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A Sampling Protocol for Composting, Recycling, and Re-use of Municipal Solid Waste

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ABSTRACT
This article reports on development of a protocol for characterizing municipal solid waste (MSW). This protocol is similar to that recommended by the American Society for Testing and Materials but includes a distinction between pure and mixed loads of MSW. Thirteen component categories were used with a focus on material feed stock for composting, recycling, and reuse. The required number of samples was determined to achieve a 80%, 90%, and 95% statistical accuracy for characterizing MSW categories at 1% and 2% sampling error. This study found that a maximum of 25 randomly collected samples of 200 pounds will reflect each component category of mixed load MSW with at least a 95% confidence level and 2% error. This protocol was successfully tested in Monongalia County, West Virginia, to provide a "snapshot" MSW characterization during early summer.

INTRODUCTION
Municipal solid waste (MSW) management has recently become a significant issue for many communities.[1] The U.S. Environmental Protection Agency (EPA) has recommended a solid waste management hierarchy which emphasizes source reduction, recycling, and composting.[2] However, to adequately plan for the integration of composting, recycling, and reuse into solid waste management, the amounts and categories of MSW must be known. Waste categorization data are the vital underpinnings of integrated MSW management. With adequate data, informed decisions about recycling and composting capacities can be made, undue financial risks can be prevented, and progress towards meeting national or local waste reduction goals can be evaluated.[2]

The EPA[2] has noted that important data gaps exist for characterizing the MSW stream. Savage et al.[3] indicated that quantitative and qualitative determination of MSW is frequently neglected in the solid waste management planning process. According to Diaz et al.,[4] a lack of solid waste characterization has substantially limited opportunities for material recycling and caused integrated waste management systems to fail when designed with insufficient and/or inappropriate quantity and composition data.

There are two basic approaches to MSW characterization: (1) the material flows approach, pioneered by Franklin & Associates and the EPA[5,6] in the late 1960s and early 1970s and (2) the site specific sampling—the sorting and weighing of MSW by category.[7] The material flows approach assumes that by analyzing what products are sold, predictions can be made as to what has been thrown away to make room for new products. While research indicates that characterization percentages from this approach can approximate local percentages,[7] this approach fails to account for the potentially wide variation in MSW composition by geographic location, season, and generator.[8]

Site specific sampling and categorization of MSW provides more suitable data for local MSW planning.[9] This approach may involve: (1) a single sampling of the waste stream;[10] (2) characterization of numerous samples over a period of time to account for seasonal variation;[9,11,12] or (3) landfill excavation.[13] Wide variations in local conditions and differences in the types of solid waste sampled make it difficult to obtain national averages from the second approach.[14]

The purpose of this study is to establish a standardized MSW sampling protocol. This protocol will enable local

IMPLICATIONS

It is impractical to separate, measure, weigh, and analyze the composition of all municipal solid waste (MSW) materials generated from multiple sources. To balance the resources available with the need for accurate results, a reliable and standardized sampling protocol was developed in this study to enable local planners to find reliable and valid results for evaluating MSW composition. This protocol is unique in making a distinction between pure and mixed loads of MSW, and was satisfactory to use, as there was little disruption to the operation of the landfill where it was tested.

planners to find reliable and valid results for MSW composition. The protocol includes collecting a consistent number of samples, sample weight, MSW component categories, and a procedure for determining MSW characterization. No consensus exists in the literature for a standard sampling and sorting methodology of solid waste.[8] Prior research on MSW characterization has emphasized incineration and/or recycling.[15,16] For this study, a sampling protocol was developed and the number of samples was determined to achieve a 80%, 90%, and 95% statistical accuracy for characterizing MSW with an emphasis on feed stock material for alternative MSW management - composting, recycling, and reuse. This protocol was tested in Monongalia County, West Virginia.

SAMPLING PROTOCOL

Data was collected from MSW received at the Monongalia County Landfill during a two-week period in June and July of 1992. This landfill was located at Laurel Point in the western end of Monongalia County, West Virginia, on State Route 19. Prior to its closure in September 1993, the Monongalia County Landfill serviced all of Monongalia County and occasionally accepted loads from neighboring Preston County.

