Composition and Characteristics of Excavated Materials from a New Jersey Landfill

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Abstract: The composition of material excavated from the Burlington County landfill in New Jersey was determined, and the major reclaimed fractions characterized. Based on a waste age map, 98 samples (80 kg each) collected from 13 gas extraction well borings were handsorted into 14 fractions and fines (<2.54 cm) that fell through the screen were collected. At least 50%, by weight, of the material was fines. The most abundant oversize materials (overs) fractions, by weight, were miscellaneous items, wood, other plastics [not polyethylene terephthalate or high density polyethylene containers], and paper. Less paper was found in the oldest (7.5–11.5 years) section of the landfill ($P < 0.10$), most likely due to microbial degradation. Several of the characteristics of the materials excavated from the landfill, such as temperature, particle size, bulk density, volatile solids, and contamination were correlated with the age of the deposits made. High levels of adherent soil will likely prove to be an insurmountable obstacle to recycling most excavated waste fractions other than fines unless further processing is pursued.

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Introduction

In 2000, the United States generated 232 million metric t of municipal solid waste (MSW); of this 55% was landfilled, 30% was recovered for recycling or composting, and 15% was combusted (USEPA 2002). However, the 1991 amendment of the Subtitle D landfill regulations of the Resource Conservation and Recovery Act has forced many landfills to close (from ~8,000 in 1988 to ~2,150 in 2000) (Goldstein and Madtes 2001). Public opposition has also made siting of new landfills a complex issue, forcing many states and municipalities to face difficult decisions on how to dispose of their MSW. As a result, MSW is in some cases transported long distances to mega landfills in less populated areas. Furthermore, finding ways to maximize existing landfill space, such as leachate recirculation to increase the degradation of organic matter in the landfill and/or landfill reclamation, has become a high priority for some landfill owners, landfill operators, and municipalities. This is especially true in the northeastern United States, where the population density is considerably higher than in most of the rest of the country.

Landfill reclamation is the excavation and processing of previously landfilled wastes for recovery of selected recyclable, reusable, or combustible fractions, site remediation, and/or the reduction of postclosure costs. Knowledge of the composition and characteristics of the excavated material is needed to determine the technical and economical feasibility of landfill reclamation. While there have been several landfill mining projects conducted in the United States, formal waste characterization studies of reclaimed materials are scarce and a statistical analysis of the data is even more infrequent (Krogmann et al. 2003). The objective of this study was to determine the composition of excavated waste from Landfill Number 1 at the Burlington County Resource Recovery Complex (BCRRC) in New Jersey, which was operated from 1989 until 1999, and to characterize major reclaimed fractions. The focus of the waste characterization was on parameters which would give an indication of the environmental conditions in the landfill, the degree of degradation, and the qualities of the reclaimed fractions that are important for the selection and design of reuse, recycling, treatment, and disposal options. The effect of age of the excavated material was evaluated, since it was expected that over the lifetime of the landfill both increasing recycling rates (decreased glass, ferrous metals, and nonferrous metals in more recently landfilled waste) and degradation (decreased food and yard waste and paper in older waste) in the landfill affected the waste composition and characteristics.

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Materials and Methods

Site Description

The studied landfill at the BCRRC covers 22 ha and has a maximum height of 40 m. At the time of this study (August 2000), 10 ha of the landfill were capped with a landfill cover consisting of a composite barrier layer (0.305 m compacted clay layer with a hydraulic conductivity of 10^{-6} cm/s and 1 mm linear low-density polyethylene geomembrane). The landfill received MSW from residential, commercial, and industrial sources within the county

Table 1. Number of Handsorted and Screened Samples

Sample type	Sample mass (kg)	Number of samples at age A (February 1989–March 1993)	B (April 1993–March 1997)	C (April 1997–November 1999)	Unknown	Total
Handsorted	80	18	24	50	6	98
Screened	1,400	3	8	7	0	18

from February 1989 to November 1999. During data analysis, the landfill age was divided in three periods: Age A, February 1989–March 1993; Age B, April 1993–March 1997; and Age C, April 1997–November 1999. During the active phase of the landfill, over 3.8 million metric t of waste were landfilled (35% residential, 25% mixed loads, 16% construction and demolition, 10% other, 8% commercial/institutional, and 5% dry industrial) in lifts ($\leqslant$3.7 m) separated by 15 cm layers of compacted cover soil. The cover soil consisted of a fine drainage sand (hydraulic conductivity: 10^{-3} cm/s) from 1989 to the spring of 1995, a mixture of fine drainage sand and wood chips from the spring of 1995 until July 1999, and a mixture of fine drainage sand, wood chips, and crushed glass from July 1999 until landfill closure. The average density of material (MSW plus cover soil) within the landfill was approximately 1,150 kg/m^3 at the time of excavation based on mass of incoming waste and cover soil and landfill volume determined by topographic surveys.

Composition of Excavated Waste

To determine the composition of the excavated material, representative samples (about 80 kg) were handsorted into major fractions. Also, larger samples (1,400 kg) were screened into a fines and an overs fraction (>2.54 cm) to confirm the amount of fines determined during handsorting.

For the handsorting, samples were taken during the installation of 24 gas extraction wells in the uncapped portion of the landfill and two replacement gas extraction wells in the capped portion of the landfill. Gas extraction wells were drilled by a 0.91 m diameter bucket auger. Based on a waste age map of the landfill, 13 borings were selected for sampling in an attempt to best represent all ages of waste deposited in the landfill. From these borings, 49 samples were taken (one sample every 6.1 m, except for the two borings in the capped portion of the landfill, where a sample was taken every 3.05 m). The content of an entire bucket was collected as a sample to prevent sampling bias associated with worker avoidance of a particular object based on hazard, size, or unknown classification. The samples were immediately wrapped in a polyethylene tarp and transported to the covered sorting area.

Handsorting of samples was conducted from August 21 to September 1, 2000, using two sorting tables (2.4 m long, 1.2 m wide, 0.3 m deep); a screen with openings of 2.54 cm acted as the work surface. Age of the waste was estimated by newspaper dates and dated mail. Each of the 49 samples was split into two subsamples before handsorting to increase the sample number (each subsample approximately 80 kg). During the statistical analysis of the data, the two subsamples were treated as replicates within each of the 49 samples. Thus, a total of 98 samples were handsorted (Table 1). Each sample was sorted into 14 fractions: paper, cardboard, food and yard waste, polyethylene terephthalate (PETE) and high density polyethylene (HDPE) containers, other plastics, glass, ferrous metals, aluminum, other nonferrous metals, textiles/rubber/leather, wood, stone/brick/concrete, miscellaneous items, and hazardous items. In addition, fines that fell through the screen were collected.

Two scales (Ohaus Corp., Florham Park, N.J.; capacities 30±0.02 kg and 100±0.005 kg) were used for weighing containers and sorted fractions. Waste fractions stored for further analysis were transferred to dry containers, which were kept tightly sealed.

The selection of borings and depths to collect the larger samples (whole 3.05 m increment equaling approximately 8–9 buckets; average mass of 1,400 kg) attempted, as the samples for handsorting, to best represent all ages of waste in the landfill. A total of 18 large samples were screened from eight borings (Table 1). After collection, the samples were stockpiled on the landfill and covered with polyethylene tarps to reduce moisture loss. In October 2000, the stockpiled samples were screened with a vibrating deck screen (1.8 m × 4.9 m, Construction & Industrial Equipment Co., Lodi, N.J.). Both the fines (<2.54 cm) passing through the screen openings and the overs were weighed at the landfill's truck scale.

