Title

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Publication Date

1980-09-01

AN ECONOMIC EVALUATION OF GREENBELT IRRIGATION WITH EFFLUENT WATER

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The research leading to this report was supported by the OFFICE OF WATER RESEARCH AND TECHNOLOGY, USDI, under the Allotment Program of Public Law 88-379, as amended, and by the University of California Water Resources Center, as part of Office of Water Research and Technology Project No. A-065-CAL and Water Resources Center Project UCAL-WRC-W-532. Contents of this publication do not necessarily reflect the views and policies of the Office of Water Research and Technology, U.S. Department of Interior, nor does mention of trade names or commercial products constitute their endorsement or recommendation for use by the U.S. Government.

TECHNICAL COMPLETION REPORT

September 1980

ABSTRACT

Land disposal of wastewater, although not a new concept, has received widespread interest in recent years because of an increased need to conserve water and a greater public concern about water pollution. While there have been numerous recent research projects on the use of wastewater for irrigation, very few have dealt specifically with the economic aspects.

The Maloney Canyon Project in California has shown that greenbelt irrigation with wastewater is feasible from the biological and physical standpoints. Based on results from the above project, this research attempted to quantify the specific monetary and energy costs associated with land application renovation of wastewater, and to a lesser extent consider the long-run implications. In the first half of this study the attempt was made to see whether land application compares favorably with other forms of advanced wastewater treatment. Relationships between the fundamental characteristics of plant types such as capacity, treatment unit type, capital cost, etc., were studied by using statistical analysis such as linear regression, crosstabulations, and factor analysis. The last objective of this paper was to estimate the fixed, variable, and total cost functions of applying water through greenbelt irrigation as those functions vary relative to capacity, design, and geography.

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INTRODUCTION

The use of effluent water for greenbelt irrigation, in all its controversy, has in recent years become a more acceptable means of "waste" disposal. Social and political concerns in their constant efforts to minimize or control the deterioration of the environment have found themselves in the dubious position of advocating the use of effluent water as a substitute for "fresh" water while at the same time promoting tighter controls and safer criteria when evaluating wastewater irrigation. This straddling of middle ground is the primary reason for the slow pace regarding land disposal of wastewater.

The original Maloney Canyon Project (1) of which this research is an extension, was developed in response to needs expressed by a number of governmental and private agencies. These needs resulted from the massive influx of people into the mountain areas of southern California which created serious problems of wildfires, wastewater disposal, and reduced domestic water supplies.

The Maloney Canyon Project has shown that greenbelt irrigation with wastewater is feasible from the biological and physical standpoints. Experiments conducted within this project have developed criteria for safe and practical wastewater irrigation which may be broadly applicable to many other locations. In the six-year study by Youngner, et al., secondarily treated sewage effluent was applied to brushlands and grasslands in a mountain chaparral ecosystem. The objectives were to determine the potential of such irrigation for fire control, wastewater renovation and groundwater recharge. Results indicated that either the brush or the grass could be used. However, the grasses were highly succulent and comparatively low-growing, thus providing excellent fire resistance as well as water renovation characteristics. Presently alfalfa is being grown with this effluent resulting in monetary renumeration and water renovation.

Land disposal of wastewater, although not a new concept, has received widespread interest in recent years because of an increased need to conserve water and a greater public concern about water pollution. Wastewater irrigation is now being practiced on crops, forests and recreational areas around the world (2). The soil-plant system acts as a "living filter" to remove pollutants before the water reaches the ground water supplies. However, the "living filter" will function satisfactorily only if the wastewater is first given partial treatment and then sprayed over the land under carefully controlled conditions (3). Application rates and frequencies will vary according to soil type, plant species, topography and climate or weather. In addition, not all sewage effuents are acceptable for spray irrigation. For example, if the quality is too low, containing large amounts of heavy metals or high levels of dissolved salts, the plant-soil system may be inadequate as a filter.

While there have been numerous recent research projects on the use of wastewater for irrigation, very few have dealt specifically with the economic aspects. Allender (4) devised a procedure for the estimation of costs for the construction and operation of a wastewater renovation system using spray irrigation on croplands. Using this procedure, Nesbitt (5) calculated the estimated costs for systems delivering one, five, and ten million gallons per day (MGD). These cost estimates compared favorably with other methods of wastewater disposal, including the cash value of the crop (Reed canarygrass) in the calculations. More recently, Young (6) has developed a simulation model for undertaking cost analyses of land application of wastewater. The "CLAW" (costs for land application of wastewater) model allows for the alteration of several key parameters and is a major step in this field.

While there are several basic similarities between agricultural irrigation with fresh water and spray irrigation renovation of wastewater, there are important differences. Agricultural systems are implemented primarily with the convenience of changing set ups and simplicity of maintenance as foremost considerations. Wastewater irrigation systems, on the other hand, must be undertaken with health and sanitation considerations foremost. In terms of operation what this means is that the system should deliver water only where it is wanted (no leaks, no over-spraying), when it is wanted (should be reliable with a minimum of malfunctions, should be automated to eliminate operator error), and how it is wanted (at a low enough precipitation rate to avoid ponding and runoff, in a fine enough spray to take advantage of aeration and ultraviolet exposure).

The importance of minimizing maintenance and operator errors is enhanced when one considers the delicate balance of the spray field ecosystem and the lingering consequences of even a single malfunction. It is the effluent flow from the treatment facility and the weekly loading rate of the irrigation site which dictates the minimum size plot which will suffice; but poor design and malfunction can quickly create added expense in terms of additional land requirements if proper care is not taken.

Several preconditions must be met before a spray irrigation field may be incorporated into an effluent renovation system. Appropriate land must be available, affordable and should be in relatively close proximity to the treatment plant. To determine if a given site is appropriate for spray irrigation renovation, several tests must be performed and much information considered. First, the soil must be permeable and the percolation rate and exchange capacity of the soil determined. Second, the site should be relatively flat and the vertical profile of the soil and underlying rock known. Third, the depth of the groundwater and its chemical and bacteriological characteristics should be known and monitored for changes. Fourth, climate must be conducive. Fifth, approval from local health authorities must be obtained. Finally, environmental impacts must be ascertained and evaluated.

All of these preconditions must be met before proceeding with any viable spray irrigation renovation system. For this analysis we assume an appropriate site exists and the necessary expense incurred for its selection has already occurred. The costs proceed from this point of preparation.

The significant variables in designing spray irrigation systems are: the effluent flow rate from the treatment plant, potential weekly loading rate of the irrigation site, hourly application rate, sprinkler and lateral spacing, nozzle size and operating pressure, piping friction loss, elevation changes, and dynamic hydraulic head. These variables are strongly interrelated by physical laws which necessitate careful engineering to assure proper system operation. For a more extensive discussion of design criteria the reader is referred to Pair (7).

In the past, the primary focus of the wastewater district has been to dispose of the flow, for which it is responsible, subject to the various cultural, economic, environmental, institutional, and legal constraints placed upon it. Currently we are witnessing a change in this "disposal" philosophy. In many regions one now finds that the assimilative capacity of the environment has been unable to meet the increased demands placed upon it by population pressures, and unacceptable levels of environmental degradation have resulted. Concomitantly, the questionable economic viability of supplying ever increasing amounts of "fresh" water has led to serious doubts about the wisdom of our current water system.

The short-run approach of dealing with these problems has led to the imposition of additional institutional and legal constraints in an attempt to relax the binding economic and environmental ones. In response to these changing constraints new forms of water supply and water disposal agencies are evolving to provide a viable long-run solution to the problem at hand. The metamorphosis emphasizes the advantages to be realized from agency integration and the avoidance of artificial boundaries whereby water changes from "fresh" to "waste." The general recognition of water quality as a continuum transversing several dimensions has given a new impetus to using water which is acceptable in the restricted critical dimensions for the limited use to which it is to be put. In this regard spray irrigation using wastewater is uniquely promising because it not only produces benefits from the harvesting of the crop cover but is capable of producing a high quality water "harvest" as well.

The intention of this paper is not to develop a system which will fit each and every need. Because of the uniqueness of each situation and the extensive list of variables affecting the cost, this system will not fit any individual situation perfectly, but it should allow decisionmakers a better means of assessing costs in determining the feasibility of adopting a spray irrigation plan and be applicable, in a general sense, to a broad range of conditions.

THE PROBLEM

This research attempted to quantify the specific monetary and energy costs associated with land application renovation of wastewater, and to a lesser extent consider the long-range implications. Each phase of wastewater treatment and renovation was analyzed, including the collection system, unit processing, trunk line, and distribution system.

In the first half of this study, the attempt was made to see whether land application renovation compares favorably with other forms of advanced wastewater treatment. Relationships between the fundamental characteristics of plant types such as capacity, treatment unit type, capital cost, etc., were studied by using statistical analyses such as linear regression, cross-tabulations, and factor analysis.

To be more precise, a list of specific relationships which were of prime importance is as follows: The relationship between total construction cost and system capacity as well as capital cost and system capacity; the correlation between system type and average operation and maintenance costs per million gallons per day; the relationship between total energy consumption and the system type in terms of the unit processes employed and the treatment train unit process configuration; the relationship between cost variations and system capacity; the relationship between treatment facility type and the associated level of energy consumption per unit of effluent flow; and the relationship between effluent flows and energy consumption. Other questions which are of concern are whether economies of scale prevail in the study group regarding operation and maintenance costs; whether energy requirements are sensitive to flow entering the system, and whether average energy costs are higher for larger system designs.

The last objective of this paper was to estimate the fixed, variable and total cost functions of applying water through greenbelt irrigation as those functions vary relative to capacity, design, and geography. Capital costs for all equipment were obtained together with capital requirements for variations in capacity and areas of application. The expected results were unit cost functions relative to capacity, design, and topography. By converting millions of gallons per day to the surface area which must be spray irrigated, it was the objective of this study to find the least cost method of an irrigation design system.

Numerous methods and designs of wastewater irrigation have been employed ranging from long, thin, narrow sections (median strips along freeways and mountainous fuelbreaks for fire suppression) to large modular parcels of land used mainly for various types of agriculture. Parks and golf courses with their unique contours and irregular dimentions are all favorite users of effluent water.

With such a varied list of users it was deemed desirable to separately investigate the above mentioned categories of alternatives.

Solid set sprinkler systems were the only practical technological approach for lengthy configurations of a firebreak and the irregular contours of golf courses and parks, while both solid set and side wheel were appropriate for large sections of regular shaped, relatively level plots.

Monetary Costs

If the various non-economic constraints are to be met by a given regimen of wastewater disposal, which procedures result in the least cost method of operation? Van Note (8) lists 123 combinations of unit processes for wastewater treatment systems ranging from primary sedimentation to ion exchanges and associates with each an expected water quality level. However, in addition to the great diversity of treatment systems from which to choose, Van Note states, "There are wide cost variations caused by factors unique to any given project, e.g., site conditions, local variations in material and labor costs and different wastewater characteristics." It is to be expected that research intended to have broad applicability for diverse geographical regions should inform the reader of the nature of the cost estimates, such as this caveat from Middleton (9), "Costs given are examples and do not apply to any specific local situation." But when one enters the realm of wastewater treatment by land application, one encounters another problem of similar magnitude.
Pound (10) noted in 1975 that, "For the most part. . . the costs were predominantly built up from typical preliminary designs since very few actual construction cost data are available for existing land application systems. It is hoped that actual costs can be used to a greater degree in future revisions of this report as more data become available." In Young's (6) work he notes the same problem and states his approach, "Simulation analysis was selected as the mode of analysis for three reasons: 1) simulation analysis

permits examination of land application treatment under a wide variety of scenarios, 2) the direct impact of individual parameters can be observed, and 3) since only a limited number of land application systems are being operated for advanced wastewater treatment, insufficient data are available for statistical analysis."

Circumstances novel to California have acted to mitigate these data restrictions: 1) because over 80 percent of water use in California is for irrigation, there was an early and strong interest in this form of renovation, 2) the depletion of groundwater aquifers and the subsequent intrusion of saltwater in certain coastal regions stimulated interest in various recharge methods, 3) the establishment of the State of California Office of Water Recycling, and 4) the extensive and costly canal system which traverses much of the state. For these reasons, and the innovative spirit of the local communities which sponsored land application renovation, there exists within the state a small but growing data base upon which to analyze the current cost situation. The authors believe that by restricting the geographical boundaries of the study area, statistically meaningful results may be obtained from the data which are currently available. Consequently the analysis conducted below is based upon actual costs incurred. No claim is made for the general applicability of the results beyond the study area.

For the spray irrigation distribution system, the discrete sizes of equipment currently available in the commercial market produce a finite number of system designs which utilize alternative equipment combinations and adhere to the constraints imposed by the laws of physics. Thus it is a formidable, but not insurmountable, problem to generate a finite set of alternative systems for any given flow rate and cost them at current market prices. While market prices fluctuate rapidly in today's market, the technology changes relatively slowly and the laws of physics remain constant.

Therefore, once system design is complete, the physical components are of a stable nature for lengthy durations such that only price change adjustments need be undertaken to update costs.

