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PREDICTING HOUSEHOLD HAZARDOUS WASTE GENERATION RATES*

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ABSTRACT

Discarded household hazardous products may contribute significant quantities of contaminants to landfills in rural communities. During 1991, a research study was undertaken in a rural resource based community to determine the weight fraction of hazardous waste in the household refuse stream and to develop and test models to predict the discard rates from households. The data collection program consisted of physical sampling of waste loads during four one week periods at the landfill, an inventory survey of households, and a sales survey of paint and detergent sales in the community. Three simple models based on stored volumes, sales volumes and combined sales and stored volumes were developed. Data were aggregated and used to predict the total discarded quantity of paint and detergent in 1991. The results were compared with the physical sampling results. An average of 3.2 percent of the household refuse are hazardous materials[1] equivalent to about 90 tonnes per year in this community of 5,400 residents. These results show that rural refuse contains more hazardous materials than urban refuse, probably because of vehicle and house maintenance activities. While the storage based model overestimates discard rates, sales and combined models approximate, respectively, within 20 percent and 5 percent the measured residential discard rates in the study community. As a result, rural municipalities need to take action to reduce the quantities entering landfills and consider collection depots and waste minimization as alternatives to the once yearly toxic collection days.

Discards of household hazardous products in refuse may contribute significant loadings of contaminants to community landfills. Rural residents have been suspected of generating larger fractions of hazardous materials in the refuse

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than urban residents. The resulting risks from leachate and gas generation are particularly sensitive to rural communities where the landfills are not likely to include sophisticated liner designs and where water supplies are often drawn from wells. As a result, the research program presented in this article focuses on determining and predicting the amounts of household hazardous products in the landfilled refuse stream in a rural community.

The study objectives consist of:

1. determining the weight fraction of household hazardous waste in a rural refuse stream;
2. determining the association of household characteristics with used and stored quantities of hazardous products in households; and
3. developing and testing models to predict household hazardous waste generation.

These objectives were achieved, respectively, through a physical sampling program at the community landfill, a household survey and the collection of sales data for common household products. The analysis provides an estimate of household hazardous waste (HHHW) disposed of in the community landfill, measured volumes of used and stored products in households and their association with household characteristics, and, as the third result, tests three models to predict household hazardous waste generation.

THEORY OF HOUSEHOLD HAZARDOUS PRODUCT USE AND DISCARD

Discarded quantities of household hazardous wastes are tested in a rurally located community to determine significant differences between urban and rural settings. Urban householders might be expected to use more hazardous materials for maintenance and cleaning activities. The social expectation of suburban neighborhoods may require more intensive care leading to use of more products. In contrast, rural householders may pursue more activities requiring the use of products of concern, for example, building maintenance, gardening, vehicle and equipment maintenance, etc. Furthermore, while urban householders might rely more heavily on service companies to carry out painting, vehicle maintenance, etc., rural residents could be expected to do more of these activities themselves. As a result, urban household hazardous wastes might be shifted into the commercial waste stream because the contractors take on the waste disposal functions, while in rural areas, the wastes are disposed of in the household refuse stream.

A predictive model is intended to provide estimates of residential discards of specific hazardous products based on easily measured or acquired data such as household characteristics or product sales. An appropriate model would require the use of current data to predict the HHHW fraction in the refuse for a desired time period for a specific community or waste catchment area. Three different

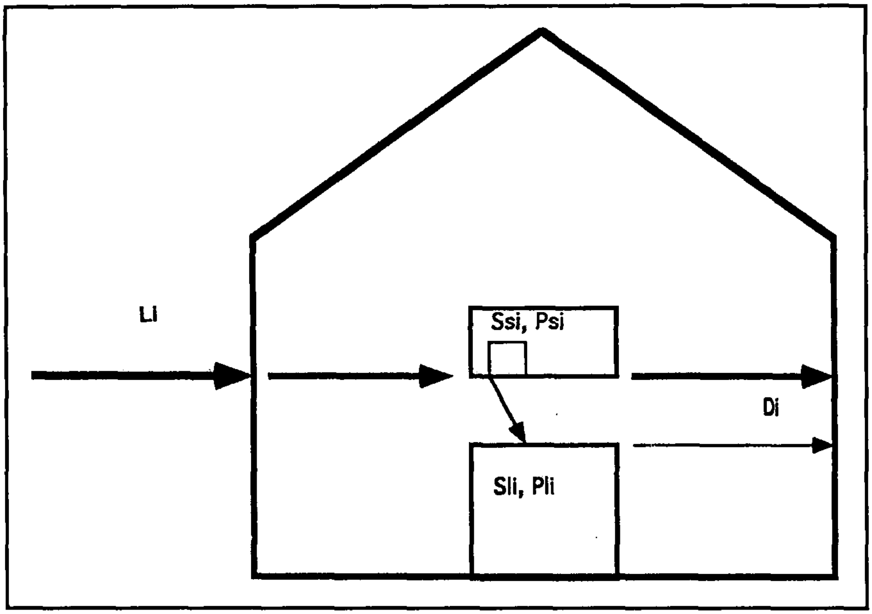

Figure 1. Household hazardous product use and discard to the waste stream.

models are derived here to account for household characteristics and product sales.