Physical and Chemical Characteristics of Excavated Waste

Every 3.05 m in all 26 gas extraction well borings, the drilling crew measured the temperature in the excavated material immediately after bringing the waste to the surface.

After handsorting, subsamples of the separated fractions were taken from 8 of the 13 sampled borings to determine selected physical and chemical characteristics of the excavated waste fractions. The handsorted waste samples were stored for up to 10 days in sealed containers on-site. For large quantity fractions (paper, other plastics, textiles/rubber/leather, wood, miscellaneous items, and fines), a total of approximately 25 samples from different aged sections and different depths were analyzed, while for the small quantity fractions, such as PETE and HDPE containers, glass, aluminum, and other nonferrous metals, the sample number depended on the availability of sampling material.

The handsorted subsamples were placed on a dry polyethylene tarp, mixed thoroughly, coned, and then divided into five portions of approximately equal volume. Portions were assigned to a particular analysis on a random basis (two for duplicate particle size analysis, two for duplicate bulk density analysis, one for further laboratory analysis such as moisture content). Duplicates for particle size and bulk density could not be taken for all samples, especially for small quantity fractions. The samples for further analysis were taken to the laboratory at the end of each working day and stored at 4°C until further analyzed.

Particle size of the handsorted overs fractions was determined on-site by screening each subsample in a handheld stack of screens (0.76 m × 0.76 m × 0.15 m screen with 15, 10, and 2.54 cm openings and a bottom tray for collection of fines). Bulk density of the handsorted overs fractions and the fines fraction

Table 2. Fines in Handsorted and Screened Samples (% by Weight, Wet Basis)

Sample type	Age A (February 1989–March 1993)	Age B (April 1993–March 1997)	Age C (April 1997–November 1999)
Screened	52 *a*	52 *a*	50 *a*
Sorted	58 *a*	50 *a*	52 *a*

Note: Means within columns followed by the same letter are not significantly different ($P<0.05$)

was determined on-site using a modified method of that described by Stessel (1996). A tared, 38-l Nalgene® container holding a subsample was lifted five times, 0.3 m above the floor, and dropped on a concrete floor. Mass and volume were recorded.

Grain size analysis of the fines fraction was conducted in the laboratory using a modified version of ASTM Standard *D 422-63* (ASTM 1999d). A 1.0 kg dry sample was placed in a mechanical shaker (W.S. Tyler Inc., Gastonia, N.C.). Two screen sizes (2.0 and 0.075 mm) were selected based on New Jersey's regulatory requirements (*N.J.A.C. 7:26-2A.8(b)18*). Additional screen sizes were chosen on the premise of having them evenly distributed in a log-scale grain size distribution. Nonsoil materials such as plastic and paper flakes and broken glass generally did not pass the 2 mm sieve. The analysis was conducted in duplicate.

Moisture content of the handsorted overs fraction and the fines fraction was determined in triplicate using a modified version of ASTM Standard *D 2216-98* (ASTM 1999c). Each sample (approximately 0.5–1.0 kg) was placed in a forced-air drying oven at $105\pm3°C$ until constant mass was achieved. To determine volatile solids, nongrindable fractions were removed (metals, plastics, glass, textiles/rubber/leather, and stone/brick/concrete). The nongrindable fraction (dry weight) accounted for about 15% of the paper, cardboard, and wood fractions, about 7% of the food and yard waste fraction, and 20% of the fines fraction. Then, 3 g dried, ground (<0.25 mm, Retsch, Inc. SM-100 hammer mill, Haan, Del.) samples were placed in a muffle furnace set at 550°C for a period of 4 h. This analysis was conducted in triplicate.

For subsamples of the paper, cardboard, food and yard waste, wood, and other plastics fractions carbon, hydrogen, nitrogen (*D-5291*, ASTM 1999b), sulfur (*D-4239*, ASTM 1999e), and ash (*E-830*, ASTM 1999a) were determined by PSC Analytical Services (Reading, Pa.). The percent oxygen was determined by calculation. Nongrindable materials were removed from the biodegradable fractions. The results were used to determine the higher heating value (HHV) using the modified Dulong formula described by Tchobanoglous et al. (1993).

To determine the degree of contamination of waste fractions by adhering particles, a contamination analysis was conducted. After moisture analysis of the degradable fractions such as paper, cardboard, and wood, solid contaminants were removed from the sample by hand, weighed, and then returned to the sample prior to further analysis. Nondegradable fractions, such as glass, plastic, and aluminum were washed to remove adhering soil and food particles. After washing, samples were oven dried at $105\pm3°C$ to constant weight.

Immediately after screening the 18 larger samples (Table 1), 24 grab samples of fines (each ~1.36 kg) were taken from stockpiles of Age A fines, Age B fines, and Age C fines. The screening was conducted about eight weeks after the drilling of the gas extraction wells. Therefore, some changes of the samples might have occurred. However, it was assumed that a storage period of screened material is typical for an excavation operation, and sampling at this point was still valid. For each age section, the grab samples were mixed and duplicate samples were sent to PSC Analytical Services to be analyzed for 109 parameters listed under the New Jersey Department of Environmental Protection's (NJDEP) Residential Direct Contact Soil Cleanup Criteria (RDCSCC). The following chemical analyses were conducted on fines samples according to United States Environmental Protection Agency (USEPA) *SW-846* methods for evaluating solid waste: volatiles (*8260B*), semivolatiles (*8270C*), pesticides/polychlorinated biphenyls (PCBs) (*8081/8082*), total cyanide (*9012M*), phenolics (*9065*), inorganic trace elements, except chromium and mercury (*6010*), hexavalent chromium (*3060/7161*), and mercury (*7471*) (USEPA 1994).

Statistical Analysis

Due to the heterogeneity of solid waste, composition data are not normally distributed and tend to be positively skewed (Carruth and Klee 1969; Tchobanoglous et al. 1993). Therefore, the composition data were transformed by the following arcsine transformation which stabilizes the variance and improves the symmetry of the data (Carruth and Klee 1969):

$$y = 2\ \text{arcsine}(x)^{1/2}$$

where x = measured waste composition fraction and y = transformed value of x.

Transformed data outside a range of the mean ±3 SD were identified as potential extreme outliers (Kitchens 1998). Six extreme outliers were found. However, since these values might be correct values, only two values were excluded as extreme outliers from the determination of the waste composition. These samples contained an unrepresentative (large) amount of stones, and were the only extreme outliers that considerably changed the composition of the excavated material. Transformed waste composition data were analyzed using the analysis of variance methods of Statistical Analysis System software (SAS Institute, Cary, N.C.) and Tukey's honestly significantly different (HSD) test was used for age separation ($P<0.10$).

Descriptive statistics of the selected physical and chemical waste characteristics include median, interquartile range, and range. In cases where the data were normally distributed the mean was also provided. Selected characteristics were analyzed using analysis of variance, *t*-test, and single linear correlation procedures. For these analyses, bulk density data were log transformed and particle size data arcsine transformed to normalize the data.

Results and Discussion

Composition of Excavated Waste

The fines fraction was the largest fraction of the excavated material in all three age categories (Table 2). Both handsorting of the 80 kg samples and screening of the 1,400 kg samples resulted in

Table 3. Mean Composition of Overs (% by Weight, Wet Basis).