Energy Costs

Another characteristic of California which is assuming increasing significance has given rise to the second thrust of this study--energy requirements. Fuel costs for utilities companies throughout the state are consistently above the national average, while current expectations are that energy prices in the United States will outpace most other price increases in their steady march upward. Although the United States Government implemented the Federal Mandatory Fuel Allocation Program which grants wastewater handling facilities 100 percent of their requirements during fuel shortages, there is a great opportunity for energy conservation by designing and operating energy efficient wastewater treatment systems. The State of California Energy Task Force (11) recognized the serious nature of the problem when it issued this warning: "Because wastewater collection and treatment is vital to the health and general well-being of Californians and is also an energy dependent process, the present energy shortage has potentially serious implications regarding the ability of California to pursue the goal of clean waters." As energy costs assume an increasingly important role in operation costs, they will determine the cost effectiveness of treatment systems to a greater extent than ever before.

The authors envision future research utilizing previously published estimates of construction and operation costs for advanced wastewater treatment systems. The results reported in this research analyze the trade-off between the higher construction costs and the lower operation costs associated with land application renovation. This analysis would proceed using appropriate amortization periods and discount rates to determine the impact energy cost escalation has upon the overall cost effectiveness of land application renovation in the long-run. In order to account for the differential rates of price escalation in the construction and energy sectors, it would be desirable to develop a simulation model similar in nature to the "CLAW" (Cost of Land Application of Wastewater) model reported upon by Young (6) which could incorporate into the anlysis alternative hypotheses concerning these volatile parameters.

Because pumping requirements are significant determinants of energy usage in the distribution sub-system, an analysis of the trade-offs between increased pressure and/or capacity of the system and higher cost land and/or equipment alternatives would be desirable as well. This trade-off results primarily from the higher land costs for more urban land, as opposed to rural land prices, and the higher energy consumption associated with friction losses in lengthy pipelines. But the site specific nature of land prices again makes simulation modeling the appropriate analysis technique.

PREVIOUS RESEARCH

Much of the previous research into the costs of advanced wastewater treatment has neglected land application renovation and instead has attempted to quantify the costs associated with mechanical and chemical renovation. As a comparison with the results reported here for land application renovation, some of the more recent cost estimates for advanced wastewater treatment are summarized.

Monetary Costs

Middleton's estimates (9) for capital and total operating costs of 10 MGD plants which produce the quality of water listed are summarized in 1974 dollars as follows:

Table 1. Capital and total operating costs of 10 MGD treatment plants which produce various quality waters.

WATER QUALITY	CAPITAL ($/mil gal)	TOTAL OPERATING ($/1000 gal)	TOTAL OPERATING ($/acre-ft)
Recreational Lakes	9,641,000	.407	133
Industrial Uses	8,237,000	.356	116
Near-Potable Water	13,181,000	.621	202
Near-Potable Water by Reverse Osmosis	11,532,000	.623	203

* After Middleton (9)

Alternatively, the California Water Resources Control Board's estimates for a 10 MGD wastewater treatment facility (12) are summarized below in dollars based on the EPA construction cost index of 200:

Table 2. Costs of producing various quality water in a 10 MGD treatment plant.

PROCESS	COST/1000 GAL (each process)	COST/1000 GAL (cum.)	COST/ACRE-FT (each process)	COST/ACRE-FT (cum.)
Secondary	.20	.20	65	65
Chemical Coagulation (lime)	.09	.29	29	94
Filtration	.07	.36	23	117
Nitrogen Removal	.11	.47	35	152
Carbon Adsorption	.10	.57	33	185
Disinfection	.01	.58	3	188
Demineralization	.40	.98	130	318

* After the California Water Resources Control Board (12)

A recent EPA publication (8) gives annual combined sludge and liquid process costs for various degrees of quality ranging from 38.9 to 60.5 cents/1000 gallons. These estimates are based on the National Average Wastewater Treatment Plant Cost Index of 177.5 for February 1973, the Wholesale Price Index for Industrial Commodities of 120 for February 1973, and labor costs of $5.00/hour. This estimate is for a 20 MGD wastewater treatment plant design for biochemical oxygen demand, suspended solids, phosphorus and nitrogen removal with effluent polishing.

An engineering analysis (13) for a proposed project to be completed in 1983 yields cost estimates for a 15 MGD wastewater treatment plant utilizing spray irrigation land application for groundwater recharge. This project is to receive secondarily treated water as its influent and thus will exhibit lower costs than plants which must process raw influent. The secondarily treated influent is to be received and treated by coagulation (aluminum sulfate is the primary coagulant and a polymer is the secondary coagulant) followed by multimedia filtration and then disinfection by chlorine. The estimated cost, based on the Engineering News Record Construction Cost Index of 4200 is:

Table 3. Projected costs for the Green Acres Project (15 MGD in 1983).

TOTAL CAPITAL COST	OUTPUT (acre-ft/year)	O & M, and CAPITAL AMORTIZATION	UNIT COST ($/acre-ft)
$27,153,000	7,961	$1,016,000/year	$128

* After PRC Toups and James M. Montgomery (13)

In addition to these cost estimates the study cites a reduction in energy demand due to the project because imported water requires 3 to 5 times as much energy to obtain as does reclaimed water.

Energy Costs

These costs consist primarily of electrical energy, with some natural gas being used to power heaters, incinerators, and vehicles. In this study, gasoline costs were not included in the energy analysis but were placed in the O & M analysis section. While the major energy expense is for electrical consumption, processes utilizing natural gas may find energy costs increasing at an exceedingly rapid pace when deregulation of natural gas in the United States occurs. A 1973 report sponsored by the EPA (14) summarizes electrical power requirements for 10 MGD wastewater treatment plants, by type of process:

Table 4. Energy consumption associated with various treatment plant types.

LEVEL OF TREATMENT	ENERGY CONSUMPTION (KwH/mil gal treated)	$ COST (@ $.03/KwH)
Primary	235	$ 7.05
Secondary		
Primary + Trickling Filters	480	14.40
Primary + Activated Sludge	880	26.40
Tertiary		
Secondary + Lime Clarification, Filtration, and Carbon Adsorption	1630	48.90
Secondary + Filtration, and Reverse Osmosis	3000	90.00

* After the E.P.A. (14)

Based upon these estimates an increase in the price of electrical energy of just one mill per kilowatt-hour would directly increase the operating costs of a 10 MGD wastewater treatment plant operating at capacity and utilizing secondary treatment plus filtration and reverse osmosis in the amount of $10,950 per year. In contrast, a 10 MGD wastewater treatment system utilizing primary and activated sludge treatment with a gravity flow spray irrigation land renovation system would incur additional operating costs of only $3,212 per year. These are direct effects only. One would expect the generally higher operating costs of advanced wastewater treatment plants to increase more than proportionally in response to energy price increases due to the indirect and induced effects which these price increases would precipitate. One must also consider the hardships imposed by employing energy intensive treatment systems in light of the U.S. Federal Mandatory Fuel Allocation Program, which gives wastewater handling systems a high priority fuel allocation.

For comparison with the actual energy costs reported below, one must also include collection system energy costs. The EPA (15) estimates of collection system energy costs updated by the fourth quarter 1978 fule and utilities component of the National Consumer Price Index are:

Table 5. Annual collection system power costs (dollars/MGD)

(Minimum)	(Median)	(Average)	Maximum)
194	1018	3,086	24,093

* After the EPA (15)

Adding the collection and treatment system's energy costs one arrives at the total system energy cost expressed here as total annual cost per MGD flow:

Table 6. Annual energy cost relationships for various collection and treatment systems (dollars/MGD).

SYSTEM	COST (Min.)	COST (Avg.)	COST (Max.)
Primary	2767	5659	29088
Secondary			
Primary + Trickling Filters	5450	8342	31771
Primary + Activated Sludge	9830	12722	36351
Tertiary			
Secondary + Lime Clarification, Filtration, and Carbon Adsorption	18042	20934	44363
Secondary + Filtration, and Reverse Osmosis	33044	35936	59365

METHODOLOGY

The actual costs incurred by a broad spectrum of wastewater districts in California for fiscal year 1977 were analyzed by least squares regression and factor analysis in an attempt to determine the relationship between the observed costs and the underlying influencing factors. In addition, special attention was given to the relationship between treatment facility type and the associated level of energy consumption per unit of effluent flow.

The purpose of designing a modular system is so that each wastewater treatment facility, depending on its own plant capacity, can cost out a distribution system that will be effective for them.

Because the use of effluent water for irrigation purposes is not restrictive to designs with regular dimensions or a few specific distribution methods, it was necessary to cost five system designs in order to have a representative sample. They are as follows: 1) solid set square section; 2) solid set narrow section; 3) side wheel; 4) center pivot; and 5) golf course. By using a ten-acre module approach, it allows the plant capacity and the site characteristics to determine the cost.

An alternative approach using linear programming was undertaken for use by organizations with at least a micro-computer capability. Linear programming is well suited to solving cost minimization problems and is readily adapted to spray irrigation system design.

Given the prices and the technical capability of the discrete units of equipment available, the standard linear programming problem is to find all the non-negative quantities of this equipment which minimizes the cost of producing the desired result, given the technical and physical constraints inherent in the nature of the problem. For a spray irrigation field, this means minimizing the equipment costs and installation costs while applying the water within the space allowed, within the time allowed, and at the rate specified subject to the laws of physics.

In matrix notation:

$$A = \begin{matrix} a_{11} & a_{12} & \cdot\ \cdot\ \cdot & a_{1k} \\ a_{21} & a_{22} & \cdot\ \cdot\ \cdot & a_{2k} \\ \cdot & & & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & & \cdot & \cdot \\ a_{n1} & a_{n2} & \cdot\ \cdot\ \cdot & a_{nk} \end{matrix}$$

$$B = \begin{matrix} b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ b_n \end{matrix}$$

$$C = \begin{matrix} C_1 & C_2 & \cdot\ \cdot\ \cdot & C_k \end{matrix}$$

$$\begin{matrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_k \end{matrix}$$

Where:

The vector X is the quantities of the discrete units of equipment currently available on the spray irrigation market which solves the equation system.

And where:

The vector C is the unit price associated with each piece of equipment.

The matrix A is the technical specifications associated with each piece of equipment.

The vector B is the constraints imposed by the problem.

Our problem is to find all the non-negative X which minimize the objective function $C * X$ subject to the linear constraints $A * X \geq B$.

Two recent developments lend special relevance to the results of this project. First, the EPA's mandate that new wastewater treatment systems must investigate the cost effectiveness of land disposal of treated wastewater. Second, the findings of studies conducted in New England which indicate that the failure of engineers to anticipate the great energy-cost escalation and to design energy-conserving wastewater systems has increased operating costs to municipalities by 40 to 90 percent.

SYSTEM RELATIONSHIPS

Data Sources

The State of California Water Resources Control Board was contacted and helpful assistance was received from both the Division of Water Quality and the Office of Water Recycling. From information contained in the Control Board's data base, 18 new and 3 expansion wastewater treatment systems utilizing land application renovation were identified. These facilities were contacted and general information regarding system operations and specific operation and maintenance cost data were obtained. To obtain construction cost data, the consulting engineers engaged for the construction of these facilities were contacted for copies of the Bid Tabulations submitted by contractors. There was no uniform procedure for handling this information by the different engineering firms, and in many instances the authors were referred to the municipalities for the actual construction cost data. In a few cases it was necessary to proceed directly to the construction firm contracted for the system erection. Three of the new systems were deemed by the authors to have inadequate data or insufficient operating experience to give meaningful results and were dropped from the study group. The final study group consists of 15 new systems and 3 expansions systems (located as indicated in Fig. B-1).

Indexing

The construction costs incurred for the 15 new plants and the original construction and expansion costs for the 3 older plants were all stated in terms of the November 1978 Engineering News Record Construction Cost Index for Los Angeles and San Francisco of 3,421 and 3,412, respectively. Systems in the Los Angeles sphere of influence were adjusted with the Los Angeles index, while systems in the San Francisco sphere of influence were adjusted with the San Francisco index.

Because the operation and maintenance costs were all from the uniform period of July 1, 1977 to June 30, 1978, no indexing of these costs was attempted. Similarly, energy requirements were gathered for this uniform period in physical units and no indexing was required for this part of the analysis.

The Analysis

Using an IBM 360/50 computer and the SAS Institute's Statistical Analysis System software package, a combined cross-section time-series regression was run on the effluent flows and energy consumption by the Fuller and Battese Method (12) to obtain a baseline estimate of energy consumption for the study population as a whole. Next, each system's effluent flow rate and energy consumption rate was analyzed by the method of ordinary least squares regression using Princeton University's Time Series Processor software package. Each system was then compared to the baseline estimate for preliminary categorization by energy usage. Having placed the systems into energy requirements per unit processed groups, the authors proceeded to determine which influences gave rise to the between-group variations in energy requirements.

Using the Statistical Package for the Social Sciences software package on a Prime 400 computer, linear regression, crosstabulation, and factor analysis were implemented. This subdivision of the statistical analysis provides the major portion of the results presented below which define the fundamental characteristics of plant types and makes inferences about the underlying influences which determine the actual costs incurred. The results are therefore presented within a framework of unit cost functions relative to capacity, treatment system type, topography, etc. The complete list of influences is given in the section presenting the results of this study.

The summary results of the statistical analysis may be observed from Tables B-4 through B-8 at the end of this report. These represent the skeletal frame around which the body of the research is structured, and from which the interpretations of this report are made.

