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PROFILING HAZARDOUS WASTE GENERATION FOR MANAGEMENT PLANNING

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Summary

Results of a survey of the hazardous wastes generated by the industrial sector of the United States' economy are presented. Although data availability and quality are still problems in portions of the country, enough information now exists to construct national and regional generation profiles. Results are presented to show how the total hazardous residual production is broken down by its industrial origins and by chemical composition. In the absence of actual production data, these results could be used to synthesize a plausible estimate of a region's hazardous waste production potential.

A method is also presented for building the results of waste generation surveys into hazardous waste management models. This requires the creation of a waste classification scheme that is tuned to the detail available on waste disposal alternatives. By this technique, framework planning may be done to develop broad disposal policies, and detailed regional or local simulations may be conducted to optimize management alternatives for minimum cost and risk.

1. Introduction

The management of hazardous waste is a problem worthy of serious concern. The dilemmas associated with the disposal of these materials are constraining industrial productivity, causing broad public concern, endangering long-term environmental quality, and leading to clear inequities in the distribution of responsibility and risk. Nearly everyone agrees that the ideal solution would be to eliminate all of these wastes. Unfortunately, this is simply not possible. It is an unavoidable fact that we now produce huge quantities of this material and will continue to do so well into the foreseeable future. This mandates that we come to grips with the technical and social problems of sound hazardous waste disposal management.

The work reported on here grew out of a study of hazardous waste elimination research priorities. This involved assembling a profile of the hazardous wastes generated by the whole manufacturing division (as defined in the Standard Industrial Classification (SIC) Code [1]) of the United States economy. The mission of this study was to produce a ranked list of "worst" hazardous

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wastes so they could be targeted for elimination research. The study focussed on industrial residual wastes (i.e., those commonly thought of as solid wastes) currently being classified as hazardous. Wastes discharged to the atmosphere or as conventional industrial wastewaters were excluded. This focus was adopted because residual wastes were the last to come under vigorous national control, and because many air and water pollution problems have been converted into residual management problems by add-on treatment technologies.

As might be expected in this context, "worst" is a very elusive concept to define. Industrial residuals vary from modest hazard substances generated in truly immense quantities, to intensely dangerous wastes produced in small lots. The type of hazards also vary from immediate and acute (as in explosives) to much more pervasive and chronic (as with potential carcinogens). It is also true that satisfactory disposal technologies are available for some wastes, while others remain frustratingly difficult to accommodate.

The work reported on here is a product of the struggle to identify "worst" industrial wastes. One method used for this was to identify the wastes that were least manageable by current disposal capabilities. To accomplish this, data from a national hazardous waste generation survey were run through disposal management scenarios. By optimization simulation, wastes that were most binding on the optimum solution were identified. This technique was found to be of modest success for identifying research priorities. However, it appears to have major potential for framework or regional hazardous waste management planning. It allows for an examination of the benefits of a mix of disposal facilities, and provides a quantification of the penalties of failing to achieve this mix. In this paper, results of the national hazardous waste generation survey will be presented, and the technique of building them into management simulations will be introduced.

2. Waste generation data sources

Historically, two major sources of U.S. industrial residual generation data have been available. The first is a series of "assessment" documents commissioned by the USEPA Office of Solid Waste Management Programs (OSWMP, c.1972—1975). These studies produced detail on the hazardous waste activities of industries assumed to have the greatest generation potential. Studies examined portions of SIC groups 22, 28, 29, 30, 31, 33, 35, and 36, to develop total waste production projections for 1977 and 1983. Waste generation factor estimates were also prepared for many industries. The technique used included statistical samplings of the industry population by mail survey, telephone contact, plant visits, and limited waste sampling. The second major data source is a series of state publications developed under EPA's State Survey Implementation Guide [2]. To date, the state response has not been unanimous, but at least 40 states have issued some form of survey or assessment of the wastes generated within their borders [3]. Although both of these data sources have come under criticism for their lack of consistency and uniformity, they remain the most extensive body of literature available. See ref. [3] for a complete bibliography of the 80 state and federal documents that make up these two primary data bases.

