LANDFILL DESIGN AND THE REGULATORY SYSTEM

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Proceedings of Sardinia 95, Fifth Int'l Landfill Symposium, Cagliari, Italy

SUMMARY: Minimizing environmental impacts and reducing long-term legal liabilities that can arise from municipal solid waste landfills are objectives that could likely be universally accepted. With illustrations from American and Canadian laws this paper discusses whether these objectives can be best achieved by prescriptive engineering design specifications or prescriptive performance standards. It also discusses some institutional techniques for evaluating the adequacy of proposed engineering designs.

INTRODUCTION

Environmental assessment regulations for municipal waste management vary substantially from country to country. Typically, environmental regulations fall into one of the following categories:

(1) Essentially no regulation.
(2) Prescriptive regulations which specify minimum design requirements such as "two liners of which at least one is a synthetic liner".
(3) Regulations requiring performance objectives e.g. "no impact" or "negligible impact" for a prescribed period of time (eg. 30 years or 100 years post-closure).
(4) Regulations requiring "negligible impact" in perpetuity (Rowe, 1991a).

Clearly, the situation where there is no regulation provides considerable latitude to the landfill proponent and designer in terms of the barrier system adopted. It also provides little assurance the environment will be protected.

Indeed, a survey prepared by Environmental Information, Ltd. in 1991 (Rivette, 1993) indicated that more than 10 American states had either no minimum requirements for non-hazardous industrial waste landfill liners, or the design was determined on a case-by-case basis with little to no legislative guidance. For municipal solid waste landfills, the EIL survey indicated that the situation was even worse, with 19 states reporting no definitive legislative guidelines for landfill liner design.

The American situation is in the course of considerable change as a result of the U.S. *Resource Conservation and Recovery Act*, (RCRA) Subtitle D regulations which took effect in October, 1993, (40 CFR 257 and 258) and which provide for a minimum engineering design for municipal landfills, (discussed below). However, the American situation in 1991 as found by the survey would not be unusual in many other jurisdictions.

In Canada, where municipal waste disposal is regulated at the discretion of each of 10 provincial and two territorial governments (supplemented in some cases by municipal requirements) some provinces have few, if any, specific legal requirements for waste landfill design. Consequently, the suitability of a design generally is determined on a case-by-case basis.

For example, the Province of Ontario (which includes Metropolitan Toronto) does not legally prescribe minimum design standards - rather both its regulations and policies on the topic are performance-based (Tidball and Lopes, 1995).

The Province of New Brunswick uses a guideline which combines a site-by-site approach with a liner requirement consisting of a minimum 0.6m 10^{-7} cm/s, recompacted clay overlain by an 80 mil HDPE geomembrane liner (New Brunswick, 1994).

The Province of British Columbia allows a landfill proponent to propose either "natural control landfills" which utilize a performance-based design or an "engineered landfill" which must utilize prescribed minimum liner specifications (British Columbia, 1993).

Which approach is preferable to minimize environmental impacts and eliminate long-term legal liabilities - prescriptive design or prescriptive performance objectives which allow flexible design?

Prescriptive design regulations do have a certain attractiveness. They:

- are relatively easy to write (e.g. "A composite liner consisting of a minimum 30 mil. flexible membrane liner in direct and uniform contact with at least 0.6m of compacted soil with a minimum hydraulic conductivity of 1×10^{-7} cm/s";
- make it easy for proponents with relatively little engineering experience to comply;
- make a determination of compliance relatively straightforward.

On the other hand, prescriptive design may create a situation where for one landfill, the design may be overly conservative while for a second landfill the design may provide no assurance the long term potential impact of the landfill will be negligible.

While prescriptive regulations are simple, they unfortunately may not recognize that potential impact is not only related to details of the barrier, but may also be highly dependent on many other factors including (but not limited to) local hydrogeological conditions, the size of the landfill (both in areal extent and thickness of waste) and the infiltration into the landfill, as well as the detailed design of the leachate collection system.