The Monongalia County Landfill was the appropriate place to conduct a MSW characterization study for Monongalia County, since the majority of Monongalia County's MSW was taken to this location. During the time of this study, there was a curbside recycling program in the county's largest city (Morgantown), which collected only small amounts of glass and aluminum because household participation rates were under 20%.[17]

Component Categories

The criteria for component categories needed to be simple, broad, and based upon MSW separation into feed stock materials for composting, recycling, and reuse markets. MSW component categories from prior characterization studies were examined.[14-17] The 12 Knapp[18] component categories, with the addition of an "other" category, were selected for this study (Table 1). Knapp developed these categories while operating a facility for reuse, recycling, and composting of MSW in Berkeley, CA. While it is possible to subdivide the Knapp categories into specific commodity markets, the 12 component categories were regarded as homogeneous in the sense that materials in each category have similar equipment requirements for handling and processing either in reuse, composting, or recycling facilities.

Table 1. MSW component categories developed by Knapp[18] and used in this study.

Component Category	*Definition*
1. paper	all materials containing only paper fibers
2. plant debris	yard waste - grass, leaves, tree trimmings, house plants
3. wood	wood demolition, lumber, furniture
4. plastics	all plastic containers and wrappings
5. metals	aluminum and steel containers, scrap metal
6. putrescibles	food waste and materials contaminated with food
7. rock, etc.	construction debris
8. reusable goods	books, small appliances, tools, toys
9. textiles	clothing and cloth
10. chemicals	chemical products and containers
11. soils	potting soil and dirt
12. glass	all colors of glass containers
13. other	composite materials and items deemed no longer usable

Sampling Technique

Sampling was conducted in two phases, each lasting one week. The first phase was to develop the protocol, and the second phase was to test the protocol. A week-long sampling period was used to reduce bias in sampling by either the type of generator (residential, apartment buildings, commercial) or geographic area in the county area, given that all trash collection was on a weekly basis. During Phase 1, it was observed that roughly two-thirds by weight of all MSW entering the landfill was comprised of mixed load MSW. Mixed load MSW was generated from numerous sources and the component categories were mixed together in compactor trucks. The other one-third of MSW arrived in open vehicles and contained primarily one component category, called a pure load. Pure loads were generated by a single source, either in the commercial sector or during special events.

Pure load MSW vehicles were identified by visual inspection and by obtaining information about the load's origin from the landfill supervisor and weighmaster. After removal of contaminants, their percentage by weight was determined. Pure load MSW was found to have more than 95% of the material by weight in one category. This definition was used during phase 2.

The procedure developed for this study followed recommendations by Constantine et al.[21] and Savage et al.[3] Worker safety precautions were based on American Society for Testing and Materials (ASTM) standards, with each worker being issued long sleeve clothes, a hard hat, safety glasses, leather gloves, and steel-toe boots. The composition of mixed load MSW in compactor trucks was determined by the following procedure:

1. Compactor trucks were randomly selected for analysis over the entire week.
2. The contents of each selected truck were emptied onto a study site adjacent to the tipping area of the landfill.
3. Because compactor trucks were measured by volume (cubic yards), the material was raked into a uniform thickness of three feet deep.
4. A grid was placed over the material, forming adjacent cubic yard cells. The cells were numbered,

beginning with the back left cell, and continued in sequence horizontally to the right as the load was dumped from the truck.

5. Each cell was brought to a sorting table—a 4' x 8' sheet of plywood with 2" x 6" x 8' rails resting at waist-height on saw horses and 55 gallon drums.
6. Material was sorted into 13 categories using 50 or 20 gallon containers. The sorting procedure was conducted by four to six people. When the containers were full or the job complete, containers were weighed on portable scales and the net weight was recorded. Cells were encoded by category using JMP IN software on an Apple Macintosh.

NUMBER OF SAMPLES

Phase 1 data were used to determine the number of samples to achieve confidence levels (80%, 90%, and 95%) at both 1% and 2% sampling error. Component category data were expressed as percentages and were assumed to follow a multinomial distribution. Individual percentages do not generally follow a normal distribution except when they are between 30% and 70%.[15] Only the paper category came close to falling within this range. Therefore, a normalization transformation was computed for all categories using the function: $Y = 2*\arcsin \sqrt{X}$, where X is the original percentage value of a category expressed as a decimal, and Y is the transformed value of X.