For the purposes of this work, the second information source was selected. Although these data must be culled very carefully, they offer two distinct advantages over the assessment document information. First, they contain much more information on the chemical composition and ultimate destination of wastes. Secondly, and more importantly, many of these publications are in their second or third generation. The more recent versions have been enriched with much more bountiful and consistent information. In fact, several states are now able to supply data directly from computerized disposal manifest accounting systems.

Booz—Allen and Hamilton, Inc. [4] elected to use the industrial assessment data for their study of the United States hazardous waste disposal capacity. Comparisons between their updated generation estimates and the results of this study were quite favorable. The major distinction (aside from the lack of waste composition information), appears to be that use of the assessment documents overestimates the relative significance of the SIC code groups studied most intensely. VanNoordwyk et al. [5] also used the assessment document (and selected state data) in their study of municipal co-disposal of industrial wastes. However, since they limited their scope to SIC codes 28, 29, 30, 31, and 36, no direct comparisons can be made with the results presented here.

3. Study methods

The hazardous residual generation study was conducted by assembling all of the published state assessment documents. In addition, the hazardous waste authorities of each state were contacted directly. Many were able to supply additional, unpublished data. From this primary information source, two master data sets were assembled. The first of these associated hazardous waste production quantities with their industrial origins. The second related production quantities to various waste composition categories. The ideal situation would be to coalesce these into a single data matrix. This would allow magnitude and composition profiles to be produced for individual industrial groups. Unfortunately, the state data are currently insufficient for accomplishing this with significance at national level. Although it can be done for a few states or regions, many states have opted to keep these information groups separate to protect industrial anonymity.

The correlation of waste generation versus industrial origin was accomplished at the two-digit SIC code level using the data from 21 states. An evaluation of the industrial worker population (U.S. Bureau of Census [6]) of these states showed that they account for well over 50% of the national population employed in the manufacturing division. Table 1 shows the percentages broken down by two-digit codes. From this, it can be seen that the aggregate sample provides a reasonable coverage across the whole industrial division. Data were

TABLE 1

Percentage of national industrial activity covered by states reporting

SIC code	Industries*	% Activity in states reporting quantities†	
		For 21 states, reporting by SIC code	For 30 states, reporting by waste type
20	Food	50.5	66.0
21	Tobacco	72.9	63.3
22	Textiles	32.8	30.0
23	Apparel	54.1	58.3
24	Lumber	44.6	65.8
25	Furniture	55.2	66.6
26	Paper	62.6	65.6
27	Printing	60.8	69.4
28	Chemicals	40.6	57.1
29	Petroleum	37.4	48.1
30	Rubber	58.4	61.9
31	Leather	58.2	75.9
32	Stone	53.4	57.1
33	Primary metals	67.8	48.5
34	Fabricated metals	62.9	64.9
35	Machinery	63.9	67.4
36	Electrical	56.5	66.8
37	Transportation	60.6	67.8
38	Instruments	64.3	77.5
39	Misc. manufacturing	56.8	74.8

* Abbreviated SIC code designation.
† % Activity based on % of production workers employed in reporting states.

also tabulated at the three digit code level, but only 9 states can supply information of this intensity. This was found to be insufficient to support national projections.

The relationship between waste generation and waste composition was developed from the data of 30 states. The significance of this population has also been indicated in Table 1. The coverage does not increase in every case because two of the 21 states in the first set could not supply information on waste composition. This second data set was much more difficult to assemble. Of the 30 states reporting waste compositions, no two use identical classification schemes. Therefore, a general scheme had to be developed that was detailed enough to fulfill the goals of the study and yet not so specific that it excluded much of the available information. It is also true that a complex scheme is not always necessary, or even desirable, for the purposes of waste management planning. It does little good to keep track of hundreds of distinct waste types if they must all be routed to the same waste disposal alternative.

The classification scheme used in this study is presented in Table 2. This was designed as a multi-tiered system flexible enough to accept data originating from the wide variety of state classification schemes. The lower levels of this were intentionally defined to be quite crude. Only selected categories of wastes with distinct disposal alternatives were featured. This was a compromise necessitated by the methods the states have used in tabulating their own information. It was also believed that, for framework planning, there is no point (from the disposal management perspective) in distinguishing among wastes destined to reach the same disposal facility. Only the first two levels of this scheme are shown here.

