Solid waste disposal in rural Arizona: application of a least- cost model

SOLID WASTE DISPOSAL IN RURAL ARIZONA:

APPLICATION OF A LEAST-COST MODEL

by

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ABSTRACT

Solid waste has become a significant pollution problem in recent years. To meet this problem, unsanitary systems of solid waste disposal are being changed by governments and by concerned individuals. The changes required for operation of a sanitary disposal system for solid waste are likely to be costly for communities. Therefore, these communities have a need for a least-cost solution to their solid waste problem.

It is the objective of this study to design a least-cost decision making model and apply the model to a rural area. The model considers the costs of establishing and operating a collection service and disposal site, and considers all possible combinations of sites and site-source assignments in designating the least-cost system. Greenlee County is selected as the study area. A least-cost system of solid waste disposal is determined for the study area given a selection of possible disposal site locations and the costs involved in setting up and operating a solid waste management system. The model specifies the least-cost facility selection, the source assignments, and the total cost of the least-cost system of solid waste disposal. An analysis of the sensitivity of the least-cost solution to changes in administrative arrangements and the cost variables used to determine the least-cost solution is also made.

CHAPTER I

INTRODUCTION

The problem of solid waste pollution in the U.S. has reached such dimensions that while not as widely recognized as water and air pollution, it is as least as acute. It has been estimated that almost a ton of solid waste is collected per year per capita in the United States--an amount which, if compacted to 800 pounds per cubic yard (Shirk, 1972) would cover a city the size of Tucson to a height of six feet (see Appendix A). By 1980, the "pile" would be 10 feet high. Today much of the solid waste disposal is done in an unsanitary, potentially dangerous, and often unsightly manner. Many disposal sites provide an excellent breeding ground for vermin and insects which transmit disease. Others are dangerous because of smoke, obnoxious odors, dangerous gases from open burning, or they may be potentially dangerous to children who wander into the sites. Blowing paper and debris and the site itself are normally offensive to our aesthetic desires. To cope with the large amounts of solid waste generated, and with the potential solid waste pollution problems, it is estimated that the U.S. spends more than $4.5 billion each year on solid waste disposal (Kiefer, 1972, p. 1).

The solid waste disposal problem in Arizona is also significant. If Arizona's solid waste, estimated to be approximately 1,618,253 tons in 1970, was collected, compacted, and piled on a football field, it would reach one-half mile high and by 1980 the "pile" will grow to approximately one mile high (see Appendix B).

Arizona's solid waste problem has quality as well as quantity dimensions. Of 156 disposal facilities reported in Arizona in 1973, only 36 are sanitary landfills while 65 are open-burning dumps and 55 are modified dumps (Shonerd, 1973). Of the 156 facilities, only the sanitary landfills meet the requirements of state law (see Appendix C). The State Department of Health and the Environmental Protection Agency (EPA) are forcing communities which presently utilize the unsanitary disposal facilities to upgrade their facilities to meet the requirements (see Appendix C).

The changes being forced by the EPA and the State Department of Health will not be costless to Arizona communities. The financial burden may be especially sharply felt in smaller communities. For example, Graham County's sanitary disposal system (disposal but no collection service), which includes six county disposal sites with one crawler tractor transported between the sites to make daily coverage, has a 1973-74 budgeted cost of $30,352. Safford, a community in Graham County, operates a municipal collection and disposal system with estimated annual collection costs of $80,100 and disposal costs of $13,900 (Rawson, 1973).

Objectives

Because of the large capital investment in setting up a solid waste disposal system and substantial operating costs, plus frequent budget restraints, communities have a need for a least-cost solution to their solid waste problem. Thus, the overall objective of this study is to develop and demonstrate a framework which will enable the design of a least-cost solid waste disposal system by the planning agencies of rural Arizona. The specific objectives are:

(1) to develop a model which analyzes alternative combinations of disposal sites, transfer stations, and source-facility assignments to determine the least-cost combinations.

(2) to test the model on a specific region in rural Arizona by determining a least-cost solution for solid waste disposal in the region,

(3) to determine how the least-cost solution varies over time as the region's solid waste generation increases.

(4) to determine the sensitivity of the least-cost solution to changes in various parameters (such as operating and transport costs) specified in the model.

Greenlee County, Arizona is the area that will be studied in the investigation. Greenlee County was selected as the study area because it has an inadequate solid waste disposal system and in the near future it must upgrade its facilities.

In the next chapter the framework of analysis, including specification of the least-cost model, is presented. The third chapter "profiles" the study area and discusses the data requirements. The empirical results of using the least-cost model and data are presented in Chapter IV. Here the least-cost systems, under different assumptions about possible disposal sites, amount of solid waste generated, costs, etc., are specified. The final chapter summarizes the results, offers suggestions for a Greenlee County system of solid waste disposal, and gives suggestions for future research.

CHAPTER II

FRAMEWORK OF ANALYSIS

To develop the framework for analysis, it is necessary to consider the components of a solid waste disposal system as well as theoretical considerations pertinent to a least-cost model. The components of the solid waste disposal system are discussed first in this chapter followed by a discussion of the importance of economies of scale and the "transportation problem." Finally the analytic model adopted for the present study is discussed.

The Solid Waste System

In designing a solid waste management system, three system stages must be considered. Storage, the first stage in the system, consists of storing the solid waste until sufficient quantities can be accumulated to warrant collection. Storage can be achieved through the use of collection bins placed at convenient locations, as often used in commercial areas, or by storage in garbage cans by the residential sector.

Collection, the second stage of the system, involves the gathering of the solid waste at the points of storage and the transportation of the solid waste to the final site for disposal. Collection is the most expensive of the three stages. "The United States spends more than $4.5 billion annually on solid waste management--and more than 80 percent of that goes for collection" (Kiefer, 1972, p. 1).

Final disposal is the third and final stage in the solid waste management system. Disposal can be accomplished in a sanitary manner with different types of disposal facilities. The most common types include the sanitary landfill and high-temperature incineration. In Arizona the sanitary operation of these facilities is subject to minimum standards of pollution control as established by the State Department of Health (see Appendix C). Accordingly, this study will investigate the alternative formulations of a solid waste management system which will meet these minimum requirements and select the formulation which exhibits the least cost.

The largest components of the total cost of a solid waste management system are collection costs and disposal costs. Annual collection costs are primarily the costs of labor (approximately 60 percent) and the costs of equipment operation (approximately 12 percent) (Danenhauer, 1973). Annual disposal costs are influenced not only by the fixed costs of the disposal facility (approximately 50 percent), but also by the equipment (approximately 21 percent) and personnel costs (approximately 28 percent) associated with the actual disposal of the waste (Weddle, 1973).

Economies of Scale

Economists have long recognized the importance of economies of scale in understanding the least-cost size of a business operation. Economies of scale refer to the lowering of the cost per unit of output by utilizing a larger, more centralized plant. In solid waste disposal, economies of scale have also been found to be significant. For example, Schreiner (1973, pp. 22-24) of Oklahoma State University states that "because of imperfect divisibility of capital inputs landfill disposal methods show significant economies of scale. Excluding land costs, expected disposal costs per ton of solid waste were more than three times as much as for the smallest landfill capacity versus the capacity for a metropolitan area of about 250,000." Sorg and Hickman (1968) also found significant economies of scale, as indicated in the graphs of Figure 1. However, these economies of scale may not be available to rural areas because of sparse population densities. "Capacities of over one million tons annually tend towards a cost of $.63 a ton, but such capacities are unrealistic for rural areas. Cost per ton almost doubles for capacities of 50 thousand tons annually over the minimum cost size and equals $3.42 per ton for capacities of only 10 thousand tons" (Schreiner, 1973, pp. 39-40). Thus, to obtain a least-cost solution the economies of scale for the disposal activity have to be balanced against the increased collection costs realized by moving to a more centralized system.

The Transportation Problem

Because of the relatively high costs of the collection stage of a solid waste system, the locations of the landfills are of prime importance in a least-cost solution. That is, site location effects the transportation costs of moving a product (solid waste) from a number of origins (generating sources) to a number of final demand centers (final disposal sites). This is the basic transportation problem. Pioneer contributions to the transportation problem were made by F. L. Hitchcock in "The Distribution of a Product from Several Sources to Numerous

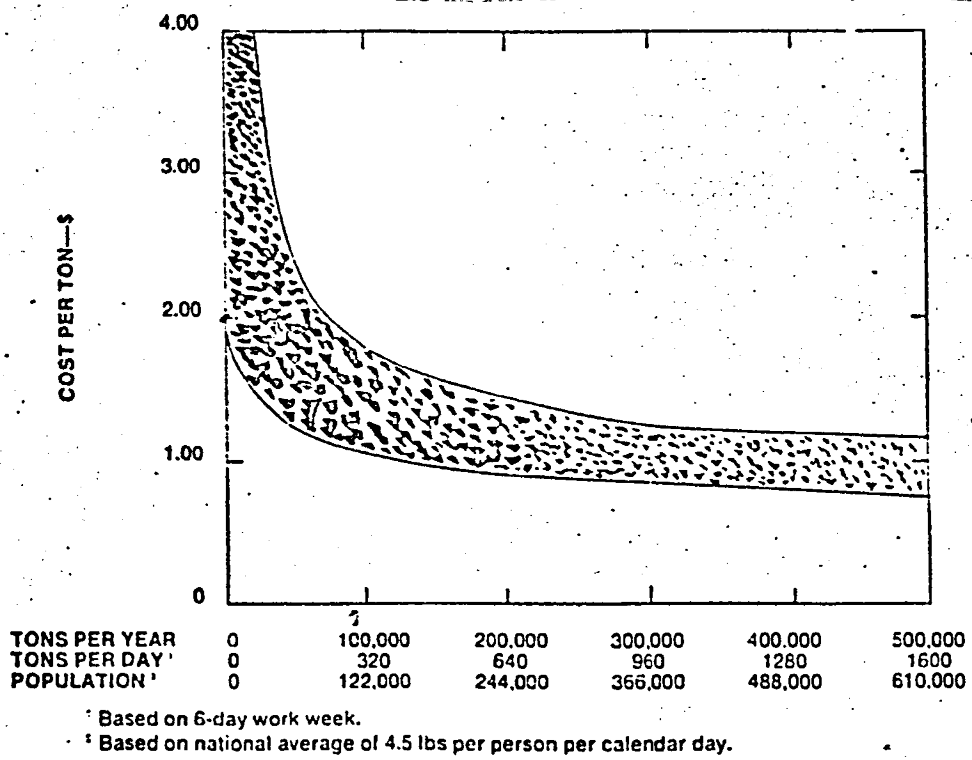

Figure 1. Economies of Scale in Sanitary Landfill Operations.

Localities" in 1941 and by T. C. Koopmans in the article "Optimum Utilization of the Transportation System" in 1947 (Thierauf and Grosse, 1970, p. 296). The solution of transportation problems has been further advanced by the use of linear programming which utilizes the digital computer.

The specification of optimum warehouse location was discussed by Robert S. Firch (1960) in "Optimum Warehouse Location: A Problem in Non-Linear Programming." The Firch study formulates a model which determines the optimum placement of warehouses for dispersion of the product to a number of final demand centers. The situation is reversed for the solid waste management problem. The basic transportation model does not allow for the optimum choice of final demand centers (final disposal sites) which is crucial if we are to balance the economies of scale of the disposal activity against the increasing costs of collection.

The Least-Cost Model

The specification of a least-cost system of solid waste disposal requires that many factors be considered simultaneously. To facilitate the analysis of these factors, a computer algorithm developed by Norman Morse and Edwin W. Roth (1970) for the Bureau of Solid Waste Management was modified and used for the analysis. Through the use of a generating subroutine the costs of all possible combinations of disposal sites and source assignments are investigated. The transportation costs and disposal costs for each of these combinations are computed and the model is designed to assign the sources to the disposal facilities in a least-cost manner. By varying the facility parameters (such as facility operating costs and transport costs) the model has the capability of exploring many potential variations within the solid waste management system. The model can also investigate the system costs of using truck transfer stations and incinerators. It can be used to generate costs for improved incineration and landfill operations. Its main use, and the focus in the present study, is in determining a least-cost system of solid waste disposal--in this case for an area of Greenlee County.

Model Specifications

The number of facilities 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" sectors of generation, approximated by point sources, 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. The fixed cost of the facility is denoted as A_j, and the variable cost of disposal at the facility is denoted by c_j. The compaction capability of the facility is denoted by p_j. The 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 the input data (solid waste quantity data, facility parameter data, and distance data) the calculation of k_{ij} for each facility is made in the following manner:

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

where: k_{ij} = the total variable cost (per truckload) of disposing of refuse generated at source "i" and disposed of in facility "j"

c_j = variable cost of disposal at site "j" (cost per truckload)

p_j = volume reduction coefficient

c_t = variable cost of transportation (cost per truckload mile)

d_{ij} = distance from source "i" to facility "j"

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

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

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

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

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

SFC_2 = the fixed cost of owning a truck and trailer to transport the crawler tractor between facilities plus the variable costs of transporting the crawler tractor among the facility sites (if there is more than one facility in the selected system).

After this initial calculation has been made assuming only one particular disposal facility, the selection routine is repeated under the assumption that a different, single facility is available. The 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 given the facilities selected, the total cost of the system with these two particular facilities is computed.

The foregoing procedure is repeated for all possible combinations of two disposal facilities, and then repeated for all possible combinations of three disposal facilities and so on until the total costs of all possible combinations of disposal facilities and facility-source assignments have been computed. The analog then prints the least-cost system.

The costs of a system including processing plants (such as incinerators or truck transfer stations) are analyzed in a similar manner. First, the variable costs (costs per truckload) of disposing 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. To this set of k_{ij}'s is added another set of k_{ij}'s computed as follows:

$$c_m = c_{p(j')} + p_{j'} [c_t \, d_{(j',j)} + c_j]$$

where: c_m = cost per truckload of processing at j' plus transporting the refuse from the processing plant j' to the disposal site j plus disposing at j

c_p = 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

The additional k_{ij}'s are then computed as:

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

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 = same as described above

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

c_t = cost per truckload mile of transporting refuse

The total costs of different combinations of disposal facilities, processing plants, and facility-source assignments is then computed in a manner similar to the way they were computed when no processing plants were considered. The difference between the two computations is that the analog also tests to determine which disposal facility should be assigned the output from the processing plant in order to minimize the cost of transportation between processing plants and facilities.

In summary, the least-cost model inspects the system costs of all possible combination of disposal sites, assignments of processing plants to disposal sites, and assignments of sources to disposal sites.

A discussion of the particular area to which the model was applied, and a description of the data calculations used in the model are presented in the next chapter.

CHAPTER III

PROFILE OF THE STUDY AREA AND A DESCRIPTION OF DATA REQUIREMENTS

A profile of the study area, including a description of the current disposal system and the proposed alternatives is given in this chapter. Also the data required by the model for determining the least-cost system are discussed.