Fraction	Landfill Number 1, Burlington County, N.J.[a] Age A (February 1989–March 1993)	Age B (April 1993–March 1997)	Age C (April 1997–November 1999)	Sandtown, Del.[b]	Edinburg, N.Y.[c]
Paper	11.3 *b*	14.3*ab*	20.8 *a*	43.6	19.4
Cardboard	5.3 *a*	6.5 *a*	5.3 *a*		
Food and yard waste	2.4 *a*	2.9 *a*	2.6 *a*	—[d]	0.0
Polyethylene terephthalate and high density polyethylene containers	0.4 *a*	0.5 *a*	0.7 *a*	13.3	20.0
Other plastics	18.2 *a*	18.0 *a*	15.2 *a*		
Glass	1.0 *a*	0.4 *b*	0.6*ab*	0.4	8.4
Ferrous metals	6.8 *a*	7.2 *a*	5.5 *a*		16.1
Aluminum	0.5 *b*	0.6*ab*	0.9 *a*	7.8	
Other nonferrous metals	0.4 *a*	0.1 *a*	0.4 *a*		—[d]
Textiles/Rubber/Leather	6.4 *a*	10.6 *a*	8.4 *a*	7.6	13.5
Wood	17.5*ab*	26.7 *a*	17.3 *b*	8.3	4.5
Stone/Brick/Concrete	4.3 *a*	2.4 *a*	3.8 *a*		9.0
Hazardous items	0.1 *a*	0.3 *a*	0.2 *a*	19.0	—[d]
Miscellaneous items	25.5 *a*	9.5 *b*	18.3*ab*		9.0

[a]Statistical significance was tested using an arcsine transformation but reported means are of untransformed data. Means within rows followed by the same letter are not significantly different ($P<0.10$).

[b]Average for Sandtown, Del., bioreactor landfill; 2–10 year old waste; 2.54 cm screen openings (Miller et al. 1991).

[c]Edinburg, N.Y.; 11–13 year old waste; 1.27 cm screen openings, oversized items (~ 1.5% of total excavated material) excluded (Salerni 1992).

[d]Not determined.

at least 50% fines, by weight. Similar amounts of fines have been found in other U.S. landfill reclamation projects: Sandtown, Del.: 45.9%, bioreactor landfill, 2–10 year old waste, 2.54 cm screen openings (Miller et al. 1991); Lancaster Co., Pa.: 41%, 1–5 year old waste, 2.54 cm openings, no final cover (Forster 1994); Collier Co., Fla.: 59.1%, 10–15 year old waste, 1.91 cm openings, no final cover (von Stein et al. 1993).

The largest fractions of the overs found during this study were miscellaneous items, wood, other plastics, and paper (Table 3). All fractions except wood were found within the range of values determined in other U.S. landfill reclamation projects, where handsorting studies were conducted (Table 3). The elevated proportion of wood in the overs of Ages B and C can be at least partially attributed to the use of wood chips in the daily cover from the spring of 1995 until landfill closure. However, there must have been more wood deposited in the studied landfill than in other landfills because Age A excavated waste, where no wood chips were used, also contained more wood than found in other landfills. Furthermore, the amount of wood in this study is comparable to the percentage of wood in raw MSW found in New Jersey as discussed below.

Generally in landfills, the food and yard waste, cardboard, and paper fractions are considered biodegradable (Eleazer et al. 1997). The only significant differences over time for these biodegradable fractions was found for paper ($P<0.10$, Table 3). Differences between the proportion of the paper fraction from Ages C and A are most likely due to the gradual degradation of paper in the landfill.

The difference in the wood percentage between Ages B and C can be partially attributed to the greater degree of degradation of paper ($P<0.10$, Table 3). However, this cannot explain the degree of difference between Ages B and C excavated waste. There were two samples with higher percentages of wood in Age B excavated waste that are mainly responsible for this difference.

A decreased percentage of recyclables (glass, ferrous metal, aluminum, PETE and HDPE containers) in the younger excavated waste was only found for glass. A significantly greater proportion of glass was determined from Age A excavated waste as compared to Age B excavated waste ($P<0.10$). This finding is supported by Burlington County's historical recycling data (Robert Simkins, personal communication January 25, 2002), which shows that the amount of glass recycled increased approximately 50% from 1989 to 1992. A significantly greater percentage of aluminum was found in Age C excavated waste than in Age A excavated waste ($P<0.10$). This is contrary to Burlington County's historical recycling data (Robert Simkins, personal communication January 25, 2002) that indicate that the tonnage of aluminum cans recycled increased by over 100% between 1989 and 1999. However, during the sorting study it was observed that aluminum cans from older parts of the landfill were physically broken down into smaller flaky objects. These cans were very difficult to identify and it is likely that a greater percentage of the aluminum fraction from the older sections of the landfill fell through the screen as fines.

The significantly higher amount of the Age A miscellaneous fraction compared to the Age B fraction is mostly due to the nature of the material excavated from the oldest sections of the landfill ($P<0.10$). These samples were visually more degraded, and thus harder to identify as belonging to other categories, than samples from more recently filled sections.

Another way to evaluate if degradation occurred in the landfill is to compare the composition of the excavated waste with the composition of the waste deposited in the landfill. However, to compare the composition of excavated material with raw MSW, the "as excavated" data need to be adjusted to account for moisture and contamination from solids, including attached soil and mis-sorted items. Mis-sorting of waste fractions was only a considerable source of error for the paper and cardboard fractions due to the similarities in color and texture between kraft paper, boxboard, and cardboard.

Table 4. Mean Composition of Excavated Overs, Adjusted for Moisture and Solid Contamination (% by Weight).

	Reclaimed MSW Landfill Number 1, Burlington County, N.J.[a]			Raw MSW	
Fraction	Age A February 1989–March 1993	Age B April 1993–March 1997	Age C April 1997–November 1999	Averages for N.J.[b]	Marion Co., Fla.[c]
Paper	6.9	9.8	13.7	22.6(23.6)	24.5
Cardboard	1.6	3.1	3.6	4.1(4.2)	9.1
Food and yard waste	4.1	5.8	4.3	18.6(17.0)	14.8
PETE and HDPE containers	0.3	0.6	0.9	1.7(1.8)	2.1
Other plastics	13.2	11.1	13.3	7.2(8.5)	10.7
Glass	1.8	0.7	0.9	2.8(2.6)	4.7
Ferrous metals	8.3	11.4	7.5	3.0(2.9)	5.4
Aluminum	0.2	0.3	0.7	0.2(0.5)	0.7
Other nonferrous metals	0.5	0.1	0.4	0.8(0.5)	0.5
Textiles/Rubber/Leather	5.2	11.3	9.1	—[d]	5.4
Wood	13.7	26.5	15.5	13.5(12.9)	7.1
Stone/Brick/Concrete	7.2	4.6	6.1	5.5(5.0)	3.1
Hazardous items	0.1	0.5	0.3	—[d]	0.8
Miscellaneous items	37.0	14.3	23.9	20.1(20.7)	11.2

Note: MSW = municipal solid waste; PETE = polyethylene terephthalate; and HDPE = high density polyethylene.

[a]These data were adjusted for moisture and solid contamination (see "Materials and Methods" section). Since no moisture content of the hazardous items could be determined, a moisture content of 10% was assumed for the adjustment of the data. Due to the high inherent moisture content of the food and yard waste fraction, moisture was not considered contamination for this fraction. Since the miscellaneous items fraction was comprised of a wide array of objects and materials, no solid contamination was assumed. Assumptions for solid contamination for which actual values were not determined: 5% for the food and yard waste and stone/brick/concrete fractions; 10% for the hazardous items fractions.

[b]Estimates based on data from all 21 N.J. counties (NJDEP 1993); adjusted for moisture and solid contamination based on data determined by Sfeir et al. (1999). Data in parentheses are the unadjusted data. Note that adjusted and unadjusted data differ by no more than 1.6%.

