SOLID WASTE DISPOSAL IN RURAL AREAS: ECONOMIC IMPLICATIONS*

Harry W. Ayer and David W. Hogan

Solid waste disposal is a significant problem. It has been estimated that almost a ton of solid waste is collected per year per capita in the United States. Solid waste disposal, especially in rural areas, is frequently done in an unsanitary, potentially dangerous and often unslightly manner. To cope with these solid waste problems, both state legislatures and the Environmental Protection Agency are now in the process of requiring communities which presently utilize unsanitary disposal practices to upgrade their facilities and management practices. A sanitary landfill operation[1] is usually the least-cost method of accomplishing these requirements, especially in rural areas.[2] Quality facilities and management practices are not costless, however. It is estimated that the U.S. spends more than $4.5 billion each year on solid waste management, and more than 80 percent of this amount is for collection [5, p. 1].

Rural communities face particularly difficult problems of solid waste disposal. First, many communities have a history of unsanitary disposal practices. Refuse has often been disposed of in a least (dollar) cost way—in open-burning dumps, modified dumps or in many cases, dumping on the open countryside. Arizona offers an example: Of 156 disposal facilities reported in Arizona in 1973, only 36 were sanitary landfills while 65 were open-burning dumps and 55 were modified dumps [9]. The second cause for particular concern in rural communities is the high cost of implementing sanitary practices for soild waste disposal. Many, if not most, rural communities are pressed to generate sufficient revenues to cover programmed costs, and addition of a sanitary landfill program would increase costs of government operations substantially. For example, in 1966-67, Arizona municipalities with 1960 populations of 25,000 and less had expenditures of $2,221,000 for solid waste disposal.[3] These expenditures represented seven percent of all general expenditures by these municipalities and were larger than expenditures on public welfare, health, hospitals, fire protection, libraries and other individual items [10]. Most likely, new regulations will force the proportion of expenditures on solid waste disposal even higher.

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[1] A sanitary landfill is a disposal site for refuse which is located and managed to prevent the occurrence of health hazards and nuisances. More specifically, it is to be located where seepage and drainage do not cause health hazards or nuisances. Management requires that refuse be covered and compacted daily with six to twelve inches of soil, and that the final layer of compacted soil be two or more feet deep. Provision is to be made for the control of insects, rodents and blowing refuse. No burning is permitted and an all-weather access road is required.

[2] Sanitary landfills are generally recognized as the least-cost method of disposal — especially in rural areas. Golueke [2] reports an average cost of disposal by sanitary landfills of $1.13 per ton of solid waste disposed, with a range in cost of from $0.50 to $2.00 per ton depending on system management. Costs of incineration, a partial substitute for sanitary landfill disposal, are reported to be from $4.00 to over $12.00 per ton. Clearly, given present technology and input costs, the sanitary landfill is the cheapest means of disposal for rural areas with an abundance of landfill sites. In certain urban areas where land sites are relatively scarce, site costs may make other techniques more advantageous.

[3] The more exact definition of this budget item, as per the 1967 Census of Governments [7], is "sanitation other than sewage" and includes "street cleaning and collection and disposal of garbage and other solid wastes."

Rural areas, as distinguished from urban settings, have unique conditions within which they must operate to minimize costs of refuse disposal. First, distances between concentrations of population are relatively great. Since transportation costs are the largest component of total solid waste disposal system costs, the distance factor makes total costs particularly sensitive to source-site assignments and the economies of centralized disposal facilities may be muted. Furthermore, it may be hypothesized that greater distances and sharply higher fuel prices will dictate more disposal sites in order to minimize total system costs.

Another characteristic of rural areas is diversity in governments which may be responsible for providing refuse disposal services. Governments of incorporated towns, unincorporated towns and the county may all provide for refuse disposal. Clearly the unilateral decision of any one governmental unit to provide disposal services for its own constituency, and possibly for others, may affect total regional costs of refuse disposal.

Research reported herein explores the consequences of these various characteristics of the solid waste disposal problem in rural areas.

