Session 6A
Municipal Solid Waste Landfills

TIPPING RATE ANALYSIS: COST AND DEVELOPMENT CONSIDERATIONS FOR SOLID WASTE LANDFILLS

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INTRODUCTION

Estimating the future tipping rate for a municipal solid waste (MSW) landfill is an important tool in evaluating economic feasibility and helping to make decisions on permitting strategies, development plans, and operational details. The importance of variables such as annual waste volume, in-place density, and permit design requirements can be evaluated using a sensitivity analysis. Whether a landfill is privately or publicly owned and operated, a tipping rate analysis can help evaluate the economic viability of new sites, major expansions, remediation and closure plans, or changes in operations.

This paper outlines some of the major considerations and provides typical cost ranges for major elements required in a tipping rate analysis. Examples of tipping rate sensitivity to variations in some of the critical parameters is presented at the end.

CASH FLOW

Cash flow is a significant consideration in establishing landfill tipping rates. Cash flow for a landfill project can be highly irregular and require large amounts of money in a short time, such as for new cell construction. Often a major hurdle for a new landfill is the initial investment required to construct the first cell. Once the first cell is constructed, revenues from the waste tipping fees are able to support sinking funds for future development, as well as service any debt incurred for the initial construction.

Sinking funds also need to be established for closure and post-closure, and could also be considered for environmental impairment insurance. Closure and post-closure funds are now becoming mandatory for municipal landfills with the new EPA Subtitle D regulations regarding financial assurance.

Care needs to be taken in planning funding requirements for landfill development. First, a reasonable and slightly conservative estimate of future cell development costs, closure costs, and post-closure costs should be made by a qualified solid waste engineer or other person with experience in landfill construction and knowledge of regulatory trends. Second, detailed planning of the cell and closure sequencing needs to be performed to provide a basis for the cost estimates, and for estimating the timing of the capital improvements. Third, the analysis parameters relating to the waste composition, in-place density, and volume need to be estimated as best as possible because these parameters have a strong impact on the tipping rate analysis. Some of these parameters are discussed in more detail below.

TYPICAL COSTS FOR MAJOR ELEMENTS OF LANDFILL DEVELOPMENT

Costs for major elements of a landfill depend on the site specific geometry and resources, and the size of the site which is usually related to the anticipated waste volumes. Major elements of landfill site development and typical cost ranges are discussed below. Cost ranges are presented in Table 1 for three typical size landfills; a "small" site receiving 30,000 tons per year (tpy), a "medium" site receiving 200,000 tpy, and a "large" site receiving 1,000,000 tpy. Certain cost items, such as siting, land use approval, and environmental mitigation are not included.

One-Time Startup Costs. These costs include several miscellaneous items needed to operate a landfill. A typical list of these items might include the following:

- leachate management facilities such as holding ponds, pipelines, treatment units, pumps, backup generators, and monitoring elements
- access and haul roads
- staging areas
- maintenance and administrative buildings
- utilities
- surface water management
- fencing and landscaping

Table 1

SITE PARAMETERS AND MAJOR COSTS FOR THREE LANDFILL SITES OF DIFFERENT SIZES

Site size	Small	Medium	Large
1,000 tons of waste per year	30	200	1,000
Site capacity (1,000 cy)	4,000	12,000	50,000
Site life (yrs)	93	42	35
Site area (ac)	50	100	350
Efficiency (cy/ac)	80	120	143
Avg cell size (ac)	4	10	20
No. of cells	12.5	10.0	17.5
Avg cell life (yr)	7.5	4.2	2.0
Liner cost, entire site ($1,000)	$15,000	$25,500	$84,000
($225,000 x no. of acres)+(no. of cells x $300,000)			
Liner cost/ac ($1,000)	$300	$255	$240
Cover cost, entire site ($1,000)	$7,000	$14,000	$49,000
(assume 10-acre increments)			
Cover cost/ac ($1,000)	$140	$140	$140
Post-clos $/yr	$54.5	$74.0	$143.5
Start-up cost ($1,000)	$800	$1,200	$2,900
(for ancillary facilities)			

MAJOR LANDFILL OPERATION AND DEVELOPMENT COSTS PER YEAR ($1,000's):