Geographic Description of Greenlee County

A geographic profile is necessary to properly understand the location of facilities and the distance data required by the model. Greenlee County lies on the eastern border of Arizona and encompasses 1,879 square miles. Elevations range from 2,800 feet to over 9,000 feet. The Gila River Valley runs east to west through Greenlee County. The upper half of the County lies in the White Mountains and is the location of the famed Coronado Trail (Employment Security Commission of Arizona, 1969, p. 31). The land ownership in Greenlee County in 1965 consisted of 81.0 percent federally owned land, 11.9 percent state owned land and 5.7 percent privately owned land. The County's population is 50.8 percent rural and 49.2 percent urban--towns of 2,500 population or greater. (Arizona Statistical Review, 1972, p. 33). The County's population is centered in the Morenci and Clifton areas and along State Highway 75 which runs from Clifton to the New Mexico border near Duncan, Arizona. U.S. Highway 70 crosses the County east to west while U.S. Highway 666 traverses the County north to south. For the purposes of this study, the County is broken down into nine subsections: the White Mountains, Morenci, Clifton, Duncan, Franklin, York Valley, Apache Grove, Verde Lee, and Loma Linda. These sections are shown on the map of Figure 2.

Local Governments and Population Profile of Greenlee County

A local government profile is necessary for an understanding of the financing and jurisdictional control of a solid waste management system. A population profile is necessary in the investigation of the solid waste problem over time.

Local government status can be broken down into four categories: county government, incorporated towns, unincorporated towns, and special districts (road districts, irrigation districts, school districts, etc.). Greenlee County has a county government, two incorporated towns, three unincorporated towns and twelve school districts. The two incorporated towns are Clifton and Duncan. The three unincorporated towns are Franklin, Plantsite, and Stargo. The twelve special districts consist of eight school districts (five elementary and three high school), three road districts (Duncan, Clifton, Morenci), and the Franklin irrigation district.

The 1970 population of Greenlee County was 10,330. Its major towns are Clifton with a 1970 population of 5,087, Plantsite with 1,077, and Stargo with 1,194. These towns are located in the central part of the County. In the southern portion of the County, Duncan is the major town with a 1970 population of 773 (Arizona Statistical Review, 1972, p. 33). The area along State Highway 75, between the New Mexico border

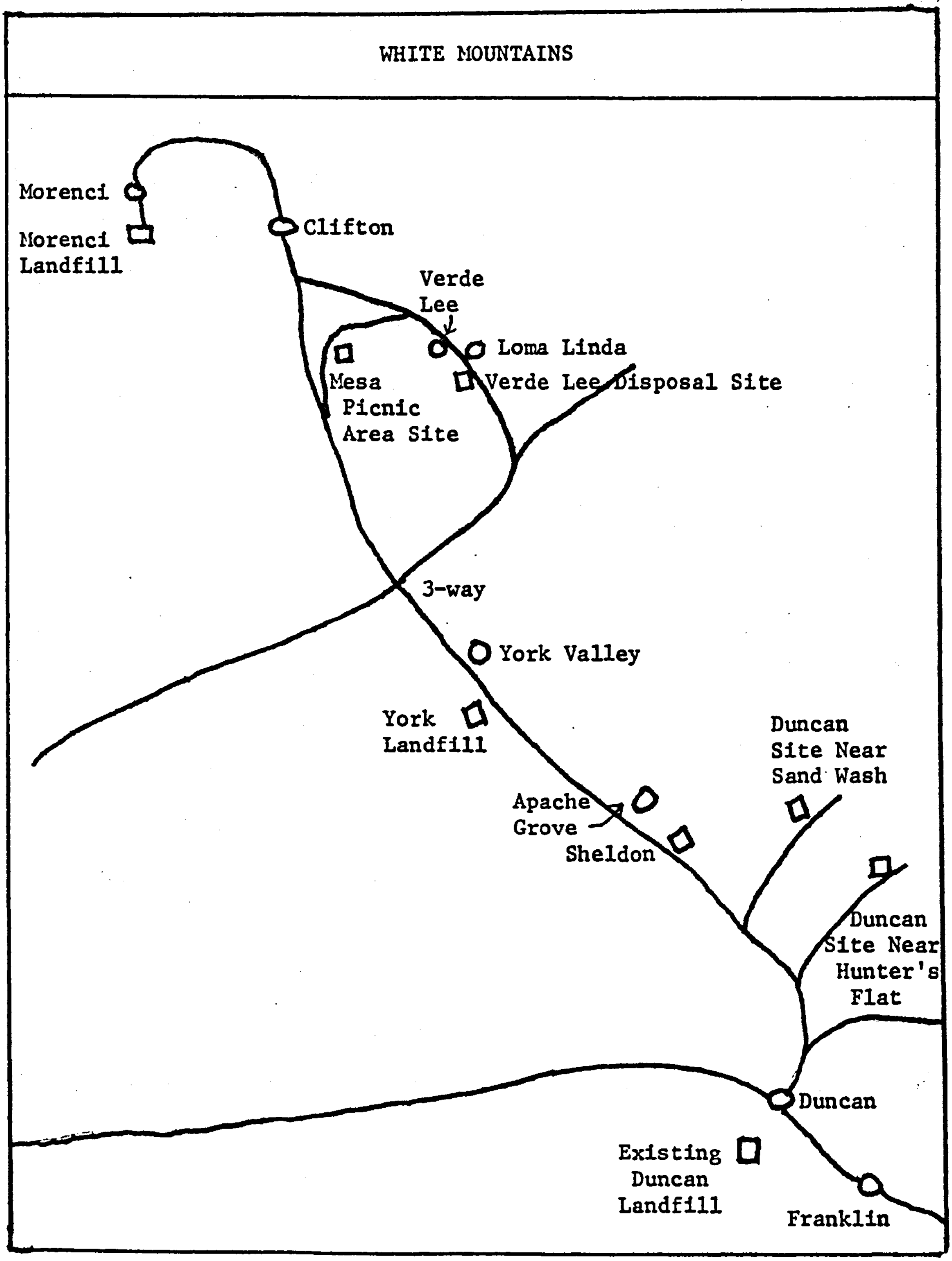

Figure 2. Map of Study Area.

and "3-Way" (see Figure 2), with the exception of Duncan, is estimated to have a 1973 population of 3,660 (Van Fleet, 1973). Between 1961 and 1971 the County population declined by 9.1 percent (Arizona Statistical Review, 1972, p. 33). This decrease, however, is not expected to continue since the Phelps-Dodge copper mine at Morenci is expected to expand operations which will provide additional employment and thus add to population growth. For the purposes of this study, a 39.4 percent growth in population and a 20 percent growth in population were assumed for Greenlee County during the period 1970 to 1980.

Economic Profile of Greenlee County

The primary economic base of Greenlee County is copper mining. Arizona's largest copper mine, in terms of annual value of output, is located in Morenci. The 1970 mineral production was $151 million. Crop farming, cattle ranching, dairying, and tourism are other important sectors of the County's economy (Arizona Statistical Review, 1972, p. 33). The economic outlook for Greenlee County is promising as Phelps-Dodge Corporation (the largest employer in the County) is expected to expand operations. This will provide jobs in the construction industry as well as employment at the mine.

The present study focuses on solid waste disposal in Greenlee County with the exception of the White Mountains and Morenci areas. The reasons for this selection are given below.

Description of Current Solid Waste Practices in Greenlee County and the Study Area

The upper part of the County, that area above Morenci, is mostly Forest Service land and all collection and disposal services are handled by the Forest Service for a nominal fee. The areas of Plantsite and Stargo, commonly called Morenci, are towns owned and operated by the Phelps-Dodge Corporation. Phelps-Dodge provides collection and disposal services for the residents of these areas. Therefore, neither of these refuse source areas are included in this study. Clifton, located adjacent to Morenci, currently has an agreement with the Phelps-Dodge Corporation which allows the town of Clifton to haul their solid waste to the Morenci landfill where the Phelps-Dodge Corporation handles the final disposal. The town of Clifton pays the Phelps-Dodge Corporation $1,000 a month for this service. The town of Clifton is included in this study in order to determine if there are economically feasible alternatives to this agreement. The other major town in the area is Duncan, located 30 miles south of Clifton. Duncan currently operates a municipal collection service within the town limits. Duncan also operates a municipal landfill on a 40-acre site which was leased under a Bureau of Land Management agreement.

The County operates two landfills in the area. One is located in the York Valley, the area between "3-Way" and Apache Grove (see Figure 2) on a 2-acre site which has almost reached capacity. The other site is located near Sheldon (10 miles north of Duncan). It is a 10-acre site leased under a Bureau of Land Management agreement. Both of these sites lack sanitary requirements insisted upon by the State Department of

Health. The County does not provide a collection service to the residents, but a private individual does collect solid waste for a fee and then deposits the solid waste at a County landfill for disposal.

Greenlee County officials have suggested four possible landfill sites in addition to those already in operation. The first site is located east of Clifton, off the Ward Canyon Road (see Figure 2). The next two sites are located near the town of Duncan. The fourth site is located near the Verde Lee and Loma Linda subdivisions on the Ward Canyon Road. All of these sites are presently undeveloped but are considered in this study. The locations of the source areas and the landfill sites used in this study are indicated on the map of Figure 2.

Greenlee County is presently using Highway Department equipment (including tractors and pick-ups) at the County landfill locations. The town of Duncan operates a D5 crawler tractor which it is using at its present disposal site and the Phelps-Dodge Corporation provides the equipment used at the Morenci landfill.

Synthesis of Data Requirements with Focus on Cost Data

The data required for the least-cost computer algorithm are classified as follows: source and facility locations and the distances between them, source quantities, facility parameters (including cost of transportation data) and system fixed costs. The data requirements are presented in detailed form in Appendix D.

Source and Facility Distance Data

The source and facility locations are shown on the map of Figure 2. The distances between the sources and facilities were obtained by odometer clockings and are shown in Table 1. If actual road distances between sources and facilities are not available, the computer algorithm has a built-in procedure for estimating these distances from an (x, y) coordinate system (Morse and Roth, 1970). In addition, the computer analog permits processing plants (truck transfer stations, incinerators, etc.) to be specified as possible activities in the solid waste system and if these are considered, it is necessary to obtain the distances between the processing plants and the sources and between the processing plants and the landfills.

Source Quantities

The source quantities are estimated using estimates of population and generation rates per capita. A generation rate of 5.0 pounds/capita/day is used for the 1973 estimates and a generation rate of 8.0 pounds/capita/day is used for the 1980 estimates. These estimates are in accord with estimates of others, including those used by Badger in Oklahoma (1972, p. 3). Population estimates for 1980 are made using a 20 percent growth and a 39.4 percent growth between 1970 and 1980. These growth rates are based on projections made by the Valley National Bank (Arizona Statistical Review, 1973, p. 10) and estimates of officials in Greenlee County. The estimated generation is adjusted to truckloads/year to conform to computer analog requirements (Morse and Roth, 1970). The

Table 1. Distances Between Sources and Facilities (d_{ij}), Miles.

Sources	Morenci Landfill	Mesa Picnic Area Site	York Landfill	Sheldon Landfill	Duncan Landfill	Duncan site near Sand Wash	Duncan site near Hunters Flat	Verde Lee disposal site
	Facilities							
Clifton	5.0	6.1	14.6	19.4	30.8	32.7	28.4	8.15
Verde Lee	10.4	2.7	10.7	15.5	26.9	28.8	24.5	2.75
Loma Linda	12.4	4.7	8.7	13.5	24.9	26.8	22.5	.75
York Valley	14.5	9.3	3.1	7.9	19.3	21.2	17.9	6.35
Apache Grove	25.4	18.4	5.8	1.0	10.4	12.3	8.0	15.25
Duncan	34.2	27.0	14.6	9.8	1.6	5.9	5.0	24.05
Franklin	37.4	30.2	17.8	13.0	4.8	9.1	8.2	27.25

conversion factor used is three tons equal one truckload (Morse and Roth, 1970, p. 72). Quantity estimates appear in Table 2.

Facility Parameters and System Fixed Costs

Five facility (processing plant or sanitary landfill) parameters are required by the least-cost analog; fixed cost of disposal (DFC or A_j)[1], cost per unit of increasing the capacity of the facility one more unit (DFCIN or a_j), the unit cost of disposal at that facility (DDC or c_j), a reduction or conversion factor (DCOMP or p_j), and the cost per mile of transporting a unit quantity of refuse delivered to the facility in collection vehicles (DCTTDS or c_t). These five parameters were estimated for all the facilities in the study area using data collected by personal interview and from published sources. The data are for the year 1973 unless otherwise stated. In addition, account must be taken of costs which accrue to the system but which cannot be preassigned to individual sites. These are labeled "system fixed costs." The facility parameters are discussed first.

The fixed costs of the disposal facilities are designated A_j (or DFC) and may be broken into seven categories. The categories, along with the cost estimates are:

(1) land acquisition costs	\$10/10 acre parcel (Van Fleet, 1973)	A_j as described in Chapter II.
(2) fencing costs	\$237/acre (Weddle, 1973)	

1. The first symbol (such as DFC) refers to the variable name within the computer program, and the second symbol (such as A_j) refers to the same factor, but is the label used in the explanation of the model in "Systems Analysis of Regional Solid Waste Handling" (Morse and Roth, 1970).

Table 2. Estimated Solid Waste Generation (q_i's) by Source Areas, in Truckloads/Year.

Sources (I)	1973[a]	1980 (39.4% Population Growth)[b]	1980 (20% Population Growth)[b]
Clifton	1,547.3	3,452.4	2,970.6
Verde Lee	45.6	101.7	87.6
Loma Linda	106.5	237.5	204.4
York Valley	504.9	1,126.2	969.4
Apache Grove	152.1	339.2	292.0
Duncan	304.2	678.4	584.0
Franklin	152.1	339.2	292.0
Totals (Q_i)	2,812.7	6,274.6	5,400.0

a. Solid waste rate of generation assumed to be five pounds per person per day. See text for discussion of this assumption and population estimates used to compute total waste generated.

b. Solid waste rate of generation assumed to be eight pounds per person per day. See text for discussion of this assumption and population estimates used to compute total waste generated.

(3) cattle guard costs	\$800/landfill (Weddle, 1973)	A_j as described in Chapter II.
(4) sign and tool costs	\$166.67/landfill (Weddle, 1973)	
(5) access road	\$5,400 undeveloped site; \$0 developed site (Van Fleet, 1973)	
(6) initial grading	\$1,200 undeveloped site; \$600 developed site (Van Fleet, 1973)	
(7) fill expense	insignificant in present case	

The various landfills were then assigned the fixed costs which applied to them. These costs are shown in Table 3, along with the other estimated parameters for each facility.

