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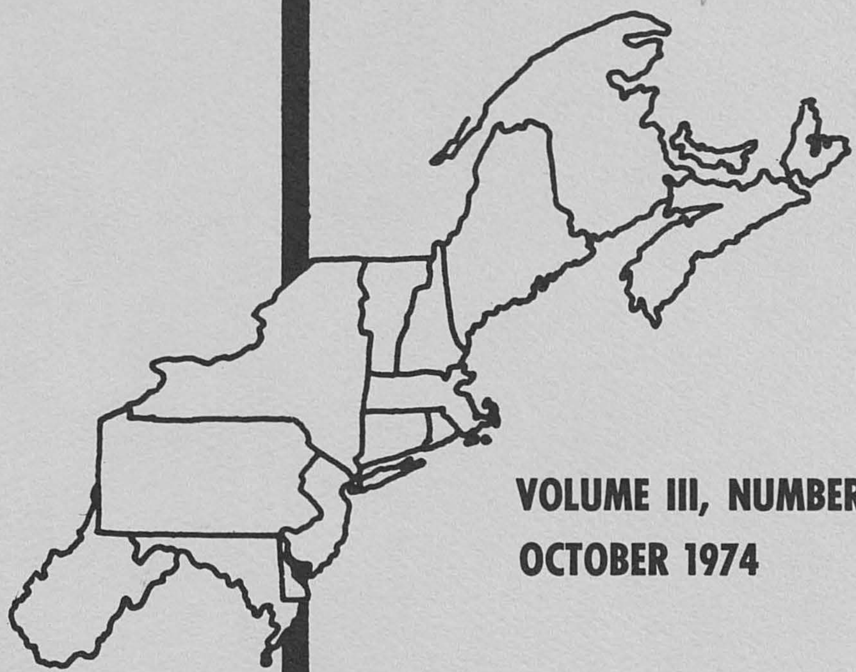

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FACTOR-COST RELATIONSHIPS FOR SLUDGE RECYCLING THROUGH LAND DISPOSAL*

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Introduction

As population increases and per capita consumption rises, secondary effects in the form of pollutants, which originate from the production of goods and services, have become increasingly evident. 1/ More of the nation's energies are required to bring about the proper management and utilization of these pollutants. Until recently, most pollutants were considered something to be disposed of at minimum or no cost. Further analysis has revealed that they are to a large extent "misplaced resources." Many can be utilized, thus reducing the cost of waste management and the use of virgin materials.

One "pollutant" that shows promise is the sewage sludge generated from municipal treatment facilities. In coastal areas the sludge is most commonly disposed by two methods: landfill and ocean dumping. Objections to these methods have been raised because of the pollution of water supplies, oceans, and streams. An alternative method of sludge disposal involves application onto the soil and utilization by plant and animal life.

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1/ For the original report see: Kasper, Victor, Jr., Michael S. Gould, Donn A. Derr and Emil J. Genetelli, "Procedure for Estimating the Cost and Investment Required for Sludge Recycling through Land Disposal," Department of Agricultural Economics and Marketing and Department of Environmental Sciences, Rutgers University, The State University of New Jersey, New Brunswick, New Jersey, August, 1973.

Background

To estimate the costs and investment requirements of sludge recycling through land disposal systems, five basic activities were identified. 2/ These are transport, dewatering, storage, application, and nutrient removal. A summary of the ways in which these basic activities may be combined is indicated in Figure 1.

For each basic activity, one or more alternative modes are available. For example, the transport modes available in the program are: (1) dump truck, (2) underground pipeline, and (3) tank truck. If the dump truck transport mode is selected, the sludge must first be dewatered to 30 percent solids. The sludge can be dewatered by either the vacuum filtration or centrifugal method. Once the sludge is at the disposal site, there is the store-no-store option -- depending upon climatic conditions. In either case, the sludge can then be directly applied to the soil. There are two application modes for dewatered sludge: plow furrow and contour furrow; five application modes are available for non-dewatered sludge: plow furrow, contour furrow, sub-sod injection, and two spray irrigation techniques. In addition, dewatering is optional at the disposal site.

There are two activities (administration and nutrient removal) in addition to those specified in Figure 1. Administration is assumed to be handled by one engineer and a secretary working at the Administration building at the disposal site. This activity is not optional and is included in all disposal systems.

The final activity of all sludge disposal systems is nutrient removal. Currently, only one mode for this activity is being considered -- Bermuda grass. The grass, which is grown to remove excess nutrients from the soil, is assumed to be grazed. Other nutrient removal modes, along with other activity modes, are currently being researched and may eventually be included in the methodology.