	Small	Medium	Large
OPERATIONS			
General & Admin	$100	$450	$1,000
Permits & fees	$19	$117	$580
Landfilling op.	$225	$540	$1,100
Equipment	$50	$225	$330
Monitoring	$60	$70	$80
Misc.	$5	$10	$20
Operations % of total	56%	55%	42%
ANNUALIZED ONE-TIME EXPENSES	$100	$150	$363
One-time expense % of total	12%	6%	5%
FUNDING			
New cells	$161	$607	$2,400
Closure	$75	$333	$1,400
Post-closure	$18	$53	$123
Funding % of total	31%	39%	53%
TOTAL ANNUAL COST	$813	$2,556	$7,396
COST PER TON FOR LIMITED ITEMS CONSIDERED ABOVE	$27.11	$12.78	$7.40

Notes:

1. Assumed in-place waste density: 0.7 tons/cy
2. Annual costs for one-time expenses, new cell fund, and closure fund are idealized as being uniform sinking funds evenly spread over the life of the landfill.
3. The costs listed above do not account for costs such as landfill siting, land use approvals, litigation, permitting, environmental mitigation, remediation, financing, profit, or the effects of large capital investments typically required in the early stages of a project.

Requirements for each of these items is site specific and depends on climate, geography, regulations, and remoteness to developed areas. It is therefore difficult to give a narrow-range cost estimate for this item. Costs can range from several hundred thousand dollars to several million dollars.

Cell Development. Landfills are typically developed in incremental phases called cells. Cell development costs include construction for the following items:

- earthwork for preparing the landfill subgrade
- installing any necessary hydraulic gradient (ground water) control systems
- installing a liner(s) and, if required, a leak detection system
- installing a leachate collection and removal system
- installing a protective soil layer upon which landfilling will begin
- constructing surface water control measures associated with each new cell

Variables in the costs include the amount of earthwork and regulatory design requirements for the liner system. The typical costs presented in Table 1 assume an average of 10 feet of excavation for the earthwork, and a single composite liner meeting the following requirements, from top to bottom:

- 1-foot soil operations layer
- geotextile or natural sand filter between operations layer and gravel layer
- 1-foot gravel leachate collection layer with embedded pipe network (geosynthetics can also potentially be used if properly designed)
- 60-mil high density polyethylene flexible membrane liner (FML)
- 2-foot low permeability soil layer ($k <= 1 \times 10^{-7}$ centimeters per second [cm/sec])
- prepared subgrade

Composite liner costs can vary depending on the available of suitable low permeability and granular soils. Assuming suitable liner soils are available on site, and granular material for the leachate collection system is available within a reasonable haul distance (less than 30 miles) the cost for a composite liner ranges from about $200,000 to $300,000 per acre. If liner soils need to be amended or imported from long distances the cost might increase an additional $50,000 per acre.

The cost is somewhat sensitive to the size of the project. For example, the cost stated above generally includes engineering and construction quality assurance. However, on small projects these costs would form a larger portion of the total than on large ones. Also, smaller projects require a proportionately greater amount of work on detailed perimeter terminations and tie-ins to previous cells than larger projects, which tends to increase unit costs. Some economy of scale is therefore realized for larger sites and contributes to the lower landfilling cost per cubic yard at these sites.

Closure. Subtitle D regulations require composite covers for most new landfills. A typical cover section, from top to bottom, would include the following elements:

- 1- to 2-foot topsoil layer
- geotextile filter
- granular or geosynthetic drainage layer
- FML
- 18-inch soil with maximum permeability of 1 x 10^{-5} cm/sec
- waste

Additional "biotic" and gas transmission layers are also sometimes considered. Another major consideration for a typical cover design is surface water control.

If on-site soils are available for the topsoil and low permeability soil, closure construction costs for the cover section described above generally range from $100,000 to $180,000 per acre, including surface water controls. As with bottom liners, a certain economy of scale is realized with larger closure construction projects than smaller ones. A well thought out closure sequencing plan should form the basis for a financial assurance closure fund as required by Subtitle D.

Landfill Gas. Air quality regulations, concern over the greenhouse effect, and public perception are all trending towards requiring landfill gas to be collected and incinerated. Collection systems are also required to control gas migration. Collection systems can be active or passive; the difference consisting of a blower creating suction on the collection piping. Methane gas produced in landfills is also collected at many sites and used to generate electricity. In some cases third parties interested in the gas as a resource completely relieve the landfill owner of gas collection costs and may even pay the owner a small royalty.