THE U.S. EPA DESIGN CRITERIA FOR MUNICIPAL SOLID WASTE LANDFILLS

In the United States, in 1993, regulations were promulgated under the *Resource Conservation and Recovery Act* stipulating locational restrictions, operating criteria, design criteria, as well as monitoring, closure and post-closure care and financial insurance criteria for municipal waste landfills.

Under Subtitle D, §258 of these regulations "Design Criteria" are stipulated. Two basic design options are provided and which may be chosen as a function of a particular American state's approval status by the U.S. Environmental Protection Agency:

(1) In approved states, a site-specific performance-based design may be used to achieve point of compliance pollutant criteria; however,

(2) In unapproved states a *composite liner* must be used. That *composite liner* must meet the following description:

> "Consisting of two components; the upper component must consist of a minimum 30 mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/s. FML components consisting of high density polyethylene (HDPE) shall be at least 60 mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component." (40 CFR, §258.40 (2)(b))

The composite liner must be constructed with a leachate collection system that is designed and constructed to maintain less than a 30 centimeter depth of leachate over the liner (Figure 1).

FIGURE 1: Schematic of a composite liner system; a geomembrane over 0.6m thick compacted clay liner.

In a 1993 article reviewing the impact of Subtitle D regulations on leachate containment capabilities of landfill liner systems, Bonaparte and Gross (1993) expressed the opinion that the composite liner system:

> "has significantly better leachate containment capabilities than either a compacted soil liner alone or a geomembrane liner alone .... It is concluded that the Subtitle D regulations will have a significant environmental benefit, in terms of reduced leachate migration into the environment, in those states that previously required a liner system consisting of only a single low-permeability soil layer or geomembrane".

The authors acknowledged that the importance of the benefit will depend "on the size of the landfill, the leachate generation rate in the landfill, the hydrogeological vulnerability of the landfill site, and the local uses of groundwater". However, even this qualification does not recognize the potential for hydraulic containment. Where natural inward gradients exist (see discussion below) the installation of a geomembrane would not necessarily improve landfill performance nor reduce potential impacts.

Despite that qualification, the authors expressed the opinion that "the benefit will be significant for many facilities" although they also observed that promulgation of this prescriptive standard "has resulted in a relaxation of stringent existing regulations" in at least one state (Bonaparte and Gross, 1993).

PERFORMANCE-BASED DESIGN

Joseph and Mather (1993) have favoured the concept of landfill design based on predictability and full management control. In their opinion, the best means of ensuring predictability, while keeping processes of biodegradation at an optimum level, were to:

> "maintain the head of leachate within the landfill site at a level below the piezometric head in the surrounding strata, thus providing genuine containment; and manage the rate of reaction and degradation so as to minimize the period between site closure and stabilization of the surface of the landfill. In order to fit in with this concept, the liner should be designed to control the flow of water into the landfill - the reverse of conventional criteria which are built around the idea of minimizing flows from the landfill into the environment."

This reasoning argues for flexibility in siting and landfill design and argues against prescriptive design requirement that require a geomembrane (which clearly would inhibit inward flow to a negligible level) and against requirement that the base of the landfill be above the groundwater level (e.g. German requirements; Jessberger, 1994). The concept advocated by Joseph and Mather (1993) is reasonably well known in some parts of the world and has been described as a "hydraulic trap" and several landfills have been designed, approved and constructed based on the concept of hydraulic containment (Burke and Haubert, 1991; Rowe et al., 1993).

FIGURE 2: Schematic of a hydraulic trap (flow from the aquifer into the landfill).

A "hydraulic trap" is illustrated in Figure 2. This design is attractive from a contaminant impact perspective since the inward advective flow of groundwater from the aquifer not only allows collection of the leachate within the waste deposit for the treatment on or off site, but also tends to inhibit the outward diffusion of contaminants. (See Rowe 1988, 1991 a, b; 1992, 1995; Rowe et al 1995).