The Data

The data represent the actual costs for the present configuration of the land disposal treatment systems studied. Construction costs were obtained from the consulting engineers, municipal administration, and construction firms. Land costs were not included in the construction cost figures. In the cases of system expansion, major repairs which extended the capital life of the operating equipment were indexed and included in system construction costs rather than maintenance costs. Operation and maintenance costs were obtained from the wastewater districts in all cases. Administrative and overhead expenses were included in the operations and maintenance costs.

RESULTS

Because utilities costs represent about 10 percent of the operations and maintenance costs for the systems studies, the total energy requirements of the individual systems were converted into British Thermal Units and then into KwH equivalent for easy cost comparison based upon a price of 30 mills per KwH. The results indicate that, on the average, land application renovation compares favorably with other forms of advanced wastewater treatment. However, the study group did display wider variations than the comparison group. Primarily due to the influences of the excess capacity, average operations and maintenance costs showed a disadvantage when compared with the EPA (15) estimates of annual average operations and maintenance costs for a 10 MGD system. The EPA's third quarter 1977 annual cost estimate of $145,270 per MGD flow is lower than the authors' fourth quarter 1978 annual cost estimate of $220,117 per MGD flow.

Construction costs are presented with respect to their influencing factors with a view toward analyzing the trade-off between higher initial investment versus lower O & M costs. Obviously, the choice of discount rate, amortization period, and volatility of O & M costs will influence the ultimate results significantly.

Energy Costs

The summary energy requirements for the study group are:

Annual Energy Costs Per MGD Flow

	Minimum	Average	Maximum
Energy in Mil BTU	132	2518	18276
$ Cost @ 3¢/KwH	$1,160	$22,128	$160,644

Based upon the estimated regression equations presented in Table B-5, one finds that total energy requirements are extremely sensitive to the flow entering the system: an additional 1 MGD inflow requiring an additional 1787 Mil BTU. However, contrary to previously reported estimates, the results here indicate that average energy costs are higher for larger system designs, while the total construction cost is relatively insensitive to the energy intensiveness of the system configuration. If these preliminary findings are borne out, the high average costs associated with constructing small scale AWT systems could be overcome by employing economical land application renovation. Some support is lent to this hypothesis by the relationship found between energy consumption and total horsepower associated with the treatment systems because increasing average costs were also found in their relationship. As a whole, however, economies of scale did prevail in the study group in terms of operations and maintenance costs. Energy costs are not presently a large enough component of total O & M costs to outweigh the other savings gained from increased system capacity. But these savings must be traded off due to the fact that systems operating at below capacity levels have been shown to have significant increases in their average operating costs when compared with costs at capacity levels of operation.

No significant relationship was found between total energy consumption and the system type in the study group in terms of the unit processes employed and the treatment train unit process configuration. The results indicate that the overriding significant factor in energy consumption is pumping costs. While there does exist a relationship between pumping requirements and the treatment train unit process configuration, this influence is small when compared to the impact of the other influencing factors. As indicated below in the section on Operation and Maintenance costs, there is a significant positive correlation between the system type and the average O & M costs per MGD, but to attribute this to energy requirements is not supported by the data. One hypothesis consistently advanced by system administrators was that, in the wake of the 1973 energy crisis, managers have attempted to substitute other inputs for energy. The result has been that the hypothesized relationship between energy requirements and system type does not show up in the analysis of the energy data, but instead has been shifted to total O & M costs which do show a significant relationship.

Operation and Maintenance Costs

Average O & M costs are heavily influenced by the degree of capacity utilization of the system. All of the study group facilities had some degree of excess capacity and the resulting O & M costs are therefore somewhat high. As the reclaimed water is recycled, additional flows will be available to be processed through the system utilizing the now excess capacity and lowering the average O & M cost. The concept of a "water flow multiplier" is helpful in noting how this result is forthcoming. As each new unit of water is added to the system, a portion of this flow is reclaimed and added to the flow in the next period. A portion of this second period flow is reclaimed and again placed in the flow in the third period. Thus in each succeeding period some fraction of the previous period's reclaimed flow is again reclaimed and adds to the available supply in the following period. For illustrative purposes, assume that one-half of the flow in any given period is reclaimed. Then an increase in the flow in the present period of one unit will result in a one-half unit increase in the flow in the next period and a one-fourth unit increase in the flow in the third. Or, 1 + 1/2 + 1/4 + 1/8 + 1/16 + 1/32 + etc., which is a well known series and in the limit converges to 1/(1-1/2)=2, or more generally as: injections divided by the fraction of leakages. Thus the initial injection of one unit of water into the system will result in a two unit increase in water flow, assuming half of the flow is reclaimed in each cycle.

Operation and maintenance costs were estimated to be $209,357 annually for each MGD flow, with fixed costs of $107,607 annually. For a 10 MGD system this amounts to annual average costs of $220,117 per MGD. The relationships between average O & M costs and system type are displayed in Tables B-6, B-7, and B-8. Wide variations were observed in O & M costs which were only partly attributable to the variations in the energy intensiveness of the systems. Other contributing factors are discussed below.

Capital Costs

The relationship found between total construction cost and system capacity was rather weak, with wide variability in the data encountered. Interestingly, there was a stronger, but still weak, relationship between the total capital cost and the actual system flows. The summary capital costs are:

Capital Costs

	Fixed Costs	Marginal Costs/MGD	Average Costs/MGD
Observed Flows	$5,348,907	$1,348,060	$1,882,950
Capacity Flows	4,562,976	811,796	1,268,093

Cost Variations

Exceedingly wide cost variations were encountered in all the categories analyzed. To account for the factors influencing this variation, alpha factor analysis was employed. To determine the extent to which planners could employ this variability to good advantage, the analysis is presented in two sections: the collection/processing system and the spray irrigation distribution system.

Collection/Processing: The greatest influence on the cost variations was system capacity. This factor accounts for 45 percent of the cost variations in the study population. In general the larger the system design flow the lower the average capital and O & M cost per MGD flow at capacity utilization levels. But there are severe penalties associated with underutilization of the design capacity. Average costs increase significantly as the flow rate falls below design capacity. Because the system must be able to handle the peak flows which occur only occasionally, much of the time there is idle capacity resulting in higher average costs. The degree of the idle capacity is directly related to the variation in the flow rate of the influent. For example, resort communities which may experience a population influx of many times the resident population have found average costs during the offseason excessive. Also, systems which have combined sewers and stromdrains enjoy lower construction costs, but the burden on the treatment plant during the rainy season often requires an increased capacity which lies idle during the dry months.

The next greatest influence upon the variation observed in the cost data comes from topographical/environmental/health constraints. This factor contributes almost 20 percent of the observed variation in the study group. Underlying this factor are determinants such as terrain, soil characteristics, nature of the ecosystem, and safeguards necessary to prevent contamination. An example of a costly area, in terms of this factor, would be one which has irregular terrain, rocky soil conditions, a delicately balanced ecosystem, and a shallow aquifer. Alternatively, an urban environment may be thought of as an example of a costly area due to the high premium paid for land, the population density, and the ease of contagion.

The third factor contributed approximately 10 percent of the observed variation and is directly related to the sludge-handling process. In the study group we observed combinations of sandbed, lagoon, vacuum, and centrifuge dewatering processes with incineration, landfill, land reclamation, soil conditioner, and ocean discharge disposal methods.

The fourth factor identified contributed nearly 10 percent of the variation observed in the study group. This factor represents the selection and the configuration in which the train of wastewater treatment unit processes are organized.

<u>Spray Irrigation Distribution</u>: The influencing factors were more well-defined for this subdivision of the system, engineering design parameters being responsible for all the observed variation in the study group. The first factor which accounts for 41.5 percent of the variation is the dynamic hydraulic head. The second factor, accounting for 26 percent of the observed variation, is the irrigation system capacity. The last factor accounted for roughly

16 percent of the variation and represents the distance for conveyance to the irrigation site. These three factors are all related by the design parameters: sprinkler spacing, application rate, nozzle size and pressure, and the loading potential of the irrigation site. Discussion of design criteria may be found in Pair (7) and computer algorithms for devising least cost sprinkler irrigation systems are available. There appears to be little room for further optimizing the system configuration in this subsection. Most of the engineering criteria are dictated by the factor which has been interpreted as topographical/ environmental/health constraints.

Non-monetary Costs

With the recent and predicted energy costs escalation, there appears to be a continuing trend of definite cost advantages associated with land renovation, but non-monetary costs in terms of land quality must be evaluated. Some soil degradation with prolonged wastewater application appears to be inevitable. The nature of this degradation will depend upon the quality of the effluent and the original soil characteristics.

Effluent irrigation studies over a 6-year period, Youngner, et al. (1) have shown that certain ions will accumulate in the soil. If sodium, common to most effluent waters, is adsorbed on clay particles in large amounts, it will have a destructive effect on soil structure. As the SAR (sodium adsorption ratio) approaches 9 or higher, soil permeability problems may be anticipated. With a loss of permeability, the soil will function poorly as a wastewater renovator and as a medium for plant growth. High effluent bicarbonate levels will further increase the sodium hazard. Although a high SAR can be corrected by the addition of calcium, this will add to the total cost of the recycling process.

Increased salinity and sometimes high boron levels may also be anticipated after several years of application, unless amounts of water are adequate for good leaching. Again, this can often be corrected but at an additional cost.

Heavy metals, present in many effluent waters, may also accumulate in amounts which could be harmful to plant growth or could prevent future use of the land for food production. The heavy metals most often found in municipal wastewater are copper, cadmium, nickel, and zinc. Fortunately, during secondary treatment a high proportion of these elements is removed in the sludge, Peterson, et al., (17).

None of these problems appear to be of sufficient magnitude to cause serious soil degradation or to render the land useless. Therefore, land degradation should seldom, if ever, be a factor preventing the recycling of wastewater by spray irrigation.

CONCLUSIONS

Land application renovation of pretreated wastewater is cost effective in producing water quality which is comparable to other methods of advanced wastewater treatment.

The area of greatest potential savings is the degree of system capacity utilization. An analysis of alternative strategies for utilizing facilities to their full design capacities could recommend policies producing appreciable savings. For example, 1) incentives/penalties could be implemented for system users during the slack/peak flow periods, 2) holding areas could be utilized to maintain a constant capacity flow into the treatment system, or 3) some combination of 1) and 2) with regulatory controls could be used.

The method of sludge handling in conjunction with the pretreatment system process train was significant in explaining the observed cost variations in the study group.

The land application sub-system of the renovation process was the most stable cost of the total system design and lends itself readily to simulation analysis for determining optimal configurations in alternative settings.

