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DEVELOPMENT OF A DYNAMIC PROGRAMMING MODEL FOR THE REGIONALIZATION AND STAGING OF WASTEWATER TREATMENT PLANTS

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

INTRODUCTION

Many cities and industries are faced with the problem of planning wastewater treatment for a growing society. The 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500) have made the job more difficult by requiring that the publically owned treatment works meet effluent standards equivalent to secondary treatment by July 1, 1977. Application of the best practical technology is required by July 1, 1983. These higher effluent standards will necessitate the expansion and upgrading of many existing wastewater treatment plants. Large capital investments will be required for new plants to be built to meet both the required hydraulic capacity and the required effluent standards.

In the early 1970's it was estimated that $15 billion would be spent on capital expansion of the United States municipal wastewater treatment systems (Wanielista and Bauer, 1972). Poor planning can result in the construction of an unnecessarily expensive, non-optimal, system. The rapidly increasing costs of construction, the increasing complexity of the treatment processes, and the limited availability of capital for investment has focused attention on the need for better planning of wastewater treatment systems.

In many urban areas there are several treatment plants which might be phased out to provide for a much larger regional plant with improved economies of scale in both capital and operation and maintenance costs. The construction and operation of small, randomly placed, wastewater treatment plants is generally accepted as being inefficient and expensive. Also in a large plant, operators are generally better qualified and the plant itself is large enough to dampen any short term operational problems.

The general purpose of this research is to present some criteria and a method which can be used to evaluate the timing and capacity expansion decisions for wastewater treatment facilities. The term capacity has been taken to mean both the hydraulic capacity and the level of treatment efficiency. The procedure consists of selecting the combinations of treatment plants and treatment levels that best meets the desired objectives at the lowest future discounted cost. The number of alternative combinations increases rapidly as the number of treatment plants and treatment levels increase. The determination of the true optimal alternative would require the examination of an unrealistically large number of possible combinations, however, the number of feasible alternatives tend to be limited by practical economic and design considerations, such as available treatment plant sites, geographical layout, and water quality regulations. Although the term "optimal" is used throughout this report, it should be understood that a best guess and not a true global optimal is being achieved.

Planning for an anticipated, persistent growth in load on treatment systems can be handled by an expansion policy which minimizes the total discounted future costs of a selected number of alternative treatment schemes. This would be considered an optimal staging policy. This policy quantifies the opposing effects of the economies of scale and the discount rate on the cost of construction and the cost of operation, maintenance, and replacement of a project over time. Although there are many other facets to be considered in project development in addition to economics, it is a fundamental part of engineering design and analysis, and it cannot be overlooked.

Among the factors affecting the staging policy are: (1) Quantity and quality of wastewater and its change with time; (2) the rate of interest and the rate of inflation; (3) the capital and the operation, maintenance, and replacement costs; (4) the treatment efficiencies; (5) the economies of scale; (6) the excess capacity; and (7) the service life.

Many types of engineering systems have been analyzed by the use of system analysis. These methods have been applied in recent years to the design and analysis of wastewater treatment systems and processes. The use of a mathematical computer model is often the only way to quantify the specific interrelationships of real life problems. With a model it is possible to abstract the economic and technical relationships from the many complexities involved in the planning processes, and to provide an insight into the planning decisions. However, a model does not take the place of a detailed analysis of the problem, but rather allows the analysis of many more alternatives than normally feasible. The validity of a model depends upon the validity of the input data and of the assumptions used to prepare the model. A properly designed model can make both a technical and an economic evaluation of available alternatives.

The destination of the effluents from most treatment plants is into a stream or lake. Depending upon the location, quantity, and quality of this effluent discharged, the receiving body of water may or may not be able to assimilate the residual pollution content. In some cases, there may be a savings incurred by using the assimilative capacity of the receiving body of water to meet stream standards rather than using a treatment plant to meet effluent standards. The optimization model of this study provides the economic effects of various timing and capacity expansion decisions necessary to meet different effluent quality standards.

The purpose of this research was to develop an economic decision model to be used as a management and planning tool by regional and local planners for the sequential expansion, upgrading, and regionalization of wastewater treatment plants at a minimum total discounted future cost. The analysis included the projected populations, wastewater quality and quantity, treatment efficiency requirements, interest rates, inflation rates, construction costs, operation, maintenance, and replacement costs, economies of scale, excess capacity, and service life. An analysis of the wastewater treatment needs of the Lower Jordan River region of Salt Lake and Davis Counties in Utah was made with the model using the available data. These results were subjected to a sensitivity analysis of the input parameters.

LITERATURE REVIEW

Review of Optimization Models

There are a variety of mathematical modeling techniques that have been used to find the least cost combination of wastewater treatment facilities in a river basin. Models have also been used to design the combinations of unit processes in an individual treatment plant to achieve desired treatment efficiencies at a minimum cost. This is a brief survey of the types of modeling techniques in current use and the application of some of these techniques to the optimization of wastewater treatment systems. The survey is in no way complete, but rather provides direction to the formulation of this problem.

