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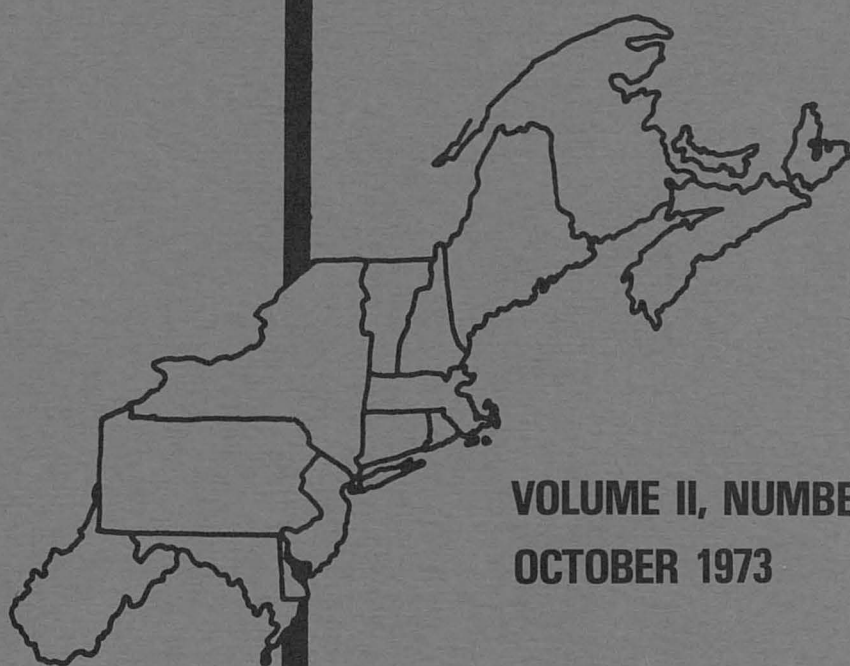
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THE ECONOMICS OF REGIONAL WASTE WATER
MANAGEMENT SYSTEMS

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The Problem

The literature on the concept of economies of size in waste water management is extensive. However, only a limited amount of research has been completed which focuses on the extent of these economies associated with the regionalization of waste water management systems.^{1/}

Regionalization of waste water management systems is often recommended as a means by which communities may make gains in economic efficiency and environmental quality control [3,1]. This recommendation is based primarily on a theoretical basis since, to date, little research on the application of the theory underlying economies of size to a specific region has been completed. Information on two important aspects of the regionalization process are lacking. These aspects are: (1) the feasibility of combining existing methodologies to develop a procedure useful in delineating the boundaries of regional waste water management systems within an area when the decision criteria is minimization of total cost per unit, subject to a water quality standard constraint; and (2) a measure of the economies of size that occur due to the regionalization process.

The increase in costs associated with the operation of relatively small systems are generally recognized but are quantitatively unknown. Formulation of a procedure that will permit the determination of the magnitude of this unknown quantitative variable and thereby suggest means by which to minimize its undesirable impacts is basically the

^{1/}In this study, the term regionalization is used to define the process by which a service area for a waste water management system is determined based on the minimization of costs given a water quality standard. This service area may be the same as an existing service area or it may require the integration of two or more areas.

problem addressed by this research effort. An evaluation of the variables affecting the magnitude of costs involved will be useful in delineating the geographic area to be included in a regional waste water management system.

The development of a procedure that permits a solution to the stated problem would have important implications in the area of waste water management and water quality control. Basically, it would allow either a higher level of water quality with the same expenditure or the existing level of water quality with a decrease in expenditure.

The Objectives

The general objective of this research is to combine existing methodologies to develop a procedure to be used in delineating the boundaries of regional waste water management systems. The specific objectives are:

- (1) To formulate and analyze alternative regionalization patterns for waste water management systems within the study area^{2/} and from these identify the system with the least cost per unit of service subject to existing water quality standard constraints.
- (2) To determine the costs incurred by the regionalization process and how these effect the selection of the alternative with the least cost per unit of service.

Development of Alternative Systems

A set of alternative water quality management systems was developed after examining the topography, present and projected demographic characteristics, levels of economic activity and effluent discharges of the area, existing water quality management systems and arrangements between these systems and the water quality standards set by the Commonwealth of Pennsylvania for the waterways of the area.

