done by anyone else for a landfill monitoring system. The main difficulty is the lack of performance data on some of the critical system components when instruments are buried as part of the design. Most instrument lifetimes are very short compared to the lifetime of the waste hazards.

Conclusion

Landfills old and new can be monitored much better than they are currently done. The approach described here is especially reliable because none of the instruments used are buried. The access for monitoring, coupled with the SEAMIST capabilities, allows several kinds of remedies using only the monitoring system. This should allow the overall cost of the monitoring and remediation system to be less than current practice, and it should allow much less risk of ground water contamination.

References

1. C. Keller, "A Serious Vadose Defense of Ground Water From Landfill Contamination - New Concept, Old Principles," *Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods*, pp. 73-86, National Ground Water Association, Las Vegas, Nevada (1992).

2. Article 5 [Water Quality Monitoring and Response Programs for Waste Management Units] and Article 10 [Definitions] of Chapter 15 "Discharge of Waste to Land" of Division 3 of Title 23 of the California Code of Regulations, (1991).

3. C. Keller, "So What Is The Practical Value of SEAMIST™?" *Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods*, pp. 59-74, National Waterwell Association, Las Vegas, Nevada (1991).

4. C. Keller, "What Constitutes A Reliable Vadose Monitoring System?" presented at the Groundwater Resources Association Annual Meeting, Napa, California (1994).

5. B. Walsh and C. Keller, "Reliability Studies: Pit Monitoring System for the Los Alamos MWDF," prepared for Los Alamos National Laboratory Environmental Restoration Program, Los Alamos, New Mexico (1994).

6. C. Keller, "New Options For Landfill Monitoring," workshop presented at the National Groundwater Association Outdoor Action Conference, National Ground Water Association, Las Vegas, Nevada (1992).

7. C. Keller, Progressive Packer report in progress, patent in hand. Contact Eastman Cherrington for details.

8. C. Keller, Withdrawn Liner permeablity measurement report in progress. Patent pending. Contact Eastman Cherrington for details.

9. C. Keller, "Improved Spatial Resolution in Vertical and Horizontal Holes for Measurement of Bioremediation Parameters and Histories," Chapter 23, *Remediation of Hazardous Waste Contaminated Soils*, ed. D. Wise, D. Trantolo (1994).

10. C. Keller, Sampling below the water table with SEAMIST. Patent pending. Contact Eastman Cherrington for details.