Linear programming

Several programming techniques have come into common use in the last two decades. The most common of these is linear programming which is used to solve a set of linear equations (Dantzig, 1963; Hadley, 1962a). This method is able to handle large numbers of variables and constraints and obtain a global optimum as long as the system can be described by linear functions. However, water resources systems and wastewater treatment systems generally have concave or other nonlinear forms of cost equations. This is due to economies of scale or discontinuities of the equations. The use of separable programming methods to break the cost equations into linear segments has been used successfully, but increases the computation time in proportion to the number of linear segments used to represent the original equations.

Nonlinear programming

Nonlinear programming has been used to more accurately represent the cost functions (Hall and Dracup, 1970; Hadley, 1962b; Kuhn and Tucker, 1950). Several forms have been developed based on differential calculus methods and gradient search procedures. Although the gradient method is very powerful, it is difficult to use for routine analysis.

Dynamic programming

Dynamic programming was developed for dealing with sequential-decision processes. It is based on Bellman's Principle of Optimality (Bellman and Dryfus, 1962), which states that "an optimal policy has the property that, whatever the initial state, and initial decision are, the remaining decisions must constitute an optimal policy with respect to the state resulting from the first decision." It is not restricted by any requirements of linearity, convexity, or even continuity (Bellman and Dryfus, 1962; Hall and Dracup, 1970; and Hadley, 1962b). While linear programming has a standard formulation of equations and a standard computer solution package, dynamic programming only provides a general systematic procedure for the determination of the optimal decisions. A particular set of equations must be developed for each individual application. Dynamic programming is well suited for many water resources problems because they possess definite sequential-decision characteristics both in time and space or location. A shortcoming of dynamic programming is the need to keep the dimensionality of the decision variables as small as possible, preferably less than two, to keep the computation time to a reasonable limit. Although this will limit the use of dynamic programming in some cases, ingenuity can often find ways of meeting the requirements of the logic and the principles of optimality in full, even though the requirements are not strictly met.

Integer programming

The operational problems of the existing modeling techniques has led to the rapid development of integer programming in the past few years (Balas, 1965; Geoffrion, 1966; Glover, 1965; Gomery, 1963; Haldi and Isaacson, 1962; Hu, 1969; Trauth and Woolsey, 1969; Watters, 1967; and Woolsey, Holcolm, and Ryan, 1969). This method has been applied to problems where the required results are integers, such as the selection of treatment levels. As in linear programming, the original integer programming formulation required the data to be linear. This problem has been overcome by the development of methods where the variables may take on only the value of zero or one, and allows the use of nonlinear equations. This method has been referred to as implicit enumeration technique (Balas, 1965; Geoffrion, 1966; and Glover, 1965). Care must be taken in the selection of the initial conditions for the model to prevent an exhaustive search of all possible alternatives. Proper formulation of this method can make it a useful tool. Other types of optimization modeling methods are available but they are not in common use in the water resources and wastewater treatment systems.

Decomposition methods

Many of the systems that have been modeled are too large and too complex for direct optimization. Decomposition and multi-level approaches have been developed that permit the use of the different programming methods to solve parts of a model prior to optimizing the entire model (Dantzig and Wolfe, 1961; Haimes, 1971; Haimes, 1972a; Haimes, 1972b; and Haimes, Kaplan, and Husar, 1972). The concept of the multi-level approach is based on the decomposition of large scale and complex systems and the subsequent modeling of the systems into independent subsystems. The decomposition may be of several types such as: (1) Geographical-political base decomposition (e.g. cities, counties, collection areas, etc.), (2) time base decomposition (e.g. hours, days, weeks, months, years, etc.), (3) model base decomposition (e.g. optimization, simulation, etc.), or (4) decision base decomposition (e.g. automatic computer control, manual policy control, etc.). Each subsystem can be optimized separately and independently using whatever modeling technique is most appropriate. This is called a first level solution. The subsystems are then joined together by coupling variables and manipulated by a second level controllers in order to obtain an optimal solution for the entire system. A third level may consist of the policy making body which establishes the constraints or standards to be obtained. Each type of problem must be analyzed to select the best method of decomposition and the levels to be used.

Applications of models

The above described modeling techniques have been applied to both water and wastewater treatment systems by a number of investigators (Table 1). The basic objectives and methods used are discussed in the following section. While these examples by no means include all the work that has been done, they are indicative of the approaches that have been applied to data to minimize the cost of water resources, water treatment, and wastewater treatment systems.

There are several factors that may be considered in the optimization of a treatment system. When the design objectives are defined in terms of a least cost approach, some cost minimization parameters are required. These may be hydraulic treatment capacity and treatment levels. Evenson, Orlob, and Monser (1969) defined some of the typical parameters to be considered in the determination of treatment levels. They are biochemical oxygen demand, BOD; chemical oxygen demand, COD; suspended solids, SS; nutrient removal; and solids treatment. This is only a partial list of the possible parameters that are subject to regulation and removal. While it is desirable to minimize the cost with respect to all of these, the problem becomes very complex. Therefore, BOD is commonly chosen as the main parameter.

Lynn, Logan, and Charnes (1962) were among the first to apply the echniques of system analysis to the design and analysis of wastewater treatment systems or processes. Linear programming was used to find the combinations of unit processes that would least expensively remove a given amount of BOD. This method was restrictive in that the constraints had to be linear or combinations of linear segments.