If resource recovery is not feasible then the landfill owner must pay for the gas collection and incineration system. Typically the collection system consists of vertical wells drilled into the waste, or horizontal trenches installed as the landfill is developed. Pipes coming from the wells or trenches are connected by a header pipe leading to a torch or a flare where the gas is incinerated. Although it is difficult to give a narrow-range cost estimate because of the number of variables in a gas system design, a typical active high efficiency flare system will cost on the order of $5,000 to $10,000 per acre. Landfill gas control costs are assumed to be included in closure costs in Table 1.

Landfill Operations. Landfill operations costs are defined here to include the following items:

- employee and management salaries and benefits
- equipment depreciation, maintenance, and fuel
- operation and maintenance of roads, leachate and gas controls, and surface water control systems
- ground water, surface water, soil, air, and any other required environmental monitoring
- annual permit and other fees
- general administrative costs

Depending on the nature and size of the operation, and its relation to other related company activities, operations costs at a particular landfill may vary significantly from "standard" estimates. Operations costs are a significant portion of the overall landfilling costs and comprise about half of the costs listed on Table 1. A large part of the difference between the landfilling costs per cubic yard for the different size landfills presented in Table 1 is the economy of scale realized in operations costs for larger projects.

Post Closure. Post closure monitoring and maintenance may occur for 30 or more years after the landfill is closed. These costs need to be funded as part of financial assurance planning required by Subtitle D.

Post closure costs to plan for include periodic site inspections, repair of eroded and settled areas, maintaining leachate and gas control facilities, and continuing environmental monitoring. Of these items, continued environmental monitoring is perhaps the largest cost item. Typical costs range from $50,000 to $150,000 per year. Some economy of scale is realized for larger landfills and thus reduces the landfilling cost per cubic yard for large sites as indicated in Table 1.

TIPPING RATE SENSITIVITY TO VARIOUS COST ELEMENTS

Given the high-risk nature of the landfill business owners should be aware of how sensitive their costs are to various parameters that affect the costs. While operational costs might be fairly predictable, especially if there is a track record, other costs, such as new cell development, can be affected by unpredictable influences such as a change in regulations. Changes in waste flow, such as banning or allowing of waste from outside jurisdictions, could have a significant impact on costs because of the loss or gain of economy of scale in the operations.

The following four parameters were selected to demonstrate tipping rate sensitivity to variations in the parameters:

1. Site capacity. For a site of a fixed footprint size, what would the impact on costs be if the site could hold 30 percent more waste? 30 percent less waste?
2. Waste compaction (in-place density). If the base case assumed an in-place waste density of 0.7 tons per cubic yard (ton/cy) (1,400 pounds per cubic yard [pcy]), what would the impact on costs be if the density were only 0.5 ton/cy (1,000 pcy)? 0.8 ton/cy (1,600 pcy)?
3. Liner design requirements. If the base case assumed a single composite liner is required, what would the impact on cost be if an additional FML and leak detection system is required? a double composite liner is required?
4. Waste flow. What would the impact on costs be if the site received 30 percent more waste per year? 30 percent less waste per year?

Using the parameters presented on Table 1 for typical small, medium, and large size landfills, each of the four parameters discussed above was varied and the effects on the landfilling costs were estimated. The results are presented in Table 2.

Site Capacity. The amount of waste a particular site can hold is largely determined by the existing site geometry. To some extent, it could also be determined by aesthetic restrictions.

Site capacity can be evaluated in terms of efficiency by looking at the ratio of the site volume to its area. The more waste a site can hold per unit area the lower the unit cost is for providing liners and covers. A change in efficiency of plus or minus 30 percent can be the difference between trying to build a landfill on a side slope or in a valley. Table 2 indicates that