These activities and options may be combined to compose 44 alternative feasible sludge disposal systems. 3/ All systems include at least four activities: transport, application, administration, and nutrient removal. The dewatering and storage activities are optional, depending upon specific needs.

The Problem Defined

In the process of estimating costs and investment requirements of the sludge disposal system, values which best represent a specific situation have been assigned to factors such as wage rates, interest rates,

2/ Estimates do not include the costs involved in the collection or treatment of raw sewage.

3/ A detailed description of the sludge disposal systems and the assumptions of each is provided in the previous cited study.

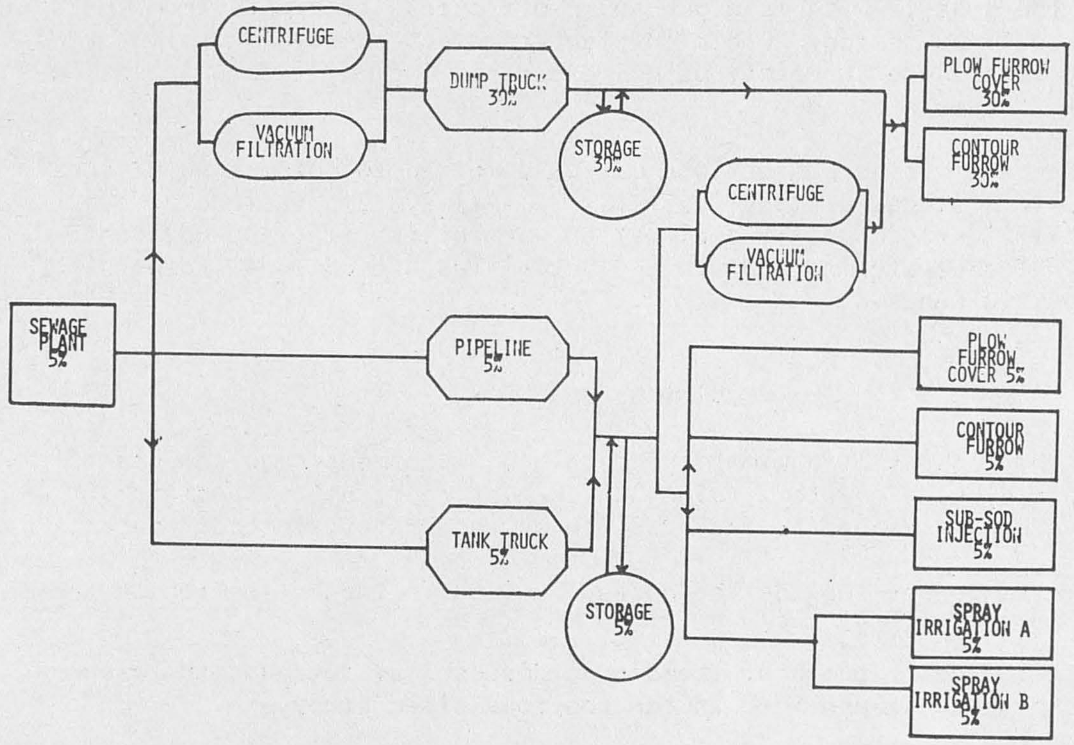
land values, etc. It is realized, however, that the values for these factors vary among different geographic locations and over time. An engineer or municipal planning official using the cost estimates for decision making is limited to specific conditions. An understanding of how different conditions affect the cost of alternative sludge disposal systems is vital to the decision-making process. The focus of this paper is to examine the effect on costs of changes in the values of selected factors used in calculating the costs of sludge disposal systems.

Procedures

Average total costs of several alternative sludge disposal systems at three volume capacities as the values of selected factors were varied were estimated. The six factors analyzed include:

(1) Number of days per year in which sludge can be applied.
(2) Hourly wage rate of labor involved in application systems.
(3) Interest rate on invested capital.
(4) Purchase price per acre of land required for land disposal.
(5) Distance in miles of a round trip between sewage plant and application site.
(6) Capacity, in dry tons per acre per year, of soil to absorb the sludge.

FIGURE 1
FLOW CHART OF ACTIVITY FROM SLUDGE SEWAGE PRODUCTION POINT TO SOIL APPLICATION



The base values, relevant ranges and intervals for each selected factor are summarized in Table 1. These factors were chosen because of their tendency to vary over time and/or geographic location and because of their importance in estimating costs.

