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ASSESSING THE TRUE COST OF LANDFILLS

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The most common means for disposing of municipal solid waste is burial in a sanitary landfill. However, many landfill owners significantly underestimate the total cost of landfill disposal by considering only land and operating costs, ignoring external physical and social costs associated with landfills. This paper proposes an approach to estimating (in monetary terms) the external costs arising from the development and operation of a landfill. All cost information is based on typical U.S. landfill cost structures. The approach is illustrated by applying it to a case study of a proposed landfill in Durham, North Carolina (U.S.A.). This case study demonstrates that the method can be applied easily and yields reasonable results.

Key Words—Refuse, landfilling, costs, U.S.A.

1. Introduction

Sanitary landfilling is currently the most common means of disposal for municipal solid waste (MSW) in the United States. When landfill costs are calculated, however, environmental and social costs are usually ignored (Dunbar & Berkman 1987, Gunnerson & Jones 1984). Ignoring such costs may underprice landfills, which in turn may inhibit the development of other waste management options, such as waste reduction, recycling and resource recovery. These options are frequently perceived as being more expensive than landfilling.

Little effort has been made to quantify the costs of the environmental and social impacts of landfills, and most published studies focus on only one of the many external costs. Perhaps the paucity of work in this area is a result of the subject's elusiveness; any generalized study of external costs will necessarily be inexact and lacking complete objectivity. Nonetheless, as Freeman (1979) notes, it is crucial to attempt to value externalities in real monetary terms, because economic analysis is usually the basis for evaluating activities which bear on the natural environment.

The objective of this paper was to propose an approach to evaluating monetarily the costs of externalities that are likely to arise from the use of MSW landfills. The *true cost* of a landfill is defined as the sum of these external costs plus standard landfill costs. The true cost thus represents the full economic cost borne by the host community as a result of a landfill's existence and usage.

Since most U.S. landfills are publicly owned, external landfill costs are herein evaluated from the perspective of the public landfill owner. The valuation techniques discussed, however, are equally applicable to privately owned landfills. In either case, the costs are ultimately borne (equitably or inequitably) by the landfill users.

The approach presented in this paper could improve the accuracy of landfill cost

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assessments. In turn, improved cost assessments may encourage improved environmental protection and energy conservation, partly due to the accelerated development of non-landfill waste management alternatives.

The next section describes the external impacts of landfills, separating them into physical and social impacts. Subsequently, an approach is proposed to evaluate the physical and social impacts of landfills, and to illustrate the application of this approach a case study is presented for a proposed landfill in Durham, North Carolina. Note that all cost information appearing in this paper is based on typical U.S. landfill cost structures.

2. External impacts of landfills

Landfills exert two types of external impacts on their surroundings, i.e. physical and social impacts. These impacts are described further.

2.1 Physical impacts

Physical impacts are those resulting directly from the products generated by the landfill. Contamination of groundwaters and surface waters by landfill leachate, migration and atmospheric release of landfill gases and fires are all physical impacts associated with landfills.

Leachate contamination of groundwater and surface waters is one of the gravest risks associated with landfill operation. Most new landfills are equipped with some type of leachate containment and/or collection system. However, these systems provide no guarantee that contamination of water resources will be avoided. As Robinson (1987) states, leachate problems persist despite "a plethora of advice and exhortation in recent years" on how to avoid them.

The difficulty in preventing leachate production stems from the impossibility of completely denying water access into the landfill. All solid waste placed in a landfill contains moisture. Several modes of failure exist for caps and final covers, the most common being erosion (Johnson 1986). Freeze–thaw and wet–dry cycles also encourage cracking of the cover and cap (Johnson 1986). When freezing conditions exist, cracks will propagate through frozen soil covers and exposed liners until tensile stresses caused by the freezing are relieved (Andersland & Al-Moussawi 1987). Subsidence and differential settling provide other mechanisms for failure, including collapsing of the cap into the void. Finally, objects which tend to "float" in landfills, such as tyres, can move upward until they breach the cap (Johnson 1986). Synthetic caps are also subject to accidental puncturing (Tchobanoglous *et al.* 1981). Both earth and synthetic liners tend to lose compressive strength and may succumb to environmental degradation (Wilson 1981).