The number of samples required for the protocol was determined by:

$$n = \frac{t^2 * s^2}{d^2} \tag{1}$$

where n = number of samples, t = the student's t statistic, s = the transformed standard deviations for the component categories, and d = the absolute value of:

$$2*\arcsin \sqrt{X} - 2*\arcsin \sqrt{X + \Delta}$$

and

$$2*\arcsin \sqrt{X} - 2*\arcsin \sqrt{X - \Delta}$$

X was the mean category component percentage expressed as a decimal and Δ is 0.01 for 1% error and 0.02 for 2% error. The number of samples was determined by initially computing a N_o for both + and - Δ with a t statistic of ∞ degrees of freedom. The number of samples was then recomputed using a new t statistic based on N_o-1 degrees of freedom. This process was continued until convergence (see ASTM[16] for an example of this process) and the larger of the two numbers was selected as the number of samples. By using a normalization transformation, the number of samples computed in (1) did not require an assumption of a normal distribution for percentages like the calculation recommended by the ASTM.[16] Phase 1 data were used to estimate both the mean and standard deviation of each component category.

Sample Weight

Phase 1 data indicated that there was more difference within a compactor truck load of mixed MSW than between loads, so that samples need not be taken from each load entering the landfill. Therefore, the decision was made to sample in weight rather than volume measurements during Phase 2. A sample weight of 200 pounds was used based on prior research,[15] personal conversations with consultants in the field, and Phase I results. The 200-pound samples were collected in four 50-pound units in order to determine if smaller sample weights were possible. Sampling accuracy comparisons were made between 50-, 100-, and 200-pound sample units based on partial correlation coefficients.

During Phase 2, daily samples were chosen randomly based on an average daily tipping of 500 cubic yards (20 compactor trucks times an average size of 25 yards). As in Phase 1, daily sampling was conducted over a one week period to reduce generator and geographic bias. When a compactor truck arrived with an identified random sample, mixed load MSW was put in a pile and four random samples of 50 pounds were selected. Such small samples from compactor trucks were possible because bulky items such as white goods and furniture were not collected in compactor trucks. The sorting procedure for the component categories remained the same as Phase 1.

MSW Characterization

During Phase 2, transportation vehicles were recorded by type of vehicle, source of material, weight, and time of arrival. The percentage of the waste stream handled by each type of truck was computed and a tally sheet was used to keep a running total of the MSW entering the landfill. Phase 2 data were used to estimate: (1) MSW generation rates per capita; (2) a breakdown of MSW arriving in pure and mixed loads; and (3) quantities and percentages for the 13 component categories of the MSW stream for Monongalia County.

RESULTS

During Phase 1, a total of 79 cubic yards of mixed load MSW was sorted. The Knapp component categories worked well, as few problems arose during the sorting process regarding categorization of waste materials. Mixed load MSW weighed from 71 to 328 pounds in a cubic yard, with a mean of 184.7 pounds. This variation was primarily due to the differing compaction ratios of the hauling vehicles.

The maximum number of samples for mixed load MSW was determined from Phase 1 data based on the assumption that component categories are of equal importance in MSW characterization. In every instance, the putrescibles category required the largest number of samples to achieve the three confidence levels at both errors. Thus, the putrescibles category was used to establish the maximum number of samples for confidence levels (80%, 90%, 95%) at each error (1%, 2%) (Table 2). The number of required samples for the other major component categories are shown in Appendix A.

Table 2. Number of samples required to estimate putrescibles category percentage based on Phase I data.

Confidence level	Error		Sample weight*	No. of samples	
80%	2%		200 lb.	11	
		1%			40
90%	2%		200 lb.	18	
		1%			66
95%	2%		200 lb.	25	
		1%			92

* Sample weight was based on the average of a cubic yard of MSW being approximately 200 pounds.

Appendix A: Number of samples required by MSW component category.

Confidence Levels	80%		90%		95%	
	Error		Error		Error	
Category	2%	1%	2%	1%	2%	1%
Putrescibles	11	40	18	66	25	92
Paper	11	38	17	62	24	87
Plant Debris	6	19	10	32	14	45
Textiles	5	16	8	26	12	36
Metals	5	15	8	25	11	35
Glass	*	8	5	13	7	19
Plastics	*	6	*	9	*	13

* N_0 was less than five and the sample number computation did not converge.