Table 1
Values and Relevant Ranges of Factors Analyzed

Factor	Base Value	Relevant Range	Interval
Application days	215 days/year	100 - 350	25
Wage rate	$3.15/hour	2.50 - 6.50	.25
Interest rate	7.5%	4.5 - 11.0	.5
Land value	$2,500/acre	500 - 10,000	500
Round trip distance	40 miles	5 - 100	5
Soil capacity	40 dry tons/acre/yr.	5 - 100	5

To simplify the analysis, five representative systems were selected from the possible 44 systems. They are described and diagramed in Figure 2. Alternative 1 involves dewatering by centrifuge, transporting by dump truck, storing in concrete basins, applying by the contour furrow method, and removing excess nutrients with Bermuda grass.

The five systems were examined at three volume capacities, 0.5, 10, and 50 MGD, 4/ because it was felt that factor-cost relationships may vary as the size of operation varies. Table 2 summarizes the approximate population served, the land, investment, and machinery requirements, and costs of the five alternative systems at the three volume levels.

The resulting average total costs were plotted against the corresponding factor values. Simple least square regression was used to estimate the mathematical relationships between costs and the six factors. Elasticities indicating the percentage change in cost resulting from a percentage change in the factors were calculated at the base levels of each factor, thereby allowing comparisons between factors.

Results

The factor-cost relationships of five alternative disposal systems serving a 10 MGD plant are plotted in Figure 3. Factor elasticities at three levels of volume are summarized in Table 3.

4/ These figures refer to the volume in million gallons per day of wastewater treated at the plants. They are representative of a small, medium, and large plant, respectively.

Table 2
Land, Investment and Storage Requirements and Costs for the Three Levels of Volume 1/

Volume	Population served	Land area	Initial capital investment	Storage capacity	Costs TFC	AFC	TVC	AVC	ATC
	No.	Acres	$	Gals.	----------------		$	----------------	
0.5 MGD									
Alternative 1	3,400	3	89,959	22,752	50,005	440	12,164	107	547
" 2	3,400	3	2,320,462	136,510	196,714	1,730	13,009	114	1,844
" 3	3,400	3	2,299,772	136,510	194,903	1,714	10,232	90	1,804
" 4	3,400	3	95,061	136,510	50,452	495	9,628	85	528
" 5	3,400	3	74,371	136,510	48,641	428	6,851	60	488
10 MGD									
Alternative 1	68,000	57	334,681	455,033	64,667	28	61,879	27	56
" 2	68,000	57	3,040,165	2,730,200	252,936	111	24,733	11	122
" 3	68,000	57	3,014,826	2,730,200	250,719	110	16,551	7	118
" 4	68,000	57	882,764	2,730,200	182,424	80	43,772	19	99
" 5	68,000	57	857,425	2,730,200	180,206	79	35,591	16	95
50 MGD									
Alternative 1	340,000	284	1,507,904	2,275,165	191,245	17	299,845	26	43
" 2	340,000	284	6,221,139	13,651,000	496,826	44	80,443	7	51
" 3	340,000	284	6,162,993	13,651,000	491,738	43	47,477	4	47
" 4	340,000	284	4,216,268	13,651,000	759,777	67	196,983	17	84
" 5	340,000	284	4,158,122	13,651,000	754,689	66	164,017	14	81

1/ The requirements and costs are based on all factors at assumed values and at 100% capacity use of the systems.

Table 3
Factor-Cost Elasticities for Five Alternative Sludge Disposal Systems Serving Three Volume Levels

Factor	Volume Levels 0.5	10.0	50.0
Application Days			
Alternative 1	-.033	.010	.015
" 2	-.010	.011	.041
" 3	0	0	0
" 4	-.034	.013	.024
" 5	0	0	0
Wage Rate			
Alternative 1	.011	.005	.005
" 2	.003	.007	.014
" 3	0	0	0
" 4	.011	.009	.008
" 5	0	0	0
Interest Rate			
Alternative 1	.054	.099	.115
" 2	.415	.411	.405
" 3	.420	.423	.428
" 4	.059	.146	.165
" 5	.050	.149	.168
Land Value			
Alternative 1	.004	.042	.054
" 2	.001	.019	.046
" 3	.001	.020	.050
" 4	.004	.024	.028
" 5	.005	.025	.029
Round Trip Distance			
Alternative 1	0	.121	.194
" 2	.758	.590	.339
" 3	.775	.613	.365
" 4	0	.511	.604
" 5	0	.535	.630
Soil Capacity			
Alternative 1	.007	.066	.085
" 2	.002	.030	.072
" 3	.003	.045	.112
" 4	.007	.037	.043
" 5	.011	.056	.066