A further application of system analysis was made by Lynn (1964) using linear programming to determine the stage development of wastewater treatment systems over time. The objective of this stage development solution was to minimize the treatment cost throughout the history of the project. Population growth, treatment requirements, availability and cost of borrowed funds, and other investment opportunities were considered for each time increment. The solution for this problem indicated the type and increment of treatment to be constructed, the amount of funds available, the amount of funds needed to be borrowed, a per capita service charge, and the schedule for investment of funds, for each increment of time.

Deininger and Su (1973) applied a linear programming formulation using Murty's (1968) ranking extreme point approach to obtain an optimal solution to a planning problem involving a number of communities and/or industries in a geographical area. The following questions were considered: Where should treatment plants be built, how many, at what time, and which intercepting sewers are necessary to connect the municipalities and industries to these plants, such that the total cost of wastewater collection and treatment is a minimum?

Marsden, Pingry, and Whinston (1972) applied the production theory to determine the optimal design of waste treatment facilities. The production function, in economic theory, is a mathematical statement relating quantitatively the purely technological relationships between the output of a process and the inputs of the factors of production. The inputs were divided into groups of similar cost characteristics and a nonlinear programming model was formulated to find the minimum BOD level possible under any possible combinations of inputs. The use of the production function compacted the system through the elimination of nonoptimal alternatives, and allowed a simplification of the model.

Table 1. Applications of optimization models.

Programming Method	Purpose of Optimization	References
Linear	Least cost combination of unit processes to remove a given amount of BOD	Lynn, Logan, and Charnes (1962)
Linear	Stage development over time of wastewater treatment systems	Lynn (1964)
Linear	Least cost of wastewater collection and treatment and staging of construction for a region	Deininger and Su (1973)
Nonlinear	Least cost combination of inputs to production function to remove BOD	Marsden, Pingry, and Whinston (1972)
Nonlinear	Least cost regional wastewater planning	Young and Pisano (1970)
Dynamic	Sequential capacity expansion of plants	Kirby (1971)
Dynamic	Multistage capacity expansion of water treatment systems	Hinomoto (1972)
Dynamic	Least cost combinations of unit processes to remove a given amount of BOD	Evenson, Orlob, and Monser (1969)
Dynamic	Serial multistage system of industrial waste treatment for BOD	Shih and Krishnan (1969)
Dynamic	Minimum total annual cost to meet given treatment requirements	Shih and DeFilippi (1970)
Dynamic	Sequencing of water supply projects to meet capacity requirements over time	Butcher, Haimes, and Hall (1969)
Approximate & Incomplete Dynamic	Capacity expansion of large multi-location wastewater treatment systems	Erlenkotter (1973)
Integer	Location and size of wastewater treatment plants and trunk sewers	Wanielista and Bauer (1972)
Integer	Least cost selection of treatment levels to meet river quality standards using zones of uniform treatment level	Liebman and Marks (1968)
Nonlinear Decomposition & Multilevel Approach	Minimization of overall regional treatment costs to meet desired river quality standards. Determination of effluent charge pricing level	Haimes (1971) Haimes (1972a) Haimes (1972b) Haimes, Kaplan, and Husar (1972)

Young and Pisano (1970) demonstrated the use of nonlinear programming to find the least cost mix of alternatives to satisfy future water demands in a region. The model considered surface water, well water, water reclaimed by electrodialysis and desalination, and water recycled from wastewater. A network of pipelines was developed to transport the waters between sources and destinations. Optimizing the network required that the relative cost of supplying water by each alternative and its concomitant transmission costs be identified for each level of projection and that the minimum cost solution be selected. The nonlinear programming method used to find the minimum was a long step gradient method called the method of feasible direction.

Kirby (1971) considered an optimal sequential capacity expansion model using a dynamic programming algorithm which treats an n-expansion problem of 2n decision variables as an n-stage decision process. It was assumed that: Capacity expansion was step function, plants had an infinite life, there was no lead time for construction, and economies of scale exist for plant investment costs. The optimal policy was found to be one in which the expansions are of equal size. Since the reliability of demand forecasts decrease with the length of the planning interval, it should be used parametrically. Their results also indicated that if short term forecasts are reliable, good estimates can be made for the optimal size of the first plant expansion.

Hinomoto (1972) applied dynamic programming methods for the multi-stage capacity expansion of a municipal water treatment system. This model determined the sizes of new treatment plants and the times that the new plants are added to the system.

Both the capital and operating costs of these plants are given by concave functions reflecting economies of scale available with an increase in capacity. The optimal solution was determined by minimizing the discounted present value of the capital and operating costs associated with new plants added to the system and the permanent chains of their successors.

Evenson, Orlob, and Monser (1969) developed a technique for the determination of the best in-plant treatment system using dynamic programming. Their objective was to find the least costly combination of treatment components to remove a specific amount of BOD. Sensitivity testing was used to determine how sensitive the minimum cost solution was to the assumed economic parameters, how the choice of unit processes is influenced by the changes in the economic parameters, and what the difference in cost between the least-costly and the next most attractive choice.