The a_j (or DFCIN) parameter is the cost per unit of increasing the capacity of the facility one more unit. It is included in the cost because of the possibility of a facility reaching its operating capacity. If operating capacity is reached, it may be necessary to incur added costs in salary and equipment expense to increase capacity. Morse and Roth (1970, p. 72) used $a_j = 0$ for a large existing landfill. The parameter a_j was assumed to be zero because a large existing landfill can handle an additional truckload with a negligible increase in expansion costs. In this study, a_j is assumed to be zero.

The variable cost (per truckload) of disposal is "c_j" (or DDC). The fixed costs associated with disposal have been separated out and have been discussed in a previous section. The "c_j" costs are estimated under the assumption that a D6C crawler tractor is used in the landfill operation. The operating costs for a D6C crawler tractor are: fuel costs, oil, grease and filter costs, and repair costs. The fuel costs

Table 3. Summary of Estimated Facility Parameters.[a]

Facility (j)	A_j ($)	a_j ($/truckload)	c_j ($/truckload)	p_j $\left(\frac{\text{volume of output}}{\text{volume of input}}\right)$	c_t ($/truckload-miles)
Morenci Landfill (Size = 40 acres)	0	0	3.32	1.0	2.53
Mesa Picnic Area Site (10 acres)	9,949.70	0	3.32	1.0	2.53
York Landfill (2 acres)	1,603.30	0	3.32	1.0	2.53
Sheldon Landfill (10 acres)	3,949.70	0	3.32	1.0	2.53
Duncan Landfill (40 acres)	11,098.70	0	3.32	1.0	2.53
Duncan Site near Sand Wash (40 acres)	17,098.70	0	3.32	1.0	2.53
Duncan Site near Hunters Flat (10 acres)	9,949.70	0	3.32	1.0	2.53
Verde Lee Disposal Site (10 Acres)	9,949.70	0	3.32	1.0	2.53

a. See text for discussion of the computation of each parameter.

are estimated by using the consumption figure of 7 gallons per hour for a D6C crawler tractor with a 90-100 horsepower engine under heavy load (Bauman, 1973). Thus, if the price of diesel fuel is \$.205 per gallon (Arizona Cotton Growers Association, 1973), fuel costs are \$1.435/hour. Oil, grease, and filter costs of the D6C crawler tractor are estimated to be 15 percent of the fuel costs of \$.215/hour (Hinz, 1973). Repair costs were estimated as follows:

$$\text{Average hourly repair costs} = \frac{\text{factor x \$1,000 of list price}}{\text{total working hours}}$$

(Bowers, 1970, p. 17).

where: factor = \$212.44 (Bowers, 1970, p. 17)

list price of D6C crawler tractor = \$46,500 (Bauman, 1973)

total working hours = 6,240 hours = 12 hours/week x 52 weeks/ year x 10 years of life (Shirk, 1972)

$\therefore$ average repair costs = \$1.583/hour

Therefore, total operating costs equals \$1.435/hour + \$.215/hour + \$1.583/ hour or \$3.233/hour. To convert total operating costs to the required units of costs per truckload, other calculations were necessary. A D6C crawler tractor requires 12 hours/week for covering and compacting of solid waste for a landfill for 2,000 people (Shirk, 1972). Using a generation rate of 5.0 pounds/capita/day (Badger, 1972, p. 3), the D6C crawler tractor will dispose of 35 tons/week. Therefore, a D6C crawler tractor disposes of 35 tons/week ÷ 12 hours/week or 2.9166 tons/hour. Cost per truckload (c_j) of \$3.324 is then derived by dividing total operating costs of \$3.233/hour by 2.9166 tons/hour, and multiplying by 3 tons/ truckload (Morse and Roth, 1970, p. 72).

The volume reduction coefficient for a sanitary landfill is "p_j" (or DCOMP). It is included in the analysis because p_j is one of the required facility parameters for the least-cost model (Morse and Roth, 1970, p. I-2). However, since the DDC value is calculated as the cost of covering and compacting solid waste, the p_j value is assumed to be 1.0.

The cost per truckload mile of transporting refuse to the disposal site in collection vehicles is "c_t" (or DCTTDS). Data to estimate these costs are primarily from Clifton (Danenhauer, 1973), where records on transportation costs have been kept. Several steps are necessary to obtain the costs of collection on a truckload mile basis. First total annual collection costs are estimated (as shown in Table 4). The annual collection cost is adjusted to a weekly basis by dividing by 52 to obtain an estimated weekly cost of solid waste collection of $746.73 per week. Next, the average miles traveled per week in making the collections is obtained as follows (Danenhauer, 1973):

$$\text{Average weekly miles} = M_1 + M_2 + M_3 + M_4$$

where: M_1 = (2) · (miles of streets in Clifton). There are two weekly collections and it is assumed that all streets are traversed.

M_2 = (5) · (2) · (distance from the garage to the collection district). Five days a week two trucks travel from the garage to Clifton.

M_3 = (5) · [2 (average number of truckloads to the landfill) - 1] · (average distance to the landfill). Five days a week the trucks make the trip to the landfill.

M_4 = (5) · (2) · (distance from landfill to garage). Five days a week the trucks return to the garage at the end of the day.

Table 4. Total Annual Collection Costs for Clifton, Arizona.

Cost Categories	Costs
Salary	\$27,600.00[a]
Equipment and supplies	861.17[a]
Truck repairs	1,604.74[a]
Truck gas	2,945.14[a]
Miscellaneous	332.07[a]
Truck Depreciation	5,486.66[b]
TOTAL ANNUAL COLLECTION COSTS	\$38,829.78

a. (Danenhauer, 1973)

b. See Appendix I.

The calculations appear in Appendix H. The average weekly miles traveled by collection vehicles was 295.55 miles. Therefore, the cost per truckload mile is as follows:

$$c_t = \frac{\$746.73/\text{week}}{\$295.55\ \text{miles/week}} = \$2.53/\text{truckload mile.}$$

A summary of these facility parameters appears in Table 3.

Parameter estimates for including a solid waste processing plant in the system (the data used in determining c_m in Chapter II) were taken directly from the study by Morse and Roth (1970, p. 74).

Another class of costs are system fixed costs which cannot be preassigned to individual landfills (since it is not known initially which landfills will enter the least-cost system). These seven costs are:

(1) Administrative expenses	\$5,400/year (Weddle, 1973)	
(2) Educational expenses	\$1,000/year (assumed)	SFC_1 as described in Chapter II
(3) Salary of crawler tractor operator	\$7,892/year (Van Fleet, 1973)	
(4) Owning costs of the crawler tractor	\$6,616-\$6,695/year (Appendix E)	
(5) Owning costs of truck to transport	\$2,060/year (Appendix F)	
(6) Owning costs of trailer used to transport	\$1,040/year (Appendix G)	SFC_2 as described in Chapter II
(7) Operating cost of transporting a crawler tractor between facilities	\$.50/mile (Appendix F)	

CHAPTER IV

EMPIRICAL RESULTS

The objective of this study is to use a computer model to investigate possible alternatives in the design of a least-cost system of solid waste disposal for Greenlee County. In Chapter II, the computer program was explained. Cost and other data necessary to determine a least-cost system were presented in Chapter III. The model considers four types of costs: disposal fixed costs, system fixed costs, direct disposal costs, and transportation costs. The model also requires: population and solid waste generation rate estimates to estimate total solid waste generation for the study years, source to facility mileage, facility to facility mileage, capacity expansion coefficients, and volume reduction estimates. These data are input into the computer algorithm in the form explained in Appendix J. The computer model then investigates (computes the cost of) all possible combinations of facility selections and source-to-facility assignments and specifies the least-cost system. Through a number of computer runs, the impact of different assumptions (such as different amounts of solid waste generated, or different possible facility locations) on the least-cost system are investigated. The alternative types of assumptions include.

(1) Assumptions of different amounts of solid waste generated, based on 1973 and 1980 projections with disposal equipment transported between landfills.

(2) Alternative facility locations.

(3) Morenci landfill and Clifton removed from 1973 analysis.

(4) Possibility of centralized landfill and rural collection system.

(5) Inclusion of transfer stations (large, self-compacting bins located at a central location for daily deposit by collection vehicles and later, perhaps weekly, transfer to the disposal site).

(6) Sensitivity analysis on the cost parameters for the various facilities.

A description of the different least-cost solutions, based on these different assumptions follows. A summary of facility selections, source assignments, and system costs of the least-cost formulations are given in Tables 5, 6, 7, and 8. A map indicating the various sources and possible disposal sites is given in Figure 2.

1973 Joint County-Municipal System

In the first investigation the primary goal is to evaluate the possible inclusion of Clifton, which presently pays $1,000/month to Phelps-Dodge for sanitary landfill services, in a county-wide system and to determine the sites, source assignments, and costs for that area. For this analysis the assumptions are as follows:

(1) There are seven sources ($I = 7$)[1]: Clifton, Verde Lee, Loma Linda, York Valley, Apache Grove, Duncan, and Franklin.

1. Symbols in parentheses refer to symbols presented in the model formulated in Chapter II.

Table 5. Summary of Least-Cost Solid Waste Systems Under Alternative Assumptions, System Cost to the Study Area (All Communities).[a]

Cost Categories	1973 Joint County-Municipal System	1980 Joint County-Municipal System (20% Growth)	1980 Joint County-Municipal System (39.4% Growth)	1973 Joint County-Municipal System II	1973 County System	1980 County System (20% Growth)	1980 County System (39.4% Growth)	1980 Facility System
	Facility Selection and Source Assignments[b]							
	1-C,VL 4-LL,Y,AG, D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-Y,AG,D,F	5-VL,LL,Y, AG,D,F	5-VL,LL,Y, AG 8-D,F	3-VL,LL,Y 5-AG 8-D,F	5-VL,LL,Y,AG, D,F
Fixed costs (A_j)	$ 1,603	$ 15,049	$ 15,049	$ 3,950	$ 3,950	$15,049	$24,999	$18,509
Direct disposal costs	9,339	17,928	20,830	9,339	4,203	8,064	9,369	9,369
Tractor costs (SFC_1)	6,617	6,617	6,617	6,617	6,617	6,617	6,617	0
Salary costs (SFC_1)	7,892	7,892	7,892	7,892	7,892	7,892	7,892	0
Administration costs (SFC_1)	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Educational costs (SFC_1)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Truck costs (SFC_2)	0	2,060	2,060	0	0	2,060	2,060	0
Trailer costs (SFC_2)	0	1,040	1,040	0	0	1,040	1,040	0
Tractor transportation costs (SFC_2)	0	3,557	3,557	0	0	3,557	8,003	0
Refuse transportation costs	47,401	72,315	84,044	47,151	28,473	36,435	26,972	63,452
TOTAL ANNUAL COSTS	$78,352	$131,957	$146,589	$80,449	$56,635	$86,214	$92,452	$96,830

a. See the text for a specification of assumptions for each system.

b. The numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

Table 6. Comparison of the Least-Cost Solid Waste System with Other Possible 1973 Joint County-Municipal Systems.

Analysis Selection	Total Cost	Facility Selection and Source Assignments[a]
Least-Cost Solution	$ 78,352	1-C,VL 4-LL,Y,AG,D,F
Second Best Alternative	79,515	1-C,VL 4-LL,Y 5-AG,D,F
Third Best Alternative	80,449	1-C,VL,LL 5-Y,AG,D,F
Present System	84,747	1-C 4-VL,LL,Y 5-AG 8-D,F
Highest Cost System	224,892	7-C,VL,LL,Y, AG,D,F

a. Numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

Table 7. Summary of Least-Cost Solid Waste Systems; Cost of Transportation to and Disposal at Duncan Site if Duncan Site Operated Independently.[a]

Cost Categories	1973 Joint County-Municipal System	1980 Joint County-Municipal System (20% Growth)	1980 Joint County-Municipal System (39.4% Growth)	1973 Joint County-Municipal System II	1973 County System	1980 County System (20% Growth)	1980 County System (39.4% Growth)
	Facility Selection and Source Assignments[b]						
	1-C,VL 4-LL,Y,AG 8-D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-Y,AG 8-D,F	5-VL,LL,Y,AG 8-D,F	5-VL,LL,Y,AG 8-D,F	3-VL,LL,Y 5-AG 8-D,F
Fixed costs	$11,099	$11,099	$11,099	$11,099	$11,099	$11,099	$11,099
Direct disposal costs	1,514	2,908	3,376	1,514	1,514	2,908	3,376
Tractor costs	6,617	6,617	6,617	6,617	6,617	6,617	6,617
Salary costs	7,892	7,892	7,892	7,892	7,892	7,892	7,892
Refuse transportation costs	3,077	5,910	6,862	3,077	3,077	5,910	6,862
TOTAL ANNUAL COSTS	$30,199	$34,426	$35,846	$30,199	$30,199	$34,426	$35,846

a. See the text for a specification of assumptions for each system.

b. The numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

Table 8. Summary of Least-Cost Solid Waste Systems; Cost of Transportation to and Disposal at Non-Duncan Sites if Duncan Site Operated Independently.

Cost Categories	1973 Joint County-Municipal System	1980 Joint County-Municipal System (20% Growth)	1980 Joint County-Municipal System (39.4% Growth)	1973 Joint County-Municipal System II	1973 County System	1980 County System (20% Growth)	1980 County System (39.4% Growth)
	Facility Selection and Source Assignments[b]						
	1-C,VL 4-LL,Y,AG 8-D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-AG,Y 8-D,F	1-C,VL,LL 5-Y,AG 8-D,F	5-VL,LL,Y,AG 8-D,F	5-VL,LL,Y,AG 8-D,F	3-VL,LL,Y 5-AG 8-D,F
Fixed costs	$ 1,603	$ 3,950	$ 3,950	$ 3,950	$ 3,950	$ 3,950	$13,900
Direct disposal costs	7,825	15,020	17,453	7,825	2,689	5,156	5,993
Tractor costs	6,617	6,617	6,617	6,617	6,617	6,617	6,617
Salary costs	7,892	7,892	7,892	7,892	7,892	7,892	7,892
Administration costs	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Educational costs	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Truck costs	0	0	0	0	0	0	0
Trailer costs	0	0	0	0	0	0	0
Tractor transportation costs	0	0	0	0	0	0	0
Refuse transportation costs	29,327	66,405	77,182	34,615	15,937	30,524	20,110
TOTAL ANNUAL COSTS	$58,764	$105,384	$118,594	$66,399	$42,585	$59,639	$67,558

a. See the text for a specification of assumptions for each system.

b. The numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

(2) There are eight possible facilities ($J = 8$): the Morenci landfill, the Mesa picnic area site, the York landfill, the Sheldon landfill, the existing Duncan landfill, the proposed Duncan site near Sand Wash, the proposed Duncan site near Hunter's Flat, and the proposed Verde Lee disposal site.

(3) The 1973 rates of generation and population estimates are used.

(4) Refuse is transported to disposal facilities in any of three ways: by a municipal collection system, by a private collection system, or by the residents themselves in their personal vehicles. For example:

[a] In the towns of Duncan and Clifton, where municipal collection is currently provided, the transportation of refuse to the disposal facility may be done by the respective town's collection vehicles.