Figure 2
Activities Selected for Five Alternative Systems of Sludge Recycling

Alternative	Dewatering	Transport	Storage	Application	Nutrient Removal
#1	Centrifuge →	Dump truck →	Concrete surface tanks →	Contour furrows →	Bermuda grass
#2		Pipeline →	Concrete surface tanks →	Sub-sod injection →	Bermuda grass
#3		Pipeline →	Concrete surface tanks →	Spray irrigation Option A →	Bermuda grass
#4		Tank truck →	Concrete surface tanks →	Sub-sod injection →	Bermuda grass
#5		Tank truck →	Concrete surface tanks →	Spray irrigation Option A →	Bermuda grass

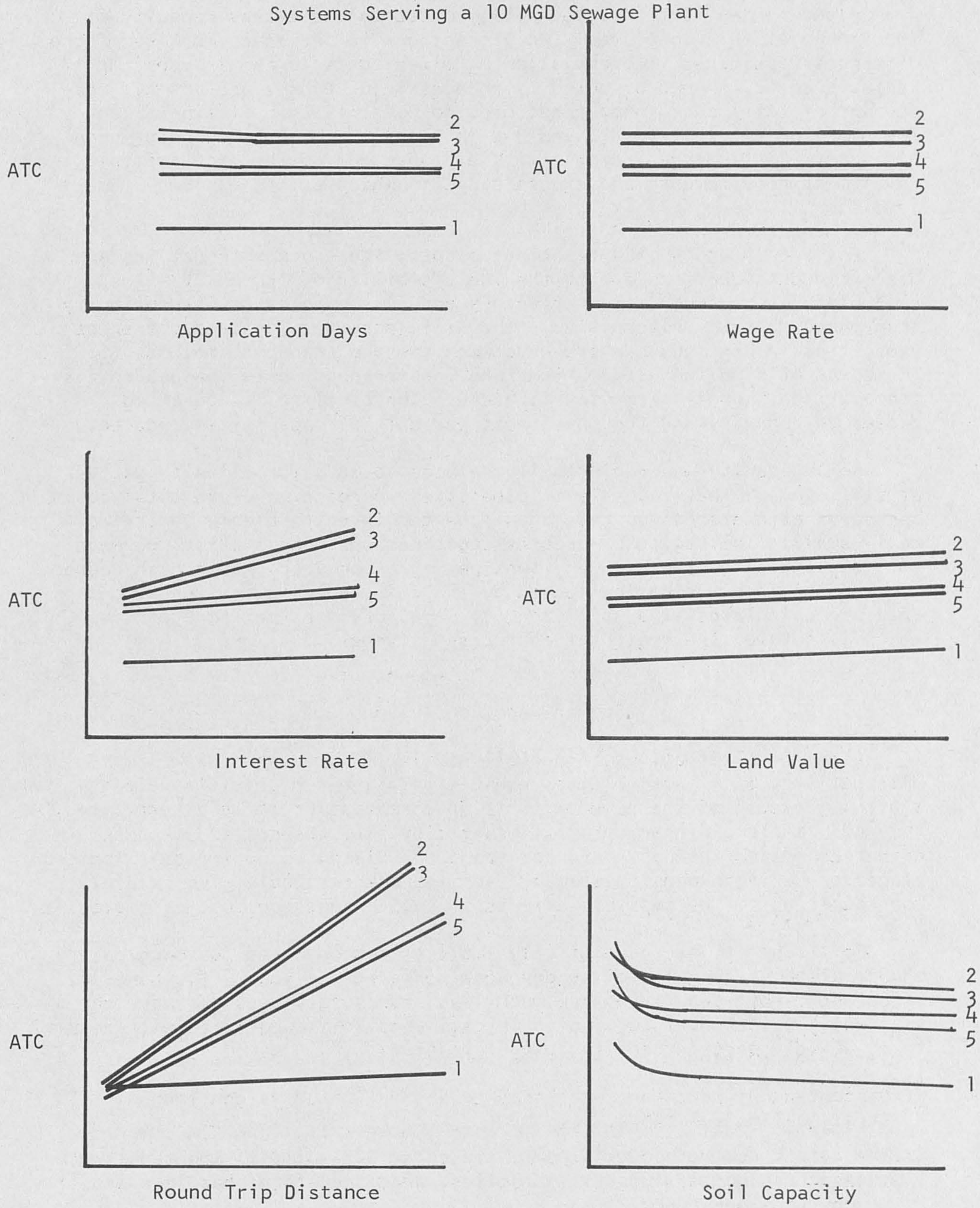
Cost per unit is relatively unresponsive to changes in the number of days in which sludge can be applied. Costs do not vary for Alternatives 3 and 5. This was expected because both alternatives involve the use of spray irrigation option A as an application technique. The capacity of this technique permits a large amount of sludge to be applied in a relatively short period of time. Since the number of application days is not a constraint on application capacity within the range of values considered, costs will remain constant as the days are varied.