THE STUDY AREA

Greenlee County, Arizona is used as a case study area. This area was selected because its present system of solid waste disposal is considered inadequate and must be changed in the near future. Also, town size and location present an opportunity to determine the economies of consolidating disposal services in small, separated rural communities. And finally, there is a diversity of governments which may provide for solid waste disposal, allowing investigation of the impact of unilateral decisions on total system costs.

Greenlee County is rural in nature – in 1970 only 10,330 people inhabited its 1,879 square miles and the largest town, Clifton, had a population of only 5,087. Next largest towns are Morenci and Duncan, with 1970 populations of 2,271 and 773, respectively. Other settlements within the study area include Franklin, York Valley, Apache Grove, Verde Lee and Loma Linda. Forty-three miles separate the most distant towns, Morenci and Franklin. Locations of the towns and settlements are shown in Figure 1.

A region's governmental structure is, in part, responsible for the type and extent of solid waste disposal services provided. In the study region, three levels of government provide these services – the county, incorporated towns and unincorporated towns. In addition, disposal services may be provided

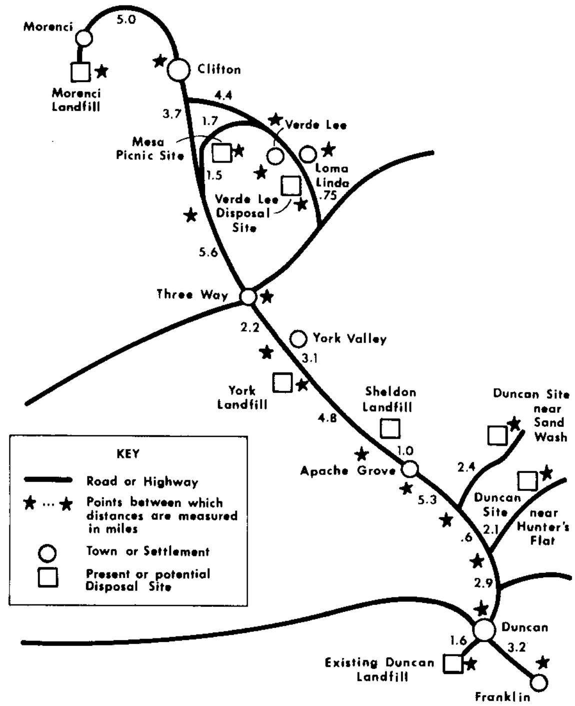

FIGURE 1. MAP OF THE STUDY AREA

by private businesses. Solid waste from the unincorporated town of Morenci is collected and disposed of by the Phelps-Dodge mining company which owns and operates the town. Because of this arrangement, disposal of Morenci's refuse is not considered in our analysis. Phelps-Dodge also provides disposal services for the nearby incorporated town of Clifton for a fee of $1,000 per month. Collection and transportation of Clifton solid waste is provided by the town. The other incorporated town, Duncan, operates both collection and disposal facilities for its residents and disposes of refuse from the unincorporated town of Franklin. The remainder of the region is serviced by the county which operates two landfill sites, a two-acre site at York Valley which has nearly reached capacity and a ten-acre site near Sheldon. County sites do not meet sanitary standards set by the state; and the county does not provide collection and transport services, but they are available through a private company. In addition to sites presently in use, four other locations were suggested by county officials as potential landfill sites. Recommendations were based on ready availability of particular sites and upon proximity to solid waste sources. Both present and potential sites are considered as possible landfill locations in determining a least-cost system of solid waste disposal for the region. Present and potential sites are depicted in Figure 1.

THE LEAST-COST MODEL

Specification of a least-cost configuration of disposal sites for solid waste disposal requires that many factors be considered simultaneously: distances between sources of solid waste and potential disposal sites, quantity of solid waste generated at each source, ownership costs (depreciation, interest, insurance, taxes) of land and capital at the disposal site, operating costs at the disposal site, ownership and operating costs of equipment for transporting solid waste from the source to disposal sites, ownership and operating costs of equipment to transport disposal equipment (a crawler tractor) between disposal sites, and administrative expenses. To facilitate analysis of these factors, a computer algorithm developed by Norman Morse and Edwin W. Roth [6] for the Bureau of Solid Waste Management was modified and used. The model has the capability of exploring many potential variations within solid waste management systems. Variations involve altering (1) site possibilities, (2) communities which might administratively be candidates for inclusion in the system, (3) amount of solid waste generated, (4) types of facilities available (such as transfer stations or processing plants), and/or (5) facility parameters such as operating and transport costs.