In selecting these alternatives, a set of criteria was formulated--subject to the limitations imposed by three important constraints.

The first of these constraints is the topography of the study area. Prospective treatment plant sites are expected to be, in general, connected to the sources of effluent with gravity fed trunk lines. This is desired in order to minimize pumping costs. However, local conditions may require some pumping stations to be utilized.

^{2/}The study area is the drainage basins of Conodoquinet Creek and Yellow Breeches Creek together with the Harrisburg Metropolitan area of Dauphin County, Pennsylvania (Figure 1).

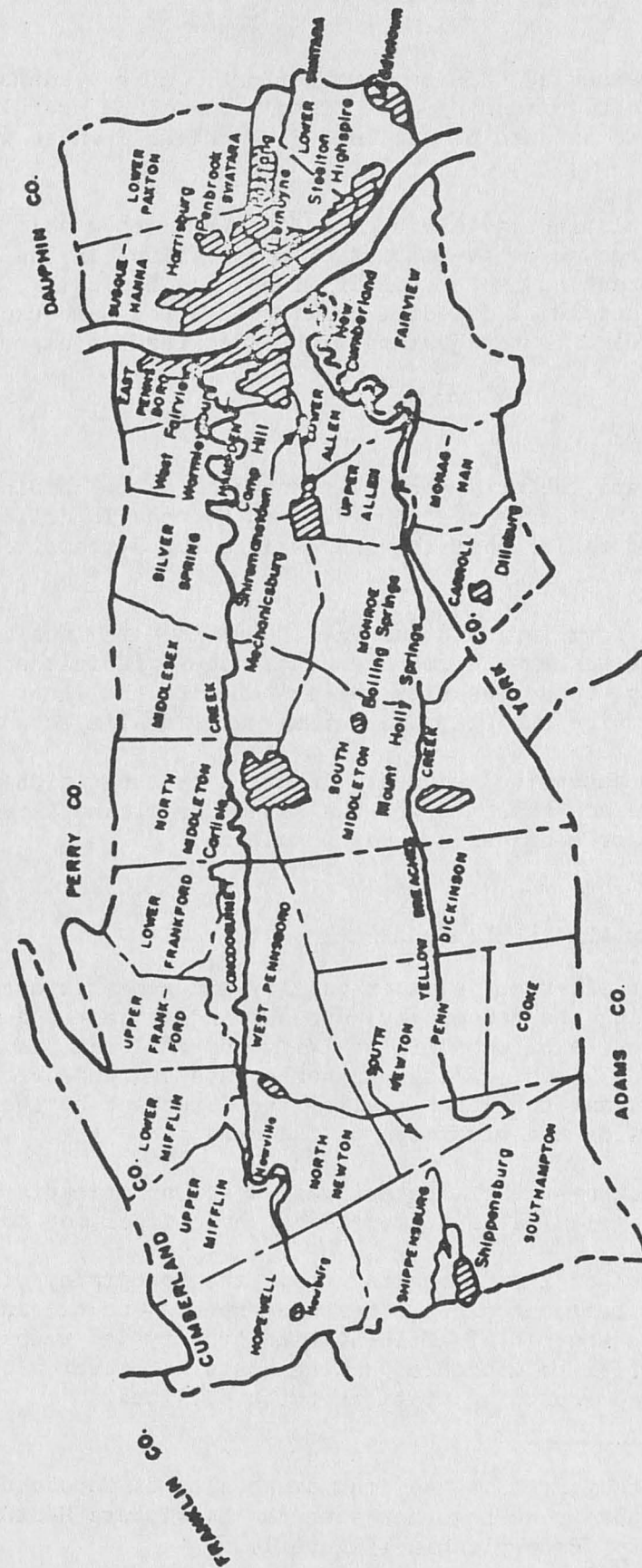


FIGURE 1. MAP OF STUDY AREA.

Second, the cost of crossing the natural barrier, the Susquehanna River, separating the East and West Shore areas will influence the degree of regionalization which the proposed alternatives will encompass.

Third, the flow of the stream into which the outfall of the treatment plant discharges is important since it will determine, in part, the degree of treatment required.