TABLE 2

Waste classification scheme

Level I	Level II
Solids	Organic solids
	Inorganic solids
	Misc. special wastes
Liquids	Halogenated organics
	Non-halogenated organics
	Acids
	Caustics
	Metal solutions
	Oils and oily wastes
	Misc. liquids
Sludges	Metal sludges
	Inorganic sludges
	Organic sludges
Unidentified	Unidentified

Table 3 presents the matrix of disposal opportunities (technologies) that have been considered for Level II categories. Most of the classifications of this level are self-explanatory. The miscellaneous special solids category was created to hold wastes such as pesticide solids and containers, explosives, pathogenic wastes, DOT "poisons" and similar residues given special treatment in the state records. The metal solutions and metal sludge categories were created for heavy metals. The wastes included in these were predominantly heavy metal residuals, but not all states were consistent in making this distinction. The liquid categories contain both dilute and concentrated solutions and (where appropriate) non-aqueous liquids. The miscellaneous liquids category was used to gather all unclassifiable liquids. The unidentified classification was used when no phase information was available.

The next level of this scheme (not shown here) includes the additional detail needed to fractionate Level II classifications into the allowable inputs of specific treatment or disposal technologies (i.e., the specific unit operations of the general alternatives described in Table 3). However, with few exceptions, it is difficult to insert most state data above Level II and several (7) cannot be used above Level I. The final level of this scheme is identical to EPA's own waste classification scheme of 500+ categories [7]. Levels above II are more appropriate for regional or local waste management planning and will not be discussed further here.

TABLE 3

Waste disposal alternatives for Level II waste classifications

	Hydrocarbon Incineration	Rotary Kiln Incineration	Halogenated Hydrocarbon Incineration	Solvent Recovery	Oil Recovery	Organic Liquid Treatment	Metals Treatment	Neutralization	Anaerobic Stabilization	Aerobic Stabilization	Activated Sludge	Deep Well Injection	Secure Landfill	Landfarming
Organic Solids		X											X	
Inorganic Solids													X	
Special Solid Wastes		X											X	
Halogenated Organic Liquids			X			X						X	X	
Non-Halogenated Organics	X		X	X		X			X	X	X	X	X	X
Acid Solutions								X				X	X	
Caustic Solutions							X	X				X	X	
Metal Solutions							X					X	X	
Oil and Oily Wastes	X	X	X		X							X	X	X
Miscellaneous Liquids									X	X	X	X	X	X
Organic Sludges		X							X				X	X
Inorganic Sludges													X	
Metal Sludges							X						X	

TABLE 4

Reported/estimated total hazardous waste generation by EPA Region

EPA Regions; states with (without) data	Reported hazardous residual generation (metric tons)	Extrapolated hazardous residual generation (metric tons)	Booz—Allen and Hamilton, Inc. estimates for 1980 based on industrial assessment (metric tons)
I ME, NH, VT, MA, CT, RI	654,600	654,600	1,104,000
II NY, NJ	1,727,500	1,727,500	3,113,000
III PA, WV, MD (VA, DE)	6,105,300	8,113,900	4,354,000
IV KY, NC, SC, MS, AL, FL (TN, GA)	7,061,300	9,525,700	10,353,000
V MN, WI, MI, OH, IL, IN	9,176,000	9,176,000	6,428,000
VI TX, OK, AR, LA, (NM)	8,847,600	9,332,000	10,536,000
VII LA, KS, MO (NE)	1,167,600	1,340,200	1,201,000
VIII MT, WY, CO (ND, SD, UT)	940,700	1,576,800	318,000
IX CA, AZ (HI, NV)	1,453,700	1,550,900	2,838,000
X ID, OR, WA (AK)	744,400	1,112,300	955,000
Totals	37,878,700	44,109,900	41,235,000

4. Generation survey results

Table 4 presents results of the generation survey based on all 38 states reporting some form of generation data. Results have been arranged by EPA Region for comparison to the results of Booz—Allen and Hamilton, Inc. [4]. Where necessary, linear extrapolations have been used based on total regional populations rather than industrial worker populations. This statistic was found to correlate best with the generation data (see Fig. 1). Although substantial regional differences may be seen between the results of these two studies, the overall agreement is quite good. In the state data, the quality of information is best for EPA Regions I, II, V, and VIII. Regions III and IX remain the least well-defined because of the limited availability of information from California and Pennsylvania. Reference [3] provides a state-by-state breakdown of these data.