The least-cost model examines costs of all possible combinations of disposal sites and source assignments to disposal sites given a specified amount of solid waste, capital and operating costs of transport and disposal, and distances between sites and sources. In making the selection of a least-cost system of sites, the model specifies which disposal sites would be used, assigns solid waste generated at each community to a particular disposal site, specifies total cost of the least-cost system, and allows costs to be partitioned among various disposal activities. A more complete, mathematical specification of the model is given in Appendix A.

RESULTS AND IMPLICATIONS

Data collected from the study area for 1973 and secondary sources are used in the least-cost computer algorithm to determine costs of alternative configurations of sanitary landfill sites for solid waste disposal for the Greenlee County area. Of particular concern are the effects of a centralized disposal site, higher fuel costs and unilateral governmental actions on the least-cost solutions.

Centralized Facilities

In investigating potential cost savings from site centralization, it is assumed that all eight potential sites are available, and that any of the seven communities could send solid waste to any site (i.e., there are no administrative restrictions to prevent such site-cource combinations). The least-cost model chooses the number of disposal sites and source-site assignments which minimizes total system costs.

Economies of partial, but not complete, centralization of solid waste facilities are found to exist. Itemized data pertaining to costs of alternative configurations of source-site assignments are given in columns (1) through (4), Table 1. The least-cost system (column 1) had two sites, and total annual costs of $78,352. The second best system (column 2) used three sites, with an annual cost of $79,505. Costs of transportating refuse are considerably less, $40,002 vs. $47,401, by using three instead of two disposal sites, but the added fixed costs of the disposal facility and the costs of transporting the crawler tractor between the added sites more than offset transport gains. The third best solution (column 3) had only two sites, resulting in higher transport costs but lower facility and tractor transport costs than the second best solution.

The system costs of two (columns 1 and 3) and three (column 2) sites were also compared to estimated costs of the "present system" which has four sites (column 4). This "present system" estimated cost is $84,726, over $6,000 more than the least-cost system. Costs of refuse transport for the "present system" are considerably less than those of systems with fewer sites, but costs to develop facilities are considerably greater.

Costs of employing only one disposal site (complete centralization) are substantially higher than any of the four alternatives noted above. If only one site is used, system costs range from $102,000 to $225,000, depending on which site is chosen.

Results show there is no generally applicable rule for minimizing costs simply by decreasing or increasing number of disposal sites. Rather, a multiplicity of factors as described above must be taken into account. Site location, for example, can make a tremendous difference in costs, as illustrated by cost estimates of a one-site system.

In summary, estimates indicate that, while site-source selection has a significant impact on system costs and partial centralization may be most economical, site development costs, site location, source-site selection and other factors must be considered simultaneously to determine a least-cost system.

The Impact of Fuel Price Increases

Effects of sharply higher fuel costs on source-site selections are shown in columns (5) and (6),