Model Development

A conceptual model of product purchase, use and discard combines the average volume Lij of product i purchased by households in the community during a time period j with the volume Si of product i that is used and stored in the average household. The period of household use and storage is called the product life denoted by Pi, that is the average length of time (per unit volume of product) from import of the product to discard into the waste stream (see Figure 1). In order to obtain the discard rate Dij as a mass per unit time, the discard volume must be multiplied with a residue factor qi to denote the mass of product, i.e., the residue of product, discarded per unit volume of container or package discarded to the waste stream.

The model generically identifies how households generally buy, use, store and discard products. While some types of products are regularly used (laundry detergents, cleaning products) and replaced, others are brought and used for special events (paints, special maintenance products, etc.). While the former results in a regular use and discard rate, the latter results in a pattern of high volume purchases, short use events followed by discards of large volumes or long term storage of leftover volumes.

Household Use and Discard of Indicator Products—Paint and Laundry Detergent

Two indicator products were selected to represent two different patterns for household product use and discard. Paints, on one hand, are used infrequently, on average about once to six times yearly for house maintenance tasks. Paints are often purchased for specific projects (a specific room, fences, etc.), the bulk of the material is applied and empty containers with residue are discarded to the waste stream very shortly after purchase and use. Paint containers with partially leftover volumes, in contrast, are stored for long periods of time, often several years, and are sometimes moved with the household. Households keep their old paint materials because they often want to have the same color for touching up or because residents frequently "never know when they might need paint again." As a result, three major elements in the paint material use and discard pattern were identified:

1. Currently purchased volumes (i.e., bought during the current year, mainly between May and September for outside paints, and during winter for inside paints) of which a large fraction is used (applied) very shortly after purchase and the containers with residues are discarded immediately.
2. The fraction of currently purchased volumes that is not used goes into storage in the households, i.e., leftover volume fractions and containers as well as full containers from uncompleted projects.
3. The residual volumes in long term storage comprise mainly leftover volumes in containers from completed projects or touch-ups; these materials are often several years old and sometimes leftover from previous homes. These materials are discarded at a slow rate, possibly, but less often than intuitively expected, on occasions like spring clean ups, and household moves.

In overview, the paint use and discard pattern consists of seasonally varying purchase, rapid use of a major portion with immediate discard to the refuse stream of the containers and residues, followed by short-term storage of a fraction of the current purchases for use within the year, and, finally, long-term storage of fairly large volumes of paint and stain materials.

Laundry detergents, in contrast, are used frequently and regularly, on average weekly. As a consequence, empty containers are regularly replaced with full ones. This use pattern leads to fairly evenly distributed purchases throughout the year [1]. The quantities found in storage in households usually consist of one to three containers with the regularly used detergents, bleach and special agents, e.g., stain remover. Additional volumes are infrequently used and can be considered long-term storage quantities. The containers and residues from the actively used component are regularly replaced and make up the major fraction of discards to the refuse waste stream.

Household Use and Discard Models

Three simple models are developed to explain and predict household use and discard of products of concerns (POC's) to the municipal landfill. The models were selected to estimate an average yearly discard rate and were developed for use with minimal, readily available data on stored quantities, frequency and quantity of volumes used, volume purchased per household and numbers of residents in the market area.

The three models consist of a storage-based approach, a sales-based approach and combined sales-storage based approach. The models are briefly presented, described and applied to households in the study area to generate estimates for paint and detergent discard rates. These estimates are then compared with the results from the landfill sampling program to test their accuracy.

1. Storage-Based Discard Model

The principle of this version of the model states that the amount (as a volume or mass of a product) discarded to the waste stream depends on the volume or mass in use in the average household divided by the average product life in the household [2]. This relationship is expressed in equation 1:

$$D_i = \left[\frac{S_{si}}{P_{si}} + \frac{S_{li}}{P_{li}}\right] q_i \tag{1}$$

where D_i = Discard rate of product i $\left[\frac{kg}{yr}\right]$

S_{si}, S_{li} = Storage quantity of product i [L], for short-term (S_{si}) and long-term (S_{li}) respectively.

P_{si}, P_{li} = Product life in household of product i per unit purchased $\left[\frac{kg}{yr}\right]$ for short-term (P_{si}) and long-term (P_{li}), respectively

q_i = Residue fraction as product weight per unit of purchased volume [kg/L]

This formula applied to long-time periods and large, homogenous populations will provide accurate estimates, because all used products will be discarded eventually. Some problems arise, however, with attempts to apply this model to POC discards:

a) The quantity in active use is often only a fraction of the stored quantity in the households, as for detergents. Therefore, the effective quantity, S_i, is not easily measured.

b) The product life P_i is similarly difficult to determine, because different values apply to the regularly used fraction and the long-term stored fraction of the stored quantity S_i. Furthermore, P_{Li} varies and may be quite high for some products. The effective life may have to be measured over a period of months to years to gain a reliable estimate.

This research project addresses these issues by measuring with a household inventory the average volumes and the product life in the household, and by determining through a subsequent household pickup program over a ten-month period product lives and discard rates of indicator products. These two sets of information were used to determine values for key variables in the storage-based equation.