[c]Average for Marion Co., Fla. (Sfeir et al. 1999); adjusted for moisture and solid contamination.

[d]Not determined.

Compared to raw MSW (after recycling), less paper, cardboard, and food and yard waste were found in the excavated overs fraction (Table 4). Although small amounts of paper, cardboard, and food and yard waste were found in the fines fraction, it is likely that the reduction of these fractions can be attributed to degradation in the landfill. Nonbiodegradable fractions, such as textiles/rubber/leather, ferrous metals, and other plastics, had slightly greater percentage values in the excavated waste from this study than those given in selected raw MSW compositional studies. A likely reason is that as the relative proportions of readily degradable organics (such as paper, cardboard, and food and yard waste) declined due to degradation, the proportion of nonbiodegradable fractions relative to the overall composition of the waste increased. Wood was slightly more abundant (except for Age B, where it was much more abundant, mainly due to two samples with higher percentages of wood as discussed above) in the excavated material in this study, as compared to raw MSW (Table 4). This is most likely due to reasons similar to those given above for the nonbiodegradable fractions. Materials with a high lignin content, such as wood and newsprint, have been shown to degrade very slowly under anaerobic conditions due to the physical association between lignin and cellulose, which extensively limits the amount of cellulose available to microbial degradation (Cummings and Stewart 1994; Stinson and Ham 1995; Clarkson and Xiao 2000). Lastly, more miscellaneous items were found in waste excavated during this study as compared to raw MSW. This was expected, since compaction and expansion of solid waste components, solids contamination, and degradation make excavated material more difficult to sort and characterize than fresh MSW.

Physical and Chemical Characteristics

There are numerous physical and chemical characteristics of the excavated waste that are of interest for the design of a landfill reclamation project. Due to time and financial constraints, the number of characteristics and the number of samples analyzed had to be limited. The selected characteristics include those that give an indication of the environmental conditions in the landfill (temperature and moisture), the degree of degradation in the landfill (volatile solids), and the quality of fines and overs, which is important for the consideration of reuse, recycling, treatment, and disposal (contamination of overs, bulk density, particle size distribution of overs, HHV, grain size of fines, and metals and synthetic organics in fines).

Temperature

Temperatures in active landfills are usually higher than ambient temperatures due to the heat generated by biological degradation of solid waste and the relatively low heat loss because of the insulating properties of the waste, cover materials, and subsoil. Most physical, chemical, and microbial processes taking place in the landfill are affected by temperature, such as solubility of waste materials and metabolites, emissions of volatile substances, and pressure conditions in the landfill.

The temperature of the excavated waste in this study varied from 22.2°C for a sample at a depth of 3.1 m to 68.3°C for a sample at a depth of 27.4 m. The temperatures increased approximately 1°C/m of depth (Fig. 1), and are of the same order of magnitude as values found in the literature (Attal et al. 1992; Gurijala and Sulfita 1993; Zornberg et al. 1999). The waste exca-

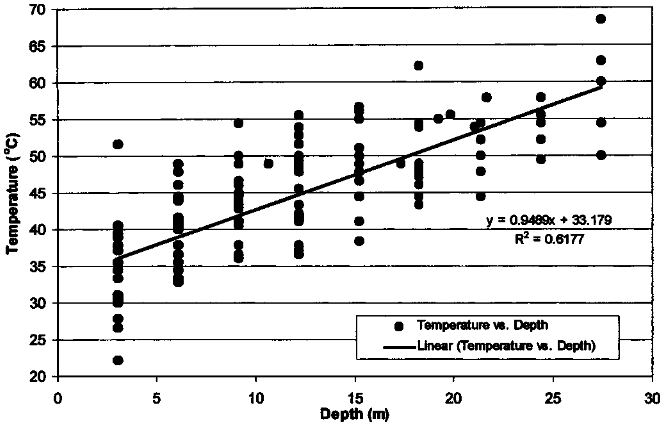

Fig. 1. Temperatures in landfill depending on depth

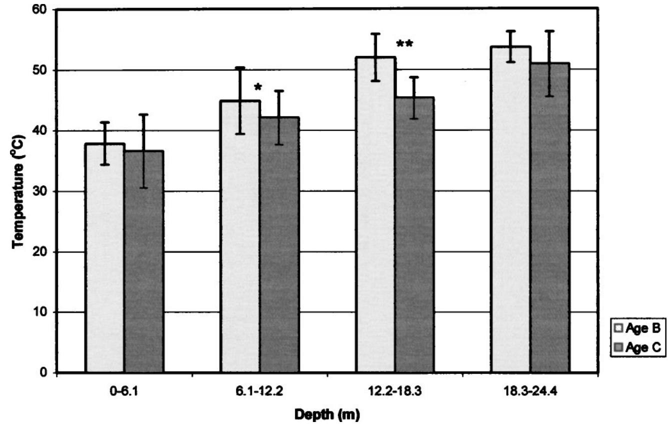

Fig. 2. Temperatures in landfill at Ages B and C

vations in this study did not reach a depth in the landfill where the heat loss to the subsoil decreased the temperatures, as found by Zanetti et al. (1997) and Attal et al. (1992), and as modeled by El-Fadel (1991).

Age B excavated waste had a higher mean temperature than Age C excavated waste over all depth intervals investigated (Fig. 2). This finding may be due to the fact that Age C excavated waste was more recently landfilled and as a result may not have reached the same level of overall degradation, and thus heat generation, as Age B excavated waste. There were not enough data points to evaluate the effect of age for Age A excavated waste.

Moisture Content

Moisture content is an important characteristic that determines the environmental conditions in the landfill and also plays a role when considering further processing of the excavated waste, such as biological or thermal treatment. Moisture content in landfills depends on several interrelated factors, including waste composition, waste type, waste properties, local climatic conditions, landfill operation procedures, gas and leachate collection, and water generation and consumption due to biological processes (Qian et al. 2002).

The mean moisture content of the excavated waste in this study was 28.3%, by weight, with moisture contents of individual excavated samples ranging from 18.8 to 41.6%. The mean moisture content of excavated waste determined in this project is similar to values previously reported in the literature for excavated waste of similar age for nonbioreactor landfills: 35.3% (Ham et al. 1993), 23.9% (Zanetti et al. 1997), 21.9% (Zornberg et al. 1999), 24% (Bäumler et al. 2001).

As expected, waste fractions that can absorb moisture such as paper, cardboard, food and yard waste, wood, textiles, and fines had much higher moisture contents than the fractions that cannot absorb water (Table 5). Except for the food and yard waste fraction, the mean moisture content of individual excavated waste fractions was considerably higher than those presented by Tchobanoglous et al. (1993) for MSW components prior to disposal. This suggests that most landfilled materials absorbed substantial quantities of water from precipitation and from materials, such as food and yard wastes, which tend to have a higher moisture content at the time of disposal than found after excavation.

For optimum biological activity in the landfill, moisture contents of 40–70% are recommended (Barlaz et al. 1990). The moisture content of the biodegradable fractions (Table 5) indicates that

Table 5. Moisture Content of Sorted Fractions (% by Weight, Wet Basis).