Landfill gas, typically 45–55% methane and 40–50% carbon dioxide, represents a potential environmental hazard in many ways. In some incidences, methane migrating from landfills has caused explosions, resulting in loss of life and property. Both methane and carbon dioxide may cause damage to vegetation. In addition, landfills make a measurable contribution to atmospheric methane, which is a greenhouse gas (Augenstein 1990). Thus, it is argued that any release of methane from a landfill must be viewed as pollution, regardless of whether any terrestrial damage occurs.

Non-methane organic compounds (NMOCs) contained in landfill gas are also under scrutiny. Some of these compounds are regarded as toxic, and under certain conditions they may present a cancer risk to specific groups of individuals. Trace components in landfill gas, such as hydrogen sulfide and organosulfur compounds, can cause the unpleasant odours associated with landfills.

Landfill fires are not believed to arise spontaneously but may occur at any time during a landfill's active lifetime where operations are run improperly resulting in the placement of burning loads or from aerobic microbial reactions in buried waste. These both serve to elevate temperatures within the landfill (Wilson 1981). Fires can also occasionally erupt during gas abstraction (Emberton & Parker 1987) or from the sparking of landfill equipment (Knowles 1987). The use of daily cover may limit the undesirable impacts of landfill fires, unpleasant odors and visual affront.

2.2 Social impacts

Social impacts are those inflicted upon society by the landfill regardless of whether the landfill produces any physical impacts. Such impacts include increased traffic, visible air pollution, noise, aesthetic degradation and limited land utility.

Refuse collection and transfer vehicles increase the traffic on roads leading to the landfill. The increase becomes more pronounced on roads closer to the site. Affected roads may also become noisier and degrade more quickly once the traffic increases.

The construction and operation of landfills generates two types of air pollution not discussed previously: (1) exhaust, from both equipment at the landfill and vehicles delivering waste, and (2) fugitive dust from the site, resulting from both equipment operation and wind erosion of cover material. Dust, particularly respirable quartz, has been identified as a hazard at landfill sites (Mozzon *et al.* 1987).

Noise at landfills can be noticeable in nearby residential areas. The USEPA (1975) notes that excessive noise can have many undesirable effects on those exposed to it. In most cases, however, the noise is simply regarded as an annoyance.

Increased traffic, localized air and noise pollution and land clearing all contribute to a reduction in aesthetic quality for properties near a landfill. In addition, the littering of roads leading to the landfill is a serious social concern in many communities.

In general, a landfill's presence affects the present and future uses of both the landfill site and surrounding land. After closure, a landfill may continue to settle for several years and will require continued aftercare. Settlement may prevent the construction of any substantial structures on the site for many years.

Emberton & Parker (1987) cite other problems associated with building on landfills, including the migration and odor of landfill gas and the chemically aggressive nature of the waste on which a structure would be built. For these reasons, landfills are often restored into parkland or other "passive" public facilities after closure. While these facilities are generally viewed as assets by a community, the landfill's existence pre-empts, at least temporarily, the community's full range of development options for the land.

It is also likely that a landfill will impact upon the use of surrounding land. An example of this component of the land utility impact is provided by the well publicized Love Canal incident in Niagara Falls, New York. Hazardous waste which had been buried in the canal leached into nearby soil, forcing residents whose homes were built near the canal to relocate. After the soil contamination occurred, the abandoned properties in Love Canal had no value. The impact would have been lessened (but nonetheless real) if the contamination somehow had rendered the land useful for e.g. agriculture, but not for human habitation.

3. Proposed approach to evaluating the external impacts of landfills

3.1 Physical impacts

Consider a rectangular hole in the ground, perhaps 100 feet (30 m) long by 50 feet (15 m) wide by 50 feet (15 m) deep, which exists to provide for the ultimate disposal of clean, uncontaminated glass bottles. The hole is filled 30 feet (9 m) deep with the bottles, and then covered with 20 feet (6 m) of cover dirt and soil.

The costs associated with this "landfill" might include: engineering fees, excavation costs, machinery rental or purchase and wages. Due to the nature of the material being buried, no preventive devices such as liners or leachate collection systems need be installed (ignoring the dictates of existing regulations).

One must consider whether, after closure, this landfill might impart any physical impacts on the surrounding environment. The argument that it would not is quite defensible, because glass is regarded as inert and non-degradable. This argument, then, suggests that the physical impacts associated with the landfill arise not from the existence of the landfill itself, but from products of the landfill's operation which escape from its boundaries.