In proposing alternative waste water management systems, the criteria to be met within the general limitations set by the above constraints are as follows:

1. The system must be capable of meeting the projected needs.
2. The system must be flexible in order that additional, larger or more efficient treatment processes could be incorporated later.
3. The system must be efficient in resource use; i.e., in both construction and operation and maintenance.
4. The system's impact on the study area must be within acceptable limits.
5. The system must be reliable.

Within the framework of the above constraints and criteria, four alternatives have been selected. Variations of these are also proposed and will be examined. Table I shows the projected average daily flow of effluent for each of the systems.

In alternative No. I treatment plant will be located on the East Shore at Middletown. This plan encompasses interconnection of the East and West Shores. Also considered will be the extent to which the extreme west end of Cumberland County is to be included in this system or left as a separate region of its own. This variation will be designated alternative I.*

In alternative No. II separate treatment plants for both the East and West Shores are proposed. These would be located at Middletown and New Cumberland, respectfully.

The third alternative consists of two separate plants on the East Shore, one at Harrisburg and the other at Middletown, with the West Shore served by one plant at New Cumberland with a possible connection to the Middletown plant on the East Shore. When this connection is in effect, the alternative is designated III.* In both III and III* the extent to which the western fringe area of the study area is to be included is examined.

Table 1.
Treatment Plant Sizes Required for
Proposed Alternative Systems I-IV.

Alternative	Number	Treatment Plants Location	Size (MGD)
I	1	East Shore	
		a) Middletown	75.99
II	1	East Shore	
		a) Middletown	32.04
	1	West Shore	
		a) New Cumberland	43.95
III	2	East Shore	
		a) Harrisburg	30.30
		Middletown	1.74
	1	West Shore	
		a) New Cumberland	43.95
	0	b) Combine with Middle- town and use East Shore Plant	
IV		East Shore	
	1	a) Middletown	32.04
	2	b) Harrisburg	30.30
		Middletown	1.74
		West Shore	
	1	a) New Cumberland	
	0	b) As Alternative I	43.95
	0	c) As Alternative III	

In alternative No. IV there are either two separate plants on the East Shore or only one at Middletown. The West Shore will have one plant at New Cumberland serving as much of the West Shore as feasible. The possibility of a connection with the East Shore will also be considered.

These four alternatives were considered the most feasible, considering the given constraints and limitations listed above. In the following section, economic analysis will be undertaken to determine the optimal proposed alternative in terms of providing service at the lowest possible per unit cost.

Two additional "alternatives" were also considered. The first of these, No. V, is based on a separate waste water management system for each minor civil subdivision. A determination of the cost of treatment under these conditions will permit an estimation of the economic gains

achieved under the existing waste water management system as compared to a system where each minor civil subdivision has a separate treatment plant.

The sixth "alternative" is utilized not as a proposed regional system but as a base from which changes in costs attributed to further regionalization can be measured. This alternative encompasses the projection of the existing waste water management systems to the year 1990. Cost estimates derived under this system can then be utilized as a base to which the cost estimates of the other alternatives can be compared.

Estimation of Waste Water Treatment Costs Utilizing National Data

Estimation of waste water treatment cost, utilizing national data, was accomplished by summing the cost of the separate functions of collection, transmission and treatment of wastes. Cost estimates of each of these functions were available in the literature. The methodology developed consisted of determining a means of combining these separate costs to derive total treatment cost estimates for the proposed alternative regionalization plans. It is described below in summary form.

Average population densities for areas felt to require service by 1990 were developed. Estimates of collection costs per acre, given these average densities, were then made utilizing Downing's data [2,p.53]^{3/}. Total cost of collection systems were derived by multiplying the cost per acre by the estimated acreage requiring service.

To determine the cost of transmission lines a system of predominantly gravity fed sewer laterals was developed to connect the sewage treatment plants in the manner proposed by the alternative regionalization plans. Design criteria set by the Commonwealth of Pennsylvania and the cost data derived by Downing were combined to derive cost estimates of the transmission lines.

Cost of sewage treatment plants were estimated using data reported by Smith. [5] From his analysis, cost estimating curves for primary, secondary, and various levels of advanced waste treatment were derived. These curves were plotted on double log paper with costs and size in terms of average daily flow on the axes.