[b] The county residents may haul their own refuse to the disposal sites.

[c] The county residents may obtain refuse collection from a private company.

It is assumed that cost per truckload mile is the same for each method of transport since even if each resident hauls his own solid waste, he incurs an opportunity cost.

(5) Any source can be assigned to any facility.

(6) It is assumed that the "fixed costs" (A_j) of the Morenci landfill (costs of grading, fencing, access road, land acquisition, etc.) are "0." That is, it is assumed that the Morenci landfill will continue in operation to service the Phelps-Dodge towns of Stargo and Plantsite (commonly known as Morenci) and that there are no additional "fixed

costs" associated with servicing any other communities assigned to this facility.

(7) One crawler tractor is assumed to be permanently stationed at the Morenci landfill (as presently is the case), and any source assigned to the Morenci site will result in operating costs of $3.32/ truckload of solid waste. If the least-cost solution includes more than just the Morenci landfill then it is assumed that at least one and possibly several D6C crawler tractors will be used in disposal. The algorithm determines whether it is cheaper to have one crawler tractor at each site, or to transport a crawler tractor among sites, assuming that a truck and lowboy trailer are used in transfer (annual costs of this transport equipment are shown, Appendices F and G). It is also assumed that the crawler tractor is stationed at the facility in the selection which is farthest north in the study area and that each site in the selection is serviced daily by the crawler tractor.

The analysis was made using the estimates of the facility parameter presented in Chapter III.

The least-cost assignments are:

(1) Clifton and Verde Lee are assigned to the Morenci landfill.

(2) Loma Linda, York Valley, Apache Grove, Duncan, and Franklin are assigned to the York landfill. The cost of this solution is $78,352 per year. A breakdown of the costs is presented in Table 5.

The least-cost system might be compared with the cost of alternative systems, such as the "second-best" solution, the "third-best" solution, the present system of collection and disposal, and the highest cost combination of sites and source assignments. A comparison of these different alternatives is presented in Table 6. The difference in annual costs between the least-cost solution (the first solution presented in Table 6) and the "next-best" solution is $1,163/year. The difference between the least-cost solution and the cost of the present system is $6,395/year. The "high-cost" solution would cost $224,892/year or $146,540/year more than the least-cost system.

For an analysis of the rural collection system (small collection bins located throughout the County) see Appendix K.

1973 Joint County-Municipal System With
Duncan Operating Own Disposal Facility

If the town of Duncan should operate its own crawler tractor (which it presently does) and dispose 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, the added costs of this system would be $10,611 per year. A breakdown of the costs incurred by the transportation to and disposal at the Duncan site, and the costs incurred by transportation to and disposal at the Morenci and York sites is presented in Table 7.

1973 Joint County-Municipal System
With Clifton "Excluded"

Another possible funding-administrative arrangement would be for Clifton to continue (as it presently does) using the municipal collection service to transport its solid waste for disposal at the Morenci landfill with Clifton residents paying both the charge for collection ($19,750 per year) and the charge by Phelps-Dodge for disposal ($12,000 per year). Under this arrangement the total cost of collection and disposal at the

York site for the remainder of the area's residents would be reduced by \$24,706--\$5,136 less for disposal of solid waste generated at Clifton and \$19,570 less in transport charges for transporting Clifton's waste to the Morenci site. Thus, the total cost of this least-cost system to the area's non-Clifton residents would be \$78,352 - \$24,706 or \$53,646. A breakdown of the costs is given in Table 8.

1980 Joint County-Municipal System

The primary goal of this analysis is to determine the changes in the solution when 1980 solid waste generation is assumed. The assumptions used in this analysis are the same as the "1973 Joint County-Municipal System" with the exception of the following:

(1) There are seven facilities (J = 7). The York landfill is removed from the analysis because it will reach its capacity before 1980.

(2) The 1980 rate of solid waste generation per capita (8 pounds) and 1980 population estimates (with a 20 percent growth in population assumed first, and then another "run" is made assuming a 39.4 percent increase in population) are used to estimate total solid waste generated.

1980 Joint County-Municipal System (20 Percent Population Growth)

The least-cost assignments for this situation are:

(1) Clifton, Verde Lee, and Loma Linda are assigned to the Morenci landfill.

(2) Apache Grove and the York Valley are assigned to the Sheldon landfill.

(3) Duncan and Franklin are assigned to the existing Duncan landfill.

The total cost of this system is $131,957 per year, or $53,605 ($131,957 - $78,352) more than the least-cost system assuming 1973 rates of generation. A breakdown of the costs is given in Table 5.

The results obtained from the 1980 "run" are compared to the "second-best" alternative, the "third-best" alternative, and the highest cost solution in Table 9.

1980 Joint County-Municipal System
(20 Percent Population Growth) With
Duncan Operating Own Disposal Facility

The 1980 cost of the least-cost system is changed if different financial-administrative arrangements are assumed, just as was the case for the 1973 "run." Thus, if Duncan continues to own and operate its own crawler tractor and the county operates another tractor for the Sheldon landfill, the total cost of this system will increase. The total cost to the area increases from $131,957 to $139,810. The costs of transportation to and disposal at the Duncan site, where Duncan and Franklin refuse is disposed, is $34,426. The remainder of the costs, $105,384, includes disposal at the Morenci and Sheldon landfills, transportation to these landfills, plus the system fixed costs of administration, education, tractor owning costs, etc. (SFC_1). These costs are summarized in Tables 7 and 8.

Table 9. Comparison of the Least-Cost Solid Waste System with Other Possible 1980 (20% Growth in Population) Joint County-Municipal Systems.

Analysis Selection	Total Cost	Facility Selection and Source Assignments[a]
Least-Cost Alternative	$131,957	1-C,VL,LL 5-AG,Y 8-D,F
Second Best Alternative	132,375	1-C,VL,LL 5-AG,Y,D,F
Third Best Alternative	134,837	1-C 3-YL,LL,Y 5-AG 8-D,F
Highest Cost System	397,574	7-C,VL,LL,Y, AG,D,F

a. Numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

1980 Joint County-Municipal System
(20 Percent Population Growth) With
Clifton "Excluded"

If Clifton continues to finance its own collection and disposal at the Morenci landfill, then the costs to the rest of the area will be reduced to $84,511 ($131,957 - $47,446). A breakdown of the costs under these financial-administrative arrangements is given in Table 10.

1980 Joint County-Municipal System
(39.4 Percent Population Growth)

Another analysis was made which assumed the 1980 population would increase by 39.4 percent instead of 20 percent, with all other assumptions remaining the same as for the "1980 Joint County-Municipal System (20 Percent Population Growth)." The source assignments and facility selections were the same as those obtained for a population growth of 20 percent between 1970 and 1980, although the total cost of the system increased from $131,957 to $146,589 per year. The cost breakdown is given in Table 5. The results obtained from the 1980 "run" are compared to the "second-best" alternative, "third-best" alternative, and the highest cost solution in Table 11.

1973 Joint County-Municipal System II

This analysis is made to investigate the changes that would occur if the York site is not available. The York site is small, only two acres, and is rapidly reaching its capacity. The other assumptions are exactly the same as the first "1973 Joint County-Municipal System." The least-cost assignments are:

Table 10. Summary of Least-Cost Solid Waste System with Clifton Excluded.[a]

Cost Categories	1973 Joint County-Municipal System	1980 Joint County-Municipal System (20% Growth)	1980 Joint County-Municipal System (39.4% Growth)	1973 Joint County-Municipal System II
	Facility Selection and Source Assignments[b]			
	1-VL 4-LL,Y,AG,D,F	1-VL,LL 5-AG,Y 8-D,F	1-VL,LL 5-AG,Y 8-D,F	1-VL,LL 5-Y,AG,D,F
Fixed costs	$ 1,603	$15,049	$15,049	$ 3,950
Direct disposal costs	4,203	8,064	9,369	4,203
Tractor costs	6,617	6,617	6,617	6,617
Salary costs	7,892	7,892	7,892	7,892
Administrative costs	4,500	4,500	4,500	4,500
Educational costs	1,000	1,000	1,000	1,000
Truck costs	0	2,060	2,060	0
Trailer costs	0	1,040	1,040	0
Tractor transportation costs	0	3,557	3,557	0
Refuse transportation costs	27,831	34,732	40,376	27,581
TOTAL ANNUAL COSTS	$53,646	$84,511	$91,460	$55,742

a. and b. See Table 5 for footnotes.

Table 11. Comparison of the Least-Cost Solid Waste System with Other Possible 1980 (39.4% Growth in Population) Joint County-Municipal Systems.

Analysis Selection	Total Cost	Facility Selection and Source Assignments[a]
Least-Cost Solution	$146,586	1-C,VL,LL 5-Y,AG 8-D,F
Second Best Alternative	147,577	1-C 3-VL,LL,Y 5-AG 8-DF
Third Best Alternative	149,930	1-C,VL,LL 5-Y,AG,D,F
Highest Cost System	455,963	7-C,VL,LL,Y, AG,D,F

a. Numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

(1) Clifton, Verde Lee, and Loma Linda were assigned to the Morenci landfill.

(2) York Valley, Apache Grove, Duncan, and Franklin were assigned to the Sheldon landfill. Thus, the Sheldon landfill replaces the York site.

The total cost of this system is $80,449 per year. A summary of the cost components is given in Table 5.

If Duncan opts to operate its own collection and disposal site, then its total cost (including the costs of transporting the solid waste from Franklin and Duncan to the Duncan site, and disposal at the Duncan site) would be $30,199. The cost of the rest of the system, including the cost of transportation to and disposal at the Morenci and Sheldon landfills and system fixed cost (SFC_1) would be $66,399 ($80,449 minus the operating costs of $1,514 of disposing of Duncan's and Franklin's refuse at the Sheldon site minus the cost of $12,536 of transporting Duncan's and Franklin's refuse to the Sheldon site). The cost breakdown is summarized in Tables 7 and 8.

1973 County System

In this "run" the least-cost system for 1973 is determined under the conditions that Clifton is not part of the system, the Morenci landfill is unavailable to communities other than Clifton, and the York landfill is unavailable. Clifton presently has an agreement with the Phelps-Dodge Corporation to dispose of Clifton's waste at Morenci, but it is not known if a similar arrangement could be made for the other communities. The present York landfill has nearly reached its capacity. All other assumptions are exactly the same as those for the "1973 Joint County-Municipal System."

All six sources are assigned to the Sheldon landfill in the least-cost solution. With the disposal equipment being stationary at the Sheldon landfill, the total cost of this system is $56,635 per year. Costs are summarized in Table 5.

1980 County System

The 1980 county system is run under the same assumptions as the "1973 County System" except that the 1980 generation and population estimates are used. Two "runs" are made using a 20 percent assumed population growth and a 39.4 percent population growth. In the 1980 county system (20 percent population growth) the least-cost assignments are:

(1) Verde Lee, Loma Linda, York Valley, and Apache Grove are assigned to the Sheldon landfill.

(2) Duncan and Franklin are assigned to the existing Duncan landfill.

The total cost of this system is $86,214 per year. A cost breakdown is given in Table 5.

In the 1980 county system, assuming a 39.4 percent population growth, the least-cost assignments are:

(1) Verde Lee, Loma Linda, and the York Valley were assigned to the Verde Lee disposal site.

(2) Apache Grove was assigned to the Sheldon landfill.

(3) Duncan and Franklin were assigned to the existing Duncan landfill. The total cost of this system is $92,452 per year. A cost breakdown is given in Table 5.

1980 Single Facility System

Some area planners have suggested that one landfill would be sufficient to service the entire area. To investigate this alternative, the same assumptions as those for the "1980 County System" (20 percent population growth) are made except that any site which entered the solution is assumed to have a crawler tractor stationed at the site. This differs from the "1980 Joint County-Municipal System" since there it is assumed that the tractor could be transported among various disposal sites. In the model specification, this difference is accomplished by transferring the system fixed costs for the tractor and tractor operator to the disposal facility fixed costs (A_j).

Under these conditions, all six sources are assigned to the Sheldon landfill in the least-cost solution. The cost of this system is $96,830 per year, and compares to the least-cost solution using the least-cost "1980 County System" of multiple landfills (Sheldon and the existing Duncan site) of $86,213 per year. Thus an annual cost increase of $10,617 is incurred if only one, instead of two disposal facilities were to service the area. The cost increase results from the increased transportation costs associated with using only one facility. Costs are summarized in Table 5.

1980 Truck Transfer Station System

This analysis was made to investigate the economic feasibility of the use of truck transfer stations in the study area. A truck transfer station is a stationary facility which has an access road, loading ramps, and large self-compacting bins. The small (25 cubic yard capacity) collection vehicles visit the transfer station, depositing their collected waste in the compaction bins. These bins are then hauled to the disposal facility, when sufficient quantities of solid waste have been accumulated, by large tractor-trailer trucks. Thus a reduction in transportation costs is accomplished by one truck making the trip to the disposal facility as opposed to many collection vehicles making the trip to the disposal facility, but costs are increased by the increase in equipment required at the truck transfer station. The assumptions for this analysis are the same as those used in the "1980 County System" (39.4 percent population growth) with the exception that:

(1) There are eight possible facilities ($J = 8$). The six disposal facilities of the "1980 County System" and the two proposed truck transfer stations.

(2) The costs associated with the truck transfer stations are as given in Systems Analysis of Regional Solid Waste Handling (Morse and Roth, 1970, p. 74).

The results of this "run" are the same as the "1980 County System" as the truck transfer stations were not included in the least-cost solution. The added cost of the equipment outweighed the reduction in transportation costs.

Sensitivity Analysis

A sensitivity analysis is made to determine the effect of possible changes in the facility parameters on the least-cost solutions. The sensitivity analysis investigates changes in DDC (variable disposal cost), and DCTTDS (cost of transportation). The other assumptions used in the sensitivity analysis are the same as the assumptions used in the "1973 County System" analysis. The values for DDC are varied, in one dollar increments, from $1.00 per truckload to $5.00 per truckload with no effect upon the source assignments or site selections. System costs range from $53,699 per year, with DDC at $1.00 per truckload to $58,762 per year with DDC at $5.00 per truckload and these compare with a total system cost of $56,635 found earlier using the computed DDC = $3.32 per truckload.

The values of DCTTDS are varied in one dollar increments, from $1.00 per truckload mile to $5.00 per truckload mile to test the sensitivity of the least-cost site selections and source assignments to changes in collection costs. There is no change in site selection or source assignment from that found earlier where DCTTDS was computed to be $2.53 per truckload mile. However, the total cost of the system varied from $35,213 per year with DCTTDS at $1.00 per truckload mile to $84,433 per year with DCTTDS at $5.00 per truckload mile.

The sensitivity analysis was repeated for the 1980 least-cost solutions. DDC variations effect neither the source assignments nor site selections. The only change occurs when DCTTDS is set at $2.00 per truckload mile and below $2.00 per mile. In that case, the least-cost solution for 1980 then becomes the same as the "1973 County System" least-cost solution.