This argument is applied to the computation of physical impact costs. Ideally, physical impacts on the surrounding environment could be eliminated by sealing the entire landfill structure with a perfectly impermeable material. Such a seal is, in reality, non-existent. Even if it were, its cost might be prohibitive. Hence, the costs of the physical impacts are evaluated as the costs of the best reasonable technologies available for containing, collecting and treating the potential pollutants. The word "reasonable" is used to suggest that a boundary exists beyond which reasonable people would agree that the marginal preventative cost does not justify the resultant increase in environmental protection. For instance, the state of New York currently requires double composite liners, and several other states appear to be moving towards the same requirement; but, there seems to be general agreement that additional composite liners add little additional environmental protection and are unnecessary. In this paper, the phrase "best reasonable technology" specifically refers to the most effective control technology which is currently required by at least one state.

Costs evaluated in this way do not reflect the total physical external costs, because no existing systems are capable of perfectly containing and collecting all of the leachate or methane that a landfill produces. One advantage to this approach, however, is that it circumvents the difficulty of predicting the magnitude of the physical impacts of leachate and methane. The costs to the environment, which are difficult to quantify monetarily, are calculated using costs for existing environmental control systems.

3.2 Social impacts

The social impacts cost has three components. They are: (1) the cumulative decrease of surrounding property values; (2) the cost associated with land utility effects, also known as an "opportunity cost"; and (3) a "hastening cost".

3.2.1 Surrounding property depreciation

It may be assumed that the impact of a landfill on surrounding property values reflects the local effects of altered traffic patterns, air pollution, visual unattractiveness and noise pollution (USEPA 1975). Thus, if property values prior to the landfill's existence are well known, the cumulative dollar value of most landfill social impacts (i.e. traffic, air, noise, aesthetics) may be found by measuring the decreases in property values.

To obtain an estimate of the potential effect of a landfill on adjacent property values, a survey was conducted on eight professional real estate appraisers and agents who were provided a map of a hypothetical town, in which a landfill was placed among several neighbourhoods with homes of pre-determined value. The map is shown in Fig. 1. The details of the survey used in this portion of the study can be found elsewhere (Hirshfeld 1989). The series of graphs shown in Fig. 2(a–f) relate distance from the outer boundary of a landfill and residential property values, based on the responses of the real estate professionals.

The scenario presented to the respondents was necessarily simplified; a rigorous analysis of the many factors contributing to a property's worth would be prohibitively time consuming and is beyond the scope of the study undertaken. Therefore, in the survey such considerations as predominant wind direction and relative locations of other amenities and disamenities besides the landfill were ignored. Furthermore, as the EPA