The next variable examined was hourly wage rate for application technicians. Cost per unit does not change readily with changes in the wage rate. This inelasticity held for the volumes considered.

Changing the interest rate resulted in a significant change in cost for Alternatives 2 and 3 at all volumes. This is primarily due to the large capital investment requirements for the pipe transport mode employed by these systems. Since fixed costs include interest on invested capital and since the total cost of the pipe modes are largely fixed costs, a change in the interest rate will result in a significant change in total costs. The tank truck alternatives become increasingly more interest-elastic at higher volumes because of an increasing rate of capital investment.

There is little variation in costs due to changes in the purchase price of the land utilized in the five disposal alternatives. Although variation is slightly larger at higher volumes, it still was small.

Figure 3
Cost-Factor Relationships for Five Alternative Sludge Disposal
Systems Serving a 10 MGD Sewage Plant



At a 0.5 MGD plant size, the truck alternatives (1, 4, and 5) show no variation in cost resulting from changes in the round trip distance from plant to application site. This is due to the excess capacity of the trucks at this low level. Only one truck is necessary for any of the distances considered, thereby allowing fixed costs to remain constant. Variable costs, though affected by changes in distance, are a small percentage of total cost, and, therefore, do not influence it significantly. The pipeline alternatives (2 and 3), in turn, are highly dependent upon distance. Cost changes readily with distance due to the high initial investment requirements and excess capacity which exists at low volume levels.

For the 10 and 50 MGD treatment plants, the truck alternatives are discontinuous functions due to the indivisibility of trucks. 5/ The cost of the tank truck alternatives (4 and 5) show greater discontinuity than the dump truck alternative. The difference results from different capacities in dry tons per truck between the two transport methods. 6/ The costs of pipeline alternatives are less responsive to changes in distance at the higher volume levels because the pipeline is operating closer to capacity and the investment per unit of capacity is reduced.

Soil capacity was reciprocally related to cost for all alternatives at all levels. That is, as soil capacities increase, average total cost decreases at a decreasing rate until changes in costs become infinitesimally small. The region of greatest cost responsiveness exists between soil capacities of 5 and 25 dry tons per acre per year. This high degree of responsiveness is not reflected by the computed elasticities since they are calculated at a soil capacity of 40 dry tons per acre per year, which is outside the region of cost responsiveness.

Summary and Conclusions

Pipeline alternatives, especially at low volumes, and tank truck alternatives, at higher volumes, exhibit relatively high distance elasticity. Because of the high per unit investments for these alternatives, they also exhibit higher interest elasticity. If changes are expected in either estimated interest rates or transport distances during the planning stages or during expansion stages, decision makers should give careful consideration to the possible effects of such changes on cost estimates.

Soil capacity has a relatively small effect on costs for marginal change at the base value of 40 dry tons per acre per year. If, however, sites where soil capacities are much less than 40 dry tons per acre per year are considered, inaccuracies in estimated soil capacities will result in relatively large errors in cost estimation.

5/ Discontinuous functions were graphed and estimated as continuous straight-line functions.

6/ The dump truck method transports sludge at 30% solids. The tank truck method transports sludge at 5% solids, and, therefore, has less capacity in dry tons per truck.

Average total costs were inelastic with respect to application days, wage rate, and land values. Since these factors do not appear to greatly influence cost, decision makers do not have to be as concerned with changes in them as opposed to the other factors.

In general, average total cost does not appear to be highly elastic with respect to any of the factors at the three levels considered. Although many factors affect the costs of individual component activities within a system, their effect on average total costs of the system can be negligible. Distance, interest rate, and soil capacities do exhibit relatively high cost responsiveness, and, therefore, should receive more careful consideration when being estimated for use in cost analysis.