Fraction	Number of samples	Mean	Median	Range	Interquartile range	Raw municipal solid waste[a]
Paper	23	44.9	46.2	30.8–53.7	40.7–48.2	6
Cardboard	22	42.8	44.0	26.9–53.4	37.8–47.1	5
Food and yard waste	20	41.7	44.1	18.2–65.4	37.7–48.5	70
Polyethylene terephtalate and high density polyethylene content	16	9.6	11.2	1.3–21.4	2.0–13.2	—[c]
Other plastics	22	21.8	20.8	8.6–36.7	17.2–29.5	2
Glass	18	0.4	0.2	0.0–1.5	0.2–0.5	2
Ferrous metals	20	4.4	2.0	1.0–15.7	1.6–4.4	3
Aluminum	17	14.0	15.2	3.9–31.2	7.9–17.1	2
Text./Rubber/Leather	22	29.9	29.4	9.6–51.7	23.1–35.1	2-10[b]
Wood	23	39.6	41.4	21.3–51.5	35.0–46.8	20
Stone/Brick/Concrete	19	3.8	2.6	1.1–8.2	1.4–4.5	—[c]
Miscellaneous items	23	24.7	23.4	13.6–42.2	19.3–28.6	—[c]
Fines	24	27.2	25.8	16.0–43.0	22.2–32.9	—[c]

[a]Typical value for residential MSW, adapted from Tchobanoglous et al. (1993).

[b]Textiles, leather: 10%, rubber: 2%.

[c]Not determined.

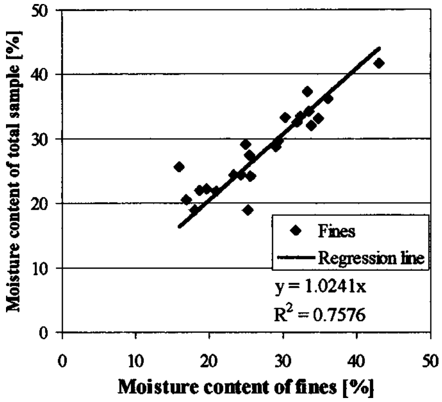

Fig. 3. Relationship between moisture content of fines fraction and total sample

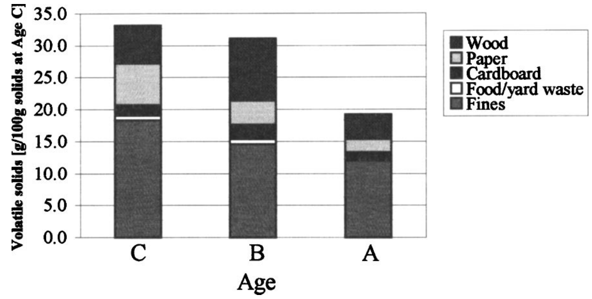

Fig. 4. Volatile solids mass of sample at various ages that consisted of 100 kg dry solids at Age C

they were at the lower end of this optimum range. The effect of capping the landfill on the moisture content of various fractions was evaluated, but none was found.

The moisture content of the excavated waste samples in this study could be predicted by the moisture content of the fines fraction (Fig. 3). The moisture content of the fines and the moisture content of samples containing all fractions were almost equal. Considering the heterogeneity of the excavated waste, the R^2 of 76% indicates a good correlation. Since representative fines samples are easier to collect than representative waste samples containing all fractions, fines samples might in the future be used to predict the moisture content in samples containing all fractions.

There is conflicting information in the literature concerning the correlation between moisture content and depth (Gabr and Valero 1995, Zornberg et al. 1999). In this study, when all data were included no correlation between moisture content and depth in the landfill was found. However, if wastes from individual gas extraction well borings were considered, the moisture content in samples from some gas extraction wells increased with depth while from others it did not.

Volatile Solids

The volatile solids (VS) content of the cardboard and food and yard waste fractions decreased with the age of the waste ($P < 0.10$, Table 6). These differences can most likely be attributed to increased amounts of adherent soil in the older excavated wastes. Although statistically not significant, a similar trend was found for the paper, wood, and fines fractions. For the fines, this trend likely represents biodegradation of the organic (measured as volatile solids) fraction.

Organic matter is one of the waste properties that might influence the field capacity (to hold water) of waste (Zornberg et al. 1999) and therefore higher moisture contents would be expected with an increase in organic matter. In this study, no correlation was found between moisture content and organic matter measured as VS except for the fines fraction ($R^2 = 0.50$).

Over the lifetime of a landfill, due to degradation of organic matter (measured as volatile solids), dry mass of waste deposited in a landfill is reduced. For Landfill Number 1, dry mass of waste decreases from Age C to Age B and Age A. To determine this reduction, the mass of VS was calculated for 100 kg of dry mass at Age C based on the composition, moisture, and VS data of this study. Then, the mass of volatile solids of these 100 kg of dry mass at Age C were calculated at Age B and Age A based on the composition, moisture, and VS data for waste at Age B and A. The calculation was made with the assumption that only the fines, food and yard waste, cardboard, paper, and wood fractions contributed to the volatile solids mass and that only these fractions degraded over time (other material masses were conserved). This assumption is on the conservative side since the differences would be even larger if the remaining fractions would also be reduced.

This calculation showed that the initial mass of volatile solids in all fractions decreased over time, although to various degrees (Fig. 4). While the 100 kg sample contained 33.1 kg volatile solids at Age C, only 19.2 kg volatile solids were left in the sample at Age A. This indicates that 13.9 kg of volatile solids in the 100 kg sample degraded over the time from Age C to A. The percentage of the volatile solids reduction from Age C to A was 35% for fines, 53% for food and yard waste, 42% for cardboard, 68% for paper, and 34% for wood. However, possibly part of the calculated degradation can be attributed to a higher contamination level of the older waste, and therefore more organic matter being

Table 6. Volatile Solids Content of Selected Excavated Waste Fractions (% by Weight, Dry Basis)

	Age		
Fraction	A: February 1989–March 1993	B: April 1993–March 1997	C: April 1997–November 1999
Paper	68.5 *a*	67.8 *a*	80.9 *a*
Cardboard	64.2 *a*	83.1 *b*	85.8 *b*
Food and yard waste	42.8 *a*	71.3 *b*	71.5 *b*
Wood	76.9 *a*	85.5 *a*	81.3 *a*
Fines	24.4 *a*	30.8 *a*	35.0 *a*

Note: Statistical significance was tested using an arcsine transformation but reported means are means of untransformed data. Means within rows followed by the same letter are not significantly different ($P < 0.10$).

Table 7. Contamination (Adhering Solids, Mis-Sorted Items, and Moisture) of Excavated Overs (% by Weight, Wet Basis)

	Age			
Fraction	A	B	C	Sfeir et al. (1999)
Paper	67.4 *a*	66.8 *a*	62.5 *a*	16.5
Cardboard	84.1 *a*	76.6*ab*	62.0 *b*	10.5
Polyethylene terephtalate and high density polyethylene containers	57.3 *a*	46.8*ab*	30.9 *b*	12.8
Other plastics	60.8*ab*	70.3 *a*	50.2 *b*	22.7
Glass	8.1 *a*	19.4 *a*	10.6 *a*	2.7
Ferrous metals	33.7 *a*	23.9 *a*	22.2 *a*	9.7
Aluminum	76.3 *a*	80.3 *a*	57.4 *b*	10.6
Textiles/Rubber/Leather	55.9 *a*	48.9 *a*	38.5 *a*	19.2
Wood	57.8 *a*	52.2 *a*	49.0 *a*	4.0

Note: Means within rows followed by the same letter are not significantly different ($P < 0.10$).

attached to the other waste fractions. This is supported by the finding of increasing contamination levels with age (see below).