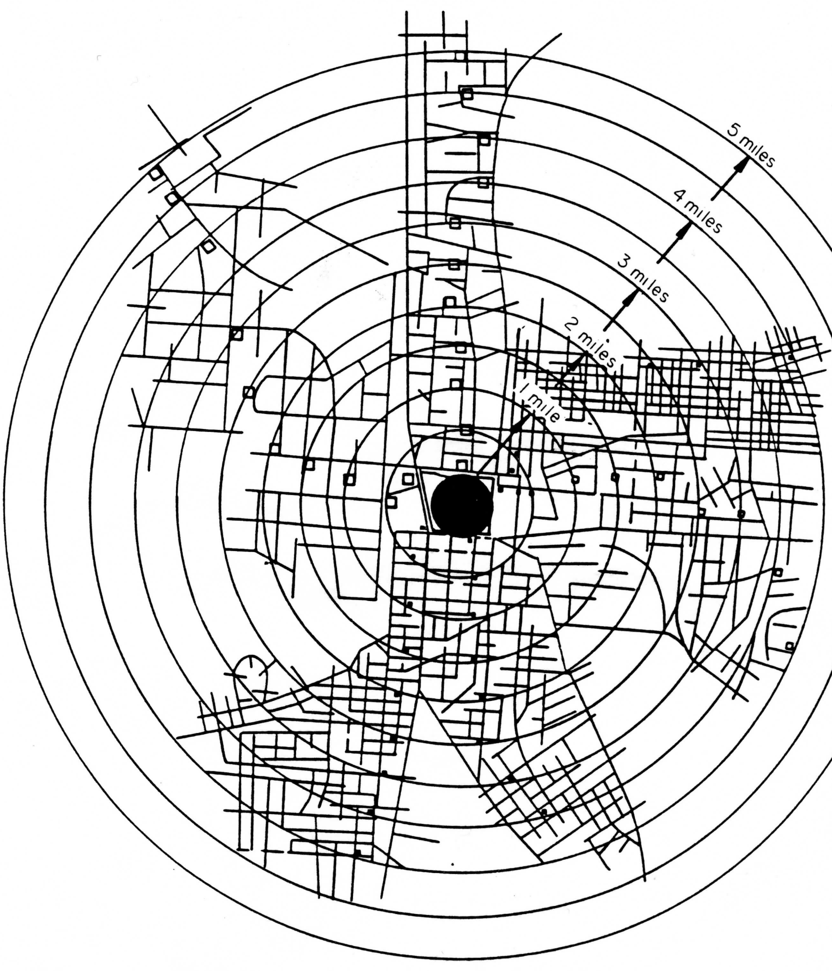
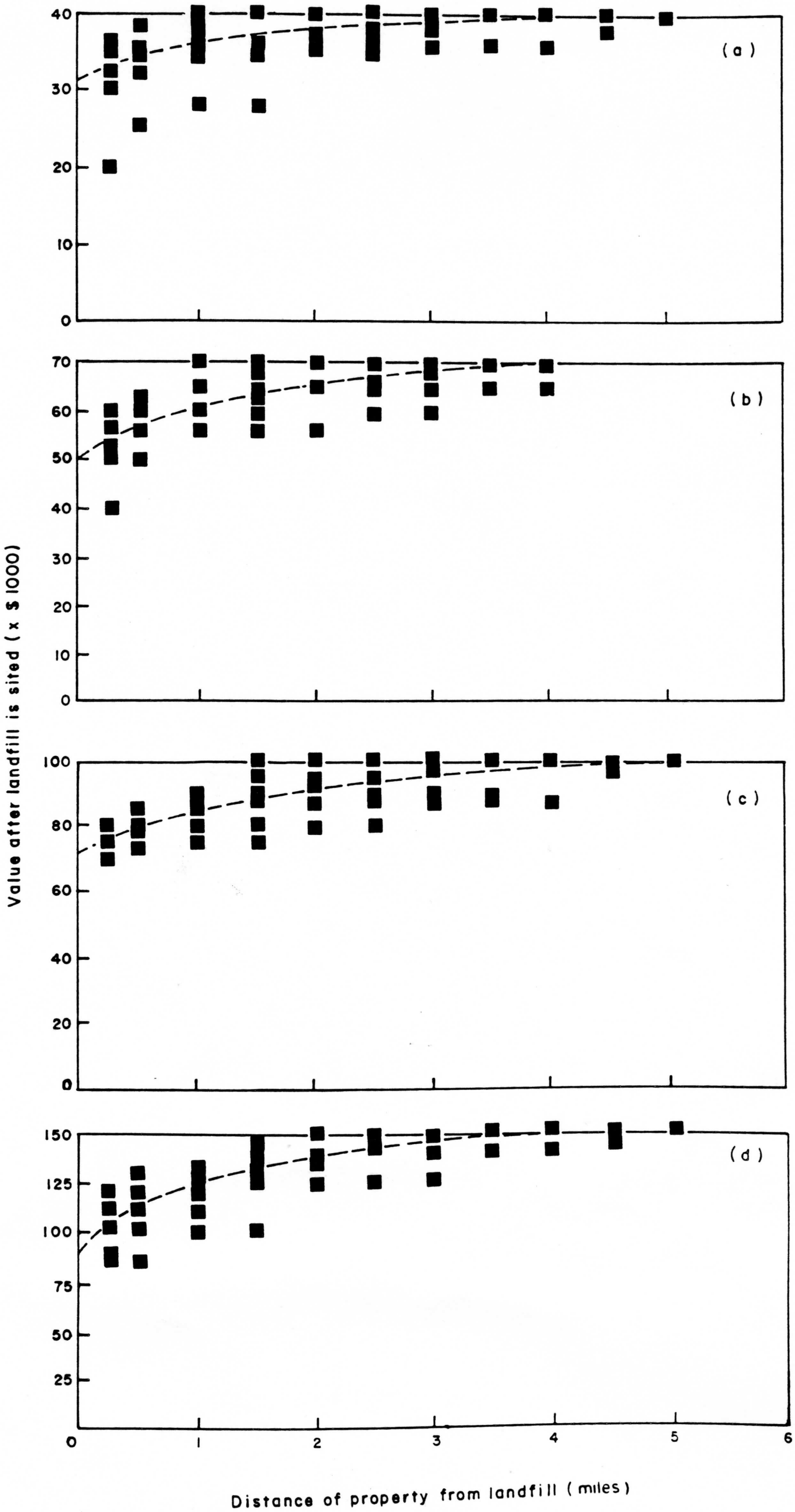


Fig. 1. Map of a hypothetical town with the landfill at the centre. ❑ = Homes.