Thus, given the average daily flow in million of gallons per day for each alternative plant and the level of treatment required, esti-

^{3/}Adjusted to 1990 dollar equivalents by regressing index values of average constructions cost and year.

mates of construction cost could be derived.^{4/}

The separate capital costs of collection and transmission systems and sewage treatment plants were totaled to determine the total investment required for each alternative. This was then amortized at 5 percent^{5/} for 25 years^{6/} to determine the per year cost of the physical structures required for each alternative.

Total cost of treatment is the summation of the fixed cost and the operation and maintenance cost of the waste water management system. Estimates of the latter were available from Smith's work. [5] In order to determine these, the size of the plant, the level of treatment and the type of treatment process utilized^{7/} were required. For each alternative, these were known so cost estimates could be made using Smith's data. Smith's operation and maintenance cost estimates were in 1967 dollars. The operation and maintenance index^{8/} utilized by the Federal Water Pollution Control Administration [6,p.99] was extrapolated in order to determine 1990 dollar equivalents.

In estimating per unit total costs, the capital costs of the alternative amortized at the various interest rate for 25 years were divided by the yearly flow of effluent in millions of gallons which yielded per unit fixed cost. Operation and maintenance cost per million gallons for the level and type of treatment rendered was then added to this to give total cost per unit.

Comparison of Alternative Regional Systems

Estimates of the total cost of each alternative were derived utilizing the technique based on national data. These estimates were made for interest rates of 5, 6, 7, and 10 percent. They were grouped by

^{4/} Index values for sewage treatment plant construction costs were available for 1965-1971. [4,p.101] A simple regression of year and index value, with the latter the dependent variable, yielded an R^2 of .908 with a coefficient of 6.8643 and a constant of -13381.7857.

^{5/} Four interest rates were examined in order to determine the sensitivity of the proposed alternatives to changes in the interest rate.

^{6/} A period of 25 years was used since this is the average period of maturity for bonds issued to finance waste water management systems. [5,p.1551]

^{7/} Activated sludge plants were used for all the alternatives since the Federal Water Pollution Control Administration suggests that in the Northeast this type of plant be used. [6,p.98]

^{8/} The index used was the Wholesale Price Index - Intermediate Manufactured Foods.

those alternatives requiring an East-West Shore connector and those not requiring one. This grouping was required since a cost estimate of a connecting lateral was not available and would be required to rank all the alternatives within one group. In the comparisons that follow, prime emphasis will be on those alternatives not requiring connection of the two shores.

At a 5, 6, and 7, percent rate of interest, the rank order within both groups remained the same. Alternative III was the most efficient of the alternatives considered that did not connect the East and West Shore area. Alternative I* was the most efficient when they were connected. Comparison between these two alternatives can only be made by finding the difference in their yearly total cost and comparing this to the cost of a connecting lateral between the two shores. If this difference were greater than an estimate of the cost of connecting the two areas, then increases in efficiency could be gained by doing so. If it were less, then the optimum alternative would be III.

At ten percent interest rate, Alternative VI and II exchange rank positions. This change would not influence the regionalization plan for the area since these are the third and fourth ranked alternatives at that interest rate. The rank order of the group requiring an East-West Shore connector remained the same as it was at the lower interest rates.

A determination of costs on a per unit basis ranged from \$520.04 (Alternative III) to \$618.74 (Alternative V) at a five percent interest rate for the alternatives not requiring an East-West Shore connection (table 2).^{9/} They ranged from \$487.69 (Alternative I*) to \$519.81 (Alternative I) for the alternatives with the connecting lateral, but not including the cost of the connecting lateral. The cost of Alternative III increased from \$520.04 at a five percent interest rate to \$746.33 at a ten percent interest rate. These per unit costs reflect the same rankings as do total costs since they are derived by dividing total cost by yearly flow.

In general, those alternatives encompassing greater degrees of regionalization resulted in greater reduction in costs per unit of effluent treated. Of those not requiring an East-West Shore connector, the highest ranked alternative, III, had three main treatment plants. The lowest ranked alternative, V, had separate plants for each minor civil subdivision. The highest ranked alternative provided for plants at Middletown and Harrisburg serving the East Shore, and one at New Cumberland, serving all the West Shore except the western edge of the study area. This was served by separate plants at Mount Holly Springs, Shippensburg and a joint Carlisle-North Middletown plant.

^{9/} Only those alternatives for which costs of regionalization were determined are included in this table.