A summary of the costs, site selections, and source assignments for 1973 and 1980 solid waste generation, and for different disposal (DDC) and collection (DCTTDS) costs is given in Table 12.

Table 12. Sensitivity Analysis of the Least-Cost Solid Waste System with DDC and DCTTDS Set At Different Levels.[a]

	1973		1980 (20% growth)		1980 (39.4% growth)	
	Total Cost	Site Selection and Source Assignment[d]	Total Cost	Site Selection and Source Assignment[d]	Total Cost	Site Selection and Source Assignment[d]
DDC (or c_d)[b]						
\$1.00	\$53,699	5-VL,LL,Y,AG, D,F	\$80,578	5-VL,LL,Y,AG 8-D,F	\$86,890	3-VL,LL,Y 5-AG 8-D,F
\$2.00	54,964	5-VL,LL,Y,AG, D,F	83,007	5-VL,LL,Y,AG 8-D,F	88,724	3-VL,LL,Y 5-AG 8-D,F
\$3.00	56,230	5-VL,LL,Y,AG, D,F	85,436	5-VL,LL,Y,AG 8-D,F	91,546	3-VL,LL,Y 5-AG 8-D,F
\$4.00	57,496	5-VL,LL,Y,AG, D,F	87,865	5-VL,LL,Y,AG 8-D,F	94,368	3-VL,LL,Y 5-AG 8-D,F
\$5.00	58,762	5-VL,LL,Y,AG, D,F	90,294	5-VL,LL,Y,AG 8-D,F	97,190	3-VL,LL,Y 5-AG 8-D,F

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Table 12. (continued)

	1973		1980 (20% growth)		1980 (39.4% growth)	
	Total Cost	Site Selection and Source Assignment[d]	Total Cost	Site Selection and Source Assignment[d]	Total Cost	Site Selection and Source Assignment[d]
DCTTDS (or c_t)[c]						
$1.00	$35,213	5-VL,LL,Y,AG, D,F	$ 53,607	5-VL,LL,Y,AG, D,F	$ 58,408	5-VL,LL,Y,AG, D,F
$2.00	50,670	5-VL,LL,Y,AG, D,F	75,191	5-VL,LL,Y,AG, D,F	83,487	5-VL,LL,Y,AG, D,F
$3.00	61,924	5-VL,LL,Y,AG, D,F	91,703	3-VL,LL,Y 5-AG 8-D,F	97,460	3-VL,LL,Y 5-AG 8-D,F
$4.00	73,179	5-VL,LL,Y,AG, D,F	100,879	3-VL,LL,Y 5-AG 8-D,F	108,120	3-VL,LL,Y 5-AG 8-D,F
$5.00	84,433	5-VL,LL,Y,AG, D,F	110,055	3-VL,LL,Y 5-AG 8-D,F	118,780	3-VL,LL,Y 5-AG 8-D,F

a. Runs made on 1973, 1980 (20 percent population growth), and 1980 (39.4 percent population growth) County Systems.

b. Transport costs c_t set at $2.53 per truckload mile.

Table 12. (continued)

c. Direct disposal costs DDC set at $3.32 per truckload.

d. Numbers denoting facilities are: (1) Morenci landfill, (2) Mesa picnic area site, (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. The letters denoting sources are: (C) Clifton, (VL) Verde Lee, (LL) Loma Linda, (Y) York Valley, (AG) Apache Grove, (D) Duncan, (F) Franklin.

CHAPTER V

SUMMARY AND CONCLUSIONS

Using the results of the computer runs described in Chapter IV, the design of several least-cost disposal systems was accomplished. The least-cost "1973 Joint County-Municipal System" indicates the Morenci landfill and the York landfill as facility selections. Clifton and Verde Lee are assigned to the Morenci landfill. Loma Linda, the York Valley, Apache Grove, Duncan, and Franklin are assigned to the York landfill. The total cost of this least-cost solution is \$78,352 per year and compares to a cost of \$84,747 per year for the present system. However, the York landfill is small and will reach its capacity in the near future. With the York landfill removed from consideration, the "1973 Joint County-Municipal System II" facility selection included the Morenci landfill and the Sheldon landfill. Clifton, Verde Lee, and Loma Linda are assigned to the Morenci landfill. The York Valley, Apache Grove, Duncan, and Franklin are assigned to the Sheldon landfill. The total cost of this system is \$80,449 per year. The least-cost "1980 Joint County-Municipal System" (20 percent population growth with the York site removed from the investigation) has a facility selection of the Morenci landfill, the Sheldon landfill, and the existing Duncan landfill. Clifton, Verde Lee, and Loma Linda are assigned to the Morenci landfill. The York Valley and Apache Grove are assigned to the Sheldon landfill.

Duncan and Franklin are assigned to the existing Duncan landfill. The total cost of this system is $131,957.

Various possible administrative arrangements, generation amounts, and assumptions about disposal and transport costs are investigated. Thus, the "1973 County System" assumes that Clifton was not part of a county disposal network, the Morenci landfill is unavailable to communities other than Clifton, and the York landfill is unavailable. The least-cost solution under these conditions uses only the Sheldon landfill as its facility selection, with all six sources (Verde Lee, Loma Linda, York Valley, Apache Grove, Duncan, and Franklin) assigned to the Sheldon landfill. The total cost of this least-cost solution is $56,635 per year. The least-cost "1980 County System" (20 percent population growth with other assumptions the same as those for the "1973 County System") includes the Sheldon landfill and the existing Duncan landfill with Verde Lee, Loma Linda, York Valley, and Apache Grove assigned to the Sheldon landfill and Duncan and Franklin assigned to the existing Duncan landfill. System costs total $86,214 per year. The "1980 County System" (39.4 percent population growth with other assumptions the same as for the preceding "run") adds the Verde Lee disposal site to the facility selection explained above. Verde Lee, Loma Linda, and the York Valley are assigned to the Verde Lee disposal site. Apache Grove is assigned to the Sheldon landfill. Duncan and Franklin are assigned to the existing Duncan landfill. The total cost of this least-cost solution is $92,452 per year.

A sensitivity analysis is also run on the facility parameters (in particular, disposal and transport costs) involved in the least-cost solution. This sensitivity analysis revealed no significant changes in the least-cost site-source assignments and therefore suggests the optimality of the results.

An inspection of the results suggests several conclusions. From the "Joint County-Municipal System" "runs" it is evident that Clifton does not have an economically feasible alternative to the Morenci landfill. From the "County System" "runs" a long range planning format for solid waste disposal in Greenlee County is suggested. The Sheldon landfill is the facility selected for the "1973 County System." As population and generation per capita increases over time, first the existing Duncan landfill and then the Verde Lee disposal site are added to the least-cost solution. Thus the results suggest that Greenlee County accomplish the following steps in obtaining a long-run least-cost system of solid waste disposal:

(1) Clifton should continue to use the Morenci landfill for its disposal needs.

(2) Plans to close the York landfill should be made.

(3) The Sheldon landfill and the existing Duncan landfill should be readied for operations.

(4) Plans for the creation of the Verde Lee disposal site should be made and plans for future operation should be accomplished (if population increases at the faster rate).

(5) The County should discuss the possibility of using the Duncan tractor at the County landfills and including Duncan in the County solid waste management system.

Limitations of the Study and Suggestions for Future Research

Implicit in the calculations of the least-cost system of solid waste disposal is the presumption that the county (or other level of government) has the legal and financial ability to carry out the operation of the system; this may not be the case. State law is presently unclear about which levels of government have the responsibility, authority, and ability to obtain revenues for and administer a solid waste disposal system. This uncertainty limits the ability to plan, and could render the least-cost solution inoperable.

An important reason for designing a least-cost system for a region is the possible cost savings resulting from economies of scale associated with larger (but fewer) landfills. For larger urban towns (those with populations over 50,000) previous empirical research indicates substantial economies of scale as disposal site capacity is increased. Unfortunately, little if any, empirical research has been done which indicates the economies of scale of disposal sites serving small, rural populations. The research of the present study investigates the economies of scale in only a tangential way. Future research is needed to determine the economies of scale for solid waste disposal sites serving rural areas. Such information would be useful not only in specifying a least-cost system, but also suggests the most appropriate level of government to be charged with funding and administering solid waste management systems.

Solid waste has always been considered as a nonusable product, but it may be a useful resource in the transformation of unusable land into useful recreational or building site land (Havlicek, Tolley, and Wang, 1969, p. 1601). Further research into the use of solid waste as a resource as well as research into the demands for solid waste for recycling in metropolitan areas is warranted.

APPENDIX A

CALCULATION OF GENERATION OF SOLID WASTE IN THE UNITED STATES

The total amount of solid waste generated in the United States and used in the example in Chapter I was calculated in the following manner. The calculation assumed:

(1) population of the U.S. in 1970 = 203,235,298;

(2) the generation rate in 1970 was 5.0 pounds/capita/day (Badger, 1972, p. 3), the compaction in a sanitary landfill was 800 pounds/cubic yard (Shirk, 1972);

(3) the area of the city of Tucson is 80 square miles (Arizona Statistical Review, 1972, p. 14).

The calculation follows:

$$203{,}235{,}298 \text{ capita} \times 5.0 \text{ pounds/capita/day} \times 365 \text{ days/year} \times \frac{1 \text{ cubic yard}}{800 \text{ lbs.}} \times \frac{\text{area of Tucson}}{14{,}080 \text{ sq. yds.}} \times \frac{3 \text{ ft.}}{\text{yd.}} = 5.61 \text{ ft.}$$

(height of solid waste over the city of Tucson).

In the 1980 calculations, the assumptions were:

(1) population of U.S. = 226,934,000

(2) the generation rate was 8.0 lbs/capita/day (Badger, 1972, p.3)

Therefore the calculation was:

$$226{,}934{,}000 \text{ capita} \times 8.0 \text{ lbs/capita/day} \times 365 \text{ days/year} \times \frac{1 \text{ cubic yard}}{800 \text{ lbs}} \times \frac{\text{area of Tucson}}{14{,}080 \text{ sq. yds.}} \times \frac{3 \text{ ft.}}{\text{yd.}} = 10.03 \text{ ft.}$$

(height of solid waste over the city of Tucson).

APPENDIX B

CALCULATION OF GENERATION OF SOLID WASTE IN ARIZONA

The total amount of solid waste generated in Arizona and used in the example in Chapter I was calculated following this procedure. The calculation of the 1970 figure assumed:

(1) population of Arizona = 1,773,428 (Arizona Statistical Review, 1972, p. 8);

(2) generation rate = 5.0 lbs/capita/day (Badger, 1972, p. 3);

(3) compaction in a sanitary landfill = 800 lbs/cubic yard (Shirk, 1972);

(4) area of a football field = 5,000 square yards

The calculation was:

1,773,428 capita x 5.0 lbs/capita/day x 365 days/year x

$$\frac{1 \text{ cubic yard}}{800 \text{ lbs}} \times \frac{\text{area of field}}{5{,}000 \text{ sq.yds.}} \times \frac{1 \text{ mile}}{1{,}760 \text{ yds.}} = .46 \text{ mile}$$ (height of solid waste over football field).

In 1980, the assumptions were:

(1) population of Arizona = 2,381,500 (Arizona Statistical Review, 1972, p. 8);

(2) generation rate = 8.0 lbs/day/capita (Badger, 1972, p. 3);

(3) compaction in a sanitary landfill = 800 lbs/cubic yard (Shirk, 1972);

(4) area of a football field = 5,000 square yards

The calculation was:

2,381,500 capita x 8.0 lbs/capita/day x 365 days/year x

$\frac{\text{1 cubic yard}}{\text{800 lbs.}} \times \frac{\text{area of field}}{\text{500 sq. yds.}} \times \frac{\text{1 mile}}{\text{1,760 yds.}}$ = 1.00 miles (height of solid waste over football field).

APPENDIX C

STATE AND FEDERAL LAWS GOVERNING SOLID WASTE DISPOSAL IN ARIZONA

The following two sets of rules and regulations (Arizona State Department of Health, 1970b, p. 3 and 1970a, p. 1-5) specify the requirements under which communities are to set up a sanitary system for solid waste disposal. The Federal legislation concerning solid waste disposal is reviewed following the presentation of the Arizona rules and regulations, in this appendix.

State Department of Health
Phoenix, Arizona

RULES AND REGULATIONS

FOR

SUBDIVISIONS

Article 2
Part 10

REG. 2-10-4.1 GENERAL

The storage, collection, transportation and disposal of refuse and other objectionable wastes shall be governed by Part 2-4 of these regulations.

(Amended Reg. November 1971)

REG. 2-10-4.2 COLLECTION SERVICE OR DISPOSAL AREA

A. Where an approved community or private refuse collection service is available, arrangements shall be made to have this service furnished to the subdivision.. A letter, from the community or private collection company, stating that the collection service will be made available to the subdivision, is required.

B. Where refuse collection service is not available, it will be the responsibility of the subdivider to notify each purchaser or tenant that the hauling of all refuse is an individual responsibility and that all refuse must be properly stored pending removal and disposed of at disposal areas specified in the plan approved by the Department.

C. Where a collection service or an existing approved disposal area is not available to the subdivision, a plan approval will not be granted unless a separate disposal area is provided by the subdivider or arrangements are made to utilize a new, conveniently located disposal area. Such arrangements shall include, but not be limited to, the written permission of the person responsible for the operation of the new site.

(Added Reg. November 1971)

State Department of Health
Phoenix, Arizona

RULES AND REGULATIONS

FOR

REFUSE AND OTHER OBJECTIONABLE WASTES

Article 2

Part 4

SEC. 2-4-1. GENERAL CONSIDERATIONS

REG. 2-4-1.1 LEGAL AUTHORITY

The regulations in this Part are adopted pursuant to the authority granted by A.R.S. 36-105., B., 10.

(Added Reg. August 1962)

REG. 2-4-1.2 DEFINITIONS

A. "Approved" means acceptable to the Department.

B. "Ashes" means residue from the burning of any combustible material.

C. "Department" means the State Department of Health or a local health department designated by the State Department of Health.

D. "Garbage" means all animal and vegetable wastes resulting from the processing, handling, preparation, cooking, and serving of food or food materials.

E. "Manure" means animal excreta, including cleanings from barns, stables, corrals, pens, or conveyances used for stabling, transporting, or penning of animals or fowls.

F. "Person" means the State, a municipality, district or other political subdivision, a cooperative, institution, corporation, company, firm, partnership or individual.

G. "Refuse" means all putrescible and nonputrescible solid and semisolid wastes, except human excreta, but including garbage, rubbish, ashes, manure, street cleanings, dead animals, abandoned automobiles, and industrial wastes.

H. "Rubbish" means nonputrescible solid wastes, excluding ashes, consisting of both combustible and noncombustible wastes, such as paper, cardboard, waste metal, tin cans, yard clippings, wood, glass, bedding, crockery and similar materials.