The maximum number of samples ranged from a high of 92 (to achieve a 95% confidence interval at 1% error) to a low of 11 (to achieve a 80% confidence interval at 2% error). The 18 samples required to achieve a minimum 90% confidence interval at 2% error was similar to the 20 samples estimated by Clarruth and Klee.[15]

During Phase 2, approximately 1,120 tons of MSW were received at the landfill. This weekly tonnage for the population served by the Monongalia County landfill gave a per capita daily discard rate of 4.24 pounds, based upon the 1990 census population. This generation rate was slightly below both the EPA per capita estimate in 1992 (4.3 pounds) and the West Virginia Solid Waste Management Board (WV-SWMB) estimate of 4.82 pounds.[22] Waste generation sources were divided into four groups: (1) residential, (2) commercial, (3) institutional, and (4) industrial. Residential waste made up almost half of the MSW in Monongalia County, with about one-third of the MSW generated by the commercial sector (Table 3).

Mixed load MSW accounted for 74.27% of the 1,120 tons and pure loads accounted for 25.73%. The one-quarter of MSW which arrived as pure loads at the Monongalia County landfill was noteworthy, *because it meant that 288 tons of material were ready to be processed into composting, recycling, or reuse programs!* If these programs were available, Monongalia County could meet West Virginia's waste reduction goal of 20% by 1994[23] with no change in current collection patterns.

Over six tons (12,120.5 pounds) of mixed load MSW was sorted into categories during Phase 2, equal to fifty-seven 200-pound samples. Based on the putrescibles category, the 57 samples taken would predict category mean percentages for mixed load MSW at a 95% level of confidence with a better than 2% error. For smaller sample weights, only the paper and putrescibles categories exhibited correlations above 0.80 between percentages for the 100-and 200-pound samples. Thus, it was decided that the sample weight should remain at 200 pounds to evaluate MSW category percentages.

Mean percentages for pure and mixed load MSW were determined at a 95% confidence interval for the larger component categories (Table 4). A complete MSW stream characterization was determined by multiplying the mixed load MSW category percentages by the 832 tons of mixed load MSW received and then adding the pure load weights for each category (Table 4).

Phase 2 data provided a "snapshot" characterization for MSW in Monongalia County during the early summer season. Substantial seasonal variation of some MSW categories, particularly plant debris, has been documented elsewhere[8] so that ideally, more than one waste stream characterization should be conducted to document MSW in Monongalia County.

In this study, paper accounted for the largest portion of MSW by weight (30.6%). Institutions such as West Virginia University produced a high percentage of paper along with newspapers and magazines from residents and office paper from commercial accounts. Because samples were taken from mixed load MSW, small amounts of moisture increased the weight of the paper category. Based on the investigator's judgment, however, moisture did not substantially alter this category's percentage compared to the others.

The second largest MSW category was putrescibles (22.1%). Prior to this study, the putrescibles category was expected to make up a small percentage of the waste stream. However, with mixed load MSW, small amounts of food waste contaminated primarily paper and some plastic products. These contaminated materials were categorized as putrescibles because recycling would be infeasible. If all MSW was source-separated, then the paper and plastic categories would make up slightly higher percentages by weight of the Monongalia County waste stream.

Wood and plastic were both slightly over 10% of MSW by weight; however, they arrived at the landfill in different ways. Nearly 40% by weight of the pure load MSW consisted of wood from demolition, lumber, or furniture sources. However, wood was only a small percentage of mixed load MSW (1.4%), consisting of generally small pieces of broken

Table 3. Source of MSW as determined during Phase II of this study.

Sources	*Weight (Tons)*	*% By Weight*
Residential	538.12	48.7
Commercial	332.27	30.1
Industrial	120.81	10.9
Institutional	114.39	10.3

furniture. Plastics were found primarily in mixed load MSW (13%) with minimal amounts in pure loads (2.6%).