CONSIDERATIONS IN PRESCRIPTIVE AND PERFORMANCE-BASED DESIGNS

An illustration of the concern that prescriptive design regulations may be easy to administer but create a situation where for one landfill the design may be overly conservative, while for a second landfill the prescriptive design may provide insufficient assurance that the long term potential impact will be negligible, can be obtained by applying the U.S. EPA prescriptive design to two proposed municipal landfills in the Greater Metropolitan Toronto (Ontario, Canada) area.

Landfill site searches were carried out under the *Ontario Environmental Assessment Act* (see further Tidball and Lopes, op. cit.), within two municipal regions.

In the case of the site proposed for Peel Region (west of Metropolitan Toronto) a proposed site was identified which is 122 hectares in size, and which would receive 10.4 million tonnes of municipal solid waste over a 20 year period on a landfill foot print of about 66 hectares.

The site is underlain by a thick clayey deposit and an aquifer with a potentiometric surface close to or above ground surface over much of the site. This hydrogeologic setting allows the design of the site to be operated as a "hydraulic trap".

Contaminant modelling has shown that given the natural hydrogeologic setting at the proposed Peel Region site, no geomembrane (flexible membrane liner) would be required in order to achieve Ontario's stipulated performance standards under the Ontario "Reasonable Use" policy (see Tidball and Lopes, op. cit.). These standards are generally more stringent than those required by the U.S. EPA (40 CFR §258.40a). For example, the U.S. EPA requirement is that vinyl chloride must not exceed 2 ug/l in the uppermost aquifer whereas the Ontario "Reasonable Use" policy (Guideline and Procedure B-7-1) would limit the concentration to 0.5 ug/l.

Put simply, given the naturally occurring inward hydraulic gradient and soil conditions at the proposed Peel site, application of the U.S. EPA prescriptive design standards would be overly conservative. A very large engineering and design cost (likely in the order of $7.3 million) would be required to design and install a 60 HDPE geomembrane liner. Yet existing conditions are such that no geomembrane (FML) is required to achieve the "negligible" environmental impact mandated under Ontario's Reasonable Use Policy.

An illustration of how the U.S. prescriptive design approach would not provide sufficient assurance of long-term negligible environmental impact is found by applying the U.S. EPA minimum design standards to another proposed large landfill in the Metropolitan Toronto area, the "York/Metro" site. In this case the landfill is larger and there is not the opportunity to develop a natural hydraulic trap. This site would occupy 270 hectares, receive 39.2 million tonnes of municipal waste over a 20 year period and would have a waste disposal foot print of 188 hectares. The proposed maximum height of landfill would be up to almost 40 meters above natural ground surface and would require an average excavation of 11 meters and maximum excavation of 24 meters below present ground surface. The bottom of the excavation either rests on or close to a till sediment complex or sand unit.

Predictive modelling carried out in respect of the proposed York/Metro site indicates that a design consisting of two composite liners underlain by a gradient control layer and a reworked/recompacted soil layer is required in order to achieve Ontario's "Reasonable Use" and Engineered Facilities policies performance standards when consideration is given to the finite service life of geomembrane liners (with a 150 year anticipated service life for the primary geomembrane liner and in excess of 200 years for the secondary liner being adopted in modelling of potential impact). The application of the U.S. EPA minimum prescriptive design would not be sufficient in the case of the York/Metro site for such performance standards to be met.

The U.S. Subtitle D approach requires either a prescriptive design as previously discussed or a design that meets performance criteria in terms of the concentration expected in the uppermost aquifer at the point of compliance (§258.40(a)). However, adoption of the prescriptive design does not necessarily mean that the impact in an underlying aquifer would necessarily need the performance standards specified. Of particular concern is the potential impact on organics such as benzene, trichloroethylene and vinyl chloride which can potentially readily diffuse through a geomembrane liner and, depending on its retardation characteristics, also diffuse through a 0.6 m thick compacted clay liner even if low head is maintained on the liner system (see Rowe et al, 1995 for a discussion of diffusion through geomembranes and compacted clay liners).