Shih and Krishnan (1969) presented an application of dynamic programming for the system optimization of an industrial wastewater treatment design. A decision inversion method for two-point boundary value was utilized for the optimization procedure of the serial multi-stage system. The model identified the optimum combinations and efficiencies of the various unit processes in a multi-stage treatment plant meeting the ultimate design requirements. BOD was used as the optimization parameter.

Shih and DeFilippi (1970) used dynamic programming to identify the optimum combinations and efficiencies of various unit processes in a multi-stage wastewater treatment plant. The model identifies the least cost unit processes which are required to meet design criteria. The decision inversion method was used because the two boundary conditions, effluent and influent quality, were fixed. The method allowed the optimum design of the entire plant as a unit rather than designing each unit process individually.

Butcher, Haimes, and Hall (1969) applied dynamic programming to determine the optimal sequencing of water supply projects. The model related the effects of the economies of scale of construction to determine the series of plants that would need to be built to meet water needs over time at a minimum cost.

Erlenkotter (1973) developed a model for capacity expansion planning of large multi-location systems using approximate and incomplete dynamic programming approaches. The model was applied to a production industry with linearly increasing demands, variable operating and distribution costs, and economies of scale in capacity expansion costs. The optimum solution was determined by minimizing the total discounted costs for investment, operation, and distribution.

Wanielista and Bauer (1972) applied an integer programming algorithm to plan the location and size of wastewater treatment plants and trunk sewers in a river basin. A network was developed with all practical connections made by interceptor sewers between one existing or proposed treatment plant and another. The optimum alternative was determined by the minimization of the present value of the initial construction costs and the sum of the discounted future costs of the first year operation, replacement, and maintenance costs over a 20 year planning period. The system component cost curves were taken to be piecewise linear approximations.

Liebman and Marks (1968) applied Balas algorithm of the integer programming formulation to provide the desired river quality at the least overall cost to the region. However, zones of uniform treatment were defined such that one contributor did not have to pay more than his share of the treatment costs. A linear input-output model was defined by dividing the stream into homogeneous sections. Using the physical parameters of flow, reaeration rate, decay rate, and diffusion rate, a matrix was constructed which showed the change in water quality in any section due to unit change in waste input at some point. Although the quality can be measured in any parameter, dissolved oxygen was used by this model. A cost-minimization solution was obtained by integrating location and unit cost of removal of waste to obtain overall least cost. The solution for this problem was essentially found by direct enumeration of all possible combinations, except that a partial solution is abandoned if a higher cost is indicated. By proper selection of initial conditions, it was found possible to minimize the computation time required for the model.

Haimes (1971) applied the multi-level approach to develop a general mathematical model to represent a system of treatment plants discharging the pollution effluent directly into the river. The water quality was represented by several variables such as BOD, DO, pH, conductivity, temperature, algae, phosphates, or nitrates. The system was decomposed into several reaches, and an overall cost function for treatment was determined. Each treatment plant or pollution source sub-optimizes its cost between its own treatment costs, costs to treat at a regional plant, and an effluent charge for direct discharge of various qualities of effluent. The regional authority, or second level controller imposes a price, represented by a Lagrange Multiplier, on the subsystems as an effluent charge. The objective is to minimize the cost of the overall system. Similar formulations were also presented in other papers (Haimes, 1972a; Haimes, 1972b; and Haimes, Kaplan, and Husar, 1972). These contained variations of the approach applied to a number of modeling problems.

Review of Capacity Expansion Models

A basis for the optimal staging for expansions or replacements of wastewater treatment plants and sewerage transportation systems is found in the "Optimum Overcapacity" principles developed by Chenery (1952) for the expansion of production facilities. An optimum relationship was developed between excess capacity and load or output that was a function of the economy of scale, the discount or interest rate, the planning period, and the rate of increasing demand when a production function and a forecast of load over time had been established. The plan that minimized the discounted total costs was the optimum plan. Excess capacity was defined as the amount of possible production exceeding the present load.

Mathematical formulations of Chenery's work in terms of optimum excess capacity has been prepared by Manne (1961). He developed the basic data for a model and utilized it to establish the design criteria for the optimum excess capacity.

Rachford, Scarto, and Tchobanoglous (1969) applied the model developed by Manne to wastewater collection and treatment systems with the objective of determining the capacity expansion policy which would best meet the demand at all times at a minimum cost. The following conditions were required by the models:

1) Deterministic, linearly increasing quantity of wastewater
2) Economies of scale, constant over time
3) Income structure a linear function of quantity of wastewater
4) Continuous discount factor
5) Infinite penalty costs
6) Interest rates reflect the true cost of money
7) An infinite time period

The theory of the model is that a design capacity can be determined that will provide the minimum present worth of all discounted future costs. The application of this model is shown in Figure 1 where x units of capacity are added whenever load or quantity of wastewater equals existing capacity, and where D represents the rate of increase of load during time period t. The total load is projected linearly with respect to time and the installed capacity is shown as a step function with equal time intervals and capacity expansions.