Textiles, metals, plant debris, and glass were between 4% and 6% of the total MSW by weight (Table 4). Textiles were 7% of mixed load MSW, but were not present in many of the samples. This category was found in a limited number of samples when a change in living situation occurred (e.g., death of a family member or moving from one home to another). The metals category was about half aluminum and half steel, with some large, odd pieces of copper. Only small amounts of plant debris (primarily grass clippings in plastic bags) was found, since this study was conducted during early summer. Glass consisted primarily of clear, brown, and green containers.

Chemicals, soils, rock/concrete, and reusable goods were found in such small quantities that sampling in separate component categories was probably not warranted. These four categories could easily be included in the other category with little loss of information about alternatives to landfill disposal. Rock/concrete and reusable goods were uncommon in mixed load MSW either because collectors refused to pick them up or (in the case of reusable goods) they were taken to charitable organizations rather than to the landfill.

Category percentages from Table 4 were compared with other waste stream characterizations generated by material flows, short-term landfill sampling, and professional experience (Table 5). The data developed from this study were not meant to validate these studies, but to produce valid and reliable data so that category differences were as important as

Table 5. Comparison of MSW component category mean percentage with other studies.

Component Categories	*EPA[24]*	*WV-SWMB[22]*	*Knapp[18]*	*Monongalia County*
Plant debris	*	—	25%	5.3%
Putrescibles	—	—	5%	22.1%
Yard and food	24.6%	9.9%	—	—
Paper	37.5%	29.7%	25%	30.6%
Metals	8.3%	5.2%	5%	5.7%
Glass	6.7%	5.3%	5%	4.1%
Plastic	8.3%	12.2%	7%	10.4%
Textiles	—	3.6%	3%	5.8%
Chemicals	—	—	2%	0.1%
Wood	—	14.4%	10%	10.7%
Soils	—	—	3%	0.9%
Rock/Concrete	—	5.9%	5%	2.3%
Reusable	—	—	5%	0.4%
Other	14.6%	13.7%	—	1.6%

* A blank space means this category was not used in the study.

Table 4. Summary of the Monongalia County MSW stream by percentage in Knapp component categories entering the landfill during Phase 2.

Component Category	*Means For Mixed Load MSW (%)*	*95% CI For Mixed Load MSW (%)*	*Pure Load MSW (%)#*	*All MSW (Tons)*	*Total MSW (%)*	*95% CI For Total MSW (%)*
Plant	6.7	5.9-7.6	1.4	59.81	5.3	4.7-6.0
Putres.	25.7	24.6-26.8	11.9	248.08	22.1	21.3-23.0
Paper	33.9	33.6-34.3	21.1	342.95	30.6	30.4-30.8
Metals	4.9	4.3-5.5	8.1	64.20	5.7	5.3-6.2
Glass	5.5	5.0-6.0	0	45.76	4.1	3.7-4.5
Plastic	13.0	12.5-13.5	2.6	116.35	10.4	10.0-10.7
Textiles	7.0	6.2-7.8	2.4	65.12	5.8	5.2-6.4
Chemicals	0.1	*	0.1	10.4	0.1	*
Wood	1.4	*	37.5	119.81	10.7	*
Soil	0.7	*	1.4	9.88	0.9	*
Rock	0.4	*	7.6	25.25	2.3	*
Reusable	0.3	*	0.7	4.36	0.4	*
Other	0.4	*	5.0	17.53	1.6	*
TOTAL				1120.1		

* Confidence levels were not computed for this component category.

\# Population sample for Phase 2.

the similarities. Overall, plant debris and putrescibles, taken together, were similar to EPA and Knapp estimates for compostable organic materials, although the plant debris category from this study was low because sampling took place in summer. The paper category was similar to the WV-SWMB estimate and fell between the EPA and Knapp extremes. The metal and glass categories were consistent with both the WV-SWMB and Knapp percentages, while the wood category was very close to the Knapp percentage. The percentages for plastics and textiles were surprisingly high compared to the Knapp estimates. However, chemicals, soils, rock/concrete, and reusable goods were much less than the Knapp estimates. These differences were attributed to the short sampling time frame of this study versus the annualized Knapp estimates.