TABLE 1. ANNUAL COSTS OF SOLID WASTE DISPOSAL UNDER ALTERNATIVE ASSUMPTIONS

Cost Categories[b]	(1) Least-Cost System	(2) Second Best System	(3) Third Best System	(4) Present System	(5) 1973 County System	(6) 1973 County System with Doubling of Costs/mile of Refuse Transport	(7) 1973 Joint County - Municipal System
	Facility-Source Assignment[a]						
	1-C,VL 4-LL,Y,AG, D,F	1-C,VL 4-LL,Y 5-AG,D,F	1-C,VL,LL 5-Y,AG,D, F	1-C 4-VL,LL,Y 5-AG 8-D,F	5-VL,LL,Y, AG,D,F	5-VL,LL,Y, AG,D,F	1-C,VL 4-LL,Y,AG 8-D,F
	dollars						
Fixed Cost of Disposal Facility	1,603	5,553	3,950	16,652	3,950	3,950	12,702
Direct Disposal	9,339	9,339	9,339	9,339	4,203	4,203	9,339
Owning Costs of Tractor	6,617	6,617	6,617	6,617	6,617	6,617	13,234
Salary of Tractor Operator	7,892	7,892	7,892	7,892	7,892	7,892	15,784
Administrative	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Educational	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Owning Costs of Truck to Move Tractor	0	2,060	0	2,060	0	0	0
Owning Costs of Trailer to Move Tractor	0	1,040	0	1,040	0	0	0
Tractor Transportation	0	1,498	0	5,054	0	0	0
Refuse Transportation	47,401	40,002	47,126	30,572	28,473	56,271	32,404
Total Annual	$78,352	$79,505	$80,424	$84,726	$56,635	$84,433	$88,963

[a]Numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area, (3) Verde Lee disposal site, (4) York landfill, (5) Sheldon landfill, (6) proposed Duncan site near Sand Wash, (7) proposed Duncan site near Hunter's Flat, (8) existing Duncan landfill. Letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

[b]Costs are derived from primary data as given in (4). A summary itemization of the costs follows:

Fixed cost of disposal facilities = land acquisition ($10/10 acre parcel) + fencing ($237/ac) + cattle guard ($800/landfill) + sign and tools ($167/landfill) + access road ($5,400 for undeveloped site; 0 for developed site) + initial grading ($1,200 for undeveloped site; $600 for developed site).

Direct disposal costs are computed from the following: A D6C crawler tractor is used in landfill operations and uses seven gallons of diesel fuel per hour of operation; fuel costs $.21 per gallon. Oil, grease and filter costs are estimated to be 15 percent of fuel costs. Repair costs are estimated to be $1.58 per hour of operation. Fuel; oil, grease and filter; and repair costs are adjusted to an hourly basis, and to a truckload basis as described in Hogan [4]. Costs per truckload are $3.32.

Owning costs of a D6C crawler tractor are based on an initial investment of $46,500, a 10-year life and salvage value at year 10 of $13,718, interest at eight percent per year on the average investment, and insurance and tax costs of two percent of the initial investment. Owning costs equal $4,617 per year.

Salary of tractor operator is estimated by county administrators at $7,892/year.

Administrative expenses are estimated by county administrators at $4,500/year.

Educational expenses are costs of informing the public of laws, restrictions and proper means of solid waste disposal, and assumed to be $1,000 per year.

Owning costs of a truck to move a crawler tractor are based on an initial investment of $14,000, a 10-year life and salvage value of $3,000 and interest at eight percent on the average annual investment. Insurance and tax costs are assumed to be two percent of the initial price. Owning costs are computed to be $2,060 per year.

Owning costs of a trailer to move a crawler tractor are based on an initial price of $8,000, a 10-year life and salvage value of $4,500, and interest at eight percent on the average annual investment. Insurance and tax costs are assumed to be two percent of the initial investment. Owning costs are computed to be $1,040 per year.

Tractor transportation costs, the operating costs of transporting a crawler tractor between facilities, are assumed to be $.50/mile. It is assumed that each landfill is open six days per week and, to meet sanitary landfill requirements, wastes are covered each day deposited.

Refuse transportation costs are based on primary data from Clifton in which annual costs were computed as follows: salary ($27,600) equipment and supplies ($861), truck repairs ($1,605), truck gasoline ($2,945), miscellaneous ($332), truck depreciation ($5,487). Costs per truckload mile are computed to be $2.53.