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APPENDIX A

LINEAR PROGRAMMING ALGORITHM

```
10   REM LINEAR PROGRAMING DESIGN APPLICATION VERSION (7-15-79)
20   REM BY DALE R. HURD, UNIVERSITY OF CALIFORNIA AT RIVERSIDE
30   PRINT "TITLE: LINEAR PROGRAMING MODEL FOR SPRAY"
40   PRINT "IRRIGATION DESIGN"
50   PRINT
60   PRINT "BY: DALE R. HURD, UNIVERSITY OF CALIFORNIA AT RIVERSIDE"
70   PRINT "DESCRIPTION: BASED UPON THE TECHNICAL SPECIFICATIONS OF"
80   PRINT "SPRAY HEADS MANUFACTURED BY TORO COMPANY THIS PROGRAM WILL"
90   PRINT "LIST THE COST MINIMIZING SOLUTION TO THE PROBLEM YOU SPECIFY"
100  PRINT
110  PRINT "WHEN PROMPTED TO DO SO ENTER THE VALUE OF THE VARIABLES"
120  PRINT "IN THE SPRAY IRRIGATION SYSTEM"
130  PRINT
140  PRINT "SLACK AND ARTIFICIAL VARIABLES WILL BE GENERATED AND THE INTITIAL"
150  PRINT "TABLEAU PRINTED.  AFTER EACH ITERATION THE BASIS WILL BE PRINTED"
160  PRINT "FINALLY THE VALUES OF THE VARIABLES AND THE DUAL"
170  PRINT "VARIABLES ARE PRINTED ALONG WITH THE VALUE"
180  PRINT "OF THE OBJECTIVE FUNCTION AND THE FINAL TABLEAU"
185  DIM  A(5,35)
190  DIM B1(4,26)
195  DIM F1(27)
200  DIM F2(27)
205  DIM F3(27)
210  DIM O(27)
215  DIM X(27)
220  DIM Y(27)
225  DIM Q(27)
230  J = 34
235  I = 5
```

```
240  M = 4
245  N = 26
250  L = 1
255  E = 0
260  G = 3
265  B = M + N + G + 2
270  W = M + 1
275  H = 1
280  Z2 = 0
285  REM INPUT THE RIGHT HAND SIDE COEFFICIENTS
290  PRINT "INPUT THE DAILY EFFLUENT FLOW IN MILLION GALLONS PER DAY"
295  INPUT D1
300  PRINT "INPUT THE APPLICATION RATE IN INCHES PER WEEK"
305  INPUT D2
310  D3 = 258 * (D1/D2)
315  D4 = D3 * 4356
320  PRINT "THE NUMBER OF ACRES OF LAND REQUIRED IS:"
325  PRINT D3
330  PRINT "OR, IN TERMS OF SQUARE FEET:"
335  PRINT D4
340  PRINT "INPUT THE WIDTH OF THE FIELD IN FEET"
345  INPUT D5
350  PRINT "INPUT THE LENGTH OF THE FIELD IN FEET"
360  INPUT D6
370  IF D5 * D6 > = D4 GOTO 410
380  PRINT "THE FIELD YOU HAVE SPECIFIED IS INCONSISTENT WITH"
385  PRINT "THE EFFLUENT FLOW RATE AND LOADING OF THE SOIL"
390  PRINT "ALL PARAMETERS MUST BE CONSISTENT"
500  GOTO 290
```

```
510  PRINT "INPUT THE HOURS PER WEEK AVAILABLE FOR SPRAY IRRIGATION"
520  PRINT "IF IT IS POSSIBLE TO WATER ALL THE TIME ENTER 168 (7 x 24)"
530  INPUT D7
540  PRINT "INPUT THE PRESSURE AVAILABLE TO THE SYSTEM IN POUNDS PER SQUARE INCH"
550  PRINT
560  PRINT "IF PRESSURE IS VARIABLE OR BOOSTER PUMPS ARE TO BE"
570  PRINT "USED, ALTERNATIVE VALUES MAY BE SPECIFIED ON LATER RUNS"
580  PRINT "AND A COMPARISON MADE"
590  INPUT D8
600  REM INITIALIZE VALUES AT ZERO
610  FOR I = 1 to W + 1
620  FOR J = 2 to B
630  A (I, J) = 0
640  NEXT J
650  NEXT I
660  REM READ CONSTRAINT COEFFICIENTS FROM DATA
670  REM NOTE REMARKS IN DATA LINES
680  FOR I = 1 to M
690  FOR J = 2 to N + 1
700  READ A (I,J)
710  NEXT J
720  NEXT I
730  REM READ PRICES FROM DATA
740  FOR J = 2 to N + 1
750  READ A (W, J)
760  NEXT J
770  REM RIGHT HAND SIDE COEFFICIENTS
780  A (1, B) = D8
790  A (2, B) = D5 * D6
```

```
800  A (3, B) = D1 * 694.444
810  A (4, B) = D1 * 116666.667/D7
820  REM NUMBER OF LATERALS, FEET OF LINE, ETC
830  FOR J = 2 to N + 1
840  O (J) = D5/(.433 * A(1, J)) - 1
850  X (J) = (D5 * D6)/(.433 * (A(1,J))) - D6 - (A(1,J) * O (J))
860  Y (J) = D5 - A (1,J)
870  Q (J) = ((D5 * D6)/((A(1,J) * .433) * (A(1,J) * .5))) * ((O(J) - 1)/O(J))
880  NEXT J
890  REM
900  FOR J = 2 to 27
910  F 1 (J) = A (2, B)/A(2, J)
920  F2 (J) =  A (3, B)/A(3, J)
930  F3 (J) =  A (4, B)/A(4/ J)
940  IF F2 (J) > F1 (J) THEN F1 (J) = F2 (J)
950  IF F3 (J) > F1 (J) THEN F1 (J) = F3 (J)
960  NEXT J
970  PRINT
975  FOR J = 2 to N + 1
980  F2 (J) = Q (J)/F1(J)
985  NEXT J
990  FOR J = 2 to N + 1
991  A(1, J2) = (A(1, J) * A(1, J)) * .217 * F1 (J) * (O(J)/(O(J) - 1))
992  NEXT J
993  REM SET UP TABLEAU, SLACKS, ETC.
994  FOR K = 2 to M + 1
995  A(K - 1, N + G + K) = 1
996  A (K - 1, 1) = K + G + N - 1
997  NEXT K
```

```
1000  FOR K = L + E + 2 TO M + 1
1010  A (K - 1, K + N - L - E) = -1
1020  NEXT K
1030  W = W + 1
1040  Q = 0
1050  FOR J = 2 TO N + G + 1
1060  S = 0
1070  FOR I = M - G - E + 1 TO M
1080  S = S + A (I, J)
1090  NEXT I
1100  A(W, J) = - S
1110  IF A(W, J) > Q GOTO 1140
1120  Q = A(W, J)
1130  C = J
1140  NEXT J
1141  S = 0
1142  FOR J = M - G - E + 1 TO M
1143  S = S + A (J, B)
1144  NEXT J
1145  A(W, B) = - S
1150  PRINT
1160  PRINT
1170  PRINT "YOUR VARIABLES" ;H; "THROUGH" ; N
1180  IF G = 0 GOTO 1200
1190  PRINT "SURPLUS VARIABLES"; N + 1; "THROUGH"; N + G
1200  IF L = 0 GOTO 1220
1210  PRINT "SLACK VARIABLES"; N + G + 1; "THROUGH"; N + G + L
1220  IF G + E = 0 GOTO 1240
1230  PRINT "ARTIFICIAL VARIABLES"; N + G + L + 1; "THROUGH"; B - 2
```

```
1240  GOSUB 2010
1250  TRANSFORMATION MATRIX
1260  PRINT
1270  PRINT
1280  IF Q = .01 GOTO 1620
1290  IF Q = 0 GOTO 1700
1300  GOTO 1830
1310  H = H + 1
1320  Q = 1. E + 38
1330  R = 0
1340  FOR I = 1 TO M
1350  IF A(I, C) < = 0 GOTO 1390
1360  IF A(I, B)/A(I, C) > Q GOTO 1390
1370  Q = A(I, B)/A(I, C)
1380  R = I
1390  NEXT I
1400  IF R > = .5 GOTO 1440
1410  PRINT "SOLUTION UNBOUNDED"
1420  GOSUB 2010
1430  STOP
1440  P = A(R, C)
1450  A(R, 1) = C - 1
1460  FOR J = 2 TO B
1470  A(R, J) = A(R, J)/P
1480  NEXT J
1490  FOR I = 1 TO W
1500  IF I = R GOTO 1570
1510  FOR J = 2 TO B
```

```
1520  IF J = C GOTO 1560
1530  A(I, J) + A(I, J) - A(F, J) * A(I, C)
1540  IF ABS(A(I, J)) > 1.E - 05 GOTO 1560
1550  A(I, J) = 0
1560  NEXT J
1570  NEXT I
1580  FOR I = 1 TO W
1590  A(I, C) = 0
1600  NEXT I
1610  A(R, C) = 1
1620  Q = 0
1630  FOR J = 2 TO N + G + L + 1
1640  IF A(W, J) > Q GOTO 1670
1650  Q = A(W, J)
1660  C = J
1670  NEXT J
1680  GOTO 1290
1690  REM CHANGE TO PHASE TWO
1700  IF W = M + 1 GOTO 1820
1710  W = W - 1
1720  IF A(W + 1, B) < 1.E - 05 GOTO 9640
1730  PRINT "NO FEASIBLE SOLUTION"
1740  STOP
1750  FOR I = 1 TO M
1760  IF A(I, 1) < = N + G + L GOTO 1800
1770  FOR J = 2 TO B
1780  A(I, J) = 0
1790  NEXT J
1800  NEXT I
```

```
1810  GOTO 1620
1820  PRINT "ANSWERS:"
1830  If Q + 0 GOTO 1850
1840  PRINT "BASIS BEFORE ITERATION"; H
1850  PRINT "VARIABLE", "VALUE"
1860  FOR I = 1 TO M
1870  IF A(I, 1) = 0 GOTO 1890
1880  PRINT A(I, 1), A(I, B)
1885  ZL = I
1890  NEXT I
1900  If Q < > 0 GOTO 1310
1910  PRINT "DUAL VARIABLES:"
1920  PRINT "COLUMN", "VALUE"
1930  FOR J = N + 1 TO B - G - 2
1940  PRINT J, A(W, J + 1)
1950  NEXT J
1960  PRINT "LEAST LOST SOLUTION="; A(W, B) + 22
1970  PRINT "IN"; H - 1; "INTERACTIONS"
1980  GOSUB 2010
1985  GOSUB 3060
1990  GOTO 9999
2000  REM SUBROUTINE TO PRINT THE ENTIRE TABLEAU
2010  PRINT "TABLEAU AFTER"; H - 1; "ITERATIONS"
2020  FOR I = 1 TO W
2030  FOR J = 2 TO B
2040  IF B > 6 GOTO 2070
2050  PRINT A(I, J);
2060  GOTO 2080
```

```
2070  PRINT A(I, J);
2080  NEXT J
2090  PRINT
2095  PRINT
2097  NEXT I
2099  RETURN
3050  PRINT "THE SYSTEM USES";
3060  PRINT X(Z1); "FEET OF 2 INCH PIPE,"
3070  PRINT "AND"; Y(Z1): "FEET OF 6 INCH PIPE."
3080  PRINT
3085  PRINT "THIS SYSTEM IS DESIGNED AROUND";
3090  PRINT A(Z1, B);
3095  PRINT "HEADS OF TYPE:"
4000  PRINT J$ (Z1)
4010  J$ (1) = "TORO 355 - 01 - 08 - STD"
4020  J$ (2) = "TORO 355 - 01 - 08 - STD"
4030  J$ (3) = "TORO 355 - 01 - 08 - STD"
4040  J$ (4) = "TORO 355 - 01 - 08 - STD"
4050  J$ (5) = "TORO 355 - 01 - 08 - STD"
4060  J$ (6) = "TORO 380 - XX - 02"
4070  J$ (7) = "TORO 380 - XX - 02"
4080  J$ (8) = "TORO 380 - XX - 02"
4090  J$ (9) = "TORO 380 - XX - 02"
4100  J$ (10) = "TORO 380 - XX - 02"
4110  J$ (11) - "TORO 634 - 03 - 33"
4120  J$ (12) = "TORO 634 - 03 - 33"
4130  J$ (13) = "TORO 634 - 03 - 33"
4140  J$ (14) = "TORO 654 - 03 - 56"
```

```
4430  DATA 74, 78, 80, 82, 82, 162, 170
4440  DATA 178, 192, 198, 120, 124, 130
4450  DATA 130, 140, 144, 150, 172, 184, 190
4460  DATA 174, 182, 192, 192, 200, 210
4470  REM PRICES FOLLOW
4480  DATA 6.5, 6.5, 6.5, 6.5, 6.5, 275
4490  DATA 275, 275, 275, 275, 64, 64, 64
4500  DATA 74, 74, 74, 74, 83, 83
4510  DATA 83, 128, 128, 128, 128, 128, 128
```

```
4150  J$ (15) = "TORO 654 - 03 - 57"
4160  J$ (16) = "TORO 654 - 03 - 57"
4170  J$ (17) = "TORO 654 - 03 - 57"
4180  J$ (18) = "TORO 674 - 03 - 73"
4190  J$ (19) = "TORO 674 - 03 - 73"
4200  J$ (20) = "TORO 674 - 03 - 73"
4210  J$ (21) = "TORO 694 - 03 - 91"
4220  J$ (22) = "TORO 694 - 03 - 91"
4230  J$ (23) = "TORO 694 - 03 - 91"
4240  J$ (24) = "TORO 694 - 03 - 92"
4250  J$ (25) = "TORO 694 - 03 - 92"
4260  J$ (26) = "TORO 694 - 03 - 92"
4270  REM PRESSURE DROP IN EACH HEAD
4280  DATA 30, 40, 50, 60, 70, 40, 50
4290  DATA 60, 70, 80, 50, 60, 70
4300  DATA 60, 70, 80, 90, 70, 80, 90
4310  DATA 60, 70, 80, 70, 80, 90
4320  REM SPRAY HEAD DIAMETER
4330  DATA 74, 78, 80, 82, 82, 162, 170
4340  DATA 178, 192, 198, 120, 124, 130
4350  DATA 130, 140, 144, 150, 172, 184, 190
4360  DATA 174, 182, 192, 192, 200, 210
4370  REM GALLONS PER MINUTE
4380  DATA 2.61, 3.02, 3.28, 3.6, 3.89, 50.6, 56.7
4390  DATA 61.4, 66, -70.2, 16.1, 17.8, 19.5
4400  DATA 21.5, 31.5, 32.9, 34.7, 52.6, 56.3, 59.8
4410 DATA 53.7, 57.2, 61.2, 67.5, 74, 78
4420 REM SPRAY HEAD DIAMETER
```