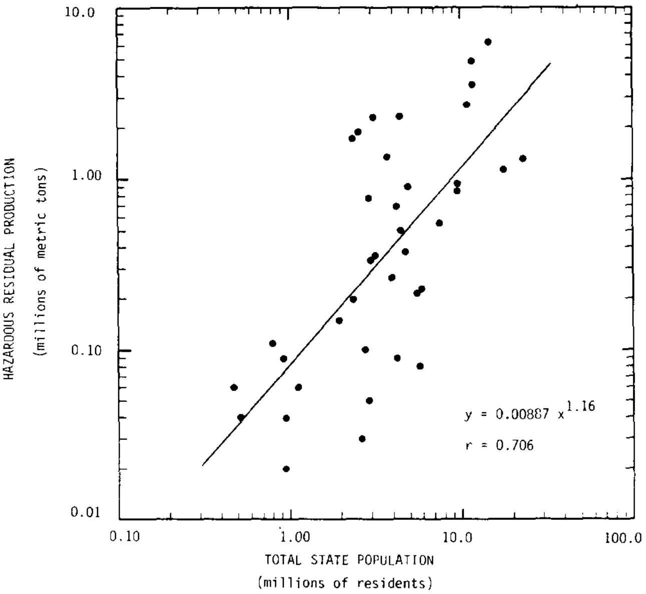

Fig. 1. Correlation between total state population and hazardous residual generation.

Table 5 presents the estimated distribution of these wastes by their industrial origins. The striking feature of this table is the predominance of the first few codes. The first three codes (the chemical and steel industries) appear to account for over 75% of the United States' hazardous waste production. The first 10 codes account for over 97% of the total.

It is not too surprising to find that the chemical industry is responsible for a great deal of this waste. It is a little more unexpected to find the older metals industries producing a waste volume that nearly rivals this. What is not at

TABLE 5

Two digit manufacturing division SIC codes ranked by their hazardous residual production

Rank	SIC	% of total	Rank	SIC	% of total
1	28	47.8	11	30	0.6
2	33	22.1	12	24	0.5
3	34	6.3	13	31	0.4
4	35	5.2	14	22	0.3
5	26	3.8	15	38	0.2
6	37	3.4	16	39	0.2
7	29	3.2	17	25	0.2
8	20	2.8	18	27	0.1
9	32	1.9	19	21	< 0.1
10	36	0.6	20	23	< 0.1

* % of total extrapolated to national estimate.

all obvious in Table 5 is that the significance of the codes below SIC 28 is much greater than has been previously reported. The reason for this appears to be an underestimation of their generation potential rather than an overestimation of the importance of SIC 28.

Additional anomalies may be uncovered by examining the composition profile of this waste inventory. The Level I (phase) distribution was found to be:

solids — 13.9% of the total
liquids — 54.4% of the total
sludges — 23.8% of the total
unidentified — 7.9% of the total.

Clearly, although these residuals are often thought of as solid wastes, the solid fraction is actually quite small. Liquid wastes are by far the most common. Any well-designed management plant must be especially equipped to handle these.

Table 6 summarizes the Level II composition distribution within each of the solid, liquid, and sludge fractions. Table 7 presents the Level II composition categories as ranked fractions of the total. Note that in Table 7 the fractions have been recalculated as percentages of the "identified" (92.1%) portion of the Level I total. From this it can be seen that the less sophisticated wastes far outweigh those of a more complex chemical nature. However, this is only by sheer quantity. It seems obvious that the actual degree of hazard per unit mass of waste must vary over several orders of magnitude. For example, one might easily suggest that the actual long-term hazard represented by a unit of chlorinated hydrocarbon is at least equal to that of 34 units (20.5/0.6) of an inorganic acid.