2. Sales-Based Model

The product sales give an estimate of the product volumes flowing into households. If these sales volumes are adjusted to reflect the product volumes purchased outside the study community (approximately 25%) [3] and prorated to per capita volumes per year, then an estimate of sales volumes can be generated. Where necessary, as for paints, the fraction of current year's sales that is placed in storage can be subtracted. The product of total sales less stored volume times the unit residue fraction q_i provides an estimate of the total mass disposed of in the landfill. This relationship is shown with equation 2:

$$D_i = (L_{ij} - S_{si})\, q_i \tag{2}$$

Sales data per household or per capita are required in addition to average volumes placed in storage. Moreover, this estimate is based on current sales and, hence, only predictive if sales can be extrapolated into the future. This method does, however, provide estimates without having to sample the waste stream.

3. Combination Sales and Storage Model

A combined approach accounts for discards from current sales volumes and from stored volumes. This approach might provide appropriate estimates for products that, like paints, are purchased and stored in large quantities and, hence, provide large pools of material for discards to the refuse stream. Using the terms defined above for the previous models, the equation for the combined model is as follows:

$$D_i = \left[(L_{ij} - S_{si}) + \frac{S_{li}}{P_{li}}\right] q_i \tag{3}$$

This approach requires combined data from both models above.

METHODOLOGY

Three methods were developed to acquire data on 1) The component of household hazardous products in the refuse stream, 2) the volumes and length of time in storage for household products, and 3) sales volumes and discard rates for the indicator products paint and laundry detergents.

Landfill Sampling Program

Residential collection vehicle and self-haul vehicle loads were systematically random sampled during four one-week sampling periods to account for seasonal characteristics. Ninety to 150 kg samples of large loads or, respectively, the entire load of small vehicles were sorted to extract hazardous products and categorize them into twenty-one product groups. Ninety-five large loads and sixty-five self-haul loads were sampled. The hazardous product weight fractions were determined by product group and as an annual average total weight fraction of the refuse stream. The standard error of the mean total weight fractions were also estimated to provide a confidence range.

Household Characteristics and Storage Inventory

The household inventory was conducted with a randomly selected sample of households in the study area. Initially, some 144 households were contacted with an introductory letter, followed by a phone call. Thirty-nine households, or 27 percent decided to participate in the survey that required a visit by an interviewer and about 30 minutes of the respondents' time. This participation rate is good considering the relatively high level of effort required from householders. Interviews were carried out by the principal investigator and graduate student research assistants during April and May 1991. The surveys were administered by the interviewers in two parts containing questions about household characteristics, activities that relate to use of POC's (hobbies, automobile maintenance and repairs, household maintenance, gardening), purchasing habits and frequency of use of the twenty-one groups of products considered to be potentially hazardous in the refuse stream. The second part of the survey consisted of a tour of the locations in the home where these products were stored to record each container or item by location, product type, phase, original volume or weight, remaining weight and number of items. The results were analyzed by Chi-square analysis of household characteristics and activities on total and product group POC weight. All tests were considered significant if the rejection of the null hypothesis was probable at a confidence level of 95 percent, or, respectively, marginally significant at a confidence level of 90 percent.

POC quantities as number of items and as weights were tested for association with those sets of independent variables that were considered to possibly cause variation. For example, motor oil containers (product group #2) and used oil (product group #4) were tested against household characteristics, number of vehicles and automobile maintenance frequency, while product groups 6, 7 and 9 (household, bathroom cleaners and laundry detergents) were tested against household characteristics and cleaning, house maintenance and laundry frequency.

Finally, the third set of independent variables consists of frequencies at which certain activities are undertaken, e.g., cleaning, auto maintenance, house maintenance, pesticide use, etc., and, in particular, whether the households participate in the paint (toxic) roundup.

Product Sales and Household Discard Rates

The research team interviewed households for product life and discard frequencies, paint and grocery stores to obtain sales volumes of paints and laundry detergents to residential customers.

The inventory survey of households (see above) determined the inventory of product weights, including those of laundry detergents (product group 9) and paints (product groups 10 and 11). Subsequently, most of the survey participants (24 households) offered upon the interviewers' requests to collect specific products, including detergents and paints, in special containers supplied to the householders. The householders were asked to mark on the container the date when the product was brought and when it was discarded to the container. These materials were then regularly picked up over a period of ten months from April 1991 to February 1992 on a monthly basis, counted, weighed and recorded with the product life.

While the number of detergent containers was large enough to provide good estimates of discard rate (2.37 L of container volume per capita per month) and of product life (0.34 months or 0.028 years per L of container volume), the values for paints of 0.13 litres container volume per capita per month and 0.873 months per litre container volume are extremely unreliable due to the small sample number of eight containers collected during the ten months of the special pickup program. As a consequence, additional survey efforts were made to determine the quantity and age of stored paints.