The construction cost for a single capacity increment of size X at the present time is given by the concave cost function:

$$C(X) = k\,(X)^{\alpha} \quad (k > 0; 0 < \alpha < 1) \; . \; . \; . \quad (1)$$

in which

$C(X)$ = present cost
k = cost coefficient
X = increment of size, Dt
α = economies of scale

The present worth of adding Dt units of capacity over an infinite number of periods of equal time t is given by

$$C(dt) = \frac{k(Dt)^{\alpha}}{1 - e^{-rt}} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

in which

$C(Dt)$ = present worth of discounted future costs
r = discount factor or interest rate
t = time period between additions, yr

The present worth, C(Dt), is minimized by taking the logarithms of both sides of Equation 2, differentiating and setting the results equal to zero. The minimum value of C(Dt) can be determined for differing conditions defined by the right hand side of Equation 2.

$$\frac{d}{dt}\,[\log C(Dt)] = \frac{\alpha}{Dt} - \frac{r\,e^{-rt}}{1 - e^{-rt}} = 0 \quad . \; . \quad (3)$$

Hereafter, optimal values of t and C(Dt) are denoted by the use of an asterisk as a superscript. Equation 3 was solved for the optimal time phasing, t*, to find the minimum cost capacity expansion program. It was assumed that t* is independent of D and is governed by α and r alone (Singh and Lonnquist, 1972). By varying the values of α, r, and t* in Equation 4, the relationships shown in Figure 2 were developed.

$$t^* = \frac{\mathrm{Ln}\left[\dfrac{t^* r}{\alpha} + 1\right]}{r} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

in which

t^* = optimum design period, yr
r = annual interest rate
α = economies of scale

Rachford, Scarto, and Tchobanoglous (1969) point out that increasing the economies of scale, indicated by decreasing the value of α, will result in an increased plant size to achieve optimality, while increasing the interest rate decreases the optimum time, t*, and size, Dt*.

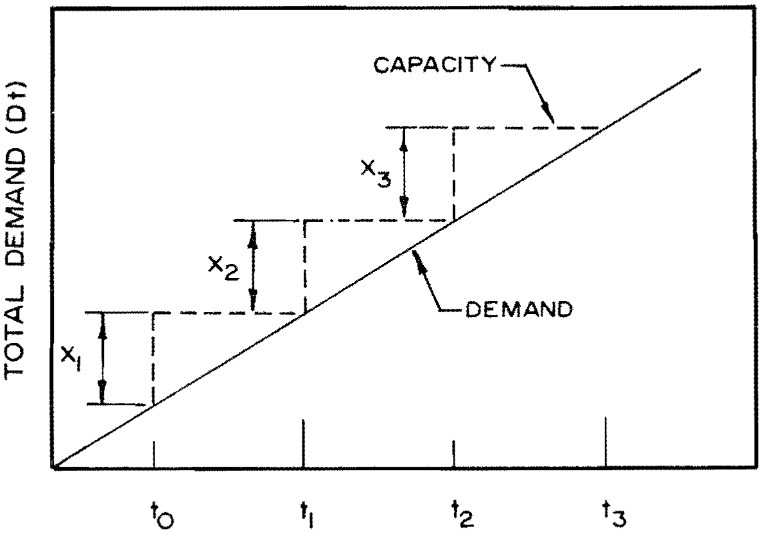


Figure 1. Time growth of demand and installed capacity (after Rachford, Scarto, and Tchobanoglous, 1969).

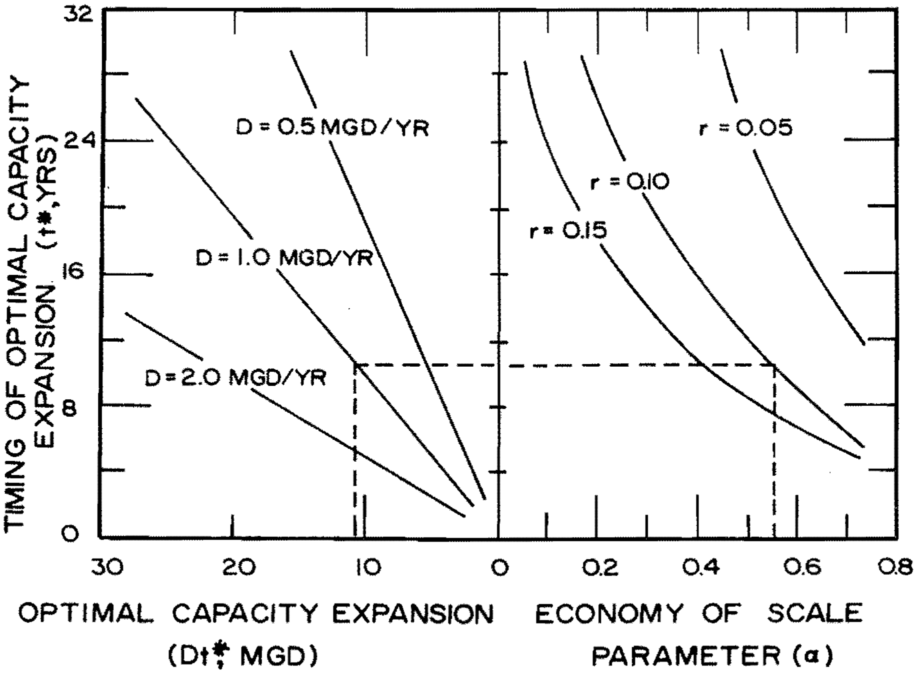


Figure 2. Optimal time-capacity expansion (after Rachford, Scarto, and Tchobanoglous, 1969).