(Added Reg. August 1962)

REG. 2-4-1.3 RESPONSIBILITY

A. The owner, agent, or the occupant of any premises, business establishment, or industry shall be responsible for the sanitary condition of said premises, business establishment, or industry. No person shall place, deposit, or allow to be placed or deposited on his premises or on any public street, road, or alley any refuse or other objectionable waste, except in a manner described in these regulations.

B. The owner, agent, or the occupant of any premises, business establishment, or industry shall be responsible for the storage and disposal of all refuse accumulated, by a method or methods described in these regulations.

C. The collection and disposal of all refuse not acceptable for collection by a collection agency is the responsibility of each occupant, business establishment, or industry where such refuse accumulates, and all such refuse shall be stored, collected, and disposed of in a manner approved by the Department.

D. All dangerous materials and substances shall, where necessary, be rendered harmless prior to collection and disposal.

REG. 2-4-1.4 INSPECTION

Representatives of the Department shall make such inspections of any premises, container, process, equipment, or vehicle used for collection, storage, transportation, disposal, or reclamation or refuse as are necessary to insure compliance with these regulations.

(Added Reg. August 1962)

REG. 2-4-1.5 COLLECTION REQUIRED

A. Where refuse collection service is available, the following refuse shall be required to be collected:

Garbage, ashes, rubbish, and small dead animals which do not exceed 75 pounds in weight.

B. The following refuse is not considered acceptable for collection but may be collected at the discretion of the collection agency where special facilities or equipment required for the collection and and disposal of such wastes are provided:

1. Dangerous materials or substances, such as poisons, acids, caustics, infected materials, radioactive materials, and explosives.

2. Materials resulting from the repair, excavation, or construction of buildings and structures.

3. Solid wastes resulting from industrial processes.

4. Animals exceeding 75 pounds in weight, condemned animals, animals from a slaughterhouse, or other animals normally considered industrial waste.

5. Manure.

(Added Reg. August 1962)

REG. 2-4-1.6 NOTICES

A. All collection agencies shall provide each householder, or business establishment served, with a copy of the requirements governing the storage and collection of refuse which shall cover at least the following items:

1. Definitions.
2. Places to be served.
3. Places not to be served.
4. Scheduled day or days of collection.
5. Materials acceptable for collection.
6. Materials not acceptable for collection.
7. Preparation of refuse for collection.
8. Types and sized of containers permitted.
9. Points from which collections will be made.
10. Necessary safeguards for collectors.

B. All such notices governing storage and collection shall conform to these regulations.

(Added Reg. August 1962)

SEC. 2-4-2. STORAGE

REG. 2-4-2.1 GENERAL

All refuse shall be stored in accordance with the requirements of this section. The owner, agent, or occupant of every dwelling, business establishment, or other premises where refuse accumulates shall provide a sufficient number of suitable and approved containers for receiving and storing of refuse, and shall keep all refuse therein, except as otherwise provided by these regulations.

(Added Reg. August 1962)

REG. 2-4-2.2 METHOD OF STORAGE

A. Garbage shall be stored in durable, rust resistant, nonabsorbent, watertight, and easily cleanable containers, with close fitting covers and having adequate handles or bails to facilitate handling. The size of the container shall be determined by the collection agency.

B. Rubbish and ashes shall be stored in durable containers. Bulky rubbish such as tree trimmings, newspapers, weeds, and large cardboard boxes shall be handled as directed by the collection agency. Where garbage separation is not required, containers for the storage of mixed rubbish and garbage shall meet the requirements specified in "A" above.

C. Manure and droppings shall be removed from pens, stables, yards, cages, conveyances, and other enclosures as often as necessary to prevent a health hazard or the creation of a nuisance. All material removed shall be handled and stored in a manner that will maintain the premises nuisance free.

(Added Reg. August 1962)

REG. 2-4-2.3 CONTAINER MAINTENANCE

Containers for the storage of refuse shall be maintained in such a manner as to prevent the creation of a nuisance or a menace to public health. Containers that are broken or otherwise fail to meet the requirements of the regulations shall be replaced, by the owner of said containers, with approved containers.

(Added Reg. August 1962)

SEC. 2-4-3. COLLECTION AND TRANSPORTATION

REG. 2-4-3.1 FREQUENCY OF COLLECTION

The frequency of collection shall be in accordance with regulations of the collection agency but not less than that shown in the following schedules:

1. Garbage only - twice weekly.

2. Refuse with garbage - twice weekly.

3. Rubbish and ashes - as often as necessary to prevent nuisances and flybreeding.

(Added Reg. August 1962)

REG. 2-4-3.2 PLACE OF COLLECTION

A. All refuse shall be properly placed on the premises for convenient collection as designated by the collection agency.

B. Where alleys are provided, collection shall be made on the alley side of the premises.

(Added Reg. August 1962)

REG. 2-4-3.3 VEHICLES

A. Vehicles used for collection and transportation of garbage, or refuse containing garbage, shall have covered, watertight, metal bodies of easily cleanable construction, shall be cleaned frequently to prevent a nuisance or insect breeding, and shall be maintained in good repair.

B. Vehicles used for collection and transportation of refuse shall be loaded and moved in such a manner that the contents, including ashes, will not fall, leak, or spill therefrom. Where spillage does occur, it shall be picked up immediately by the collector and returned to the vehicle or container.

C. Vehicles used for collection and transportation of rubbish or manure shall be of such construction as to prevent leakage or spillage, and shall provide a cover to prevent blowing of materials or creating a nuisance.

(Added Reg. August 1962)

SEC. 2-4-4. DISPOSAL

REG. 2-4-4.1 GENERAL

A. All refuse shall be disposed of by a method or methods included in these regulations and shall include rodent, insect, and nuisance control at the place or places of disposal. Approval must be obtained from the Department for all new disposal sites and may change in the method of disposal prior to use.

B. Carcasses of large dead animals shall be buried or cremated, unless satisfactory arrangements have been made for disposal by rendering or other approved methods.

C. All public "dumping grounds", provided in compliance with A.R.S. 9-441., shall be maintained and operated in accordance with the requirements of these regulations.

D. Manure shall be disposed of by sanitary landfill, composting, incineration, or used as fertilizer in such a manner as not to create insect breeding or a nuisance.

(Added Reg. August 1962)

REG. 2-4-4.2 METHODS OF DISPOSAL

Approval must be obtained from the Department for any method or methods used for the disposal of refuse prior to the start of operations, and shall be accomplished by one or more of the methods listed below:

A. Sanitary Landfill - Consists of the disposal of refuse on land and the daily compaction and covering of the refuse with 6 to 12 inches of earth so as to prevent a health hazard or nuisance. The final compacted earth cover shall be a minimum of 2 feet in depth. Where sanitary landfill operations are proposed, the Department will require the following.

1. The landfill shall be located so that seepage will not create a health hazard, nuisance, or cause pollution of any watercourse or water bearing strata.

2. Adequate and proper surface drainage shall be provided to prevent ponding or erosion by rainwater of the finished fill.

3. Provision shall be made for the control of insects, rodents, wind blown refuse, and accidental fire.

4. Burning of refuse is prohibited.

5. An all weather access road is required.

6. Suitable equipment and operating personnel shall be provided.

7. Salvaging, if permitted, shall be rigidly controlled.

B. Incineration --Where incineration is to be employed, the plans and specifications, along with any other information necessary to evaluate the project, shall be submitted to the Department and approval received prior to construction. In addition, an approved method for the disposal of non-combustible refuse is required. Where incineration is proposed, the following items shall be provided.

1. The capacity of the incinerator shall be sufficient for the maximum production of refuse expected.

2. Noncombustible refuse shall be disposed of by methods approved by the Department.

3. Skilled personnel to assure the proper operation and maintenance of the facilities in a nuisance-free manner.

C. Composting - This method of disposal is acceptable to the Department under the following conditions:

1. That plans and specifications and other information necessary to evaluate the project are submitted to the Department and approval received prior to start of construction.

2. That provisions are made for the proper disposal of all refuse not considered suitable for composting.

3. Skilled personnel shall be provided to assure the proper operation and maintenance of the facilities in a nuisance-free manner.

D. Garbage Grinding - This method, involving the separate collection and disposal of garbage into a community sewerage system through commercial type grinders or mandatory community-wide installation of individual household grinders, will be acceptable to the Department provided that suitable means shall be provided for the disposal of all remaining refuse.

E. Hog Feeding - This method of disposal will only be approved under the following conditions:

1. The garbage is collected and stored in suitable containers.

2. Only approved type vehicles are used for collection.

3. All garbage is effectively heat-treated in accordance with Chapter 7, Article 3, A.R.S. 24-941., through 949.

4. All remaining refuse, including nonedible garbage, is collected and disposed of separately by methods approved by the Department.

F. Manure Disposal - Manure shall be disposed of by sanitary landfill, composting, incinerating, or used as a fertilizer in such a manner as not to create insect breeding or a nuisance.

(Amended Reg. November 1971)

Federal Legislation on Solid Waste Disposal

A review of the federal legislation is as follows (U.S. Department of Health, Education, and Welfare, 1965, 1970a, 1970b):

Solid Waste Disposal Act of 1965 (PL89-272)

Title II of this congressional act authorizes the Department of Health, Education, and Welfare or HEW (The Bureau of Solid Waste Management was under HEW's control at this time), "(1) to initiate and accelerate a national research and development program for new and improved methods of proper and economic solid waste disposal; and, (2) to provide technical and financial assistance to state and local governments and interstate agencies in the planning, development, and conduct of solid waste disposal programs" (U.S. Department of Health, Education, and Welfare, 1965, p. 5). As used in this act, solid waste disposal means the collection, storage, treatment, utilization, processing, or final disposal of solid waste.

Resource Recovery Act of 1970 (PL91-512)

"This act amended or deleted most of the provisions of the 1965 act. Key amendments are that it provides for training grants in occupations involving the design, operation, and maintenance of solid waste disposal systems; and make the general provisions of the earlier act applicable to not only disposal of solid wastes, but also resource recovery . . . Resource recovery means a solid waste management system which provides for collection, separation, recycling, and recovery of solid wastes, including disposal of non-recoverable waste residues" (U.S. Department of Health, Education, and Welfare, 1970a, p. 2). Section

207(a) of the act authorizes "grants to State, interstate, municipal, and intermunicipal agencies, and organizations composed of public officials which are eligible for assistance under section 701(g) of the Housing Act of 1954, of not to exceed 66 2/3 percentage of the cost in the case of an application with respect to an area including only one municipality and not to exceed 75 percentum of the cost in any other case" (U.S. Department of Health, Education and Welfare, 1970, p. 64). Under Section 208, grants may be obtained for construction of a new or improved solid waste disposal facility, varying from 50 to 75 percent of the cost depending on the status of the state's plan for solid waste disposal (U.S. Department of Health, Education and Welfare, 1970). The grants under this section may not be used for land acquisition, or for operating or maintenance costs. This act provides grants for planning, training, and research but not for the actual control of solid waste disposal.

Reorganization Plan #3 of 1970

This plan established the Environmental Protection Agency (EPA). This plan transferred the departments concerned with pollution control from the Department of Health, Education, and Welfare to the EPA. This included the Bureau of Solid Waste Management. Under the EPA the National Air Pollution Control Administration is responsible for administering the Clean Air Act, which involves designating air quality regions, approving state standards, and providing financial and technical assistance to state control agencies to enable them to comply with the Clean Air Act's provisions. Although the EPA does have more power because of the air pollution provisions of the Clean Air Act, Section 3251, Title 42(6) states "that while the collection and disposal of solid waste should continue to be primarily the function of state, regional, and local agencies the problems of waste disposal as set forth above have become a matter national in scope and in concern and necessitate Federal action through financial and technical assistance and leadership in the development, demonstration, and application of new and improved methods and processes to reduce the amounts of waste and unsalvageable materials and to provide for proper and economical solid waste disposal practices" (U.S. Department of Health, Education and Welfare, 1970a, p. 154). The EPA has entered into solid waste disposal concerns by issuing court injunctions and cease and desist orders under the provisions of the Clean Air Act to stop the open burning of refuse in the disposal facilities around the state.

These acts typify the federal government's attitude towards pollution control. Pollution control is the concern of the states and the only time the federal government will become involved is in disputes between states. The federal government will also provide funds for research into pollution control but will not provide finances to operate a solid waste disposal system.

The Arizona State Department of Health is currently attempting to set up a state-wide solid waste management system. Copies of the two laws under which the Department of Health is now trying to force the communities to provide sanitary disposal of solid waste are in the first part of this Appendix. These are the <u>Rules and Regulations for Refuse and Other Objectionable Wastes</u>, Article 2, Part 4 and <u>Rules and</u>

Regulations for Subdivisions, Article 2, Part 10. Currently there are no laws which mandate compliance with these rules. Therefore, air pollution and subdivision laws are being used to obtain compliance.

APPENDIX D

DATA REQUIREMENTS FOR LEAST-COST MODEL

In designing a solid waste management system, several data requirements must be met. These requirements are presented in outline form:

I. Area data

   A. population estimates for years under consideration

   B. possible landfill locations

      1. size of these landfills in acres

      2. capacities of these landfills (total waste disposed of during life of site)

   C. changes in commercial and industrial sectors over time

   D. road distances between sources and potential disposal sites

II. Collection data

   A. The number of collection trucks available in present system.

      1. volume capacity of these trucks

      2. number of truck operators

   B. The number of collection bins in present collection system.

      1. Capacity of bins.

III. Disposal Data

A. Location of existing landfills.

1. Capacity of these landfills (total amount of waste that can be disposed during the life of the sites).

2. Size of these landfills in acres.

3. Average daily number of truckloads delivered to each landfill.

4. Amount of fill required by landfills (only include if it is required to haul in fill).

5. Sanitary report on existing facilities.

IV. Cost Data

A. Collection Cost Data

1. Fixed costs.

a. purchase price of collection bins

b. collection supervisor's salary

c. collection operator's salary

d. interest, insurance, taxes, and depreciation on collection equipment

e. interest, insurance, taxes, and depreciation on collection bins

2. Variable costs.

a. annual cost of oil, gas, and repairs for collection trucks

b. miles traveled annually by collection vehicles

B. Disposal cost data.

1. Fixed costs.

a. land acquisition cost

b. purchase price of disposal equipment

c. fencing cost

d. cost of access road

e. cost of initial grading

f. planning and designing costs

(i) legal fees

(ii) consulting fees

(iii) surveying costs

(iv) potential site investigation costs

g. administrative costs

h. depreciation costs on disposal equipment

i. educational costs--costs of informing the residents of benefits of sanitary, efficient solid waste management

j. interest on initial investment on disposal facilities and disposal equipment

k. overhead costs (utilities, supplies, etc.)