(a)
(b)
(c)
(d)
Value after landfill is sited (x $ 1000)
Distance of property from landfill (miles)

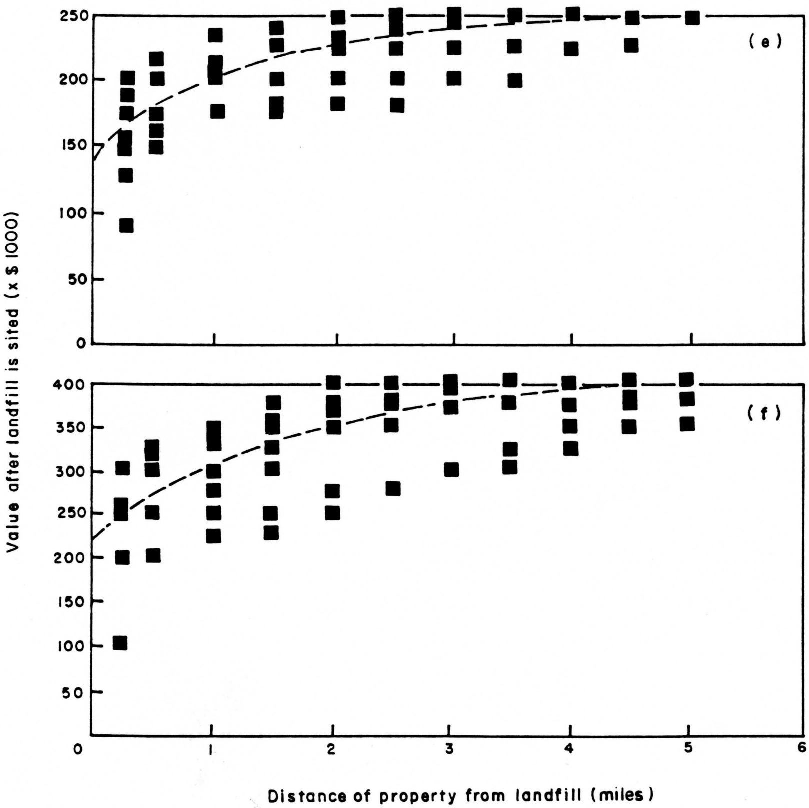


Fig. 2. Property values *vs.* distance from landfill. Original values: (a) $40,000; (b) $70,000; (c) $100,000; (d) $150,000; (e) $250,000; (f) $400,000. Note: 1 mile ≈ 1.6 km.

(1975) suggests, due to the uniqueness of each property and the dynamic nature of property values, the results of a similar study, using real data, cannot be applied confidently to areas other than those from which the data were obtained.

This survey, however, provides a general methodology by which these costs can be approximated. Furthermore, the trends reflected in Fig. 2 argue strongly that property values are affected by their proximity to a new landfill. Specifically:

- Properties closer to a landfill lose more value than properties further away from it.
- The amount of property depreciation decreases with distance from the landfill.
- At a given distance from a landfill up to 2 miles (3.2 km), more valuable properties lose a greater percentage of their worth than do less valuable ones.
- Landfills can depress the values of properties up to 3 miles (4.8 km) away.

These observations suggest that a landfill is likely to inflict the greatest cumulative property depreciation in high density urban areas, where property values are high and distances between adjacent properties are small.

In Fig. 2(a–f), a graph curve has been drawn through the data points. The resultant set of curves can be used to approximate impacts for a range of property values and locations. For instance, a residence in a neighbourhood of $400,000 homes, located 0.5 miles (0.8 km) from a landfill site, is worth approximately $275,000 after the landfill is in place. A $150,000 home at a distance of 1.25 miles (2 km) from a landfill decreases in value to $130,000 after the landfill is built.

Our results differ from several previous studies which have focused on rates of property appreciation (Gamble *et al.* 1982, Anon. 1983, Pettit & Johnson 1987, Price 1988). Most of these studies suggest that properties developed near a landfill have comparable rates of appreciation to those for similar properties far from the landfill. However, Price found that in some cases properties near landfills appreciate more slowly and in these instances more expensive homes are impacted to a greater degree than less expensive ones.