APPENDIX B

PROJECT DATA

THE STUDY AREA

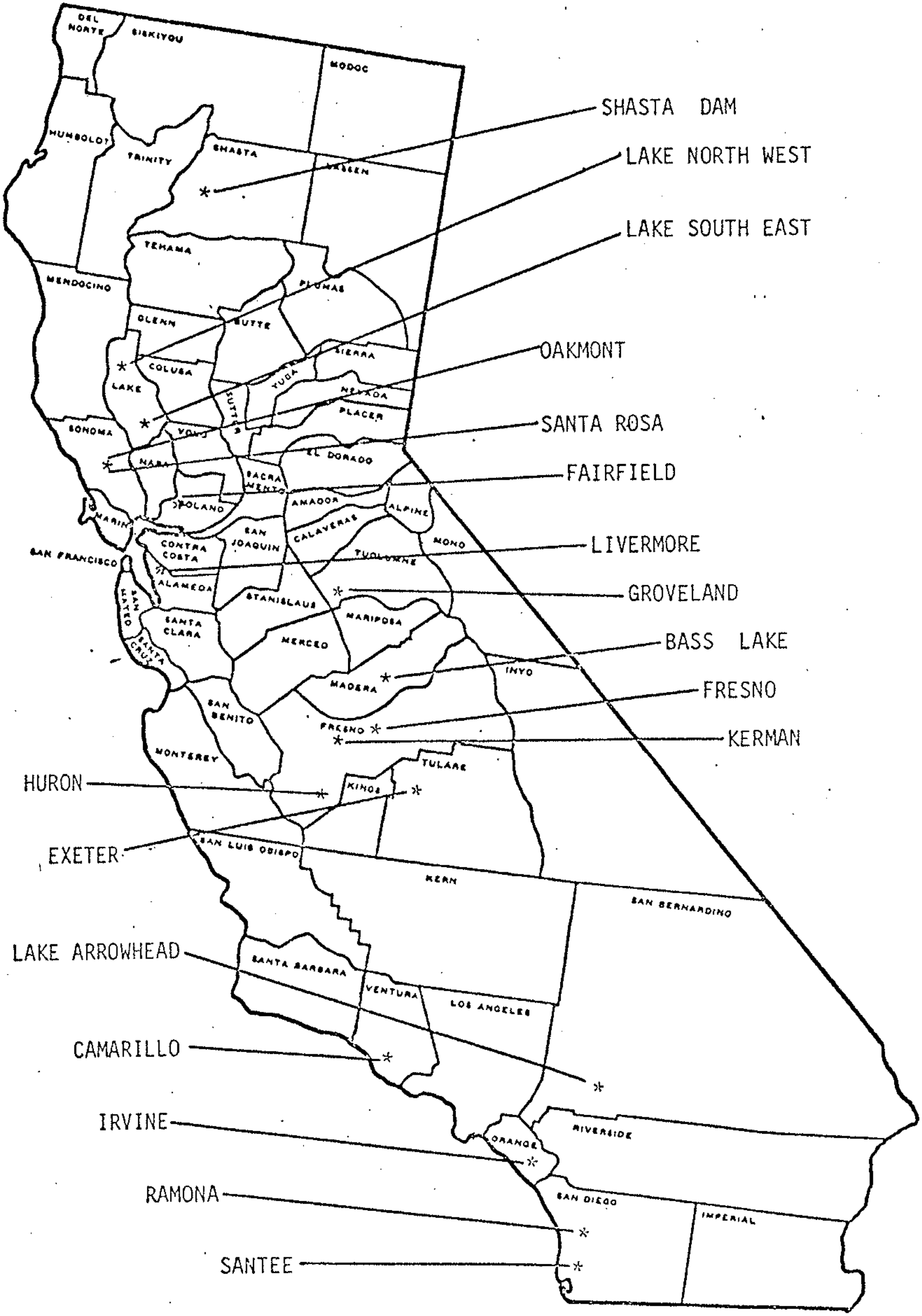


Table 1. Percent Distribution of the Study Group by Type System and Topographical Setting

TYPE SYSTEM	TOPOGRAPHICAL SETTING Mountainous	Rolling Hills	Valley	Plains	Raw Percent Total
Activated Sludge	11.1	5.6	16.7	0	33.3
Extended Aeration	0	5.6	0	5.6	11.1
Activated Sludge with Extended Aeration	0	5.6	5.6	0	11.1
Activated Sludge with Waste Stabilization Pond and Percolation Bed	0	5.6	0	0	5.6
Activated Sludge with High Rate Trickling Filter	0	0	5.6	0	5.6
Activated Sludge with Contact and Extended Aeration	5.6	0	0	0	5.6
Activated Sludge with Coagulation Filter	0	5.6	0	0	5.6
Activated Sludge with High Rate Trickling Filter and Tertiary	0	0	5.6	0	5.6
Waste Stabilization Pond	0	0	0	5.6	5.6
Other	0	11.1	0	0	11.1
Column Percent Total	16.7	38.9	33.3	11.1	

Raw Chi-Square = 30.78458 with 27 degrees of freedom. Significance = 0.28.

Table 2. Percent Distribution of the Study Group by Type Treatment Plant and Distribution System

	DISTRIBUTION SYSTEM				
TYPE SYSTEM	Agriculture	Golfcourse	Greenbelt	Other	Raw Percent Total
Activated Sludge	16.7	5.6	5.6	5.6	33.3
Extended Aeration	11.1	0	0	0	11.1
Activated Sludge with Extended Aeration	11.1	0	0	0	11.1
Activated Sludge with Waste Stabilization Pond and Percolation Bed	11.1	0	0	0	11.1
Activated Sludge with High Rate Trickling Filter	5.6	0	0	0	5.6
Activated Sludge with Contact and Extended Aeration	0	0	0	5.6	5.6
Activated Sludge with Coagulation Filter	0	0	0	5.6	5.6
Activated Sludge with High Rate Trickling Filter and Tertiary	5.6	0	0	0	5.6
Waste Stabilization Pond	0	0	0	5.6	5.6
Other	11.1	0	0	0	11.1
Column Percent Total	61.1	5.6	5.6	27.8	100.0

Raw Chi-Square = 18.54544 with 27 degrees of freedom. Significance = 0.8860.

Table 3. Percent Distribution of the Study Group by Distribution System and Topographical Setting

	TOPOGRAPHICAL SETTING				
Distribution System	Mountainous	Rolling Hills	Valley	Plains	Raw Percent Total
Agriculture	5.6	22.2	27.8	5.6	61.1
Golfcourse	0	5.6	0	0	5.6
Greenbelt	5.6	0	0	0	5.6
Other	5.6	11.1	5.6	5.6	27.8
Column Percent Total	16.7	38.9	33.3	11.1	100.0

Raw Chi-Square = 8.15064 with 9 degrees of freedom. Significance = 0.5190.

Table 4. Factor Analysis Results Using Alpha Factor and Varimax Rotation.

COLLECTION/PROCESSING

Factor	Eigenvalue	% of Variation	Cum %
(1) Capacity	5.40417	45	45
(2) Topographical/ Environmental/ Health	2.37856	19.8	64.8
(3) Sludge Handling	1.23782	10.3	75.1
(4) Process Train	1.1348	9.5	84.6

DISTRIBUTION/IRRIGATION

Factor	Eigenvalue	% of Variation	Cum %
(1) Hydraulic Head	3.2269	41.5	41.5
(2) Capacity	2.07713	26	67.5
(3) Conveyance Distance	1.30007	16.3	83.7

Table 5. Estimated Relationships (t statistics in brackets)

[1]TOTAL ENERGY = -290 + 1107 [2]RATED CAPACITY
[8.76]* R^2 = .638

TOTAL ENERGY = 981 + 1787 [3]INFLOW
[8.69]* R^2 = .825

[4]TOTAL COST = 6,054,325 + 572 TOTAL ENERGY
[3.7]* R^2 = .462

[5]O & M = 312,454 + 43,584 RATED CAPACITY
[5.0]* R^2 = .638

TOTAL ENERGY = -2178 + 5.283 [6]TOTAL HORSEPOWER
[3.1]* R^2 = .549

O & M = 107,607 + 209,357 INFLOW
R^2 = .868

TOTAL COST = 5,348,907 + 1,348,060 INFLOW
[5.6]* R^2 = .663

TOTAL COST = 4,562,976 + 811,796 RATED CAPACITY
[5.1]* R^2 = .635

* Significant at the .005 level.

[1] In Millions of British Thermal Units

[2] In Units of Million Gallons per Day

[3] In Units of Million Gallons per Day

[4] In November 1978 Dollars

[5] In November 1978 Dollars

[6] In Units of One Horsepower

Table 6. Distribution of Annual Average Operations and Maintenance Cost per MGD Flow by Type of Sludge Disposal.

Disposal Type	Low ($3,300)								Average O&M Cost									High ($1,726,000)
Incineration																	X	
Land Fill								X										
Land Reclamation				X		X							X		X	X		X
Soil Conditioner		X	X								X	X						
Other	X				X		X		X	X				X				

Each entry represents one system's placement in the low to high range.

Table 7. Distribution of Annual Average Operations and Maintenance Cost per MGD Flow by Type of Sludge Process.

Process Type	Low ($3,300)									Average O&M Cost								High ($1,726,000)
Sand Beds	X		X	X	X				X		X	X	X		X	X		X
Lagoons						X		X										
Vacuums																	X	
Centrifuge										X								
Other		X					X							X				

Each entry represents one system's placement in the low to high range.

Table 8. Distribution of Annual Average Operations and Maintenance Cost per MGD Flow by Type of Treatment System

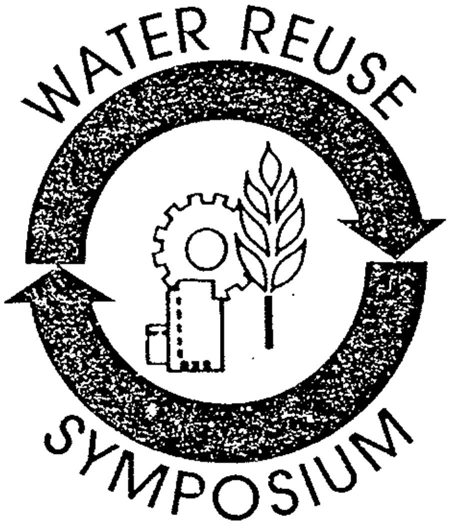
Treatment Type	Low ($3,300)			Average O&M Cost			High ($1,726,000)
Activated Sludge			X X X	X		X X	
Extended Aeration		X X					
Activated Sludge with Extended Aeration					X	X	
Activated Sludge with Waste Stabilization Pond and Percolation Bed					X		
Activated Sludge with Contact and Extended Aeration.							X
Activated Sludge with Coagulation Filter				X			
Activated Sludge with High Rate Trickling Filter and Tertiary					X		
Waste Stabilization Pond	X						
Other		X X					

Each entry represents one system's placement in the low to high range.

APPENDIX

PROCEEDINGS— VOL. 2

March 25-30, 1979
Washington, DC



Theme:
"Water Reuse—From
Research to Application"

Co-sponsored by:

American Water Works Association Research Foundation
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U.S. Army Medical Research and Development Command
U.S. Environmental Protection Agency
National Science Foundation
Water Pollution Control Federation

THE COSTS FOR SPRAY IRRIGATION LAND DISPOSAL OF MUNICIPAL WASTEWATER IN CALIFORNIA

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THE SETTING

In the past the primary focus of the wastewater district has been to dispose of the flow for which it is responsible subject to the various cultural, economic, environmental, institutional, and legal constraints placed upon it. Currently we are witnessing a change in this "disposal" philosophy due to the synergistic influence of several factors, primarily the increasing population and burgeoning technological sophistication. In many regions one now finds that the assimilative capacity of the environment has been unable to meet the increased demands placed upon it by population pressures and unacceptable levels of environmental degradation have resulted. Concomitantly the questionable economic viability of supplying ever increasing amounts of "fresh" water has led to serious doubts about the wisdom of our current water system.

The short-run approach of dealing with these problems has led to the imposition of additional institutional and legal constraints in an attempt to relax the binding economic and environmental ones. In response to these changing constraints new forms of water supply and water disposal agencies are evolving to provide a viable long-run solution to the problem at hand. The metamorphis emphasizes the advantages to be realized from agency intergration and the avoidance of artificial boundaries whereby water changes from "fresh" to "waste." The general recognition of water quality as a continum transversing several dimensions has given a new impetus to using water which is acceptable in the restricted critical dimensions for the limited use to which it is to be put. In this regard spray irrigation using wastewater is uniquely promising because it not only produces benefits from the harvesting of the crop cover but is capable of producing a high quality water "harvest" as well.

THE PROBLEM

This research attempted to quantify the specific monetary and energy

costs associated with land application renovation of wastewater, and to a lesser extent consider the long-run implications.

Monetary Costs

If the various non-economic constraints are to be met by a given regimen of wastewater disposal, which procedures result in the least cost method of operation? Van Note (1) lists 123 combinations of unit processes for wastewater treatment systems ranging from primary sedimentation to ion exchanges and associates with each an expected water quality level. However, in addition to the great diversity of treatment systems from which to choose Van Note states that, "there are wide cost variations caused by factors unique to any given project, e.g., site conditions, local variations in material and labor costs and different wastewater characteristics." It is to be expected that research intended to have broad applicability for diverse geographical regions should inform the reader of the nature of the cost estimates, such as this caveat from Middleton (2), "Costs given are examples and do not apply to any specific local situation." But when one enters the realm of wastewater treatment by land application one encounters another problem of similar magnitude. Pound (3) noted in 1975 that, "For the most part. . .the costs were predominantly built up from typical preliminary designs since very few actual construction cost data are available for existing land application systems. It is hoped that actual costs can be used to a greater degree in future revisions of this report as more data become available." In a more recent work by Young (4) he notes the same problem and states his approach, "Simulation analysis was selected as the mode of analysis for three reasons: (1) simulation analysis permits examination of land application treatment under a wide variety of scenarios, (2) the direct impact of individual parameters can be observed, and (3) since only a limited number of land application systems are being operated for advanced wastewater treatment, insufficient data are available for statistical analysis."

Circumstances novel to California have acted to mitigate these data restrictions: i) because over 80 percent of water use in California is for irrigation there was an early and strong interest in this form of renovation, ii) the depletion of groundwater aquifers and the subsequent intrusion of saltwater in certain coastal regions stimulated interest in various recharge methods, iii) the establishment of the State of California Office of Water Recycling, and iv) the extensive and costly canal system which traverses much of the state. For these reasons, and the innovative spirit of the local communities which sponsored land application renovation, there exists within the state a small but growing data base upon which to analyze the current cost situation. The authors believe that by restricting the geographical boundaries of the study area, statistically meaningful results may be obtained from the data which are currently available. Consequentl the analysis conducted below is based upon actual costs incurred, but no claim is made for the general applicability of the results beyond the study area.