A subsequent additional survey was conducted in November 1991 through January of 1992 of twenty-one households wherein the age of each paint container was obtained, albeit as recollected by the householders. Yet the interviewers observed extremely good recall by respondents of the projects and events that had led to the original paint purchases. As a result, the age estimates were judged to represent the product life in the household. The drawback to this method was, of course, that the material was still in storage with the household and, hence, had not yet reached the end of its product life. Therefore, the obtained values represent a lower bound of the product life for long-term storage of paints. Simultaneously, the researchers identified that on average 14.2 litres per household of new paint had been bought in 1991 and added to storage compared with the average of 10.71 litres already in storage from previous years. The total average of 24.9 litres, is, however, somewhat lower than the 35.3 litres found in the first household inventory survey. By accounting for different average household sizes in the respective surveys, however, similar results were obtained on a per capita basis of 8.6 litres to 10.1 litres in storage.

The product sales were obtained through interviews with store owners and managers and, where necessary, the extrapolation of the data to determine the total sales in the trading area. These sales were divided by 0.75 to reflect the 25 percent of purchases of these products completed outside the study area [3]. The sales were then divided by 7,450 residents to include the town residents and 15 percent of the 12,500 (obtained from the study survey) in the rest of the trading area to obtain the per capita sales. Then, the per capita values were multiplied with the 11,000 residents to estimate total sales in the catchment area of the landfilled waste stream. Paint sales data were obtained from five (of 8) stores spanning the range of store size in the study area. Total volumes as well as the ratio of residential to commercial sales were determined. The obtained sales volumes were extrapolated to obtain an average annual sales volume for the community. Sales volumes of laundry detergent were obtained from the two large supermarkets in the study area as well as from two (of three) drug stores. Sales from the two convenience stores were estimated by discussions with operators as being equivalent to one half the sales from a drug store. The sales were observed to be fairly constant over the study period.

RESULTS

Household Hazardous Waste in the Landfilled Refuse Stream

The average annual weight fraction of hazardous products in self-haul loads amounts to 3.0 percent of the refuse with a standard error of 1.4 percent, while the values for large collection vehicle loads consist of a mean of 3.4 percent and a standard error of 0.6 percent. The combined weighted mean as a percentage of the household waste stream is 3.2 percent, with a standard error of the annual mean of 0.6 percent. The resulting 95 percent confidence range is between 2.0 percent and 4.4 percent. This fraction amounts to a total of approximately 90 metric tons of household hazardous waste disposed of with the 5,058 metric tons per year of municipal solid waste from the town. In order to explain these higher values, specific products were identified by type of load.

The weight and composition of the landfilled hazardous products are indicated in Figure 2. In contrast to the total 90 metric tons of household hazardous waste disposed of in the landfill in the study period of one year, the community toxic