TABLE 6

Composition distribution of major industrial residual categories

Category	% of total
Solids	
Organic solids	11.8
Inorganic solids	28.0
Miscellaneous special wastes	60.2
Liquids	
Halogenated organics	1.0
Non-halogenated organics	8.6
Acids	34.8
Caustics	18.8
Metal solutions	11.4
Oils and oily wastes	7.6
Miscellaneous	17.8
Sludges	
Organic sludges	41.8
Inorganic sludges	33.5
Metal sludges	24.7

TABLE 7

Ranked order of Level II waste classifications

Rank	Waste class	% of total*
1	Acids (L)	20.5
2	Caustics (L)	11.1
3	Organic sludges (SL)	10.8
4	Miscellaneous liquids (L)	10.5
5	Miscellaneous special wastes (S)	9.1
6	Inorganic sludges (SL)	8.7
7	Metal solutions (L)	6.7
8	Metal sludges (SL)	6.4
9	Non-halogenated organics (L)	5.1
10	Oil and oily wastes (L)	4.5
11	Inorganic solids (S)	4.2
12	Organic solids (S)	1.8
13	Halogenated organics (L)	0.6

L = Liquid   S = Solid   SL = Sludge

* Total omits the 7.9% of waste that could not be assigned a Level I classification.

5. Evaluation by management simulation

As an initial evaluation of the overall manageability of this hazardous waste inventory, cost functions were developed for each of the disposal technologies considered. These functions (summarized in Table 8) were based on the economic analysis of A.D. Little, Inc. [8], EPA [9], GCA Corp. [10] and SCS Engineers [11]. The functions have been linearized with at least two line segments to allow for economics of scale. Where appropriate, the costs of several unit operations were averaged to produce composite functions. These curves include capital and operating costs, but not profit. Since many industries operate their own facilities, and since profit at independent facilities is extremely situation-dependent, no attempt was made to incorporate this cost.

Reconnaissance simulations of the hazardous waste management problem were made by formulating it as a simple routing problem. Initially, the whole residual inventory was taken to be thirteen source nodes corresponding to the thirteen Level II waste composition categories. All the disposal options were treated as either trans-shipment or ultimate sink nodes. This allowed for the inclusion of the underflow from "treatment" disposal alternatives. Constraints on the inputs to disposal options were controlled by the structure of allowable transportation links. Transportation costs were not considered. Optimum solutions were then achieved by using EPA's Waste Recovery Allocation Program (WRAP) to minimize total cost ([12], or see ref. [13] for a summary of the formulation and capabilities of WRAP). Although this method relies upon bold simplifications of a very complex problem, solutions of this model provided valuable insight into the evolution and current status of the hazardous waste disposal industry.

Example WRAP solutions are presented schematically in Figs. 2 and 3. Figure 2 illustrates the optimum solution if all options are presumed to be available in unlimited capacity. From this it can be seen that the crude economics (i.e., omitting factors such as transportation, profit, or refined unit operation costs) favor low technology, "storage" facilities over more desirable "destruction" technologies. Figure 3 illustrates how this situation would change if an alternative such as deep well injection is constrained away. Since bulk liquid disposal is not desirable at a secure landfill, the liquid waste fraction becomes a significant management problem and the "state" of the cost solution increases considerably.

Because solutions of this type rely on numerous simplifications, their greatest value would be for broad framework management planning. At this level they allow one to study the ramifications of mixes and capacities of disposal alternatives without becoming overwhelmed by unmanageable detail. Obviously, this approach does not include enough detail to support regional or local planning. For smaller space scales it is much more desirable to treat individual industries and their specific waste inventories as distinct source nodes. It is also true that transportation costs (or risks) have an important role to play and can even become the binding constraints for off-site treatment.

TABLE 8

Linearized cost functions for residual disposal options ($/ton)