Our study differs from the above studies in two respects. First, it focuses on actual property values not rates of appreciation. Second, it assumes that a landfill is to be situated near an established neighbourhood and the loss in property value is then directly felt by the owners at the time the landfill is sited. Our scenario no doubt causes greater community reaction and loss of property values, and it is less realistic than allowing development to occur around a landfill. Our results may therefore be considered the "worst case" in the loss of property values.

The depreciation curves describe the losses experienced by homeowners who live near a landfill. Depreciations experienced by property owners could be alleviated by governmental compensation. Various compensation strategies are considered by Lang (1990), Zeiss & Atwater (1987) and O'Hare (1977).

3.2.2 Land opportunity cost

An opportunity cost is the value of goods or services foregone by the production of some other goods or services with the same resources (Atkinson 1982). Thus, any reduction in property value caused by a landfill's presence is an opportunity cost. The land utility effects discussed above may be represented by opportunity costs.

The landfill opportunity cost has two components: (1) that of the landfill site itself; and (2) that of any surrounding area whose future use is somehow affected by the presence of the landfill (Dunbar & Berkman 1987, USEPA 1975).

Publicly owned landfills sit on publicly owned (i.e. government owned) land. Typically, a government must either purchase or condemn (and then purchase) the land on which it builds a landfill. Once the government owns the property, no property taxes are collected on it for its entire duration under public ownership. Thus, the first component of the landfill's opportunity cost is the sum of the annual property tax revenues that the government will fail to collect for the land as long as it is publicly owned. Considering the typical reuse options available for landfill sites, this period could be 50 years or more.

Evaluating the site opportunity cost in this way provides only its lower bound. This approach assumes that, were the property not used for a landfill, it would remain undeveloped. However, if the property were developed, its value would increase, increasing the tax revenue that the government would receive.

This approach therefore also neglects the potential secondary revenue which might be generated by any such structures. An example of secondary revenue is the sales tax that would result from patronage of stores built on the land parcel in question.

The cost of surrounding areas may be evaluated similarly to the site opportunity cost, as the property tax lost due to property depreciation caused by the landfill's presence. If a property worth $200,000 *a priori* is devalued to $100,000 by a nearby landfill, the landfill causes the state and local governments to lose property tax revenue on $100,000 worth of property. This cost will persist as long as property values are adversely affected by the landfill's presence.

3.2.3 Hastening cost

In addition to property depreciation and land opportunity costs, a landfill imparts a hastening cost on its owner, because each ton of waste deposited in the landfill hastens the moment at which a new landfill must be opened. Landfill space, like gold or salt, is a commodity with limited availability. The hastening cost is defined as the interest that could be earned on the initial investment required for a replacement facility, over the period by which disposal of the current ton of waste hastens that investment. While the hastening cost concept is useful, the cost itself is usually negligible.

3.2.4 Allocation of social costs

The proper allocation of social costs is not obvious. Some costs associated with landfills are borne by the governmental body owning the landfill, and thus are borne (it is hoped equitably) by all citizens within that community. These costs must be paid by the citizens in the form of taxes or fees. The reduction of taxable land values results in a cost to the community, because it must increase other sources of revenue to compensate for those lost taxes.

On the other hand, the loss of property values is borne directly by the property owners affected and is not shared equally by all of the citizens of that community. Likewise, opportunity costs must be borne by the property owners, although tax revenues will of course also be reduced if a lower level of development occurs. It may be reasonable to redirect property value losses and opportunity costs to the entire community, because everyone uses the landfill.

4. Case study

The above methodology is applied to a proposed MSW landfill for the city of Durham, North Carolina (see appendix 1). This future landfill would be located on a 750 acre (304 ha) site, 200 acres (81 ha) of which would be actual fill area. With an average depth of 50 feet (15 m) and typical compaction, landfill capacity would be about 6.5 million tons (5.9 million tonnes). Preliminary plans call for this landfill to have a single composite liner, a leachate collection system and a gas collection system. Leachate will not be pretreated on-site, and it is assumed that no provisions for off-site leachate treatment are figured into the tipping fee. An initial estimate of the tipping fee is $32.00 per ton ($35.20 per tonne). The tipping fee is calculated by the City and is intended to reflect the costs of land, construction, operation, closure and post-closure activities.