Energy Costs

Another characteristic of California which is assuming increasing sig ficance has given rise to the second thrust of this study; energy requirements. Throughout the state fuel costs for utilities companie are consistently above the national average, while current expectatio are that energy prices in the United States will outpace most other price increases in their steady march upward. Although the United States Government implemented the Federal Mandatory Fuel Allocation Program which grants wastewater handling facilities 100 percent of their requirements during fuel shortages, there is a great opportunity for energy conservation by designing and operating energy efficient wastewater treatment systems. The State of California Energy Task Force (5) recognized the serious nature of the problem when it issued this warning: "Because wastewater collection and treatment is vital to the health and general well-being of Californians and is also an energy dependent process, the present energy shortage has potentially serious implications regarding the ability of California to pursue the goal of clean waters." As energy costs assume an increasingly important role in operations costs they will determine the cost effectiveness of treatment systems to a greater extent than ever before.

The authors envision future research utilizing previously published estimates of construction and operation costs for advanced wastewater treatment systems, and the results reported in this research, analyzing the trade-off between the higher construction costs and the lower operation costs associated with land application renovation. This analysis would proceed using appropriate amortization periods and discount rates to determine the impact energy cost escalation has upon the overall cost effectiveness of land application renovation in the long-run. In order to account for the differential rates of price escalation in the construction and energy sectors it would be desirable to develop a simulation model similar in nature to the "CLAW" (Cost of Land Application of Wastewater) model reported upon by Young (4) which could incorporate into the analysis alternative hypotheses concerning these volatile parameters.

PREVIOUS RESEARCH

Much of the previous research into the costs of advanced wastewater treatment has neglected land application renovation and instead has attempted to quantify the costs associated with mechanical and chemical renovation. As a comparison with the results reported here for land application renovation some of the more recent cost estimates for advanced wastewater treatment are summarized.

Monetary Costs

Middleton's estimates (2) for capital and total operating costs of 10 MGD (million gallon per day) plants which produce the quality of water listed is summarized below in 1974 dollars:

WATER QUALITY	CAPITAL ($/mil gal)	TOTAL OPERATING ($/1000 gal)	($/acre-ft)
Recreational Lakes	9,641,000	.407	133
Industrial Uses	8,237,000	.356	116
Near-Potable Water	13,181,000	.621	202
Near-Potable Water by Reverse Osmosis	11,532,000	.623	203

Alternatively the California Water Resources Control Board's estimates (6) for a 10 MGD wastewater treatment facility is summarized below in dollars based on the EPA construction cost index of 200:

PROCESS	COST/1000 GAL (each process)	(cum.)	COST/ACRE-FEET (each process)	(cum)
Secondary	.20	.20	65	65
Chemical Coagulation (lime)	.09	.29	29	94
Filtration	.07	.36	23	117
Nitrogen Removal	.11	.47	35	152
Carbon Adsorption	.10	.57	33	185
Disinfection	.01	.58	3	188
Demineralization	.40	.98	130	318

A recent EPA publication (1) gives annual combined sludge and liquid process costs for various degrees of quality ranging from 38.9 to 60.5 cents/1000 gallons. These estimates are based on the National Average Wastewater Treatment Plant Cost Index of 177.5 for February 1973, the Wholesale Price Index for Industrial Commodities of 120 for February 1973 and labor costs of $5.00/hour. This estimate is for a 20 MGD wastewater treatment plant design for biochemical oxygen demand, suspended solids, phosphorus and nitrogen removal with effluent polishing.

An engineering analysis (7) for a proposed project to be completed in 1983 yields cost estimates for a 15 MGD wastewater treatment plant utilizing spray irrigation land application for groundwater recharge. This project is to receive secondarily treated water as it's influent and thus will exhibit lower costs than plants which must process raw influent. The secondarily treated influent is to be received and treated by coagulation (aluminum sulfate is the primary coagulant and a polymer is the secondary coagulant) followed by multimedia filtration and then disinfection by chlorine. The estimated cost, based on the Engineering News Record's Construction Cost Index of 4200 is:

The Green Acres Project (15 MGD in 1983)

TOTAL CAPITAL COST	OUTPUT (acre-ft/year)	O & M AND CAPITAL AMORTIZATION	UNIT COST ($/acre-ft)
$27,153,000	7,961	$1,016,000/year	$128

In addition to these cost estimates the study cites a reduction in energy demand due to the project because imported water requires 3 to 5 times as much energy to obtain as does reclaimed water.

Energy Costs

These costs consist primarily of electrical energy with some natural gas being used to power heaters, incinerators, and vehicles. In this study gasoline costs were not included in the energy analysis but were placed in the O & M analysis section. While the major energy expense is for electrical consumption, procresses utilizing natural gas may find energy costs increasing at an exceedingly rapid pace when deregulation of natural gas in the United States occurs. A 1973 report sponsored by the EPA (8) summarizes electrical power requirements for 10 MGD wastewater treatment plants, by type of process:

LEVEL OF TREATMENT	ENERGY CONSUMPTION (KwH/mil gal treated)	$ COST (@$.03/KwH)
Primary	235	7.05
Secondary		
Primary + Trickling Filters	480	14.40
Primary + Activated Sludge	880	26.40
Tertiary		
Secondary + Lime Clarification, Filtration, and Carbon Adsorption	1630	48.90
Secondary + Filtration, and Reverse Osmosis	3000	90.00

Based upon these estimates an increase in the price of electrical energy of just one mill per kilowatt-hour would directly increase the operating costs of a 10 MGD wastewater treatment plant operating at capacity and utilizing secondary treatment plus filtration and reverse osmosis in the amount of $10,950 per year. In contrast a 10 MGD wastewater treatment system utilizing primary and activated sludge treatment with a gravity flow spray irrigation land renovation system would incur additional operating costs of only $3,212 per year. These are direct effects only, one would expect the generally higher operating costs of advanced wastewater treatment plants to increase more than proportionally in response to energy price increases due to the indirect and induced effects which these price increases would precipitate. One must also consider the hardships imposed by employing energy intensive treatment systems in light of the U.S. Federal Mandatory Fuel Allocation Program which gives wastewater handling systems a high priority fuel allocation.

For comparison with the actual energy costs reported below one must also include collection system energy costs. The EPA (9) estimates of collection system energy costs updated by the fourth quarter 1978 fuel and utilities component of the National Consumer Price Index are:

ANNUAL COLLECTION SYSTEM POWER COSTS ($/MGD)

(Minimum)	(Median)	(Average)	(Maximum)
194	1018	3,086	24,903

Adding the collection and treatment system's energy costs one arrives at the total system energy cost expressed here as total annual cost per MGD flow:

ANNUAL ENERGY COST RELATIONSHIPS ($/MGD)

SYSTEM	COST		
	(Min.)	(Avg.)	(Max.)
Primary	2767	5659	29088
Secondary			
Primary+Trickling Filters	5450	8432	31771
Primary+Activated Sludge	9830	12722	36351
Tertiary			
Secondary+Lime Clarifi., Fil., and Carbon Adsor.	18042	20934	44363
Secondary+Filtration, and Reverse Osmosis	33044	35936	59365

METHODOLOGY

The actual costs incurred by a broad spectrum of wastewater districts in California for fiscal year 1977 were analyzed by least squares regression and factor analysis in an attempt to determine the relationship between the observed costs and the underlying influencing factors. In addition special attention was given to the relationship between treatment facility type and the associated level of energy consumption per unit of effluent flow.

Two recent developments lend especial relevance to the results of this project. First, the EPA's mandate that new wastewater treatment systems must investigate the cost effectiveness of land disposal of treated wastewater. Second, the findings of studies conducted in New England which indicate that the failure of engineers to anticipate the great energy-cost escalation and to design energy-conserving wastewater systems has increased operating costs to municipalities by 40 to 90 percent.

Data Sources

The State of California Water Resources Control Board was contacted and helpful assistance was received from both the Division of Water Quality and the Office of Water Recycling. From information contained in the control board's data base 18 new and 3 expansion wastewater treatment systems utilizing land application renovation were identified. These facilities were contacted and general information regarding system operations and specific operation and maintenance cost data were obtained. To obtain construction cost data the consulting engineers engaged for the construction of these facilities were contacted for copies of the Bid Tabulations submitted by contractors. There was no uniform procedure for handling this information by the different engineering firms and in many instances the authors were referred to the municipalities for the actual construction cost data. In a few cases it was necessary to proceed directly to the construction firm contracted for the system erection. Three of the new systems were deemed by the authors to have inadequate data or insufficient operating experience to give meaningful results and were dropped from the study group. The final study group consists of 15 new systems and 3 expansion systems; located as indicated in Figure 1.

Indexing

The construction costs incurred for the 15 new plants and the original construction and expansion costs for the 3 older plants were all stated in terms of the November 1978 Engineering News Record Construction Cost Index for Los Angeles and San Francisco of 3,421 and 3,412 respectively. Systems in the Los Angeles sphere of influence were adjusted with the Los Angeles index while systems in the San Francisco sphere of influence were adjusted with the San Francisco index.

Because the operation and maintenance costs were all from the uniform period of July 1, 1977 to June 30, 1978 no indexing of these costs was attempted. Similarly, energy requirements were gathered for this uniform period in physical units and no indexing was required for this part of the analysis.

The Analysis

Using an IBM 360/50 computer and the SAS Institute's Statistical Analysis System software package a combined cross-section time-series regression was run on the effluent flows and energy consumption by the Fuller and Battese Method (10) to obtain a baseline estimate of energy consumption for the study population as a whole. Next, each system's effluent flow rate and energy consumption rate was analyzed by the method of ordinary least squares regression using Princeton University's Time Series Processor software package. Each system was then compared to the baseline estimate for preliminary categorization by energy usage. Having placed the systems into energy requirements per unit processed groups, the authors proceeded to determine which influences gave rise to the between-group variations in energy requirements.

Using the Statistical Package for the Social Sciences software package on a Prime 400 computer, linear regression, crosstabulation, and factor analysis were implemented. This subdivision of the statistical analysis provides the major portion of the results presented below which define the fundamental characteristics of plant types and make inferences about the underlying influences which determine the actual costs incurred. The results are therefore presented within a framework of unit cost functions relative to capacity, treatment system type, topography, et cetera. The complete list of influences is given in the section presenting the results of this study.

The summary results of the statistical analysis may be observed from tables 4 through 8 at the end of this report. These represent the skeletal frame around which the body of the research is structured.

The Data

The data represents the actual costs for the present configuration of the land disposal treatment systems studied. Construction costs were obtained from the consulting engineers, municipal administrations, and construction firms. Land costs were not included in the construction cost figures. In the cases of system expansion major repairs which extended the capital life of the operating equipment were indexed and included in system construction cost rather than maintenance costs. Operation and Maintenance costs were obtained from the wastewater districts in all cases. Administrative and overhead expenses were included in the operations and maintenance costs.

RESULTS

Because utilities costs represent about 10 percent of the operations and maintenance costs for the systems studied the total energy requirements of the individual systems were converted into British Thermal Units and then into KwH equivalent for easy cost comparison based upon a price of 30 mills per KwH. The results indicate that, on the average, land application renovation compares favorably with other forms of advanced wastewater treatment, however, the study group did display wider variations than the comparison group. Primarily due to the influences of the excess capacity, average operations and maintenance costs showed a disadvantage when compared with the EPA (9) estimates of annual average operations and maintenance cost for a 10 MGD system. The EPA's third quarter 1977 annual cost estimate of $145270 per MGD flow is lower than the author's fourth quarter 1978 annual cost estimate of $220117 per MGD flow.

Construction costs are presented with respect to their influencing factors with a view toward analyzing the trade-off between higher initial investment vs. lower O & M costs. Obviously the choice of discount rate, amoritization period, and volatility of O & M costs will influence the ultimate results significantly.

Energy Costs

The summary energy requirements for the study group are:

Annual Energy Costs Per MGD Flow

	MINIMUM	AVERAGE	MAXIMUM
Energy in Mil BTU	132	2518	18276
$ Cost @ $0.03/KwH	$1160	$22128	$160644

Based upon the estimated regression equations presented in Table 5 one finds that total energy requirements are extremely sensitive to the flow entering the system: an additional 1 MGD inflow requiring an additional 1787 Mil BTU. However, contrary to previously reporte
estimates, the results here indicate that average energy costs are higher for larger system designs, while the total construction cost is relatively insensitive to the energy intensitivity of the system configuration. If these preliminary findings are borne out the high
average costs associated with constructing small scale AWT systems could be overcome by employing economical land application renovatio
Some support is lent to this hypothesis by the relationship found between energy consumption and total horsepower associated with the treatment systems because increasing average costs were also found in their relationship. As a whole, however, economies of scale did prevail in the study group in terms of operations and maintenance costs. Energy costs are not presently a large enough component of total O & M costs to out-weigh the other savings gained from increas
system capacity. But these savings must be traded off due to the fa
that systems operating at below capacity levels have been shown to h
significant increases in their average operating costs when compared with costs at capacity levels of operation.