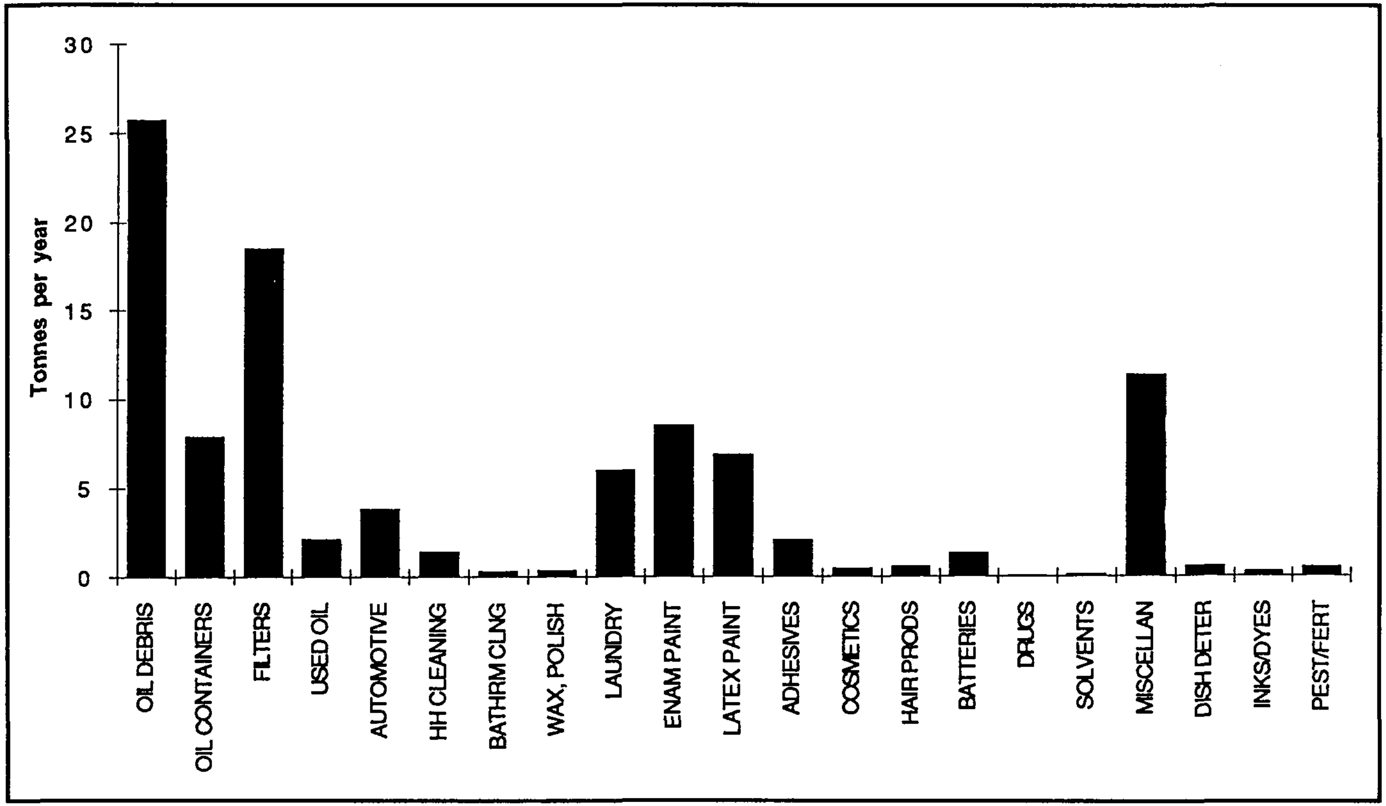

Figure 2. Household hazardous products—discard rates to landfill in 1991.

roundup program in May 1991 collected from the town and surrounding rural residences a total volume of 4,600 litres of material, or about 5 percent of the town's HHHW.

These results are significantly higher than previously reported household hazardous waste fractions of 0.3 percent to 1.0 percent [4-6]. The higher values found in the rural study community are likely due to the contributions from small private and commercial vehicle loads as well as from large rural transfer station and collection vehicle loads. However even the large town vehicles contain approximately 2.5 percent of hazardous products.

Household Characteristics and Hazardous Product Inventory

In order to use the survey results to represent the community, the characteristics of the sample had to be compared with the census values for residents in the study area.

The surveyed households tend to represent slightly more owner occupied single-family residences with slightly higher occupancy (at 3.5 residents) and incomes than the average of the town. Apartment dwellers are slightly underrepresented because of low participation despite sampling and contact of fifteen additional apartment households in addition to the twenty-two households on the original list. This low response is, however, not atypical for this type of survey [7]. A similar study revealed lower quantities of POC's in apartments, so that the estimates from the current sample are likely to be conservatively high [6].

Table 1. Comparison of Population and Survey Sample of Households

Characteristics	Drayton Valley	Sample
Type of residence		
Single family	68%	77.5%
Apartment	15%	5%
Mobile home	11%	12.5%
Other	6%	5%
Ownership		
Owned	71%	87%
Rented	29%	13%
Number of residents (average)	2.9	3.5
Household income (average)	$42,921	$48,888