Table 1.[4] Fuel cost was not the largest budget item in refuse transport. For example, 1973 fuel cost for this in Clifton, where primary data were available, was approximately $3,000 of a total transport cost of nearly $39,000. Salaries were by far the largest component, and for Clifton equaled $27,000. Total cost per truckload mile of transporting refuse is computed to be $2.53; doubling the price of fuel from approximately $0.25 per gallon raises the cost per truckload mile to approximately $3.00. Even if the price per truckload mile is raised to $5.00, implying fuel costs of over $2.50 per gallon and the assumption of column (6), site-source assignments remain unchanged. Thus, policy regarding the optimum configuration of sanitary landfill sites should not be altered as a result of higher fuel costs — they are too small a fraction of total transport costs.

Consequences of Unilateral Decisions in a Multigovernment Region

In discussing "the importance of centralized facilities," the least cost set of sanitary landfill sites was found to be $78,352. This solution assumes that governments representing the area's people could and would choose disposal sites and assign sources to the sites in a way which minimizes costs. Diversity of governments in the region may inhibit such an allocation, however. For example, if the town of Duncan operates its own crawler tractor (which it presently does) and disposes of solid waste delivered to the Duncan site from Duncan and Franklin (as is presently the case), and the county operates a separate crawler tractor to service the York landfill, *added* costs of disposing of the area's solid waste would be $10,611 per year. A comparison of itemized costs is shown in columns (1) and (7) of Table 1. These data show that although costs of transporting refuse are decreased because of the additional site, added fixed costs of another disposal facility and duplicate ownership costs of a crawler tractor and tractor operator increase total system costs substantially.

Another possible administrative arrangement would be to assume Clifton sends its solid waste to the Morenci site, and that the Morenci site is unavailable to other towns for refuse disposal. Clifton presently has an agreement with Morenci-Phelps Dodge authorities to dispose of its solid waste, but it is unknown if refuse from other localities would be accommodated at Morenci. It might also be assumed that the York landfill is unavailable since it has nearly reached capacity. Given these circumstances, the least-cost solution calls for all solid waste outside Clifton to be disposed at the Sheldon landfill. Costs of collection, transport and disposal at Sheldon are $56,635 (column 5, Table 1). Costs of collection and disposal of Clifton refuse are approximately $50,000. Thus, total system costs are over $106,000, nearly $28,000 more per year than if the least-cost method, disregarding unilateral administrative actions, had been followed.

SUMMARY OF CONCLUSIONS

Some economies of centralization of solid waste disposal may well exist in rural areas. In the case studied, significant annual savings result in having only two instead of the present four disposal sites. Studies by Clayton and Hine [1], Hardy and Grissom [3], and Schreiner, *et.al.* [8] showed cost savings from consolidation of solid waste systems within rural regions. However, the high cost of transportation in a disposal system dictates against using only one disposal site for the case studied. No simple generalization can be made for the degree of centralization which all rural communities should adopt for a least-cost configuration of sanitary landfill sites for solid waste disposal. As demonstrated, several factors must be considered simultaneously in devising a least-cost system. Besides number of sites and distances between them and the sources, it is essential to consider site location, costs of developing various sites, costs of transporting the crawler tractor between sites and other items.

A second important finding of the study is that a large increase in fuel costs (to over $2.50 per gallon of gasoline) does not affect the least-cost number of disposal facilities and source-site assignments. Fuel costs are simply too small a portion of total transport costs.

Finally, it was demonstrated that unilateral policy pertaining to solid waste disposal on the part of one of a region's various governments may significantly affect total costs of disposing of the region's refuse. Salkin [7] reached this same conclusion for a set of Oklahoma communities. While this analysis refers to a particular set of communities in Arizona, many of the conditions prevailing in these communities are similar to other rural areas and general implications of these results are expected to be applicable in many rural areas.

[4]The "1973 County System" displayed in columns (5) and (6) differed from the system of columns (1) — (4) because of assumed initial conditions within which costs were minimized. In contrast to the conditions assumed in columns (1) — (4), the "1973 County System" assumed Clifton not part of the system and Morenci and York landfills unavailable for waste generated at remaining sources. These conditions are plausible given the administrative arrangement which presently enables Clifton to use the Morenci disposal site, and the limited size of the York site. The fact that the "1973 County System" was used to test the impact of higher fuel prices is coincidental.