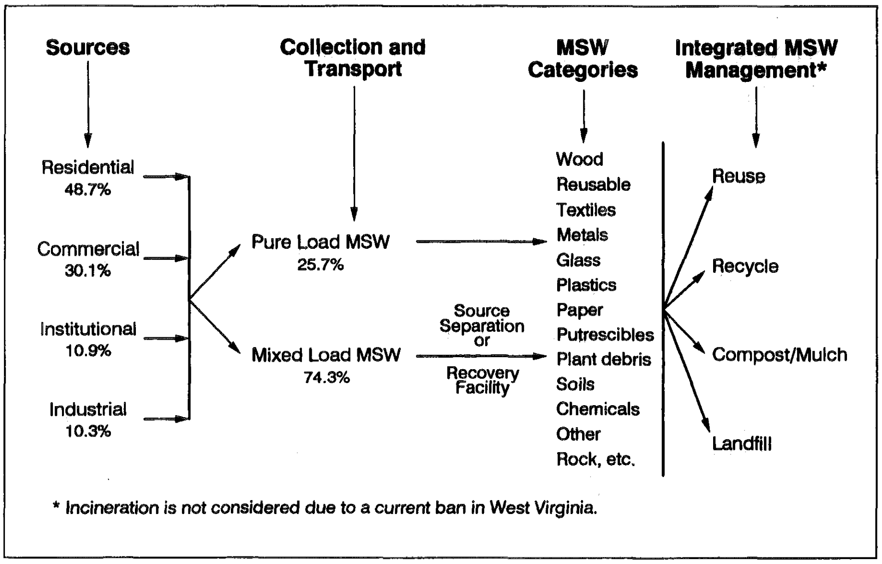

Figure 1. Integrated MSW management in Monongalia Couonty, West Virginia.

SUMMARY AND CONCLUSIONS

It is impractical to separate, measure, weigh, and analyze the composition of all MSW materials generated from a multitude of sources. To balance the resources available with the need for accurate results, a reliable and standardized sampling protocol for MSW was developed in this study. This protocol proved satisfactory to use, as no difficulties were encountered by the workers and there was little disruption to the operation of the landfill. An unique feature of the protocol developed in this study was its distinction between pure and mixed load MSW.

For mixed load MSW, the results of this study show that sample weights smaller than 200 pounds did not accurately represent 200-pound samples. This result confirmed a previous recommendation of 200 pounds.[15] The maximum number of samples was determined to achieve a 80%, 90%, and 95% statistical accuracy for characterization of MSW, given 1% and 2% sampling error for component category percentages. The maximum number of samples recommended ranged from 11 to 92 based on the category requiring the largest number of samples (putrescibles). A maximum of 25 samples was required to obtain a confidence level of 95% at a 2% margin of error.

The mixed load MSW sampling procedure developed in Phase 1 and used during Phase 2 was similar to the procedure recommended by the ASTM.[16] Selection of samples from piles of mixed load MSW was altered to allow for 50-pound samples rather than the 200-pound sample weight in the ASTM recommendations.

This protocol was successfully tested on a MSW characterization for Monongalia County, West Virginia. One result of this characterization was that a surprisingly high percentage of MSW (25%) which entered the Monongalia landfill was in the form of a pure load. No other study has produced data showing that as much as one-quarter of MSW can be reused, recycled, or composted with no change in the method of collection or transport.

Figure 1 summarizes MSW generation, collection, and integrated MSW management for Monongalia County, West Virginia. The MSW component categories provide potential feed stock for resource recovery facilities that utilize management techniques of composting/mulching, reusable goods exchange, and processing of recyclable materials. Previous MSW characterization studies have found up to 70% of MSW could be either recycled or composted,[25] but do not consider material reuse opportunities available, particularly for paper, textiles, and wood categories.

Actual MSW management strategies for reuse, recycle, compost, and landfill should be based on a combination of criteria including market availability; net cost of material collection, transport, handling and processing; and desirability of the end product. Landfill disposal costs provide economic incentives for an integrated MSW management strategy. With cost being the dominant problem in MSW management,[26] it is important to identify those component categories most likely to generate landfill disposal savings which exceed the costs associated with reuse, recycling, or composting. The sampling protocol evaluated in this study can be utilized for integrated MSW management both: (1) prior to development for facility sizing and equipment needs; and (2) after initiation to track landfill diversions from alternative strategies.

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