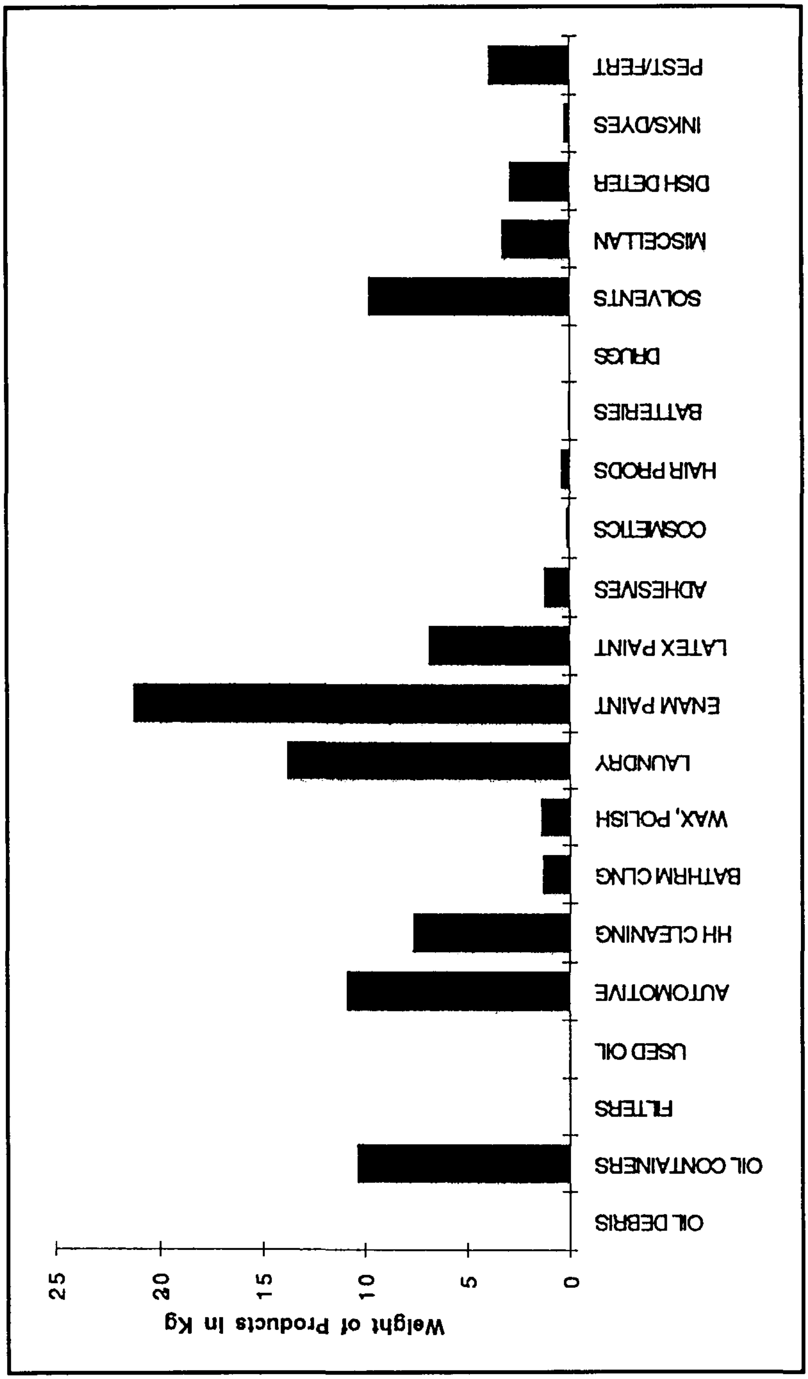

Figure 3. Hazardous product weights stored in households.

Table 2. Household Inventory—Average Weights of Hazardous Products by Location

Product	Product Group	Location in Household: Basement g	Bathroom g	Garage g	Kitchen g	Main Floor (other) g	Garden Shed g	Porch g	Row Summary
Oily debris	1	0	0	0	0	0	0	0	0
Oil containers	2	368	0	9,364	0	26	192	424	10,374
Oil filters	3	0	0	0	0	0	0	0	0
Used oil	4	0	0	0	0	0	0	0	0
Automotive products	5	687	0	7,309	443	362	568	1,536	10,905
Household cleaners	6	1,925	618	386	3,948	818	0	4	7,698
Bathroom cleaners	7	190	581	0	431	149	0	0	1,352
Waxes, polishes	8	292	96	170	721	148	0	0	1,427
Laundry products	9	10,715	118	185	728	2,044	0	0	13,789
Enamel paints	10	14,222	1	6,049	112	496	357	2	21,239
Latex paints	11	3,667	0	2,867	24	351	0	0	6,909
Adhesives	12	421	179	478	76	33	17	69	1,274
Cosmetics	13	5	118	0	2	16	0	0	141
Hair products	14	26	363	0	1	28	0	0	419
Batteries	15	0	0	58	0	0	0	0	58
Prescription drugs	16	0	0	0	0	0	0	0	0
Solvents, flammables	17	270	99	7,121	216	109	1,893	103	9,811
Miscellaneous	18	488	297	1,559	443	359	19	4	3,269
Dish detergents	19	271	89	0	2,422	109	0	0	2,891
Inks, dyes	20	247	1	0	0	0	0	0	248
Pesticides/Fertilizers	21	275	34	3,086	263	161	106	0	3,926
Column Summary		34,069	2,592	38,731	9,832	5,210	3,152	2,141	95,728 g

Note: All weights in grams.

Table 1 shows a comparison of the survey sample with the census figures for the study area.

The average home in the sample is furthermore characterized by an average age of fifteen years, contains three and a half bedrooms and two baths with an average floorspace of 930 ft^2 on an average lot size of 6,100 ft^2. Of surveyed homes 80 percent have basements, while 68 percent have garages. Households own on average 3.6 vehicles of all kinds; this average consists mainly of 1.4 passenger vehicles and 1.0 trucks per household with lower averages of snowmobiles, off-road vehicles, motorcycles and tractors.

Inventory of Hazardous Products in Households

Through the survey of thirty-nine households and detailed inventory of products and weights, the average stored weights in the twenty-one product groups (P.G.'s) were estimated. The results are shown in Figure 3; the average weights were broken down to show the location in the household in Table 2.

The total average remaining weight of 95.73 kg/household is notable. As well, the storage locations with high quantities appear to be, for paints, laundry detergents and household cleaners, the basement, and for oils, automotive products, paints, solvents and pesticides/fertilizers, the garage. Kitchen, bathrooms and other main floor locations tend to have low quantities with the exception of cleaning and laundry products.

The total POC quantity is influenced by household characteristics (type of residence, lot size, ownership, basement, garage), activities (auto maintenance and frequency, gardening), and, marginally, by participation in the toxic roundup. Specific products, however, are affected by different variables, e.g., oils (product groups 2 and 4) and automotive product (product group 5) are affected by the number of vehicles, lot size and the presence of basement and garage, while household and bathroom cleaner quantities are influenced by type of residence (size, floor space, and ownership). Waxes and polishes (P.G. 8), because they are used for vehicle care and for home care, are influenced by vehicles and by household characteristics. Paints (P.G.'s 10 and 11) are influenced by lot size, ownership, income and the presence of a garage. Products in groups 12, 13, 14 and 15 show low association with any group of characteristics. Solvents and flammables (P.G. 17), however, show association with ownership, presence of garage and basement, number of vehicles and frequency of auto and house maintenance activities. Dish detergent quantities relate only to frequency of cleaning; inks and dyes are scarcely found and were not tested. Finally, pesticides and fertilizers are related to type of residence, lot size, ownership, and house and garden maintenance activities. In summary, the observed patterns, although not consistently associated with one group of variables, nonetheless related logically to those specific variables that may be expected to influence them.