The basic equation for concave costs given in Equation 1 is not an accurate representation for all costs found in a wastewater treatment plant according to the data established by Smith (1968). There are several different forms of equations representing the construction cost of the various components of a wastewater treatment plant. Each is a function of the design parameters of that component. Rachford, Scarto, and Tchobanoglous (1969) derived optimum capacity expansion equations for each of these cost equations (Table 2).

Table 2. Optimum capacity-expansion models (after Rachford, Scarto, and Tchobanoglous, 1969).[a]

Number	Equation Type	Derived Result
1	$C(x) = k(x)^{a}$	$a = \frac{rx}{e^{rt} - 1}$
2	$C(x) = a + kx^{a}$	$a = \frac{2rx}{e^{rt} - 1}$
3	$C(x) = ax + kx^{a}$	$a = \frac{2rx}{e^{rt} - 1} - 1$
4	$C(x) = a + bx + kx^{a}$	$a = \frac{3rx}{e^{rt} - 1} - 1$

[a] $x = Dt$.

These equations do not affect the basic principles behind the capacity expansion model. The curves shown in Figure 2 are valid only for Equation 1 in Table 2, however, similar cost curves can be developed for each equation. The use of an optimum capacity expansion model requires that current reliable cost data be used to make the model valid.

The optimal cost function, C(Dt*), provides further insight into the effects of the optimization of capacity expansion. The cost ratio, C(Dt*)/k, for various optimal times and a given set of parameters, a and r is shown in Figure 3. The flat curves shown in Figure 3 indicate the relative insensitivity of the cost ratio to changes in the decision variable, t*. This indicates that even a very substantial error in the forecasting parameters may not lead to an extremely bad choice of capacity increment. As the cost of capital is increased the total costs do become more sensitive to the capacity increment.

This type of analysis can be used to determine the capacity expansion policy of the entire treatment plant or of the individual unit processes. The cost function for the entire facility is the weighted average of the unit component costs, each of which are unique.

Other types of demand functions are possible other than the linear form required by Rachford. Manne (1961) assumed that no backlogs were possible, or that the cost of not treating all the

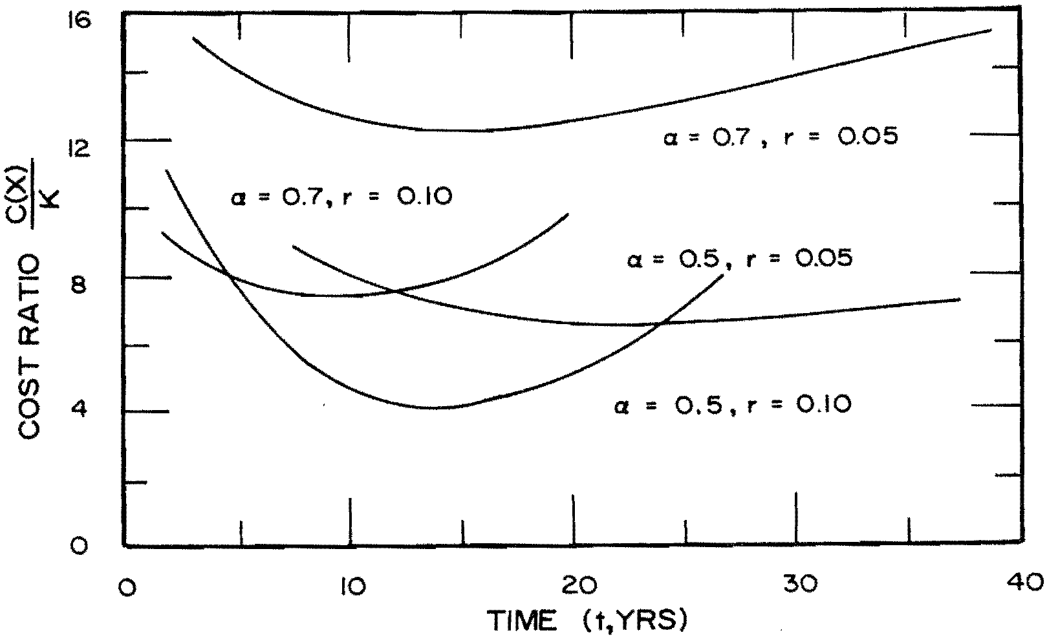


Figure 3. Discounted cost ratio (after Rachford, Scarto, and Tchobanoglous, 1969).

wastewater was infinite, and applied a probabilistic growth of demand. He found that the optimal level required a higher expected discounted cost and also the installation of somewhat larger increments of plant capacity than would have been required for a linear growth equal to the expected value of the probablistic growth.