No significant relationship was found between total energy consumpti
and the system type in the study group in terms of the unit processe
employed and the treatment train unit process configuration. The results indicate that the over-riding significant factor in energy consumption is pumping costs. While there does exist a relationshi
between pumping requirements and the treatment train unit process configuration this influence is small when compared to the impact o
the other influencing factors. As indicated below in the section o
Operation & Maintenance costs there is a significant positive correlation between the system type and the average O & M costs per MGD, but to attribute this to energy requirements is not supported by th
data. One hypothesis consistently advanced by system administrator
was that in the wake of the 1973 energy crisis managers have attemp
to substitute other inputs for energy. The result has been that th
hypothesized relationship between energy requirements and system ty

does not show up in the analysis of the energy data, but instead has been shifted to total O & M costs which do show a significant relationship.

Operations & Maintenance Costs

Average O & M costs are heavily influenced by the degree of capacity utilization of the system. All of the study group facilities had some degree of excess capacity and the resulting O & M costs are therefore somewhat high. As the reclaimed water is recycled additional flows will be available to be processed through the system utilizing the now excess capacity and lowering the average O & M cost. The concept of a "water flow multiplier" is helpful in noting how this result is forthcoming. As each new unit of water is added to the system a portion of this flow is reclaimed and added to the flow in the next period. A portion of this second period flow is reclaimed and again placed in the flow in the third period. Thus in each succeeding period some fraction of the previous period's reclaimed flow is again reclaimed and adds to the available supply in the following period. For illustrative purposes assume that one-half of the flow in any given period is reclaimed. Then an increase in the flow in the present period of one unit will result in a one-half unit increase in the flow in the next period and a one-fourth unit increase in the flow in the third. Or, $1+1/2+1/4+1/8+1/16+1/32+\text{etc.}$, which is a well known series and in the limit converges to $1/(1-1/2)=2$, or more generally as; injections divided by the fraction of leakages. Thus the initial injection of one unit of water into the system will result in a two unit increase in water flow, assuming half of the flow is reclaimed in each cycle.

Operation and maintenance costs were estimated to be $209,357 annually for each MGD flow, with fixed costs of $107,607 annually. For a 10 MGD system this amounts to annual average costs of $220,117 per MGD. The relationships between average O&M costs and system type is displayed in tables 6,7,&8. Wide variations were observed in O & M costs which were only partly attributable to the variations in the energy intensiveness of the systems, other contributing factors are discussed below.

Capital Costs

The relationship found between total construction cost and system capacity was rather weak, with wide variability in the data encountered. Interestingly there was a stronger, but still weak, relationship between the total capital cost and the actual system flows. The summary capital costs are:

Capital Costs

	Fixed Costs	Marginal Costs/MGD	Avg. Costs/MGD
Observed Flows	$5,348,907	$1,348,060	$1,882,950
Capacity Flows	4,562,976	811,796	1,268,093

Cost Variations

Exceedingly wide cost variations were encountered in all the categories analyzed. To account for the factors influencing this variation alpha factor analysis was employed. To determine the extent to which planners could employ this variability to good advantage the analysis is presented in two sections: the collection/processing system and the spray irrigation distribution system.

Collection/Processing

The greatest influence on the cost variations was system capacity. This factor accounts for 45 percent of the cost variations in the study population. In general the larger the system design flow the lower the average capital and O & M cost per MGD flow at capacity utilization levels. But there are severe penalties associated with under utilization of the design capacity. Average costs increase significantly as flow rate falls below design capacity. Because the system must be able to handle the peak flows which occur only occasionally, much of the time there is idle capacity resulting in higher average costs. The degree of the idle capacity is directly related to the variation in the flow rate of the influent. For example, resort communities which may experience a population influx of many times the resident population have found average costs during the off season excessive. Also, systems which have combined sewer and storm drains enjoy lower construction costs, but the burden on the treatment plant during the rainy season often requires an increased capacity which lies idle during the dry months.

The next greatest influence upon the variation observed in the cost data comes from topographical/environmental/health constraints. This factor contributes almost 20 percent of the observed variation in the study group. Underlying this factor are determinants such as terrain, soil characteristics, nature of the ecosystem, and safeguards necessary to prevent contamination. An example of a costly area, in terms of this factor, would be one which has irregular terrain, rocky soil conditions, a delicately balanced ecosystem, and a shallow aquifer. Alternatively, an urban environment may be thought of as an example of a costly area due to the high premium paid for land, the population density, and the ease of contagion.

The third factor contributed approximately 10 percent of the observed variation and is directly related to the sludge handling process. In the study group we observed combinations of sand bed, lagoon, vacuum, and centrifuge dewatering processes with incineration, land fill, land reclamation, soil condition, and ocean discharge disposal methods.

The fourth factor identified contributed nearly 10 percent of the variation observed in the study group. This factor represents the selection and the configuration in which the train of wastewater treatment unit processes are organized.

Spray Irrigation Distribution

The influencing factors were more well defined for this subdivision of the system, engineering design parameters being responsible for all the observed variation in the study group. The first factor which accounts for 41.5 percent of the variation is the dynamic hydraulic head. The second factor, accounting for 26 per cent of the observed variation, is the irrigation system capacity. The last factor accounted for roughly 16 percent of the variation and represents the distance for conveyance to the irrigation site. These three factors are all related by the design parameters: sprinkler spacing, application rate, nozzle size and pressure, and the loading potential of the irrigation site. Discussion of design criteria may be found in Pair (11) and computer algorithms for devising least cost sprinkler irrigation systems are available. There appears to be little room for further optimizing the system configuration in this subsection. Most of the engineering criteria are dictated by the factor which has been interpreted as "topographical/environmental/health constraints."

NON-MONETARY COSTS

With the recent and predicted energy costs escalation there appears to be a continuing trend of definite cost advantages associated with land renovation, but non-monetary costs in terms of land quality must be evaluated. Some soil degradation with prolonged wastewater application appears to be inevitable. The nature of this degradation will depend upon the quality of the effluent and the original soil characteristics.

Effluent irrigation studies over a six-year period, Youngner et. al., (12), have shown that certain ions will accumulate in the soil. If sodium, common to most effluent waters, is adsorbed on clay particles in large amounts is will have a destructive effect on soil structure. As the SAR (sodium adsorption ratio) approaches 9 or higher, soil permmeability problems may be anticipated. With a loss of permeability, the soil will function poorly as a wastewater renovator and as medium for plant growth. High effluent bicarbonate levels will further increase the sodium hazard. Although a high SAR can be corrected by the addition of calcium, this will add to the total cost of the recycling process.

Increased salinity and sometimes high boron levels may also be anticipated after several years of application unless amounts of water are adequate for good leaching. Again, this can often be corrected but at an additional cost.

Heavy metals, present in many effluent waters, may also accumulate in amounts which could be harmful to plant growth or could prevent future use of the land for food production. The heavy metals most often found in municipal wastewater are copper, cadmium, nickle and zinc. Fortunately, during secondary treatment a high proportion of these elements are removed in the sludge, Peterson et al., (13).

None of these problems appear to be of sufficient magnitude to cause serious soil degradation or to render the land useless. Therefore, land degradation should seldom if ever be a factor preventing the recycling of wastewater by spray irrigation.

CONCLUSION

Land application renovation of pretreated wastewater is cost effective in producing water quality which is comparable to other methods of advanced wastewater treatment.

The area of greatest potential savings is the degree of system capacity utilization. An analysis of alternative strategies for utilizing facilities to their full design capacities could recommend policies producing appreciable savings. For example, i) incentives/penalties could be implemented for system users during the slack/peak flow periods, ii) holding areas could be utilized to maintain a constant capacity flow into the treatment system, or iii) some combination of i, ii, and regulatory controls might be used.

The method of sludge handling in conjunction with the pretreatment system process train was significant in explaining the observed cost

variations in the study group.

The land application sub-system of the renovation process was the most stable cost of the total system design and lends itself readily to simulation analysis for determining optimal configurations in alternative settings.

Acknowledgment

This research was conducted with support from the University of California Water Resources Center (project No. W-532) and the United States Office of Water Research and Technology (project No. A-065-CAL).

The authors would like to thank the consulting engineers, municipal administrations, construction firms, and the California Water Resources Control Board whose cooperation made this report possible.

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FIGURE 1

THE STUDY AREA

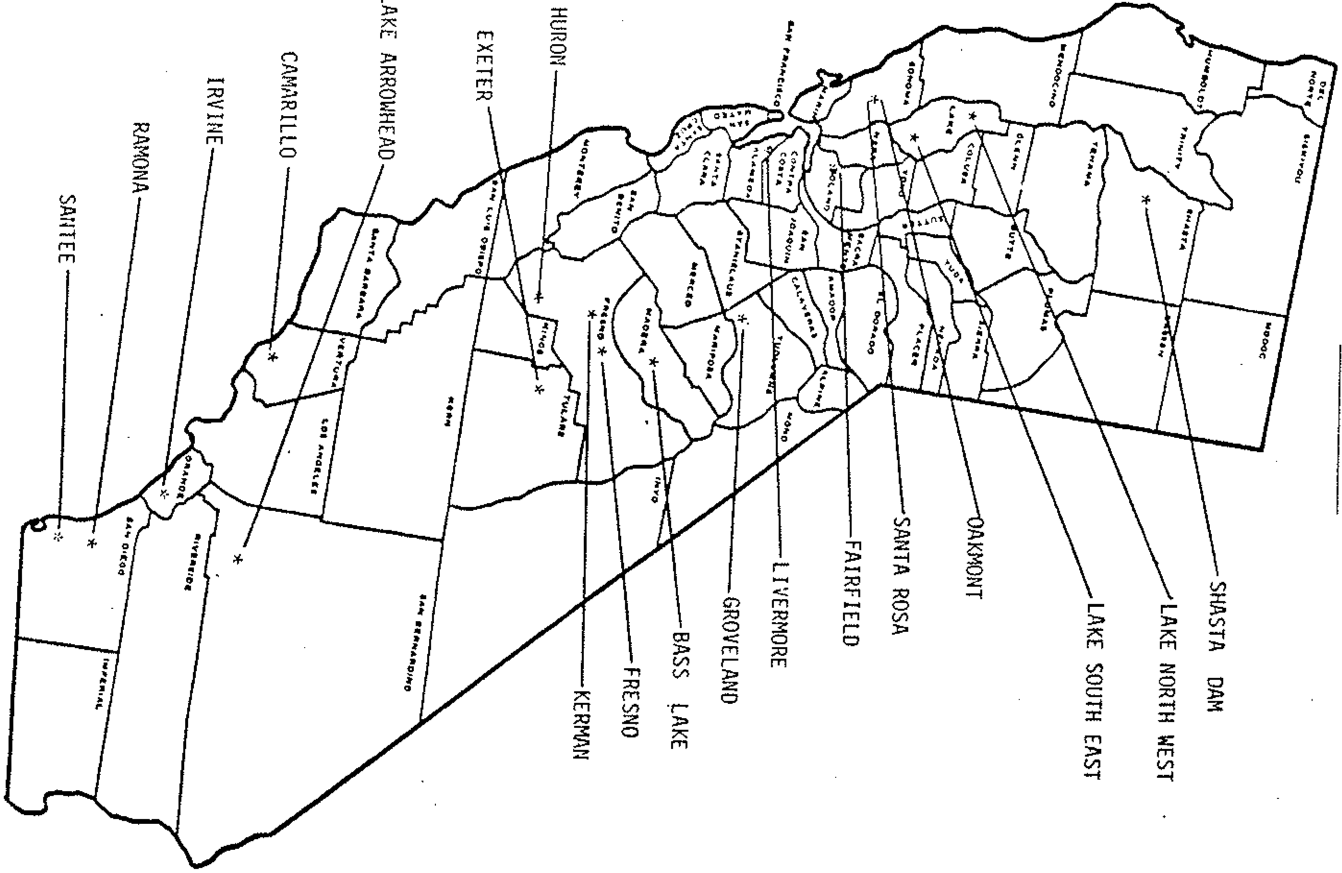


TABLE 1
Percentage Distribution Of The Study Group By Type System And Topographical Setting

TYPE SYSTEM	TOPOGRAPHICAL SETTING Mountainous	Rolling Hills	Valley	Plains	Row Percent Total
Activated Sludge	11.1	5.6	16.7	0	33.3
Extended Aeration	0	5.6	0	5.6	11.1
Activated Sludge with Extended Aeration	0	5.6	5.6	0	11.1
Activated Sludge with Waste Stabilization Pond and Perculation Bed	0	5.6	0	0	5.6
Activated Sludge with High Rate Trickling Filter	0	0	5.6	0	5.6
Activated Sludge with Contact and Extended Aeration	5.6	0	0	0	5.6
Activated Sludge with Coagulation Filter	0	5.6	0	0	5.6
Activated Sludge with High Rate Trickling Filter and Tertiary	0	0	5.6	0	5.6
Waste Stabilization Pond	0	0	0	5.6	5.6
Other	0	11.1	0	0	11.1
Column Percent Total	16.7	38.9	33.3	11.1	

Raw Chi-Square = 30.78568 with 27 degrees of freedom. Significance = 0.28.