Another potential problem inherent in prescriptive design is that the prescriptive design may only be sufficient to achieve negligible impact for an assumed minimal number of years. For example §258.40(1) of U.S. Subtitle D does not specify a time constraint on the period of concern for assessing potential impact. However §258.61(c) specifies a post closure cap period of 30 years (except as provided in §258.61(b)) including groundwater monitoring (§258.61(a)(3). In practice this is often interpreted to mean that one is only concerned with potential impact during the operating and post closure period (i.e. for 30 years or, in some states, 100 years post closure). Since diffusion is a slow process this can mean that modelling is terminated prior to the time at which peak impact would actually occur. While diffusion is slow, it is a remarkably predictable process (see Rowe et al, 1995) and long time periods to reaching a peak impact are usually accompanied by a long period of potential contamination if that peak impact is unacceptable. This may simply mean that the impact of the facility is being passed on to future generations.

Accordingly, a prescriptive design which imports or implies an arbitrary containment time but which does not require a calculation of impact beyond that time will not achieve the objective of minimizing environmental impacts or limiting legal liability.

An additional factor to be considered is the concept of entombment of waste that is implicit in some prescriptive requirements. For example, The U.S. Subtitle D regulation for unapproved states at §258.60(a) requires that:

"Owners or operators of all MSWLF units must install a final cover system that is designed to minimize infiltration and erosion. The final cover system must be designed and constructed to (1) have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present...."

For a landfill with a composite liner system this might be taken to imply that a similar system would be required for the cover to meet the requirement of a "permeability less than or equal to the permeability of any bottom liner system". This is a difficult, and onerous, objective to meet. However of greater interest are the implications arising when this design objective is met. The limitation of infiltration through the cover to the waste will obviously minimize leachate generation. It will also severely limit degradation of the waste but will not prevent diffusion of contaminants that are generated through the barrier system. This issue has been discussed by Lee & Jones-Lee (1993) and others. While not necessarily agreeing with the entire thesis of Lee & Jones-Lee, the issue is an important one since the entombment of waste does mean that the problem of potential contaminant impact is at best being deferred until either the cover degrades and/or the geomembrane degrades. While a geomembrane liner may well last for many hundreds of years in the base of a MSW landfill it is far less certain that the cover will be maintained for this period of time and, eventually, one must anticipate degradation of the geomembrane liner. Thus, entombment of waste would not appear to provide assurance of long term environmental protection. A useful discussion of this issue and some options has been provided by Bonaparte (1995).

As noted above and discussed by Tidball and Lopes (1995) the Province of Ontario, Canada utilizes a performance criterion for the acceptability of landfill engineering design. The Ontario "Reasonable Use" policy is similar to the alternative performance design criteria stipulated by the U.S. Environmental Protection Agency for an approved state.

Under the U.S. Subtitle D "Design Criteria for an Approved State", an engineering design may be approved if it ensures that the concentration values listed in Table 1 of the regulation will not be exceeded in the uppermost aquifer at the relevant point of compliance as specified by the Director of an approved state. That point of compliance must be no more than 150 meters from the waste management unit boundary and must be located on lands owned by the owner of the municipal landfill.

As of 1994 the U.S. EPA had prescribed concentration limits which must be met at the point of compliance for 24 chemicals.

The American regulations do not specify how the designated approval agency is to determine whether the design will "ensure" that the concentration values will not be exceeded at the relevant point of compliance in the uppermost aquifer. However, the only way to address this issue is by modelling advective-diffusive transport through the barrier system. In some states this is done using finite layer contaminant transport models which can model transport through a thin geomembrane and compacted clayey liners to an underlying aquifer (e.g. Rowe & Booker 1988, 1994; Rowe et al, 1995).

Under the U.S. EPA regulation, the determination of acceptability of a design can be made by the chief administrative officer of a state agency responsible for implementing the state municipal solid waste permit programme which has been approved by the U.S. EPA. There is no provision in the U.S. Federal regulatory system which requires that the decision by the state approval agency must be made only after hearings or other forms of independent peer review or public input. (However, when a state submits an application for approval to the EPA it must discuss the process for public participation during site permitting.)