Volatile solids determination, although not a measure of available organic matter, is a relatively simple and inexpensive way to assess the potential degradability of waste excavated from a landfill. However, in future studies, it would be desirable to determine another parameter that better characterizes the degradable portion in the excavated waste. No parameter of this sort has gained universal acceptance, but various methods including biochemical (Stinson and Ham 1995; Fricke et al. 2002), gravimetric (Müller et al. 1998), chemolytic (Pichler and Kögel-Knabner 2000), and solid-state 13C nuclear magnetic resonance spectroscopic methods (Pichler et al. 2000; Bäumler et al. 2001) are in use and/or in development.

Contamination of Overs

If moisture, adhering solids, and mis-sorted items are taken into account, considerably less materials are recovered from the excavated waste than the composition of the excavated waste (Table 3) indicates. The level of contamination of the overs (moisture, adhering solids, and mis-sorted items) also helps to determine their recycling potential, since contamination affects the degree to which the recyclables can be marketed. The highest contamination levels, over 60–80%, were found for the paper, cardboard, other plastics, and aluminum fractions. These levels of contamination exceed contamination levels found for raw MSW (Sfeir et al. 1999). However, it should be noted that in this study a considerable portion of the contamination of the paper and cardboard fractions was caused by mis-sorted items. About 5% of the paper and about 15% of the cardboard fraction in this study was due to the inclusion of kraft paper in the cardboard samples and cardboard in the paper samples.

There was also increasing contamination found for the cardboard, PETE and HDPE containers, other plastics, and aluminum fractions with time in the landfill (Table 7). This may be due to the fact that many older excavated materials were more degraded and/or deteriorated, making separation more difficult.

Bulk Density

Bulk density of excavated waste is important for the design of systems for its transportation, treatment, recycling, reuse, and disposal. There is very limited information available in the literature concerning the bulk density of materials excavated from landfills, but the results from this study (Table 8) are similar for most fractions to values found for excavated waste from the Town of Moriah landfill in New York (Reis 1995). An exception is the glass fraction, whose bulk density was approximately 2.9 times greater in this study than determined for excavated waste from the Town of Moriah landfill, and about 3.4 times greater than found in raw MSW (Tchobanoglous et al. 1993). A possible explanation is that in this study mainly very small glass shards were found.

The bulk density of the fines fraction in this study ranged between 370 and 1,206 kg/m^3 with a median of 742 kg/m^3. This value is considerably lower than the range of values determined in previous landfill reclamation studies (Forster 1994; Reis 1995). Possible explanations for this discrepancy include the method of separation of fines and overs, the method of determining bulk density, and the original cover soil composition. The waste characterization results of this study were based on analyses of hand-sorted samples, as compared to other cited studies, which analyzed screened excavated material. Thus, a greater proportion of low-density materials was probably present in the fines fraction of this study because of the increased contact time with the screen. Each of the other cited studies measured the bulk density of fines by weighing "filled" rolloff containers of known volume where a higher compaction can be expected. Lastly, cover soil in this study contained wood chips starting in 1995, which might have also resulted in a lower bulk density of the fines fraction.

Several fractions showed increasing bulk density with age (Table 8). Most likely this can be attributed to increased contamination of older material (Table 7) as well as increased degradation

Table 8. Bulk Density of Selected Fractions (kg/m^3)

	Age			
Fraction	A	B	C	Moriah, N.Y.[a]
Paper	424*a*	320*ab*	297*b*	303
Cardboard	409*a*	225 *b*	219*b*	—[b]
Other plastics	177*a*	153*ab*	79*b*	159
Textiles/Rubber/Leather	293*a*	275*ab*	202*b*	392
Wood	324*a*	344 *a*	266*a*	303
Fines	893*a*	776*ab*	651*b*	—[b]

Note: Means within rows followed by the same letter are not significantly different ($P < 0.10$). Analysis of variance was performed with log transformed data, and back transformed means are reported.

[a]Reis (1995). Moriah data given for other plastics is for plastic films fraction; overs are considered screening rejects greater than 3.81 cm.

[b]Not determined.

Table 9. Particle Size of Selected Fractions (% Less than Stated Screen Size in Each Aged Section, Wet Basis)

	Screen size								
	2.54 cm Age			10.2 cm Age			15.2 cm Age		
Fraction	A	B	C	A	B	C	A	B	C
Paper	14.4*a*	11.8*ab*	6.8*b*	70.4 *a*	60.1 *a*	61.4 *a*	89.5 *a*	79.8 *a*	86.1 *a*
Cardboard	14.9*a*	7.6*ab*	4.6*b*	60.7 *a*	34.3 *a*	42.5 *a*	94.3 *a*	61.5 *b*	68.8 *b*
Other plastics	19.5*a*	16.8 *a*	10.5*b*	64.9 *a*	61.2 *a*	57.1 *a*	80.7 *a*	77.7 *a*	76.6 *a*
Ferrous metals	12.6*a*	11.0*ab*	5.5*b*	77.6 *a*	52.4 *a*	62.5 *a*	92.9 *a*	62.5 *a*	86.0 *a*
Textiles/Rubber	6.6*a*	6.8 *a*	5.4*a*	33.8 *a*	31.7 *a*	20.7 *a*	47.4 *a*	59.3 *a*	44.7 *a*
Wood	11.2*a*	11.7 *a*	8.5*a*	62.7 *a*	68.4 *a*	63.2 *a*	93.7 *a*	92.5 *a*	87.3 *a*

Note: Statistical significance was tested using an arcsine transformation but reported means are of untransformed data. Means within a single screen size within a row followed by the same letter are not significantly different ($P<0.10$).

and deterioration. For the fines, this trend likely represents biodegradation of the organic (VS) fraction and the absence of wood chips in the excavated waste of Age A.

Particle Size Distribution of Overs

The particle size distribution of excavated overs is an important parameter in the design of landfill reclamation process operations, particularly for the sizing of mechanical separation and grinding equipment such as trommel screens, magnetic separators, and hammer mills. In this study, some excavated waste might have been cut or broken by the auger. Nonetheless, the presented data (Table 9 and Fig. 5) might be useful for a feasibility study or preliminary design of a mining operation because of the limited data available in the literature.

Age can affect the particle size distribution (Table 9). Several of the excavated waste fractions of the older waste (Age A) have greater proportions of material less than 2.54 cm ($P<0.10$). The differences within the paper, cardboard, and ferrous fractions can be attributed to increased contamination of older material (Table 7) as well as increased degradation and deterioration. Differences for the other plastics fraction were most likely due to increased contamination of the older material.

Higher Heating Value

The HHVs calculated for the paper, cardboard, plastics, and wood fractions (as excavated) were considerably lower (Table 10) than values reported for raw MSW (Neissen 1977; Tchobanoglous et al. 1993). Likely reasons are the higher moisture content and the lower volatile solids contents (adhering fines) of the excavated fractions. The HHV of food and yard waste was approximately equal to the HHV of food and yard waste in raw MSW. This was probably caused by the lower moisture content of food and yard waste when excavated from the landfill compared to raw waste.

There were four paper samples that showed unusually high HHVs. The carbon-to-oxygen ratio of these samples indicates that they consisted mainly of material other than cellulose, the main constituent of paper. Possibly, the paper was contaminated with hydrocarbons, which is supported by the carbon-to-oxygen ratio and the gasoline smell that was detected when processing these samples.