	DISTRIBUTION SYSTEM				
TYPE SYSTEM	Agriculture	Golfcourse	Greenbelt	Other	Row Percent Total
Activated Sludge	16.7	5.6	5.6	5.6	33.3
Extended Aeration	11.1	0	0	0	11.1
Activated Sludge with Extended Aeration	11.1	0	0	0	11.1
Activated Sludge with Waste Stabilization Pond and Perculation Bed	11.1	0	0	0	11.1
Activated Sludge with High Rate Trickling Filter	5.6	0	0	0	5.6
Activated Sludge with Contact and Extended Aeration	0	0	0	5.6	5.6
Activated Sludge with Coagulation Filter	0	0	0	5.6	5.6
Activated Sludge with High Rate Trickling Filter and Tertiary	5.6	0	0	0	5.6
Waste Stabilization Pond	0	0	0	5.6	5.6
Other	11.1	0	0	0	11.1
Column Percent Total	61.1	5.6	5.6	27.8	100.0

Raw Chi-Square = 18.54544 with 27 degrees of freedom. Significance = 0.8860.

TABLE 3

Percentage Distribution of the Study Group by Distribution System and Topographical Setting

	TOPOGRAPHICAL SETTING				
Distribution System	Mountainous	Rolling Hills	Valley	Plains	Row Percent Total
Agriculture	5.6	22.2	27.8	5.6	61.1
Golfcourse	0	5.6	0	0	5.6
Greenbelt	5.6	0	0	0	5.6
Other	5.6	11.1	5.6	5.6	27.8
Column Percent Total	16.7	38.9	33.3	11.1	100.0

Raw Chi-Square = 8.15064 with 9 degrees of freedom. Significance = 0.5190.

* * *

TABLE 4

Factor Analysis Results Using Alpha Factor and Varimax Rotation

COLLECTION/PROCESSING

Factor	Eigenvalue	% of Variation	Cum %
(1) Capacity	5.40417	45	45
(2) Topographical/ Environmental/ Health	2.37856	19.8	64.8
(3) Sludge Handling	1.23782	10.3	75.1
(4) Process Train	1.1348	9.5	84.6

DISTRIBUTION/IRRIGATION

Factor	Eigenvalue	% of Variation	Cum %
(1) Hydraulic Head	3.2269	41.5	41.5
(2) Capacity	2.07713	26	67.5
(3) Conveyance Distance	1.30007	16.3	83.7

TABLE 5

ESTIMATED RELATIONSHIPS

(t statistics in brackets)

TAL ENERGY = -290 + 1107 [2]RATED CAPACITY R² = .638
[8.76]*

TAL ENERGY = 981 + 1787 [3]INFLOW R² = .825
[8.69]*

TAL COST = 6,054,325 + 572 TOTAL ENERGY R² = .462
[3.7]*

& M = 312,454 + 43,584 RATED CAPACITY R² = .638
[5.0]*

TAL ENERGY = -2178 + 5.283 [6]TOTAL HORSEPOWER R² = .549
[3.1]*

& M = 107,607 + 209,357 INFLOW R² = .868

TAL COST = 5,348,907 + 1,348,060 INFLOW R² = .663
[5.6]*

TAL COST = 4,562,976 + 811,796 RATED CAPACITY R² = .635
[5.1]*

Significant at the .005 level.

Millions of British Thermal Units
Units of Million Gallons per Day
Units of Million Gallons per Day
November 1978 Dollars
November 1978 Dollars
Units of One Horsepower

TABLE 6

Distribution of Annual Average Operations & Maintenance Cost per MGD Flow by Type of Sludge Disposal

Average O&M Cost

Disposal Type	Low ($3,300)																	High ($1,726,000)
Incineration																	X	
Land Fill								X										
Land Reclamation				X		X							X		X	X		X
Soil Conditioner		X	X								X	X						
Other	X				X		X		X	X				X				

Each entry represents one system's placement in the low to high range.

****

TABLE 7

Distribution of Annual Average Operations & Maintenance Cost per MGD Flow by Type of Sludge Process

Average O&M Cost

Process Type	Low ($3,300)																	High ($1,726,000)
Sand Beds	X		X	X	X				X		X	X	X		X	X		X
Lagoons						X		X										
Vacuums																	X	
Centrifuge										X								
Other		X					X							X				

Each entry represents one system's placement in the low to high range.

TABLE 5

ESTIMATED RELATIONSHIPS

(t statistics in brackets)

[1]TOTAL ENERGY = -290 + 1107 [2]RATED CAPACITY
[8.76]* R^2 = .638

TOTAL ENERGY = 981 + 1787 [3]INFLOW
[8.69]* R^2 = .825

[4]TOTAL COST = 6,054,325 + 572 TOTAL ENERGY
[3.7]* R^2 = .462

[5]O & M = 312,454 + 43,584 RATED CAPACITY
[5.0]* R^2 = .638

TOTAL ENERGY = -2178 + 5.283 [6]TOTAL HORSEPOWER
[3.1]* R^2 = .549

O & M = 107,607 + 209,357 INFLOW
R^2 = .868

TOTAL COST = 5,348,907 + 1,348,060 INFLOW
[5.6]* R^2 = .663

TOTAL COST = 4,562,976 + 811,796 RATED CAPACITY
[5.1]* R^2 = .635

* Significant at the .005 level.

[1] In Millions of British Thermal Units
[2] In Units of Million Gallons per Day
[3] In Units of Million Gallons per Day
[4] In November 1978 Dollars
[5] In November 1978 Dollars
[6] In Units of One Horsepower

TABLE 6

Distribution of Annual Average Operations & Maintenance Cost per MGD Flow by Type of Sludge Disposal

Disposal Type	Low ($3,300)									Average O&M Cost								High ($1,726,000)
Incineration																	X	
Land Fill								X										
Land Reclamation				X		X							X		X	X		X
Soil Conditioner		X	X								X	X						
Other	X				X		X		X	X				X				

Each entry represents one system's placement in the low to high range.

****

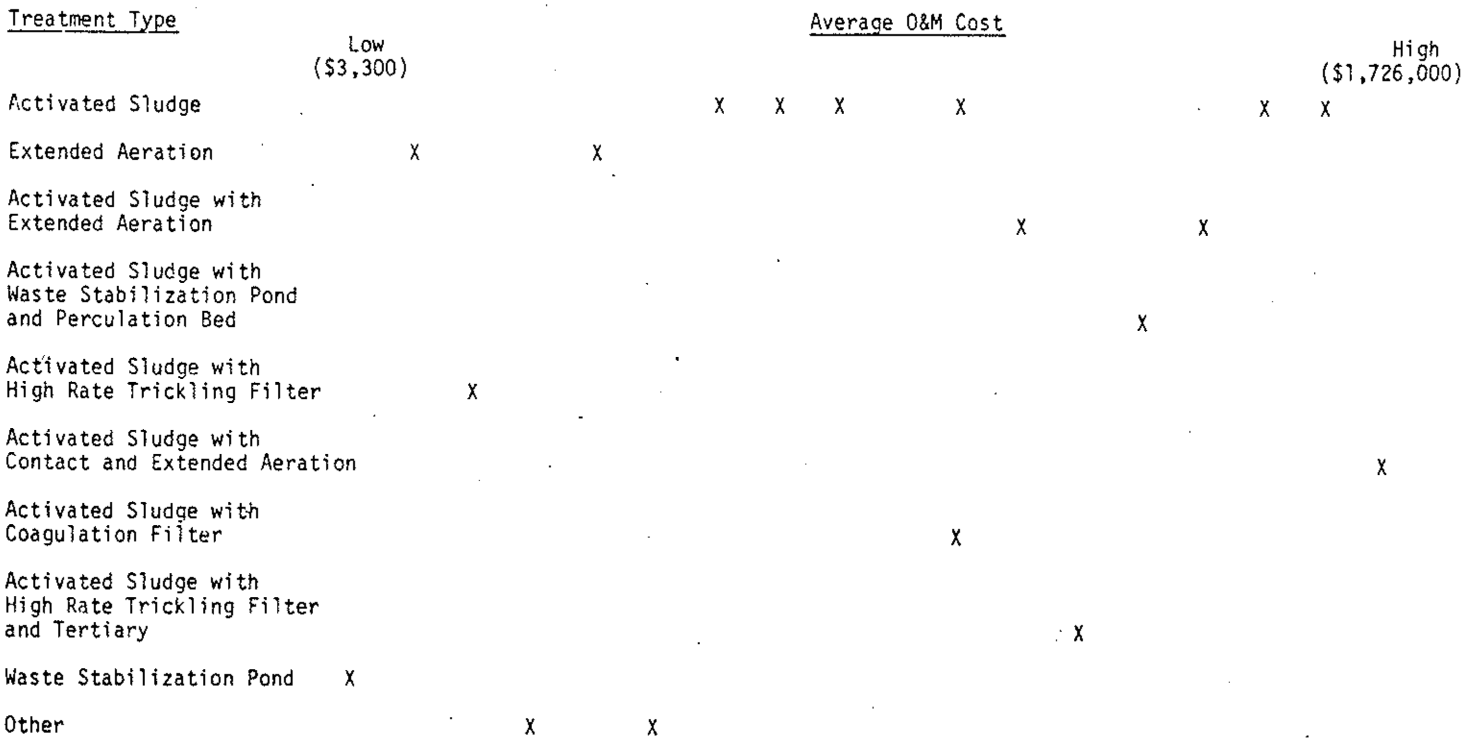
TABLE 7

Distribution of Annual Average Operations & Maintenance Cost per MGD Flow by Type of Sludge Process

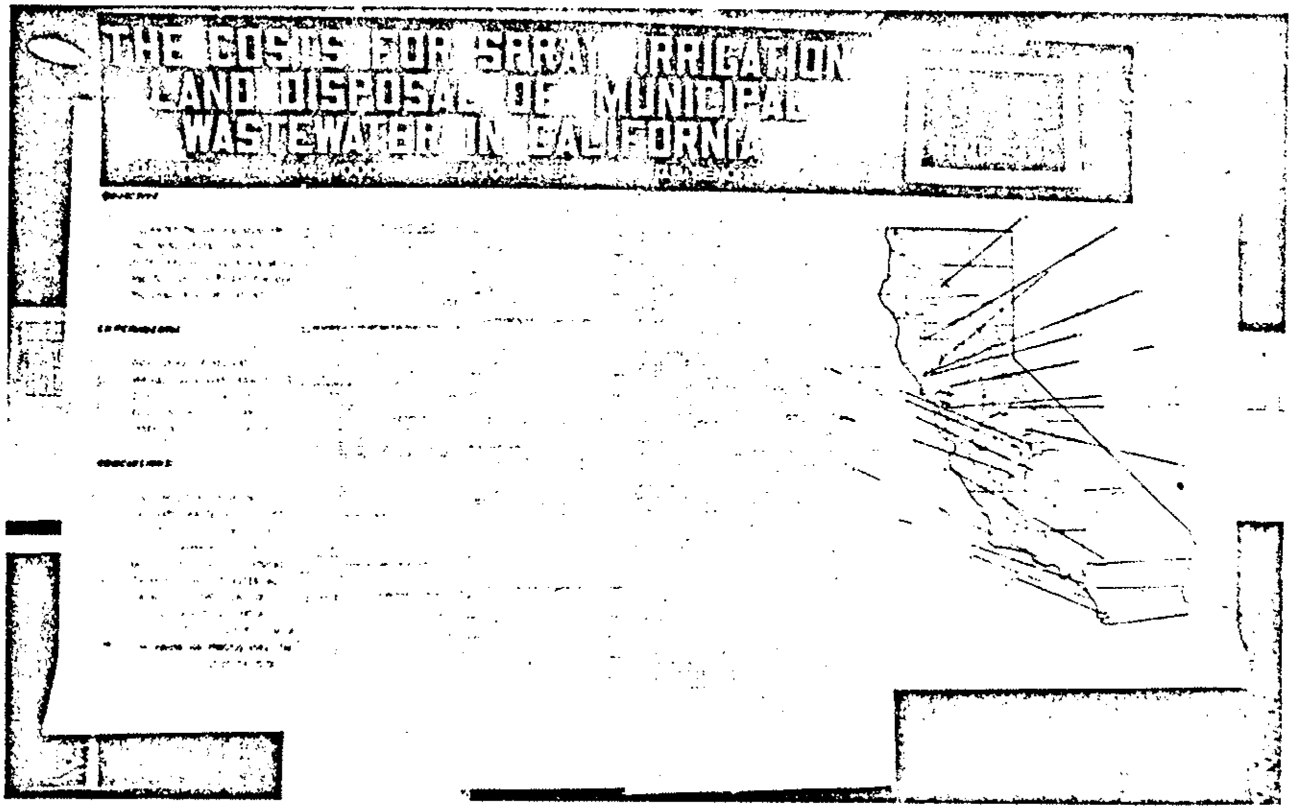
Process Type	Low ($3,300)									Average O&M Cost								High ($1,726,000)
Sand Beds	X		X	X	X				X		X	X	X		X	X		X
Lagoons						X		X										
Vacuums																	X	
Centrifuge										X								
Other		X					X							X				

Each entry represents one system's placement in the low to high range.

Distribution of Annual Average Operations & Maintenance Cost per MGD Flow by Type of Treatment System



Each entry represents one system's placement in the low to high range.



THE COSTS FOR SPRAY IRRIGATION LAND DISPOSAL OF MUNICIPAL WASTEWATER IN CALIFORNIA