Disposal technology	Line segment	Capital cost		Operating cost		Reference
		Slope	Intercept	Slope	Intercept	
Hydrocarbon incineration	1	5.99	23.3	41.5	420.0	A.D. Little, Inc. (1979)
	2	5.40	30.5	31.6	581.0	
Rotary kiln	1	144.4	71.0	619.0	1395.0	A.D. Little, Inc. (1979)
	2	107.3	471.0	613.0	1457.0	
Halogenated hydrocarbon incineration	1	70.1	68.6	395.0	543.0	A.D. Little, Inc. (1979)
	2	53.3	159.7	324.0	929.0	
	3	35.7	348.5	212.7	2131.0	
Solvent recovery	1	15.3	0.0	256.6	0.0	A.D. Little, Inc. (1979)
	2	7.7	16.0	83.9	360.0	
	3	3.8	32.1	48.8	506.4	
Oil recovery	1	3.48	11.1	176.5	464.0	A.D. Little, Inc. (1979)
	2	2.8	20.4	124.1	1188.0	
	3	2.3	35.2	120.7	1280.0	
Organic liquid treatment	1	4.1	8.6	9.28	48.9	EPA (1980) & GCA Corp. (1980)
	2	2.6	30.1	5.6	106.0	
Metals treatment	1	0.43	87.0	0.418	62.0	GCA Corp. (1980)
	2	0.20	426.0	0.31	233.0	
Neutralization	1	0.14	26.6	0.58	211.1	GCA Corp. (1980)
	2	0.07	133.1	0.49	361.2	
Anaerobic stabilization	1	0.10	35.7	0.08	15.6	EPA (1980)
	2	0.05	137.6	0.04	83.3	
	3	0.03	471.0	0.022	444.0	
Aerobic stabilization	1	0.01	30.2	0.022	26.7	EPA (1980)
	2	0.009	32.0	0.01	44.4	
	3	0.007	71.0	0.007	89.0	
Activated sludge	1	0.02	24.9	0.018	38.0	EPA (1980)
	2	0.015	36.0	0.016	67.0	
Deep well	1	1.92	0.79	1.86	0.22	GCA Corp. (1980)
	2	1.04	4.40	1.52	1.70	
	3	0.55	24.90	1.20	15.00	
Secure landfill	1	19.5	134.5	58.1	566.6	A.D. Little, Inc. (1979)
	2	11.3	178.7	54.0	588.0	
Landfarm	1	7.90	42.3	1.67	6.8	EPA (1980)
	2	5.02	63.3	1.23	10.0	

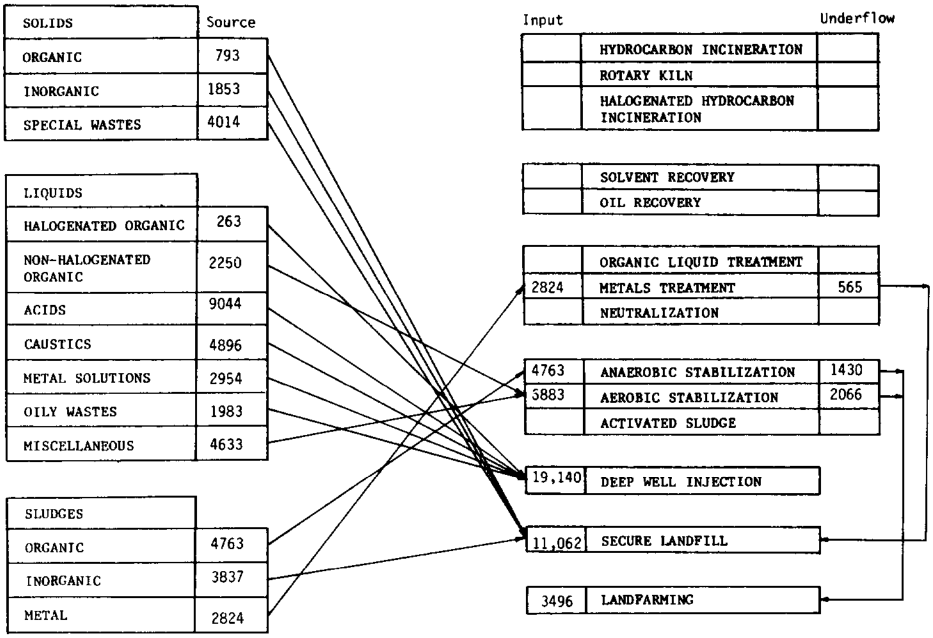

Fig. 2. Unconstrained least-cost hazardous residual routing solution (activities in thousands of metric tons).