Table 2 Total Cost Estimates of Proposed Regional Systems With Varying Interest Rates (1990 Dollars).

Alternative	Total Cost Per Year								Average Cost Per Million Gallons				Average Cost Per Family			
	Rank	5%	Rank	6%	Rank	7%	Rank	10%	5%	6%	7%	10%	5%	6%	7%	10%
<u>Alternatives Not Requiring an East-West Shore Connector</u>																
II	3	15,592,087	3	17,032,352	3	18,543,722	4	23,197,384	563.07	615.08	669.66	837.71	42.74	46.68	50.83	63.58
III	1	14,400,599	1	15,632,892	1	16,915,960	1	20,868,459	520.04	564.04	604.97	746.33	39.47	42.85	45.92	56.65
IV	2	14,978,409	2	16,275,282	2	17,625,601	2	21,785,206	540.90	587.74	636.50	786.71	41.06	44.61	48.31	59.71
V	5	17,133,714	5	19,286,005	5	20,810,776	5	25,307,287	618.74	696.46	751.52	913.90	46.96	52.86	57.04	69.37
VI	4	16,108,803	4	17,691,740	4	19,115,464	3	22,595,620	581.73	638.89	690.30	815.98	44.15	48.49	52.39	61.93
<u>Alternatives Requiring an East-West Shore Connector</u>																
I	3	14,394,215	3	15,729,248	3	17,138,411	3	21,477,219	519.81	568.02	618.91	775.59	39.45	43.11	46.98	58.87
I*	1	13,504,851	1	14,690,419	1	15,939,156	1	19,784,277	487.69	530.50	575.60	714.45	37.02	40.27	43.69	54.23
III*	2	14,053,825	2	15,288,326	2	16,573,721	2	20,533,303	507.52	552.10	598.51	741.50	38.52	41.90	45.43	56.28

At a five percent interest rate, the per unit costs for Alternative III and V were \$520.04 and \$618.74 respectively. Using the former as a base, the savings resulting from regionalization were estimated as approximately nineteen percent.

At a ten percent interest rate, the costs were \$746.33 and \$913.90 for the same alternatives. This reflected a reduction in per unit cost of approximately twenty-two percent which would result if the systems regionalized. A comparison of per unit cost between the relationship that existed in 1969 (Alternative VI) and the most efficient alternative (III), at a five percent interest rate, reflected a difference in costs of approximately twelve percent for those alternatives not requiring a connector.

The above reductions in costs of treatment are measures of the economics of size gained through regionalization for this specific area. Their magnitude differed from the fifty-nine percent reported by Vonic and Bumstead for the New York's Hudson River Bend area [7,p.563]. This is due to the differing local characteristics of the two regions. However, both sets of figures reflect that substantial economies of size are gained through regionalization.

When costs are measured on a per family basis,^{10/} the above percent savings remain the same. The average cost per family per year, with a five percent interest rate, ranged from \$41.06 to \$46.97 for Alternatives III and V, respectively. At a ten percent interest rate, these costs ranged from \$56.65 to \$69.37 for the same alternatives. Industrial and commercial waste water generators could expect similar reduction in the costs of treatment of their effluent, excluding the cost of any required pretreatment,^{11/} if regionalization occurred.

In general, reductions in per unit cost of treatment resulted through regionalization except when small quantities of effluent were transported great distances. This was evidenced by the cost differences

^{10/}Per family costs were determined as follows. Estimates of per family discharge were derived by dividing the 1970 Pennsylvania population by the number of households in Pennsylvania in 1970. This yielded an average of 3.2 people per family. This number was multiplied by the average discharge of 65 gallons per capita per day to derive daily discharge per family. This times 365 yielded yearly family discharge. Yearly family discharge times per unit cost provided an estimate of per family cost per year.

^{11/}Costs of pretreatment of industrial wastes, when required to make the industrial wastes compatible with domestic wastes, were not included in the cost estimates of the alternatives. There would be no savings on this cost due to the proposed regional systems. However, it may be possible for industry to develop its own regional system for pretreatment.

between Alternative II and IV. In Alternative II, the distant systems serving Mount Holly Springs, Shippensburg, Carlisle, and North Middletown were included. In Alternative IV, these boroughs were not included. The result was a decrease in per unit cost of \$22.17, or approximately five percent at a five percent interest rate.