As a result, estimates of total POC weights and particularly, of cleaners, paints and pesticides should be increased for household size, lot size and owned dwellings, while oils and automotive products reflect the number of vehicles, and waxes and solvents are associated with household size and number of vehicles. Total POC quantities are also higher for homes with basements and garages.

Household Hazardous Product Generation Rates

The compilation and analysis of paint sales to residential customers in the community results in an average sales volume of 5.1 litres per capita per year (see Table 3). This value compared reasonably with the estimated overall average paint sales (including sales to commercial and industrial purchasers) of seven to eight litres per capita per year [8].

Stored paint volumes were determined from both household surveys. The combined results indicate that volumes stored for the short term, that is, the volumes brought in the current year and not yet used, average 0.69 L per capita, while the volumes in long-term storage (that is which were purchased before the current year) average 3.1 L per capita. The corresponding product lives average for the short-term storage volumes 0.072 years per litre and for long-term storage 3.1 years per litre. The large difference is notable because it emphasizes the typical use pattern of rapid use after purchase, followed by lengthy storage of often several years of the leftover volumes. The average amount of residue paint was measured by weighing fifty-five paint cans which had been sorted from the landfill waste stream and subtracting the container weight. An average residue weight of 0.165 kg per litre of container volume was determined.

Laundry detergent sales were obtained through the courtesy of the two large grocery stores and several small stores in the town. The average sales volume amounted to nineteen litres per capita per year or 1.58 litres per capita per month. This value seemed reasonable and was accepted. The stored volume from the household survey averaged 4.6 litres per capita with an average product life of 1.14 years per litre. These values seemed an order of magnitude too high and were revised through careful examination of the product use pattern. It was observed that most households actively use only a small fraction of the total detergent volume on hand, usually consisting of one detergent box or bottle and one or two containers for additional cleaning products (bleach, fabric softener, etc.). As a result, each household actively uses a storage of 4 to 6 litres which is equivalent to an active short-term storage quantitiy of 1.7 to 1.8 litres per capita. A value of 1.7L was used. The respective short- and long-term product lives were determined from the household pickup program and the inventory as 0.028 years per litre and 1.14 years per litre. The use pattern that appears here again is one of regular use and discard of a currently used stored volume with a large volume of dormant volume that is simply stored indefinitely.

Table 3. Hazardous Product Use and Storage Data

	Product	
Variables	Paint	Laundry Products
Stored Volume		
Short term		
— Mean	0.69 L/cap	1.7 L/cap
— Sample size n	21	—
— Std. Error	0.41 L/cap	—
Long term		
— Mean	3.5 L/cap	4.6 L/cap
— Sample size n	21	37
— Std. Error	0.8 L/cap	2.5 L/cap
Product Life		
Short term		
— Mean	0.072 yr/L	0.0283 yr/L
— Sample size n	21	65
— Std. Error	0.016 yr/L	0.0083 yr/L
Long term		
— Mean	3.1 yr/L	1.14 yr/L
— Sample size n	21	21
— Std. Error	0.71 yr/L	0.47 yr/L
Sales Volume		
— Mean	5.1 L/cap-yr	1.58 L/cap-yr
— Sample size n	5 stores	Population
— Std. Error	1.7 L/cap-yr	—
Residue factor		
— Mean	0.162 kg/L	0.005 kg/L
— Sample size n	55	141
— Std. Error	0.031 kg/L	0.0006 kg/L
Discard rate		
— Mean	—	2.37 L/cap-month
— Sample size n	—	65
— Std. Error	—	0.32 L/cap-month

The residue weight per litre of container volume was determined from actual detergent containers which had been extracted from the landfill waste stream. The average residue weight is 0.005 kg per litre of container volume. Finally, the discard rate of detergents was calculated from discards in the pickup program. The average volumes amount to 2.4 litres of container volume with residue per capita per month (see Table 3).

Table 4. Household Hazardous Products—Predicted Discard Rates

Product	Model	Predicted Discard Rate tons/year	Difference to Actual % of Actual Discard Rate
Paint	1. Storage	9.37	+89%
	2. Sales	4.46	−10%
	3. Combined sales-storage	4.85	−2%
Laundry products	1. Storage	1.76	+174%
	2. Sales	0.51	−20%
	3. Combined sales-storage	0.62	−3%
	4. Discard rate	0.75	+16%

Estimates for the discard rates of paints and laundry detergents were generated by applying storage-based, sales-based and combined discard models to the compiled data. The estimated results were multiplied by the town population of 5,400 residents and compared with the discarded weights of 4.96 metric tons per annum of paints and 0.64 metric tons per annum of laundry detergents as determined by the landfill waste stream analysis (see Table 4).

The storage-based model vastly overestimates quantities of paint and detergent products. This is likely caused by the unexpectedly high volumes of unused stored products. Thus, simply taking the entire stored volume as the pool to estimate discards will result in vastly overestimated discard rates and weights.

The sales-based model provides weights estimates that are about 10 to 20 percent below the actual discarded weights. These results provide some confidence because the data were obtained in similar fashion and the results are both reasonably and consistently close. The combined sales and storage model provides an excellent value for paints and laundry detergents. Estimates for both products are within 3 percent of the actual discard weights. Again, the pool of stored paint material is large and contributes somewhat to the discarded material volume. In contrast, the measured discard rates for laundry products from the household pickup program exceed the actual by 16 percent, probably because of the sensitivity to small variations in the average discard rates from the participating households.