APPENDIX A

THE LEAST-COST MODEL

Specification of a least-cost system of solid waste disposal requires that many factors be considered simultaneously. To facilitate analysis of these factors, a computer algorithm developed by Morse and Roth (1970) [6] is modified and used in the analysis.

The number of potential facilities in the model is designated by "J". A facility is either a processing plant (i.e., incinerator, truck transfer station) or a disposal site (sanitary landfill) and is indexed by "j" with $1 \leq j \leq J$. There are "I" solid waste source locations indexed by "i" with $1 \leq i \leq I$. The quantity of refuse originating in "i" is denoted by q_i. Each facility (i) has parameters associated with it which describe its operation. Fixed cost of the facility is denoted as A_j, and variable cost of disposal at the facility is denoted by c_j. Compaction capability of the facility is denoted by p_j. Cost of transporting a unit quantity of refuse (one truckload) to a facility in collection vehicles is denoted by c_t per mile. The distance factor d_{ij} is the distance from source "i" to facility "j".

Using facility parameter data, calculation of k_{ij}, variable cost per truckload of disposing of refuse generated at source "i" and disposed of at facility "j", for each facility is computed as:

$$k_{ij} = (c_j \cdot p_j) + (c_t \cdot d_{ij})$$

The computer analog begins a selection process to determine the total system cost for different combinations of facility selections and source-facility assignments. The initial selection computes system costs if only one of the "j" possible facilities is used. The total system costs are:

$$TC = K_{ij} + \sum_{1}^{j} A_j + SFC_1 + SFC_2$$

where

TC = total annual cost of the disposal system, including both collection and disposal costs

K_{ij} = total variable costs (cost per truckload times number of truckloads) of collection and disposal = $\sum_{1}^{i} k_{ij} \cdot q_i$

SFC_1 = fixed cost of a crawler tractor and operator to dispose of the area's waste, plus costs of administration and education needed for the system and

SFC_2 = fixed cost of owning a truck and trailer to transport the crawler tractor between facilities plus variable costs of transporting the crawler tractor among the facility sites.

After the initial calculation has been made assuming only one disposal facility, the selection routine is repeated under the assumption that a different facility is available. Total costs of this system are computed. After total costs are computed for all systems in which only a single disposal facility is available, the analog investigates total system costs if two facilities are available. In this case the analog "inspects" the variable costs of collection and disposal (k_{ij}) of assigning a particular source to each of the possible facilities, and assigns the source to the facility with the smallest k_{ij}. This procedure is accomplished for each source, and total cost of the system with these two particular facilities is computed.

The foregoing procedure is repeated for all possible combinations of various numbers of facilities and total costs for each combination of facilities and sources computed.

Costs of a system which could include processing plants "j′" (such as incinerators or truck transfer stations) is analyzed in a similar manner. Variable costs per truckload of refuse generated at source "i" and disposed of in facility "j", are computed as k_{ij} as before without going through a processing plant. Then another set of k_{ij}'s are computed such that:

$$k_{ij} = c_m \cdot p_j + (d_{ij'} \cdot c_t)$$

where

k_{ij} = cost per truckload of disposing of refuse generated at source i and disposed of in facility j, after being processed in processing plant j′

c_m = cost per truckload of processing at j′ plus transportating refuse from the processing plant j′ to the disposal site j plus disposing at j

$= c_{p(j')} + P_{j'} (c'_t \, d_{(j',j)} + c_j)$

$c_{p(j')}$ = cost per truckload of processing at "j′"

$P_{j'}$ = volume reduction coefficient of the processing plant

c'_t = cost per truckload mile of transportation from processing plant j′ to disposal at j

$d_{(j',j)}$ = distance from processing plant j' to disposal site j

c_j = cost per truckload of disposal at j

$d_{ij'}$ = distance between source i and processing plant j'

c_t = cost per truckload mile of transporting unprocessed refuse and

p_j = volume reduction coefficient.

Total costs for each system are computed much the same as with no processing plants considered. In this case however, the analog also determines which disposal facility should be assigned output from the processing plant in order to minimize cost of transportation between plants and facilities.

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