In Ontario, as described by Tidball and Lopes (1995), all proposed landfills which accept the equivalent waste of more than 1,500 persons must only be approved following public hearings (unless that requirement is set aside by a relevant Minister of the government). As discussed by Tidball and Lopes,these hearings usually result in extremely detailed scrutiny of hydrogeological and engineering design details.

The Ontario Ministry of the Environment policies require not only that these performance standards be met in an aquifer at the downgradient boundary of the landfill property but that the proponent demonstrate that the engineering design required to control what would otherwise be unacceptable levels of contaminants will outlast the "contaminating life span" of the waste, which for large landfills may be measured in hundreds of years.

Several questions arise in connection with performance based engineering design. These can be grouped into two categories of issues:

(a) "Engineering" Related Issues, such as:

- the prediction of the site's "contaminating life span";
- the evaluation of the service life of engineered components such as leachate collection systems, geomembrane liners etc.;
- the predictive modelling of contaminant strengths and declines and eventual contaminant impacts;
- the reasonableness of applying present engineering technology to a source of contaminants which may be required to be controlled for hundreds of years;

(b) Institutional Decision-Making Issues, such as:

- whether, given the significant environmental impacts and legal liabilities that may be created by landfills, there is justification for a rigorous, but what can also be a relatively lengthy and expensive, approval process involving the justification of engineering judgments, including assumptions as to contaminating life span, service life and modelling, in addition to hydrogeological evaluation, in structured legal proceedings similar to those used in a court;
- what level of investigation and engineering design should be required pre-approval versus post-approval but prior to construction;
- whether detailed post-construction monitoring together with pre-approval assessment of the feasibility of contingency measures (including consideration of the use of technology not yet developed but which may emerge within a hundred plus years of the contaminating life span) provide a more reasonable criteria for approval.

These and other potentially difficult issues arise within a rigorous prior approval process such as Ontario's for sites which may have contaminating life spans of hundreds of years and which require the demonstration that throughout that period the performance and engineering standards specified by the Reasonable Use and Engineering Policy requirements will be met.

Indeed, problems have arisen when approving authorities in Ontario have attempted to base their conclusions as to an adequate design on preliminary hydrogeological information which, when supplemented based on more detailed testing, indicated that the original approved design was inadequate (e.g. see Rowe et al, 1993).

On the other hand, the value of the rigorous Ontario process has also been demonstrated on numerous occasions. The authors are familiar with several instances where proponents submitted approval applications and supporting materials to the Ontario Ministry of the Environment and received only nominal comments from that agency. Yet when the applications were subsequently subjected to the quasi-judicial legal hearing process before Ontario's Environmental Assessment Board the applications were found to be based on either inadequate hydrogeological investigations or on engineering designs which were faulty. In other words, the rigorous quasi-judicial hearing process resulted in either rejection of faulty applications which were otherwise acceptable to the Ministry staff or significant changes to the proposal, including approvals contingent only on further investigations and further engineering design changes.

It is instructive to compare the rigorous, although admittedly potentially lengthy, Ontario approval process requirements to the U.S. EPA requirements. As indicated above, under the U.S. Subtitle D regulations there are no pre-determined legal requirements as to how such applications must be assessed. The clearest and basically only U.S. requirement is that "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."

There is no equivalent in the Subtitle D regulations to the Ontario "Engineered Facilities" policy which requires a demonstration that the proposed technology will outlast the contaminating lifespan, which in turn requires a calculation of the contaminating life span and which also implicitly requires an evaluation of the efficacy of service lives and the ability to replace engineered components during the contaminating lifespan.

Indeed, the U.S. EPA "Design Criteria" portion of the Subtitle D regulations occupy only one page, whereas what might follow after approval i.e. groundwater monitoring and corrective action requirements, occupy almost 12 pages of regulatory text. To an outside observer it would appear that the U.S. regulations prioritize site monitoring and corrective action requirements as opposed to detailed requirements as to what should be done to consider the contaminating life span and the requisite design that is required to ensure functioning design/containment measures during the contaminating lifespan.

The U.S. federal regulatory measures can further be contrasted to that of Ontario with respect to "post-closure" care requirements.