The proportions of tipping fees generally attributable to leachate control and gas control (as one cost item) and to associated environmental monitoring have been reported by Glebs (1988) and SWANA (1989) as 31 and 3%, respectively. Applying these numbers to the estimated tipping fee, expected leachate and gas control costs would be about $10 per ton, and monitoring costs would be about $1 per ton. We assume that, as is typically the case, surrounding property depreciation, opportunity costs and hastening costs are not included in the tipping fee. Note that the above percentages correspond to leachate control, gas control and environmental monitoring over a landfill's lifetime.

TABLE 1
Case study cost estimates

Tipping fee	$32.00/ton
Leachate, gas and monitoring costs	$22.00/ton
Property depreciation	$ 1.10/ton
Opportunity cost, landfill site	$10.90/ton
Opportunity cost, adjacent properties	$ 0.40/ton
Total	$66.40/ton ($73.00/tonne)

Applying our methodology to the future landfill yields the cost estimates shown in Table 1. Our calculations indicate that the largest component of the external cost is the physical cost of leachate generation. For other landfills, the relative magnitudes of the different external cost components may vary and the total external costs almost surely will.

The sum of the external costs is significant compared to the tipping fee, and particularly significant compared to the estimated leachate and gas control cost ($10/ton). This suggests that the tipping fee does not reflect the landfill's true cost. According to Table 1, the tipping fee for the new Durham landfill should be about $66 per ton. This fee would more accurately and equitably cover the true cost of the landfill described in this study.

4. Conclusion

Although landfilling is a well established waste disposal method, many municipalities (and other landfill owners) significantly underestimate their landfill costs. This is primarily a result of failure to place reasonable costs on the physical and social impacts associated with landfills.

Physical impacts result from the natural generation of products, particularly leachate and landfill gas, which have the potential to cause environmental damage. Social impacts are a consequence of the landfill's existence. The important social impacts are adjacent property depreciation (which reflects the adverse effects of noise pollution, air pollution, visual unattractiveness and increased traffic to and from the landfill) and land opportunity costs. The opportunity cost has two components, one relating to the landfill site and the other to surrounding properties.

Losses in property values typically are borne unfairly by residents living close to new landfills. In fact, public opposition to the siting of new landfills is due largely to anticipated losses in property values. Given the typical strength of such opposition, and the equal utility that a municipal landfill provides for all users, regardless of proximity to the landfill, it seems reasonable that the community consider compensating property owners living near a proposed landfill site.

Although it is difficult to assess a landfill's true cost accurately, an effort must be made to do so. This paper offers one approach for making such assessments and demonstrates that its application can yield reasonable results. For use in a practical evaluation of waste management options, the true cost of a landfill should be compared to those of other waste treatment options. True costs for each alternative waste management option should be determined using an analogous approach.

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Appendix 1

Assumptions and calculations for case study

Basic data and assumptions

• Total land area	750 acres (304 ha)
• Fill area	200 acres (81 ha)
• Average depth	50 feet (15 m)
• Landfill assumed to have square area	
• Assumed volume of cover	20% of total volume
• Assumed in-place refuse density	1000 lb/yd^3 (590 kg/m^3)
• Land cost	\$10,000/acre (\$24,700/ha)
• Average annual rainfall in Durham, NC	40 inches (102 cm)
• Leachate/precipitation ratio (once field capacity is reached)	0.4
• The landfill has reached field capacity	
• Twenty years after closure, leachate generation is negligible	
• Rate of filling	750 tons/day (682 t/day)
• Period for which landfill property will be publicly owned after closure	60 years
• Real annual appreciation of land (excluding inflation)	4%
• Annual property tax rate	\$1.50 per \$100 of assessed value (a.v.)
• Typical value of residences within 3 miles of the landfill	\$70,000
• Property value depreciations end when landfill is closed	

Unit costs

• Clay liner (assuming 2 ft depth)	\$4.00/yd^3 (\$5.23/m^3)
• Synthetic liner	\$0.01/mil-ft^2 (\$0.11/mil-m^2)
• Geotextile	\$0.15/yd^2 (\$0.16/m^2)
• Drainage net	\$0.25/yd^2 (\$0.27/m^2)
• Lift station	\$30,000 each
• Leachate storage tank	\$30,000 each
• On-site leachate pretreatment facility, capital	\$150,000 each
• On-site leachate pretreatment facility, operations	\$0.005/gal (\$0.001/l)
• Leachate hauling and treatment	\$0.03/gal (\$0.008/l)