Some reductions in per unit cost of treatment had previously been achieved through the existing arrangements between various authorities. Per unit costs were estimated to have been reduced by approximately six percent. This figure was derived by comparing the cost of Alternative VI (existing system) and Alternative V (each subdivision with its own system). Additional gains would result from further regionalization.

The capital intensity of the alternatives was such that changes in the interest rate had substantial effects on total yearly costs of all the systems. The total yearly cost of the most efficient alternative not requiring an East-West Shore connector, increased from \$14,400,599 to \$20,868,459 when the interest rates increased from five to ten percent. The least efficient alternative in the same group increased from \$17,133,714 to \$25,307,287 under the same conditions. This was approximately a 45 and 48 percent change, respectively.

Costs of Regionalization

It is also necessary to consider the costs involved in converting the waste water management systems which existed in 1969 to the various proposed regional systems. The determination of these conversion costs will be limited to those alternatives which appeared most likely to be considered in light of the analysis of the previous chapter. These alternatives include I* which yielded the least cost per unit of treatment when crossing of the Susquehanna River was required and III which yielded the least cost per unit of treatment when the river crossing was not required. Also considered will be Alternative IV which required a separate East and West Shore regional plant plus three separate plants servicing the western edge of the study area.

The costs of regionalization are those associated with either the scrapping of the present sewage treatment plants prior to their full depreciation, or the continued operation and maintenance of these plants when more efficient alternatives existed. In either case, the total costs of waste water management will be higher than those derived in the last section. The objective of this section is to determine the sequence of regionalizing within the area which will minimize the total cost.

Phased Regionalization

When phasing of the regionalization process was considered, the method of determining the costs of regionalization became more complex.

In general, comparisons were made between the costs of continued operation of the existing system over the period of its useful life,^{12/} the costs of scrapping the existing systems and the savings in operation and maintenance achievable through regionalization.

Each plant was examined with respect to: (1) the date its design capacity was exceeded; (2) the date it was fully depreciated; and (3) the relation of the system to other systems in the local area. A decision criteria was made concerning replacement of plants. The general guidelines was to replace the plant (enter a regional system) at the time its design capacity was exceeded or at the time it became fully depreciated.

Table 2 reflects the costs incurred in achieving these regional systems. In all cases, the increase in costs were very slight, relative to the reductions in treatment costs achieved by regionalization. The costs ranged from \$122,477 (Alternative III) to \$241,800 (Alternative I*) when a 5 percent interest rate was considered. They increased to \$159,264 and \$302,308 respectively at a 10 percent interest rate. This increase is approximately 2 percent (Alternative I*) and 1 percent (Alternative III) of the total costs of the regional system. These increases in costs were reflected through both per unit and per family costs per year. The rank order of all the alternatives remained the same as when the costs of phased regionalization were not included in the total costs of waste water treatment.

Summary and Conclusion

In general, reductions in the per unit costs of treatment resulted through regionalization except when small quantities of effluent were transported great distances. Approximate measures of these gains were obtainable utilizing the procedure developed. Gains to date, realized by partial regionalization, were estimated to be approximately six percent. Those achievable through further regionalization were estimated to be approximately twelve percent. The procedure developed provided a means by which to examine a set of alternative regionalization plans for a specific area and from them determine the regional system providing the lowest per unit cost.

In summary, the central hypothesis of this research project was supported by the findings of the analysis. Reductions in costs of waste water management were attained through regionalization under the conditions prevailing in the study area. These were due primarily to the economies of size encountered both in construction and operation and maintenance of larger systems. However, as was indicated by the rank

^{12/} Useful life is defined as the number of years remaining until the sewage treatment plant is either fully depreciated or until the plant's design capacity is exceeded, whichever is the lesser.

order of the alternatives, the factors of prime importance influencing the magnitude of these costs reductions were the size of the sewage treatment plant and the distance the effluent had to be transported given the spatial distribution of the effluent generators within the area to be serviced.

The major conclusion drawn from the economic analysis carried out in this study was that the cost of developing a regional waste water management system from the existing systems within the study area are very small relative to the reductions in per unit costs of treatment achieved by regionalization. This is likely true for other areas as well; however, both the costs incurred by the regionalization process and the reductions in cost achievable depend on local conditions.

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