2. Operating costs.

a. operating personnel costs

b. cost of oil, grease, filters, and repairs on disposal equipment

APPENDIX E

CALCULATION OF TRACTOR ANNUAL OWNERSHIP COST

This calculation was made by totaling the component costs of owning a D6C crawler tractor. These component costs are the depreciation costs, interest costs, and insurance and tax costs. The depreciation costs were calculated as:

$$\text{annual depreciation} = \frac{\text{initial price - salvage value}}{\text{years of life}}$$

where: initial price = \$46,500 (Bauman, 1973)

salvage value at year 10 = \$13,717.50 (Bowers, 1970, p. 35)

life is assumed to be 10 years.

$$\text{therefore, annual depreciation} = \frac{\$46{,}500.00 - \$13{,}717.50}{10} = \$3{,}278.25\text{/year.}$$

The interest costs were assumed to be 8 percent of the average investment where:

$$\text{average investment} = \frac{\text{beginning investment + salvage value}}{2}$$

were: beginning investment = \$46,500

salvage value = \$13,717.50

Therefore, average investment = \$30,108.75

The interest cost then is 8 percent of \$30,108.75 or \$2,408.70. The insurance and tax cost were estimated to be 2 percent of the initial price or \$930. Therefore, the annual ownership costs were \$3,278.25 + \$2,408.70 + \$930.00 or \$6,616.95.

APPENDIX F

CALCULATION OF ANNUAL OWNERSHIP AND OPERATING COST OF TRUCK USED TO HAUL CRAWLER TRACTOR BETWEEN LANDFILLS

The annual cost of the truck required to haul the D6C crawler tractor between the landfills in the final solution was estimated by totaling the component owning costs. The component owning costs are the depreciation costs, interest costs, and insurance and tax costs. The depreciation costs were calculated as:

$$\text{annual depreciation} = \frac{\text{initial price - salvage value}}{\text{years of life}}$$

where: initial price = \$14,000 (Sundquist, 1973)

salvage value at end of year 10 = \$3,000 (Sundquist, 1973)

Assuming a 10 year life, the depreciation costs equal $\frac{\$14,000 - \$3,000}{10}$ = \$1,100/year.

The interest cost was assumed to be 8 percent of the average investment where:

$$\text{average investment} = \frac{\text{beginning investment + salvage value}}{2}$$

where: beginning investment = \$14,000 (Sundquist, 1973)

salvage value = \$3,000 (Sundquist, 1973)

therefore, average investment = \$8,500

The interest costs then are 8 percent of \$8,500 or \$680.

The insurance and tax costs were estimated to be 2 percent of the initial price or \$280. Therefore the annual owning costs were \$1,100 +

$680 + $280 or $2,060/year. The operating costs of the truck were assumed to be $.50/mile (Sundquist, 1973).

APPENDIX G

CALCULATION OF ANNUAL OWNERSHIP COST OF TRAILER

The annual cost of the low-boy trailer required to haul the D6C crawler tractor between the landfills in the final solution was estimated by totaling the component owning costs. The component owning costs are the depreciation costs, interest costs, and insurance and tax costs. The depreciation costs were calculated as:

$$\text{annual depreciation} = \frac{\text{initial price} - \text{salvage value}}{\text{years of life}}$$

where: initial price = \$8,000 (Sundquist, 1973)

salvage value at end of year 10 = \$4,000 (Sundquist, 1973)

Assuming a 10 year life, the annual depreciation costs = $\frac{\$8,000 - \$4,000}{10}$ or \$400 a year. The interest cost was assumed to be 8 percent of the average investment where:

$$\text{average investment} = \frac{\text{beginning investment} + \text{salvage value}}{2}$$

where: beginning investment = \$8,000 (Sundquist, 1973)

salvage value = \$4,000 (Sundquist, 1973)

Therefore, the average investment = \$6,000

The interest costs then are 8 percent of \$6,000 or \$480. The insurance and tax costs were estimated to be 2 percent of the initial price or \$160. Therefore, the annual owning costs were \$400 + \$480 + \$160 or \$1,040.

APPENDIX H

CALCULATION OF M VALUES

The calculation of the average weekly mileage traveled by Clifton collection vehicles (presented in Chapter III) was estimated in the following manner:

(1) M_1 = 2 (number of street miles in Clifton)
There are 13 miles of streets in Clifton (Danenhauer, 1973).
$M_1 = 2 \times (13) = 26$ miles/week.

(2) $M_2 = (5) \times (2) \times$ (distance from garage to collection districts). It is 1/4 mile from garage to center of Clifton (Danenhauer, 1973).
$M_2 = (5) \times (2) \times (1/4) = 2.5$ miles/week.

(3) $M_3 = 5$ [2 x (average number of truckloads to the landfill/day) - 1] (average distance to the landfill).
The average distance to landfill = 5.0 miles (Danenhauer, 1973). The average number of truckloads to the landfill was estimated by: population x generation x tons/pounds x truckloads/tons = truckloads/day where population = 5,087 people (Danenhauer, 1973);
5.0 lbs/capita/day (Badger, 1972, p. 3), tons/lbs = 1 ton/2,000 lbs;
truckloads/tons = 1 truckload/3 tons (Morse and Roth, 1970, p. 72) therefore average number of trucklaods = $5{,}087 \times 5.0 \times \frac{1}{2000} \times \frac{1}{3} = 4.891$ truck/day and $M_3 = 5\,[2 \times (4.891) - 1] \times (5.0) = 219.55$ miles/week.

(4) M_4 = (5) x (2) x (distance from landfill to garage).
The distance to garage from landfill = 4.5 miles[1]
therefore M_4 = (5) x (2) - (4.75) = 47.5 miles/week.

Thus average weekly miles = $M_1 + M_2 + M_3 + M_4$ or

26.0 + 2.5 + 219.55 + 47.5 = 295.55 miles/week.

---

1. 5.00 miles to Morenci landfill from Clifton
 - .25 miles to garage from Clifton on the same road
 4.75 miles from Morenci landfill to garage

APPENDIX I

CALCULATION OF ANNUAL OWNERSHIP COST OF COLLECTION VEHICLE

The annual cost o= the collection vehicle used in the estimate of the cost of transportation (c_t) was estimated by totaling the component owning costs. The component owning costs are the depreciation costs, interest costs, and insurance and tax costs. The depreciation costs were calculated as:

$$\text{annual depreciation} = \frac{\text{initial price - salvage value}}{\text{years of life}}$$

where: initial price = \$27,000 (Wentworth, 1972, p. 52)

assumed salvage value = \$5,000

Assuming a 6 year life the depreciation costs equals $\frac{\$27,000 - \$5,000}{6}$ or \$3,666.66/year.

The interest costs were assumed to be 8 percent of the average investment where:

$$\text{average investment} = \frac{\text{beginning investment + salvage value}}{2}$$

where: beginning investment = \$27,000 (Wentworth, 1972, p. 52)

assumed salvage value = \$5,000

Therefore, the average investment equals \$16,000.

The interest costs then are 8 percent of \$16,000 or \$1,280/year. The insurance and tax costs were estimated to be 2 percent of the initial price or \$540/year. Therefore the annual owning costs were \$3,666.66 + \$1,280 + \$540 or \$5,486.66/year.

APPENDIX J

DESCRIPTION OF INPUT FORMAT FOR COMPUTER PROGRAM

The computer program used in this study was adapted from Systems Analysis for Regional Solid Waste Handling (Morse and Roth, 1970, p. I-3, I-8). The program follows seven basic steps. They are:

(1) Read input data.

(2) Calculate k_{ij} values for all sources and facilities.

(3) Call generating subroutine for first possible selection.

(4) Make facility and source assignments.

(5) Calculate total cost of these assignments.

(6) Print cost.

(7) Call generating subroutine for next selection. Repeat procedure until all possible selections are generated.

The program deck is followed by the input data. The input data is given in three sections: system data, facility parameter data, and distance data. The system data is input in the following order:

Card 1: NCASE = number of cases

Card 2: NS = number of sources

Third set of cards: (Q[I]) = source quantities (NS of them) eight to a card

Fourth set of cards: (x,y coordinates of sources) = source locations (NS pairs) four pairs to a card

Card 5: N = number of facilities

NPP = number of processing plants

NDS = number of disposal sites

Card 6: JIN (J) = facility names (N of them) eight to a card (usually the first N integers are used).

Seventh set of cards: (x,y coordinates of the facilities) = facility locations (N of them) four pairs to a card.

Next the facility parameter data is input into the computer. For each facility in the analysis a facility card is required. The program is set up to make multiple runs. If this is done a new facility card is required for each run. Therefore if you have NCASE runs and N facilities you must have NCASE x N cards in all. If processing plants are in the analysis each processing plant card must include:

PFC = processing plant fixed costs

PCIN = capacity expansion coefficient

PPC = variable costs of processing plant

PCOMP = volume reduction coefficient of the processing plant

PCTO = transportation cost per mile of hauling a unit quantity of output of the processing plant to the disposal facility

PCTTPP = transportation cost per mile of hauling a unit quantity of refuse to the processing plant in collection vehicles

Each disposal site card must include:

DFC = disposal site fixed costs

DFCIN = capacity expansion coefficient

DDC = direct disposal costs of the disposal facility

DCOMP = volume reduction coefficient of the disposal facility

DCTTDS = transportation cost per mile of hauling a unit quantity of refuse to the disposal site in collection vehicles

There are N facility cards, each containing the corresponding information of that facility. Next the distance data is input into the computer program in the following format:

Tenth set of cards: d_{jj}'s = distance from processing plants to disposal sites (NNP distances per cards)

Eleventh set of cards: D_{ij}'s = distances from sources to facilities (N distances per card) (NS cards in all)

Accordingly the entire deck will be set up in the following sequence:

(1) Program deck

(2) System data (7 sets of cards)

(3) Facility parameter data (N cards)

(4) Distance data

(a) with processing plants (NDS cards) + (NS cards)

(b) without processing plants (NS cards)