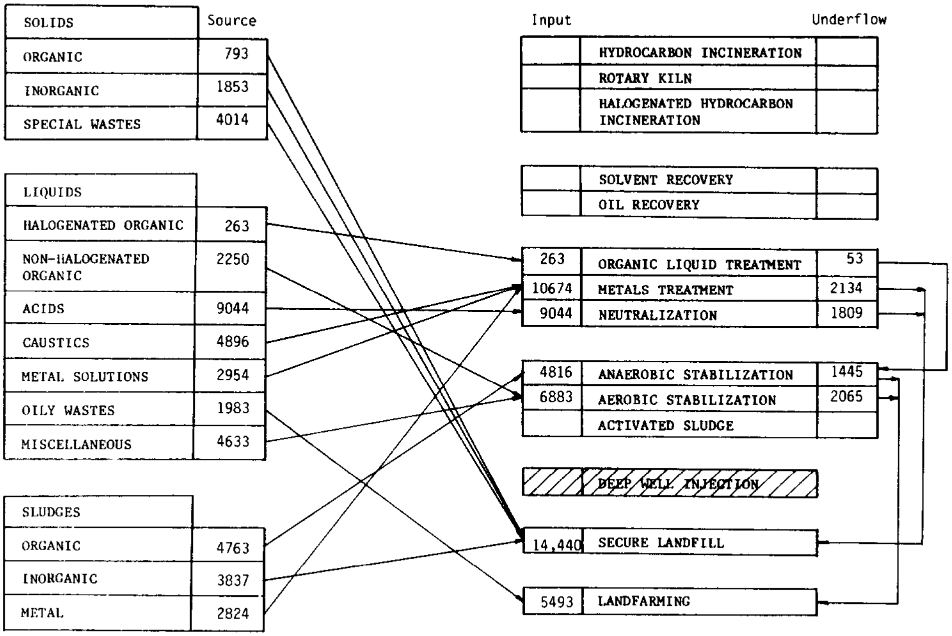

Fig. 3. Least-cost hazardous residual routing solution if deep well injection is omitted (activities in thousands of metric tons).

Finally, as presented, this technique is far too mercenary. It is unreasonable to expect that hazardous waste management problems will be solved based only on disposal economics. There is simply too much risk at stake and too much genuine concern about risk to ignore it.

Sholar [14] has shown that realistic regional management plans may be formulated to include the above considerations within the context of a WRAP solution. It is not intrinsically more difficult to treat a reasonable number of industries as individual source nodes, and to assign their waste inventories at these locations. Actual transportation economics may then be imposed. This allows for a more realistic study of the efficiencies of on-site versus off-site management. The economics of disposal may also be enriched with much more precise information once specific unit operations have been specified.

Jennings [3] and Sholar [14] have also shown that the acute and chronic risks of transportation and disposal may be imposed on the transportation problem as alternative penalty functions. When these considerations are organized into a cardinal risk scale, WRAP may be used to achieve the optimum solution at minimum total risk. Sholar used the DARE algorithm of Klee [15] to produce the required risk scale, but any of several currently available techniques would suffice [16]. By using this modelling procedure, the relative risks of management scenarios may be quantified, and the trade-offs between risk and cost may be explored.

6. Summary and conclusions

The results of a survey of the United States hazardous waste generation have been presented. It was found that although data availability in some portions of the country is quite marginal, sufficient information exists to construct profiles of generation by industrial origin and by chemical composition. Although several states reported that the availability and quality of information was expected to improve markedly as a result of RCRA [17] regulations, a surprisingly large number apparently have no plans for assembling additional information. In the absence of better alternatives, the results of this survey could be used to synthesize a regional waste profile sufficient for framework management planning. This would be done by constructing the local SIC code industrial profile (from [6]) and then applying the generation factors of Table 5.

A method of analysis has also been presented that allows the existing data to be incorporated into residual management planning models. This is based on a simplified waste reclassification scheme that reduces the number of categories to the relative few that possess unique treatment and/or disposal possibilities. It has been shown that this allows existing routing problem solvers such as WRAP to be used to study the cost and risk trade-offs of proposed management scenarios.

Although the methods reported here evolved from a search for research priorities, it is believed that their greatest potential is in the area of disposal planning and management. The modelling technique has proven to be quite resilient and responds well to the increased intensity of data necessary for realistic regional planning. The Waste Resources Allocation Program has also proven to be a sufficiently flexible tool for accomplishing these more detailed plans.

Acknowledgement

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