In Ontario it is clear that post-closure care requirements must continue for as long as there is a "contaminating life span" i.e. potential for effluent emanating from the site which would violate the "Reasonable Use" policy.

In contrast, the U.S. Subtitle D regulations stipulate that the owner/operator must conduct post-closure care only for 30 years. This period may be decreased by the appropriate director of a state environmental agency if there is a demonstration that the reduced period is sufficient to protect human health and the environment. This period may also be increased if the director determines that the length and period is necessary to protect human health and the environment. However, without modelling it is not practical to even estimate the period of time monitoring is likely to be required. Furthermore the "entombment" concept discussed earlier does imply essentially indefinite potential for impact and is contrary to a specified post-closure period for monitoring.

There is potentially some linkage between the volume of waste that might be disposed of at a site and the length of time required for post-closure care insofar as §258.40(3) of Subtitle D does indicate that in assessing or approving a design that complies with paragraph (a)(1) of §258.40 the director must consider among other things "the volume and physical and chemical characteristics of the leachate". However, that is a much less direct and very obscure way of arguing or even approaching the thesis that an operator could be engaged in post-closure care for a contaminating life span that might last hundreds of years. In the American system unless something is quite clear an arguably onerous requirement would likely be struck down by the courts.

If post-closure care is considered to be, as the authors believe, important for minimizing environmental impacts and long-term legal liability, it is appropriate that the landfill approvals process provide that the methods for achieving these objectives are articulated and assessed. In that context the Ontario Engineered Facilities guideline is useful provided that it is used as a means of forcing consideration of this issue and not as a means of preventing approval of sites which make use of technology that has not existed for hundreds of years.

CONCLUDING COMMENTS

1. Prescriptive engineering design specifications have two primary, related benefits:

- for the regulator, minimizing the burden of approval by providing a process which essentially allows a "check list" comparison to be made between the proposed engineering design and the prescribed design requirements;

- for the proponent, facilitating the receipt of regulatory approval because the regulator can easily determine if the proponent's application complies with the prescriptive specifications.

However, there are also potential disadvantages of prescriptive engineering design specifications, which include:

- formula specifications may not be sufficient to assure minimization of environmental impacts and elimination of long-term legal liabilities, particularly in complex hydrogeological environments or environments which provide little natural hydrogeological protection;

- recognizing that prescriptive engineering design specifications cannot provide adequate environmental protection for all circumstances can result in undue emphasis (and perhaps unwarranted technological hope) being placed on post-construction monitoring and achievement of mitigation measures.

2. Prescriptive performance standards, which may be met by flexible engineering designs, have a number of benefits:

- Allowing landfill designers to bring "state-of-the-art" engineering concepts in designs to achieve these performance standards, which in turn will likely encourage both theoretical and practical research investigations and the application of evolving technology in the field.

- Puts emphasis on pre-approval design examination rather than on post-construction monitoring and mitigation or remedial measures.

- Will likely lead to more in-depth scrutiny by regulators and concerned members of the public as to the adequacy of the proposed designs prior to approval and a corollary review of the particular hydrogeologic environment in which the landfill would be sited.

Prescriptive performance standards also may have disadvantages:

- While encouraging innovative design and engineering they equally present an opportunity for considerable debate amongst regulators and more likely the public as to whether "state-of-the art" designs are practically proven or have a sufficiently reliable track record.

- In the absence of required outside peer review or public participation, under-staffed or underqualified regulatory agencies may tend to "rubber stamp" the sufficiency of proponents' applications which may only superficially address the performance design specifications.

Overall, the authors are of the view that despite the relatively greater uncertainty of obtaining an approval for a performance-based design or the complexity of the approvals process that may be associated with judging whether "state-of-the-art" designs are sufficient to meet performance standards, the benefits of tailoring the design to a particular hydrogeologic environment and demonstrating the likelihood of satisfactory site-specific performance, together with the benefits of encouraging research and development of innovative technology, are preferable to prescriptive engineering design specifications which can result in underestimating or ignoring potential environmental impacts and legal liabilities and placing unwarranted emphasis on post-construction remediation.

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