Srinivasan and Manne (1967) considered the case of a constant geometric growth rate of demand. The optimal increment of capacity was found to be geometrically proportional to time and required the installation at equally spaced time points. The more general case of arbitrarily increasing demand has been considered by Veinott and Manne (1967).

MODEL THEORY

The determination of the optimal combination of treatment plants, treatment levels, and trunk sewers over a planning horizon that is experiencing increasing rates of interest and inflation is best handled by the use of a dynamic programming model. This method is well suited for problems that involve sequential decisions, but is limited when more than two decision variables are used. Normally, a problem of such a large scale as the optimization of treatment systems would not be amenable to dynamic programming; however, in this case a special decomposition procedure was developed. The entire optimization problem was decomposed into sub-optimizations of each of the alternative treatment systems for each year to produce a single cost parameter for each alternative that could be used to optimize the entire system. Since the costs in question will be incurred at a variety of different times in the future, the term cost refers to the sum of equivalent present, or discounted, values of the future costs of building, expanding, or upgrading the treatment plants and trunk sewers, and the costs of the operation and maintenance of the entire system.

The discussion of the model is presented in three steps. The first of these is the generalized overview of the model as presented in Figure 4. Following this is the mathematical formulations of the input data and the sub-optimization steps of one alternative, shown as subheadings in Figure 4. The concluding portion is a discussion of the optimization of the model through dynamic programming.

Generalized Approach to Problem

A brief overview of the entire model can be represented by several generalized concepts shown in Figure 4. The initial state of the system is represented by the capacity, capital debt, and treatment level of the wastewater treatment plants, and the capacity, capital debt, slope, and length of the proposed and existing trunk sewers between the treatment plants. Since the model estimates the state of the system at various points in time, the effect of time on the interest rates, capital recovery factors, and cost indexes must be estimated. The projected wastewater loads on the treatment plants are determined from the population projections using a per capita wastewater production multiplied by a peak flow factor. This wastewater is transported by trunk sewer to another plant if the chosen alternative treatment scheme requires that its intended plant be closed.

All alternative treatment systems (consisting of treatment plants, treatment levels, and trunk sewers) to be considered by the model are specifically designated by the user. This is accomplished by means of 0-1 integer matrix system indicating which treatment plants and trunk sewers used for each alternative. The designation of any given alternative does not change the fact that the existing system of the previous year still has its capacity and debt.

The sub-optimization of a treatment alternative provides the least cost system that will meet the required loads on the treatment system in terms of quantity and quality. Since there is a lag in time between the decision to build a treatment plant or trunk sewer and the actual completion, it was necessary to compare existing capacity with the projected flows at a time in the future equivalent to the construction lag time. When the required capacity or treatment level exceeds the existing conditions, the treatment plant or trunk sewer is expanded. For treatment plants, a design index was developed to indicate changes in the level of treatment between the existing and the proposed treatment plant. This information was necessary for both the cost equations and design period calculations.

The design period for both the treatment plants and trunk sewers was based on determining the optimum amount of excess capacity that a facility must have to minimize total future discounted costs. The quantity of capacity addition was determined by multiplying the design period times the projected annual increase in quantity of wastewater to be handled.

The cost of building, expanding, or upgrading the treatment plants and trunk sewers was determined using the appropriate cost equations. These costs were added to the capital debt and an annual capital repayment was calculated on the basis of the previous years debt. The capital debt remaining was reduced by this amount. The annual operation and