The change of proportions of various fractions in the excavated waste compared to raw MSW, with an increase of the higher caloric fractions such as plastic and decrease of lower

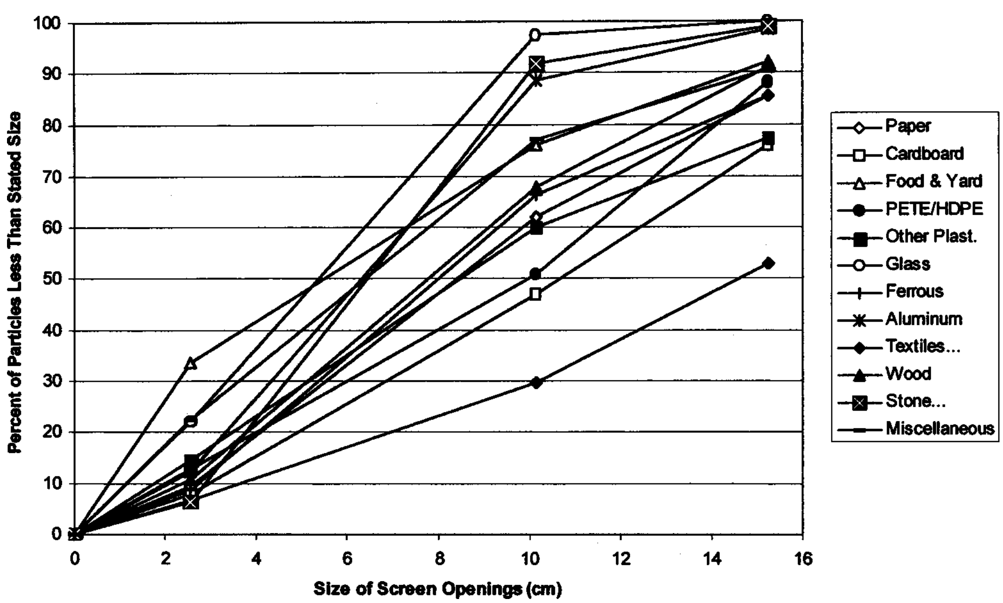

Fig. 5. Particle size of selected fractions

Table 10. High Heating Value of Selected Fractions (kJ/kg, as Excavated)

Fraction	Number of samples	Mean	Median	Range	Interquartile range	Residential raw MSW[b]
Paper[a]	15 (19)	8,000 (10,600)	7,700 (8,300)	6,200–10,200 (6,200–23,500)	7,400–8,700 (7,400–10,200)	11,600–18,600
Cardboard	3	8,200	8,100	7,400–9,100	—[d]	14,000–17,400
Food and yard waste	2	5700	—[d]	4,600–6,900	—[d]	2,300–18,600
Other plastics	14	16,600	15,600	3,000–32,000	12,300–20,200	28,000–37,200
Wood	15	8,900	8,600	6600–12,100	7,900–10,000	17,400–19,800
MSW	—[d]	—[d]	—[d]	—[d]	—[d]	9,300–14,000[c]

Note: MSW=municipal solid waste.

[a]Four samples were excluded because the carbon-to-oxygen ratio indicated that these samples consisted mainly of materials other than cellulose. Contamination with hydrocarbons was suspected. Data in parentheses include these four data points.

[b]Excluding fractions now recycled. Adapted from Tchobanoglous et al. (1993).

[c]For MSW including commercial waste a value of 10,700 kJ/kg is given in Tchobanoglous et al. (1993).

[d]Not determined.

caloric fractions such as food and yard waste, is expected to result in a HHV of the overs closer to the HHV of raw MSW. This is supported by findings from Salerni (1997).

Grain Size of Fines

No age effect was observed for the grain size of the fines (Fig. 6). This can be attributed to the fact that some fines samples consisted mainly of cover soil, while others were mainly waste or a mixture of soil and waste. This factor far outweighed any effect of age, including the presence of wood chips in the daily cover starting in the spring of 1995 or smaller grain size due to decomposition of degradable waste components.

Chemical Analyses of Fines

Results of the chemical analyses of the six samples tested for the 109 parameters of NJDEP RDCSCC showed that all criteria were met, except for two samples that showed elevated concentrations of PCBs and two samples that had elevated concentrations of bis (2-ethylhexyl) phthalate. However, the excavation, screening, and transport processes prior to sampling and the six week storage after excavation, undoubtedly reduced the concentrations of volatile and semivolatile compounds in the excavated material, and thus additional parameters may have exceeded the NJDEP RDCSCC. Detailed results are reported elsewhere (Krogmann et al. 2003). Even though trace metals did not exceed the current NJDEP RDCSCC, some elements exceeded New Jersey soil background levels and the Rutgers Cooperative Extension recommended levels when applying sewage biosolids to agricultural land (Table 11).

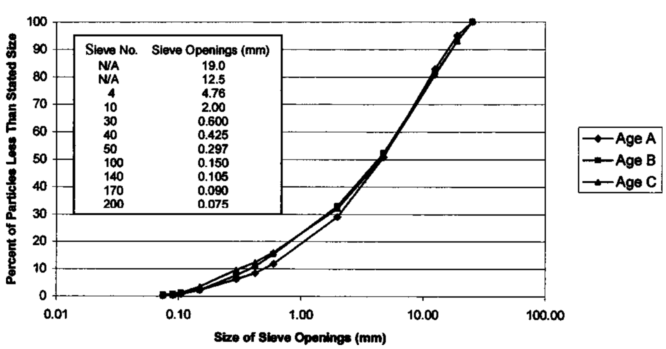

Fig. 6. Grain size distribution of fines

Implications

Effect of Age

Age differences were found for the waste composition, for the temperature, and for the particle size distribution and bulk density of several biodegradable fractions, suggesting that degradation had indeed been occurring within the landfill. The effect on particle size and bulk density is not only an effect of biodegradation but also of the constant chemical and physical impacts on the materials within the landfill.

Increasing recycling rates seemed to have had only a limited age effect on the composition of the excavated materials. The only effect was found for glass. One reason for the limited effect was that only a small portion of the waste fractions (i.e., aluminum and glass) deposited in 1989 was diverted by additional recycling in 1999.

Contamination, mainly from adherent soil, showed an increasing trend with age in the landfill. This was also found by Steg-

Table 11. Selected Trace Metal Concentrations in Excavated Fines (ppm, Dry Basis)

Trace metal	Mean (median) concentration in excavated fines	Background concentration in N.J. soils[a]	Rutgers Cooperative Extension suggested soil limits[b]	NJDEP RDCSCC
Arsenic	9.1 (8.6)	4.53	1–20	20
Cadmium	1.2 (1.2)	0.25	2	39
Chromium	26 (24)	11.0	—	240 (120,000)[c]
Mercury	0.4 (0.4)	0.18	1	14
Lead	55 (46)	63.2	150	400
Zinc	487 (406)	69.0	130–200	1,500

Note: NJDEP=New Jersey Department of Environmental Protection; and RDCSCC=Residential Direct Contact Soil Cleanup criteria.

[a]N.J. data, sample size=72; 19 urban, 18 suburban, 35 rural soil samples, arithmetic mean (Fields et al. 1992).

[b]Limits are suggested when land applying sewage biosolids to agricultural land, not for sandy soils (RCE 2000).

[c]Hexavalent Cr for inhalation pathway. Value in parentheses is for trivalent Cr.

mann and Heyer (1995). Not surprisingly, given this finding, volatile solids content for biodegradable fractions showed a decreasing trend with age in the landfill.