Basic calculations

• Landfill volume (200 ac) × (43,560 ft^2) × (50 ft) × (yd^3/27 ft^3)	16,133,330 yd^3 (12,334,890 m^3)

- Usable landfill volume — 12,906,660 yd^3 (9,867,910 m^3)
  (16,133,330 yd^3) × (0.80)
- Final landfill tonnage — 6,453,330 ton (5,866,660 t)
  (12,906,660 yd^3) × (1000 lb/yd^3) × (ton/2000 lb)
- Total land cost — $7,500,000
  (750 ac) × ($10,000/ac)
- Length of landfill side — 2,952 ft (890 m)
  $[(200 \text{ ac}) \times (43{,}560 \text{ ft}^2/\text{ac})]^{1/2}$
- Landfill surface area — 9,302,400 ft^2 (864,220 m^2)
  [(200 ac) × (43,560 ft^2)] + 4 × [(50 ft) × (2952 ft)]
- Landfill lifetime — 23 years
  (12,906,660 yd^3) × (1000 lb/yd^3) × (ton/2000 lb)
  × (day/750 ton) × (year/365 day)
- Annual leachate generation — 86,887,680 gal/yr (329,304,310 l/yr)
  [(40 in/yr) × (ft/12 in)] × [(200 ac) × (43,560 ft^2/ac)]
  × (0.4) × (7.48 gal/ft^3)

Leachate costs

Because the study landfill will have one composite liner, leachate cost calculations include the cost of one additional composite liner.

- Clay liner (1) — $2,756,270
  ($4.00/$yd^3$) × (9,302,400 ft^2) × (2 ft) × (yd^3/27 ft^3)
- Synthetic liner (1) — $6,511,680
  ($0.01/mil-$ft^2$) × (70 mil) × (9,302,400 ft^2)
- Geotextile (1 layer) — $155,040
  ($0.15/$yd^2$) × ($yd^2$/9 ft^2) × (9,302,400 ft^2)
- Drainage net (1 layer) — $2,325,600
  ($0.25/$ft^2$) × (9,302,400 ft^2)
- Lift station — $30,000
- On-site treatment facility
  - Capital — $150,000
  - O & M — $18,680,850
  (86,887,680 gal/yr) × ($0.005/gal) × (43 yr)
- Leachate hauling and treatment — $112,085,100
  (86,887,680 gal/yr) × ($0.03/gal) × (43 yr)

Total — $142,694,540

Total per ton — $21.95/ton ($24.15/t)
($142,724,540)/(6,453,330 ton)

Landfill gas costs

Because the landfill will have gas control equipment, there is no physical cost related to landfill gas generation.

Total — $0

Property depreciation
Residences about the proposed landfill site are distributed as follows:

	Distance from site boundary (miles)		
Relative location	Within 0.25	0.25–0.5	0.5–3
West	99	55	1
South	17	12	15
East	54	127	83
North	5	6	46
Totals	175	200	145

Property depreciations are obtained by referring to Fig. 2(b). A $70,000 home that is within 0.25 mile of a landfill boundary depreciates, on average, by $18,000. A home between 0.25–0.5 miles from the landfill depreciates by $15,000. A home between 0.5–3 miles from the landfill depreciates by about $7,000.

Total $7,165,000
[(175 homes) × ($18,000/home)] + [(200 homes) × ($15,000/home)] + [(145 homes) × ($7,000/home)]

Total per ton $1.11/ton ($1.22/t)
($7,165,000)/(6,453,330 ton)

Opportunity cost for landfill site
Site opportunity cost is dependent on rate of appreciation; for instance, if 0% real appreciation were assumed, the opportunity cost would be $1.45/ton ($1.60/t). In this case, as noted above, a real appreciation rate of 4% is assumed.

Total $70,109,690
($10,000/ac) × [$\Sigma^{n=0,82}$ $(1.04)^n$] × ($1.50/$100 a.v./yr) × (750 ac)

Total per ton $10.86/ton ($11.95/t)
($70,109,690)/(6,453,330 ton)

Opportunity cost for adjacent properties
Total $2,471,925
($7,165,000) × ($1.50/$100 a.v./yr) × (23 yr)

Total per ton $0.38/ton ($0.42/t)
($2,471,925)/(6,453,330 ton)