Sensitivity Analysis

An analysis was conducted of the sensitivity of the models to measurement errors in the input variables. The results are easily verified by inspection of the model equations (1) through (3). The sensitivity was measured as the percentage change of the dependent variable (discard rate) in response to a 10 percent change of each independent variable.

Storage models are strongly and proportionally affected by the accuracy of the estimated stored volumes and product lives. As previously mentioned, the difficulty in distinguishing actively used products from dormant products renders results inaccurate. Errors in sales volumes translate linearly into approximately equally large errors in discard rates for the sales model and the combined model, because sales volume dominates the results. Errors in storage volumes and product lives (of 10%) cause changes of less than 0.3 percent in the discard rates. The residue factors significantly and linearly affect discard estimates from all models and should be measured with extreme accuracy.

DISCUSSION

Household hazardous discard rates of 2.6 percent of the refuse waste stream, as measured at the community landfill in a rural community, are significantly higher than for urban and suburban areas. The difference is probably caused by rural residents' more frequent and widespread household and vehicle maintenance activities. Household inventories indicate an average weight of stored weight of 95.7 kg of hazardous products in each home. The amount of products in the average household's inventory depends on the size of the home, the number of vehicles, income level and on the presence of basement and garage. Although these variables are obvious factors, their influence on discard rates is not straightforward.

Results from the storage, sales and combined discard models show that the storage based models greatly overestimate the discard rates for the indicator products paints and detergents. The errors probably stem from inaccurate estimates of the actively used stored volume, because households keep larger volumes of both paint and laundry detergents (and other product groups) in dormant storage. Furthermore, the data collection effort to estimate storage volumes and product lives is high because a visit of about one-half to one hour to each household is required.

The sales model, in contrast, is very simple and requires only aggregated basic sales data. Although this approach is appropriate for small communities where the number of outlets for any given product group is small, data collection could be daunting for large metropolitan areas. Basic per capita sales data from manufacturers or distributors may be adequate for an initial estimate, but these estimates may be averages that include sales to commercial purchasers and, hence, may overestimate sales to households. As a result, analysts may have to rely on cooperation from retailers and augment the results with their own surveys (possibly at the outlets) to determine retail trading area, percentage of residential sales and seasonal fluctuations of sales. The accuracy of the sales data is low, with a resulting confidence intervals between 30 and 167 percent of the man for paints. The results are also very sensitive to these errors. Furthermore, sales may over- or underestimate discards because of purchasers outside the study area, and, particularly in rural areas, because residents may dispose of some products easily in their own garbage pits or in burn barrels.

The simple sales model is improved by accounting for the large pool of stored hazardous products in households. Although the data collection effort is substantial to determine volumes and long-term product life, the accuracy improves to within 5 percent. Providing that the analyst can determine an accurate estimate of the residue fraction (i.e., the mass of product left in a unit volume container), possibly using the values given here as initial estimates, then the combined model accounts plausibly for discards from new purchases and existing storage volumes. Except when rapid shifts or uncertain trends occur this model provides current estimates of discards if adequate current sales data are available.

CONCLUSIONS

The comprehensive study of household hazardous wastes in a resource based community in a rural area shows that the HHHW fraction on the landfilled refuse stream is significantly higher, at 3.2 percent, than previous results from urban and suburban residential areas. The cause for the difference appears to stem from rural residents' more frequent household and vehicle maintenance activities. The predictive power of simple sales based models can be improved if the volume of hazardous products stored in households is accounted for in a combined sales-storage model. The implications for rural communities and landfill operators are twofold. First, rural landfill owners/operators need to make special efforts to eliminate household hazardous products from vehicle loads by listing and checking loads for these materials (oils, paints, automotive products, etc.). This is necessary to reduce the owner/operator's liability as well as to prevent large quantities from entering rural landfills that may not be equipped with liners and leachate collection systems. The second implication pertains to the staging of once-yearly toxic roundup programs. While these programs often show increasing public participation (as measured by the number of vehicles, etc.) the quantity of household hazardous material that is actually captured is less than five percent of the material that is disposed of in the landfill. This is bound to happen because of the particular use, storage and discard patterns described in this article whereby people purchase products, use most of them quickly and discard the container with residue. The leftover material is kept, stored and will generally not be discarded for long periods. As a result, toxic roundups should be staged frequently and regularly during spring, summer and fall in order to capture the rapidly used and discarded fraction of the product sales (paints, stains, oils, etc.). While curbside pickup programs, similar to the blue box programs, or "toxic taxis" for pickup at the household location reduce the storage period until removal, the constant flow of small quantities of certain regularly used products probably will not warrant the cost to the householder in the first case, or the effort to call for pickup in the second. These options are likely to collect more household hazardous products, but at substantial cost. Alternatively, a collection depot would provide the permanent access required to improve the rate of capture of household hazardous wastes in rural communities. If a network of depots can be established that is dense enough and convenient for customers, say, to return empty containers at the outlet where they were purchased, then this option is expected to improve the capture rate over a one day per year collection effort.

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