Potential End Uses

Reuse of Fines

Potential end uses for fines excavated from the landfill include landfill cover material on site or off site or as clean fill off site. If the excavated fines are to be reused as daily cover in New Jersey, certain state standards concerning size and organic matter content must be met. The NJDEP requires all landfill cover to meet four standards (*N.J.A.C. 7:26-2A.8(b)18*). These standards were designed to ensure daily cover materials have the necessary properties to serve as a fire break (standard 1: VS $<$ 12%), to minimize seepage of leachate from the side slopes of the landfill (standard 2: less than 20% $\leqslant$ 0.075 mm), to allow even grading (standard 3: more than 40% $\leqslant$ 2 mm), and to impede vectors from entering the waste and to control malodorous emissions (standard 4: 100% $<$ 15.2 cm).

All fines samples met standards 2 and 4. Twenty of the 23 samples of excavated fines exceeded the maximum concentration for volatile solids of 12% (Standard 1). However, stones were excluded before grinding the fines samples for the volatile solids analysis. Assuming that 20% stones were removed before grinding, the mean volatile solids would be 19.4% at Age A, 24.6% at Age B, and 28.0% at Age C. Even though this reduces the volatile solids content in the fines, Standard 1 still would not be met. Five of 37 fines samples met Standard 3. If the screen openings were reduced to 1.27 cm, 18 of 37 samples analyzed would meet this criterion. Other excavation projects did not mention any limitations of excavated fines for use as landfill cover.

If off-site uses other than daily cover (for road sides, for example) were pursued, the fines would have to meet state standards for certain chemicals. Although the number of samples analyzed for the 109 chemical contaminants currently listed under New Jersey's RDCSCC is not sufficient to allow for the excavated fines to be used off site, they do offer insight into what compounds and concentrations, for pesticides, PCBs, and metals, can be expected in the fines fraction.

The fines were aesthetically unpleasing due to contaminants such as plastic and glass, as also found by Reis (1995). If all visual contaminants are to be removed, a screen with 2 mm openings is needed and the fines mass will be reduced by 70%.

Recycling of Selected Excavated Waste Fractions

High levels of physical contamination have proven to be an insurmountable obstacle to the recycling of most of the materials excavated in other landfill reclamation projects (Miller et al. 1991; Salerni 1992; von Stein et al. 1993; Reis 1995). Ferrous metals, however, were in a marketable condition for recycling in the reclamation project in Sandtown, Del. (Miller et al. 1991). From the contamination data and visual observations, it has been concluded that most of the excavated overs fractions could not be recycled without drying and additional processing. Further information regarding additional processing can be gained from the experience with MSW composting and mechanical-biological residual waste processing currently practiced in Europe (Müller et al. 1998; Heering et al. 1999; Fricke et al. 2002). While technologically feasible, currently costs might be prohibitive under U.S. conditions.

Combustibility of Selected Excavated Waste Fractions

Treatment processes to reduce the volume of excavated overs to be relandfilled include, but are not limited to, incineration. As discussed, the HHVs of most individual waste fractions from the excavated MSW of Landfill Number 1 were lower than from raw waste due to elevated moisture and contamination. However, the overall HHV of reclaimed overs is expected to be closer to that of raw MSW due to the increased proportion of high energy content fractions, such as plastics and wood, in the excavated MSW.

Incineration of excavated material in a MSW incinerator as a part of a fuel mixture with fresh MSW has been successfully employed on a full-scale basis in Lancaster County, Pa. (Forster 1994). A test burn performed by Salerni (1997) determined the energy content for a 50/50 mixture of composted reclaimed waste and raw waste to be approximately 13,100 kJ/kg, which closely approximated 24 h averages for 100% fresh waste. A more in-depth study performed by Forster (1994) showed that a mixture of raw waste components (MSW, tire chips, wood chips, and selected residual wastes) and reclaimed waste in a 4:1 ratio reached approximately the energy content of raw MSW. However, equipment wear, ash generation, and hydrogen chloride emissions were higher when processing a mixture of raw and reclaimed waste. Composting was suggested to dry the excavated waste before thermal processing, which would improve the screening efficiency for the removal of the fines, as well as reduce adhering solids and therefore reduce the ash generation during thermal processing (Collins et al. 2001).

Landfill Volume for Relandfilling Excavated Waste

Reductions of 8–30% in required landfill volume were reported for German landfill mining projects related to site remediation where excavated MSW was relandfilled without recycling or reuse of the excavated fractions (Collins et al. 2001). The extent of the reduction depends on the degree of degradation of the biodegradable fraction and the compaction of the landfill prior to excavation. Using data from Landfill Number 1 [average in-place density of 1,150 kg/m^3 at time of excavation (see site description), average moisture content of 28.3%] and an equation developed by Collins et al. (2001) based on pilot-scale experiments, a volume reduction of 22% is estimated. According to Collins et al. (2001), recompacting waste excavated from a landfill results in a substantial volume reduction due to reduction of pore spaces and voids caused by biodegradation. Volume reductions caused by recompacting excavated waste should be further investigated. Additional volume reductions are expected if certain fractions such as fines are reused or recycled.

Summary and Conclusions

In this study, representative samples of different age materials were collected from Landfill Number 1 at the Burlington County Resource Recovery Complex in New Jersey, which was operated from 1989 until 1999. Based on these samples, the composition of the materials and selected characteristics were determined and statistically analyzed. Such a statistical analysis could not be found in the literature.

The fines fraction, representing about 50% of the mass, was the largest fraction of excavated material. Main fractions of the overs, which represented the remaining 50%, were miscellaneous items, wood, other plastics (not PETE or HDPE containers), and paper. Less paper was found in the older waste most likely indicating that microbial degradation had occurred in the landfill. The moisture content of the excavated waste samples in this study could be predicted by the moisture content of the fines fraction. Since representative fines samples are easier to collect than representative waste samples containing all fractions, fines samples might in the future be used to predict the moisture content in samples containing all fractions. Several of the characteristics of the materials excavated from the landfill, such as temperature, particle size, bulk density, volatile solids, and contamination, were correlated with the age of the deposits made. While the fines fraction can be reused at least as daily cover in landfills, other fractions except ferrous metals were of low quality and could be recycled only after intensive processing, if at all. The HHVs of the paper, cardboard, plastics, and wood fractions (as excavated) were considerably lower than values reported for raw MSW. However, the overall HHV of reclaimed overs is expected to be closer to that of raw MSW due to the increased proportion of high energy content fractions, such as plastics and wood, in the excavated MSW.

The methodology to determine the reclaimed waste composition used in this study can be recommended for studies at other landfills. Using whole bucket samples avoided sampling bias. In future studies, it might be advisable to determine another parameter (besides volatile solids) that better characterizes the degradable portion in the excavated waste. In addition, the methodology to determine bulk density should be modified taking the exerted pressure into account to better reflect bulk densities at various process stages (e.g., loose on conveyor, loose in truck, compacted in truck).

Whether a formal waste characterization study, as performed here, is needed for other landfills considering landfill reclamation depends on the required precision of the waste composition and characteristics information and the objectives of the landfill reclamation. For example, regarding composition it was found that the order of magnitude was similar to other projects. However, the wood portion was higher than in other projects, which would be important, if energy recovery was planned.

Even though no costs were determined in this study, the low recyclability suggests that landfill reclamation is currently only an economic option under specific circumstances. This is also the case in central Europe. Reasons for landfill reclamation in central Europe include: availability of special cleanup funds for contaminated sites; cheaper or more accepted (by the public) remediation option for landfills contaminating drinking water; cleanup of sites for housing development, especially in densely populated, high prized areas; enabling the operation of regional MSW incinerators at full capacity; providing fuel for the cement industry; reuse of already available landfill infrastructure, simplification of the permitting process; and gaining of landfill space if the landfill was only moderately compacted.

Acknowledgments

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