Table 2

SENSITIVITY OF TIPPING COST TO VARIATIONS IN FOUR PARAMETERS

	SITE CAPACITY[3]		WASTE DENSITY (Base case 0.7 ton/cy)		BOTTOM LINER (Base case single composite)		WASTE FLOW	
Base Case cost per ton[1]	Increase by 30%	Decrease by 30%	0.5 ton/cy	0.8 ton/cy	composite plus FML w/leak detection	double composite liner	Increase by 30%	Decrease by 30%
Small Site $27.11	$25.16 -$1.95 (-7%)	$30.73 +$3.62 (+13%)	$30.45 +$3.34 (+12%)	$26.03 -$1.08 (-4%)	$28.45 +$1.34 (+5%)	$29.34 +$2.23 (+8%)	$23.62 -$3.49 (-13%)	$33.58 +$6.47 (+24%)
Medium Site $12.78	$11.64 -$1.14 (-9%)	$14.91 +2.13 (+17%)	$14.76 +$1.98 (+15%)	$12.16 -$0.62 (-5%)	$13.67 +$0.89 (+7%)	$14.27 +$1.49 (+12%)	$11.39 -$1.39 (-11%)	$15.37 +$2.59 (+20%)
Large Site $7.40	$6.49 -$0.91 (-12%)	$9.08 +$1.68 (+23%)	$8.96 +$1.56 (+21%)	$6.91 -$0.49 (-7%)	$8.15 +$0.75 (+10%)	$8.65 +$1.25 (+17%)	$6.82 -$0.58 (-8%)	$8.47 +$1.07 (+14%)

Notes:

(1) Base case cost parameters include only items defined in Table 1.
(2) Site specific conditions may cause an actual site to be more or less sensitive to certain parameters compared to the example given above. For example, if a site does not have a good source of low permeability soil, that site would have a higher sensitivity to double composite liner requirements.
(3) Increased or decreased site capacity relates to site efficiency; i.e. average number of cubic yards waste capacity per acre.

landfilling costs can be very sensitive to capacity efficiency (affecting costs by over 20 percent), and that costs at a larger site are more sensitive to capacity efficiency than smaller sites.

Larger sites tend to be more efficient than smaller sites because the dimensional relationship of volume to area is geometric rather than arithmetic. This is part of the reason for the large difference in unit costs for the three sizes of landfills presented in Table 1.

Waste Density. In-place waste density for MSW has a large influence on a tipping rate analysis. MSW density can range from less than 0.5 ton/cy (1,000 pcy) to over 0.8 ton/cy (1,600 pcy) depending on the climate, type of equipment, lift thickness, and number of passes. A reasonable and somewhat conservative estimate of the in-place density should be made for purposes of establishing the tipping rate. Table 2 suggests that landfilling costs could be nearly $4 per ton lower at a small facility if good compaction equipment and techniques are used rather than poorer methods. Even though the cost difference at a large landfill is less (about $2 per ton), the impact is greater because it is a greater percentage of the total unit cost.

There will be some trade offs in operational costs in achieving greater compaction densities. Heavier, more expensive equipment will be required and the waste will need to be compacted in thinner lifts with more passes of the equipment. The extra cost for proper equipment and good operational practices pays off in the long run.

Bottom Liner. Even though it is probably prudent to use the recommended Subtitle D standard liner design for estimating development costs, there may be instances where an even more stringent liner design is required. Table 2 presents cost impacts for the addition of an FML liner and a leak detection system (sand layer with collection pipe between the primary composite liner and the additional FML), and for a double composite liner system that would have leak detection capabilities between the two liners. The results suggest that these additional liner requirements could add $1 to $2 per ton to the tipping fee, or between about 5 and 20 percent of the costs listed in Table 1.

Waste Flow. Recent trends in regionalization have shown the benefits of combining waste flow to reduce tipping fees. The impact of waste flow on tipping fees is evidenced in Table 1 by the dramatic difference between costs for small, medium, and large landfills. Table 2 shows how each of these categories in turn would be affected by changes in the base flow quantity. The results suggest that small landfills would be most affected by changes in waste flow, with a swing in costs of up to $10 per ton between

30 percent more or less waste. A major industrial shutdown or strong recession could drastically impact tipping fees at a rural landfill, whereas a large regional landfill could buffer larger swings in volume.

CONCLUSIONS

A tipping rate analysis for landfills involves unique, complex issues. Special considerations should be given to the following areas:

- A detailed cash flow analysis is very important to setting tipping rates. The analysis should be performed considering initial funding, debt service, cell and closure sequencing, and funding for new cells, closures, and post closure.

- Waste flow projections need to be carefully evaluated and used conservatively in setting a tipping rate.

- Waste density is a controllable variable that has a significant impact on costs. There are well defined operational and equipment parameters that have been gained through experience in the industry to provide guidelines to operators.

- New landfill sites can vary widely in their site capacity efficiency. Optimum sequencing at a given site can also provide better efficiency and provide a more favorable cash flow.

- New and pending regulations should be considered to the best extent possible in forecasting design requirements used to estimate costs.

- Due to the high risks of the landfill business, owners should include contingencies in all cost estimates or provide for accelerated funding for development.