The following six pages are a listing of the computer program.

```
      PROGRAM FACSEL(INPUT,OUTPUT)
      COMMON/JOB/ ITST,N,K,JIN(20),JOUT(50),JOJTT(50),ITAB(50),DISTPD(
     120,20),DISTSF(200,20)
      COMMON/COST/ PFC(20),PCIN(20),PPC(20),PCOMP(20),PCTO(20),PCTTPP(
     220),DFC(20),DFCIN(20),DOC(20),DCOMP(20),DCTTOS(20),C(20),Q(200),
     2JEQUAL(200),JPREQ(200),XS(200),YS(200),XF(20),YF(20),AK(200,20),
     3JTEMP(200),JPRINT(200)
      DIMENSION DJJ(8,8)
      DJJ(1,1)=0.00
      DJJ(1,2)=11.10
      DJJ(1,3)=13.15
      DJJ(1,4)=19.60
      DJJ(1,5)=24.40
      DJJ(1,6)=33.40
      DJJ(1,7)=37.70
      DJJ(1,8)=35.90
      DJJ(2,1)=11.10
      DJJ(2,2)=0.0
      DJJ(2,3)=5.45
      DJJ(2,4)=12.40
      DJJ(2,5)=17.20
      DJJ(2,6)=26.20
      DJJ(2,7)=30.50
      DJJ(2,8)=28.60
      DJJ(3,1)=13.15
      DJJ(3,2)=5.45
      DJJ(3,3)=0.0
      DJJ(3,4)=9.45
      DJJ(3,5)=14.25
      DJJ(3,6)=23.55
      DJJ(3,7)=27.55
      DJJ(3,8)=25.85
      DJJ(4,1)=19.60
      DJJ(4,2)=12.40
      DJJ(4,3)=9.45
      DJJ(4,4)=0.0
      DJJ(4,5)=4.80
      DJJ(4,6)=13.90
      DJJ(4,7)=18.10
      DJJ(4,8)=16.20
      DJJ(5,1)=24.40
      DJJ(5,2)=17.20
      DJJ(5,3)=14.25
      DJJ(5,4)=4.80
      DJJ(5,5)=0.00
      DJJ(5,6)=9.00
      DJJ(5,7)=13.30
      DJJ(5,8)=11.40
      DJJ(6,1)=33.40
      DJJ(6,2)=26.20
      DJJ(6,3)=23.55
      DJJ(6,4)=13.80
      DJJ(6,5)=9.00
      DJJ(6,6)=0.0
      DJJ(6,7)=4.50
      DJJ(6,8)=6.60
      DJJ(7,1)=37.70
```

```
      DJJ(7,2)=30.50
      DJJ(7,3)=27.55
      DJJ(7,4)=18.10
      DJJ(7,5)=13.30
      DJJ(7,6)=8.50
      DJJ(7,7)=0.0
      DJJ(7,8)=7.50
      DJJ(8,1)=35.80
      DJJ(8,2)=28.50
      DJJ(8,3)=25.65
      DJJ(8,4)=16.20
      DJJ(8,5)=11.40
      DJJ(8,6)=6.60
      DJJ(8,7)=7.50
      DJJ(8,8)=0.0
      EPSL=.00001
      READ 5100,NCASE
      READ 5100,NS
 5100 FORMAT(I10)
      READ 1001, (Q(I),I=1,NS)
      READ 1001, (XS(I),YS(I),I=1,NS)
 1001 FORMAT(8F10.0)
      READ 1000, N,NPP,NOS
      READ 1000, (JIN(I),I=1,N)
 1000 FORMAT(8I10)
      READ 1001, (XF(I),YF(I),I=1,N)
      KNOS1=NOS+1
      DO 5000  ICASE=1,NCASE
      IF(NPP.EQ.0) GO TO 2000
      READ 2001,(PFC(I),PCIN(I),PPC(I),PCOMP(I),PCTO(I),PCTTPP(I),I=K
     1NOS1,N)
 2000 READ 2002, (DFC(I),DFCIN(I),DOC(I),DCOMP(I),DCTTOS(I),I=1,NOS)
 2001 FORMAT(6F10.0)
 2002 FORMAT(5F10.0)
      DO 600 II=1,50
  600 JOUTT(II)=0
      DO 601 I=1,200
      JTEMP(I)=0
  601 JPRINT(I)=0
      KOUT=0
      PRINT 5001
 5001 FORMAT(1H1)
      PRINT 5002, ICASE
 5002 FORMAT(25X,*CASE NUMBER*,I3,//////)
      PRINT 3000, (JIN(I),I=1,N)
 3000 FORMAT(10X*FACILITIES*/10I10)
      PRINT 3001, (Q(I),I=1,NS)
 3001 FORMAT(10X*QUANTITIES*/(8E12.5))
      PRINT 1002, NS,N,NPP,NOS
 1002 FORMAT(10X*NOS OF SOURCES AND FACILITIES*4I10///)
      PRINT 1003, (XS(I),YS(I),I=1,NS)
 1003 FORMAT(10X*SOURCE COORDINATES*/(5X,4E15.5))
      PRINT 1053, (XF(I),YF(I),I=1,N)
 1053 FORMAT(10X*FACILITY COORDINATES*/(5X,4E15.5))
      IF(NPP.EQ.0) GO TO 2003
      PRINT 1004,(PFC(I),PCIN(I),PPC(I),PCOMP(I),PCTO(I),PCTTPP(I),I
     1=KNOS1,N)
```

```
 1004 FORMAT(10X*PROCESSING PARAMETERS*/(5X,6E15.5))
 2005 PRINT 1054, (OFC(I),DFCIN(I),DDC(I),DCOMP(I),DCTTDS(I),I=1,NDS)
 1054 FORMAT(10X*DISPOSAL PARAMETERS*/(5X,5E15.5))
    1 AMIN= 10**20
      ITST= 1
      IF(NPP.EQ.0) GO TO 2003
    2 CONTINUE
      KK= NDS+1
      READ 412,((DISTPD(J1,J2),J1=KK,N),J2=1,NDS)
  412 FORMAT(2F10.2)
 2003 CONTINUE
      IF(NPP.EQ.0) READ 414
  414 FORMAT(1X)
      READ 413,((DISTSF(I1,I2),I2=1,N),I1=1,NS)
  413 FORMAT(8F10.2)
    3 K=1
    5 ITST=1
    6 DO 104 I=1,50
      JOUT(I)=0
  104 ITAB(I)=0
    4 CALL COMB
C     JOUT(I)  I=1,2,3,---K  COMES BACK FROM COMB
    7 IF(ITST.EQ.1)GO TO 4141
   11 IF( JOUT(1).GT.NDS ) GO TO 4
C     JOUT HAS AT LEAST ONE JUMP SITE
C     BEGIN COMPUTATION OF C(J)
   13 J=1
      JJ=0
  200 J1= JOUT(J)
  201 IF(J1.GT.NDS) GO TO 206
  202 JJ=JJ+1
      BJ= DCOMP(J1)*DDC(J1)
      C(J1)= DFCIN(J1)+BJ
  203 IF(J.GE.K) GO TO 14
  205 J=J+1
      GO TO 200
  206 J2=1
      BJ=10**20
  207 J22= JOUT(J2)
      TEMP=PCTO(J1)*DISTPD(J1,J22)+DDC(J22)+DFCIN(J22)
      TEMP= PCOMP(J1)*TEMP+PPC(J1)
  208 IF(TEMP.GE.BJ) GO TO 209
  212 BJ= TEMP
  209 IF( J2.LT.JJ) GO TO 210
  211 C(J1)= PCIN(J1)+BJ
      GO TO 203
  210 J2=J2+1
      GO TO 207
   14 DO 300 I=1,NS
      DO 300 J=1,K
      J1=JOUT(J)
      IF(J1.GT.NDS) GO TO 301
      AK(I,J)=C(J1)+DCTTDS(J1)*DISTSF(I,J1)
      GO TO 300
  301 AK(I,J)=C(J1)+PCTTPP(J1)*DISTSF(I,J1)
  300 CONTINUE
   15 AKMIN= 10**20
```

```
  401 TMP=0
      DO 905 I=1,NS
  905 JEQUAL(I)=0
  402 I=1
  403 J=1
      AKMIN=10**20
  404 IF(AK(I,J).LT.AKMIN-EPSL) GO TO 405
  406 IF(J.GE.K) GO TO 408
  407 J=J+1
      GO TO 404
  405 AKMIN=AK(I,J)
      JTEMP(I)=JOUT(J)
      JIND=J
      GO TO 406
  408 TMP=AKMIN*Q(I)+TMP
      J3=JIND+1
      IF(J3.GT.K) GO TO 409
  903 TT=ABS(AK(I,J3)-AKMIN)
      IF(TT.LT.EPSL) JEQUAL(I)=1
      IF(J3.GT.K) GO TO 409
      J3=J3+1
      GO TO 903
  409 IF(I.GE.NS) GO TO 411
  410 I=I+1
      GO TO 403
C  MIN  AK(I,J) COMPUTED AND IS LOCATED IN TMP
  411 AMP=0
      DO 500 I=1,K
      J1=JOUT(I)
      IF(J1.GT.NDS) GO TO 501
      AMP=AMP+DFC(J1)
      GO TO 500
  501 AMP=AMP+PFC(J1)
  500 CONTINUE
C   SUM AJ COMPLETED AND IS IN AMP
      CMP=AMP+TMP
C THIS DO LOOP CALCULATES TRACTOR TRANS COSTS
      TOTALD=0.0
      DO 520 III=1,50
      IF(III.EQ.1)IDESTN=JOUT(1)
      IF(III.EQ.1) GO TO 519
      IF((JOUT(III).EQ.0))IORIGIN=IDESTN
      IF((JOUT(III).EQ.0))IDESTN=JOUT(1)
      IF(JOUT(III).EQ.0.AND.JOUT(1).EQ.1)IDESTN=JOUT(2)
      IF((JOUT(III).EQ.0)) GO TO 518
      IORIGIN=IDESTN
      IDESTN=JOUT(III)
  518 IF(IORIGIN.EQ.1) GO TO 520
      IF(IDESTN.EQ.1) GO TO 520
      TOTALD=TOTALD+DJJ(IORIGIN,IDESTN)
      IF(IORIGIN.EQ.1)TOTALD=TOTALD-DJJ(IORIGIN,IDESTN)
      IF(IDESTN.EQ.1)TOTALD=TOTALD-DJJ(IORIGIN,IDESTN)
      IF((JOUT(III).EQ.0)) GO TO 521
  519 CONTINUE
  520 CONTINUE
  521 TOTALD=TOTALD
      SFC1=20008.95
```

```
      SFC2=4100+(156*TOTALD)
      IF(TOTALD.EQ.0.0)SFC2=0.0
      IF(JOUT(1).EQ.1.AND.JOUT(2).EQ.0)SFC1=0.0
      IF(JOUT(1).EQ.1.AND.JOUT(2).EQ.0)SFC2=0.0
      SFCII=SFC1+SFC2
      TEMP=SFCII+CMP
      PRINT 5011
      PRINT 9990, (JOUT(J1),J1=1,K)
 9990 FORMAT(//* THE FACILITIES BEING CONSIDERED ARE *,20I4)
      DO 602 I=1,NS
      JPREQ(I)=JEQUAL(I)
  602 JPRINT(I)=JTEMP(I)
   17 AMIN=TEMP
      KOUT=K
      DO 700 J=1,K
  700 JOUTT(J)=JOUT(J)
      JJ=0
      J=1
  801 J1= JOUTT(J)
  802 IF(J1.GT.NDS) GO TO 807
  803 JJ=JJ+1
  804 PRINT 850,J1
  850 FORMAT(10X*DISPOSAL SITE NUMBER = *I3)
  805 IF(J.GE.K) GO TO 853
  806 J=J+1
      GO TO 801
  807 J2=1
  808 BJJ=10**20
  809 J22= JOUTT(J2)
  810 TEMP=PCTD(J1)*DISTPD(J1,J22)+DDC(J22)+DFCIN(J22)
  811 IF(TEMP.LT.BJJ-EPSL) GO TO 812
  813 IF(J2.GE.JJ) GO TO 815
  814 J2=J2+1
      GO TO 809
  812 JDUMP= J22
      BJJ= TEMP
      GO TO 813
  815 PRINT 851, J1,JDUMP
  851 FORMAT(5X*PROCESSING PLANT NO = *I3,5X,*DISPOSAL SITE NO. = *I3)
C     INSERT BLOCK 4
  900 J2= JDUMP+1
  902 IF(J2.GT.JJ) GO TO 805
      J22= JOUTT(J2)
      TEMP=PCTD(J1)*DISTPD(J1,J22)+DDC(J22)+DFCIN(J22)
      TMBJ= ABS(TEMP-BJJ)
      IF(TMBJ.LT.EPSL) PRINT 851, J1,J22
      IF(J2.GE.JJ) GO TO 805
      J2=J2+1
      GO TO 902
  853 PRINT 904, AMIN
  904 FORMAT(10X*MINIMUM COST = *E12.6//)
      PRINT 852, (I,JPRINT(I),JPREQ(I),I=1,NS)
  852 FORMAT(10X,*SOURCE NO.       FACILITY ASSIGNMENT        EQUALITY TE
     1ST*/(I15,I20,I25))
      GO TO 4
 4141 IF(K.GE.N) GO TO 10
    9 K=K+1
```

```
      GO TO 5
   10 PRINT 5001
      PRINT 9970
 9970 FORMAT(50X,*COMPLETE COST MATRIX*,///)
      DO 9981 I=1,NS
 9981 PRINT 9982, (I,J,AK(I,J),J=1,N)
 9982 FORMAT(/,5(2X,I4,2X,I4,2X,E11.5))
 5000 CONTINUE
      STOP
      END
```

APPENDIX K

CALCULATION OF ANNUAL COST OF COLLECTION BINS USED IN RURAL COLLECTION SYSTEM

Residents and solid waste disposal planners may wish to know what it would cost to set up a rural collection system. The rural collection system consists of a packer truck (25 cubic yard capacity) which collects solid waste stored in collection bins (8 cubic yard capacity) stationed at convenient locations in the rural areas of the County. The collection bins provide a convenience to the residents, since they would often be closer to the bins than the disposal sites. Thus not only would their transportation costs be decreased, but home sanitary conditions may be improved if residents "dispose" of refuse more frequently.

Since Duncan and Clifton have municipal collection systems their sources are excluded from the analysis. Using the 1980 generation rate of 8.0 lbs/capita/day (Badger, 1972, p. 3) and assuming a 50 percent capacity of the collection bins to allow for excess during peak periods of use, the number of people that can use one collection bin can be determined. Assuming bi-weekly collections and 8.33 cubic yards of uncompacted solid waste equals 1 ton of refuse, the calculations to determine the number of people who can use one collection bin are:

8 cubic yards = .96 tons or 1,920 lbs.

Therefore one 8 cubic yard collection bin can handle .96 tons/week; and

8.0 lbs/capita/day x 7 days = 56.0 lbs/capita/week, therefore

1,920 lbs/week ÷ 56.0 lbs/capita/week = 34.286 people.

Thus one 8 cubic yard collection bin can handle the generation of 34 people each week. By dividing the population of each rural area by the bin capacity (service 34 people) the number of bins needed to serve each area is determined:

	1980 Population	Number of Collection Bins
Verde Lee	209	6
Loma Linda	488	14
York Valley	2,314	68
Apache Grove	697	20
Franklin	697	20
TOTAL	4,405	128

8 cubic yard containers cost \$460 a piece and a 10 year life with a zero salvage value is assumed (Heise, 1973). Therefore the annual cost is:

128 bins x \$460/bin = \$58,880 cost of bins

yearly cost equals $\frac{\$58,880}{10}$ = \$5,888 per year.

LIST OF REFERENCES

Arizona Cotton Growers Association. Newsletter. October 5, 1973.

Arizona State Department of Health. Rules and Regulations for Refuse and and Other Objectionable Wastes, Article 2, Part 4. Phoenix, Arizona. 1970a.

Arizona State Department of Health. Rules and Regulations for Subdivisions, Article 2, Part 10. Phoenix, Arizona. 1970b.

Arizona Statistical Review. 28th edition. Valley National Bank, Economic Research Department. Phoenix, Arizona. 1972.

Arizona Statistical Review. 29th edition. Valley National Bank. Economic Research Department. Phoenix, Arizona. 1973.

Badger, Daniel. "Wastes Go Underground." Agriculture at O.S.U. O.S.U. Press: Stillwater, Okla. Fall 1972, pp. 35-42.

Bauman, R.F. Sales Representative. Empire Machinery Co. Phoenix, Arizona. Personal communication. Nov. 15, 1973.

Bowers, Wendell. Modern Concepts of Farm Machinery Management. Champaign, Illinois: Stipes Publishing Company. 1970.

Danenhauer, Edward. Clifton City Clerk. Clifton, Arizona. Personal communication. Oct. 19, 1973.

Employment Security Commission of Arizona. "Arizona Basic Economic and Manpower Data." Arizona State Employment Service. Phoenix, Arizona. September, 1969.

Firch, Robert S. "Optimum Warehouse Location: A Problem in Non-Linear Programming." Unpublished M.S. Thesis, Purdue University. 1960.

Havlicek, Joseph Jr., Tolley, George S., and Wang, Yi. "Solid Waste - A Resource?" American Journal of Agricultural Economics, LI, No. 5, Dec. 1969, pp. 1598-1602.

Heise, Cliff. Salesman. National Refuse Equipment. Tucson, Arizona. Personal communication. Nov. 19, 1973.

Hinz, Walter. Agricultural Engineering Specialist. Tucson, Arizona. Personal communication. Nov. 7, 1973.

Kiefer, Irene. "Mathematical Analysis of Solid Waste Collection" as condensed by David H. Marks and Jon D. Liebman. U.S. Environmental Protection Agency. Washington, D.C.: U.S. Government Printing Office. 1972.

Morse, Norman and Edwin W. Roth. Systems Analysis of Regional Solid Waste Handling. U.S. Department of Health, Education, and Welfare. Washington, D.C.: U.S. Government Printing Office. 1970.

Rawson, Osgood. Safford City Manager. Safford, Arizona. Personal communication. Sept. 13, 1973.

Schreiner, Dean F. "A Planning Framework for Rural Public Sector Analysis." Paper prepared for the North Central Regional Center for Rural Development Conference on Planning for Services in Rural Areas. Lincoln, Nebraska. April 24-26, 1973.

Shirk, Brian J. Solid Waste Control Representative, Pima County, Department of Sanitation. Personal communication to Professor Quentin M. Mees, Civil Engineering Department, University of Arizona. Tucson, Arizona. June 7, 1972.

Shonerd, Wesley. Public Health Engineer, Division of Sanitation, Environmental Health Services. Phoenix, Arizona. Personal communication. Feb. 23, 1973.

Sorg, Thomas J. and H. Zanier Hickman. Sanitary Landfill Facts. Washington, D.C.: U.S. Government Printing Office. 1968.

Sundquist, Lee. Salesman. Omega Rentals. Tucson, Arizona. Personal communication. Nov. 27, 1973.

Thierauf, Robert J. and Richard A. Grosse. Decision Making Through Operations Research. New York: John Wiley and Sons, Inc. 1970.

U.S. Department of Health, Education and Welfare. Reorganization Plan #3 of 1970. Washington, D.C.: U.S. Government Printing Office. 1970a.

U.S. Department of Health, Education and Welfare. Resource Recovery Act of 1970. Washington, D.C.: U.S. Government Printing Office. 1970b.

U.S. Department of Health, Education and Welfare. Solid Waste Disposal Act of 1965. Washington, D.C.: U.S. Government Printing Office. 1965.

Van Fleet, Paul. Greenlee County Sanitarian. Clifton, Arizona. Personal communication. June 15, 1973.

Weddle, Darvin. Graham County Sanitarian. Safford, Arizona. Personal communication. Sept. 13, 1973.

Wentworth, Douglas L. "Solid Waste Management Plan." Planning Department of Cochise County, Bisbee, Arizona. (Mimeographed) 1972.