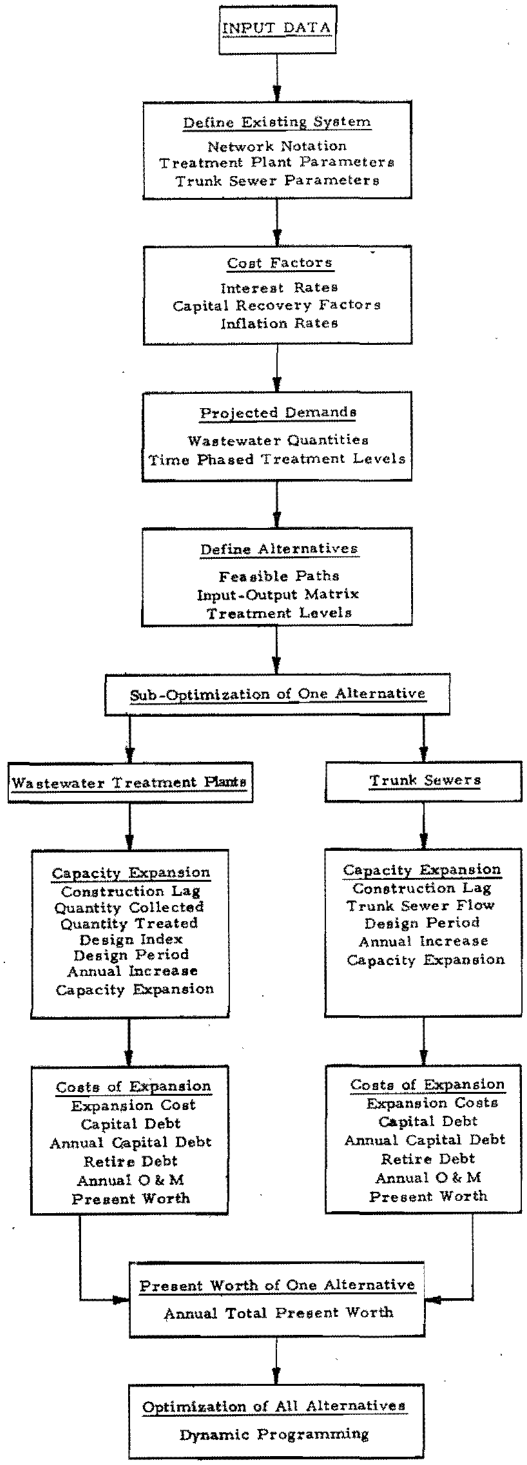


Figure 4. Generalized flow chart of optimization model.

maintenance costs were determined on the basis of the current flows. The total annual costs were determined for each plant and sewer, and these were converted to present worth values at the base year of the study. The total present worth of this alternative was now available for use in the optimization process of the dynamic programming model.

The value of the present worth of each alternative provides a single decision variable that can be used by the dynamic programming model. The details of this model will be discussed in detail in a later section.

Mathematical Formulations

The need for uniformity of notation dictated the use of the following subscripts:

i = source of input to node
j = wastewater treatment plant node
k = destination of output from node
ℓ = year of analysis
m = alternative treatment scheme

and control parameters:

J = number of wastewater treatment plants
L = number of planning years
M = number of alternatives being analyzed

Generalized network notation

The model notation was based on the Kirchoff Node Law (Lynn, Logan, and Charnes, 1962) as shown in Figure 5. The basic principle is that whatever flows into the node also flows out. The general statement which describes the node condition is

$$\text{Input} - \text{Output} = 0 \quad \ldots\ldots\ldots\ (5)$$

It is possible to have any number of inputs but the wastewater treatment plant is limited to one output. This fact does not change whether it is discharging treated effluent or acting as a collection point for transmission to another treatment facility.

Treatment plant parameters

The existing capacity, capital debt, and treatment level of each treatment plant is required to initialize the model.

$CAPP_j$ = capacity of treatment plant j, mgd . (6)

$DEBTP_j$ = capital debt of treatment plant j, mil \$ . . . . (7)

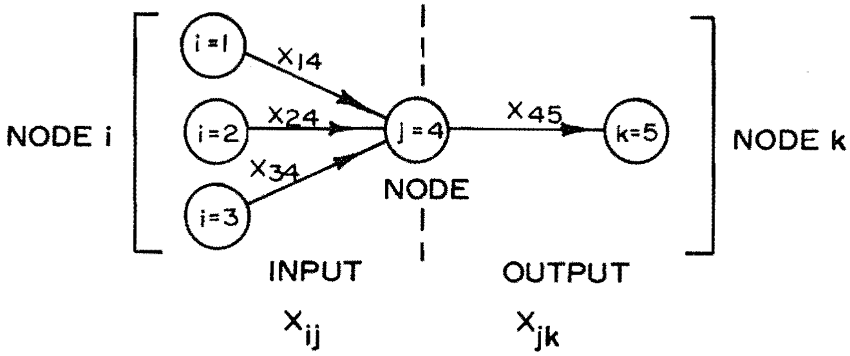


Figure 5. Input and output at a node (after Lynn, Logan, and Charnes, 1962).

$ELEV_j$ = elevation of treatment plant j, ft . . (8)

$LTREAT_j$ = treatment level of plant j . . . . . (9)

in which
$j = 1,2,..,J$

Trunk sewer parameters

The existing capacity, capital debt, slope, and length of each existing or proposed trunk sewer is required to initialize the model.

$CAPS_{jk}$ = capacity of trunk sewer jk, mgd . .(10)

$DEBTS_{jk}$ = capital debt of trunk sewer jk, mil \$.(11)

$DIST_{jk}$ = length of trunk sewer jk, ft. . . . . .(12)

in which
$j = 1,2,..,J$
$k = 1,2,..,J+1$

Interest rates

Interest rates have been showing an upward trend and must be adjusted each year during the planning period.

$$r_\ell = R + ANRATE * \ell \quad . . . . (13)$$

in which
r_ℓ = annual rate of interest in year
R = annual rate of interest in base year
ANRATE = annual increase in the rate of interest
ℓ = planning year, 1,2,..,L

Capital recovery factor

The repayment of capital debts for treatment plants and trunk sewers is a function of the repayment period and the interest rate.

$$CRF_\ell = \frac{r_\ell \, (1.0 + r_\ell)^{PER}}{(1.0 + r_\ell)^{PER} - 1.0} \quad . . . . . (14)$$

in which
CRF_ℓ = capital recovery factor in year ℓ (Note: will be different for plants and sewers)
PER = capital return period (e.g. 20 years for treatment plants and 50 years for trunk sewers)
r_ℓ = annual rate of interest in year ℓ

Inflation rates

Cost indices are a measure of the rate of inflation being experienced by the treatment systems. Capital costs and operation and maintenance costs have different inflation rates. The cost equations have all been adjusted to June 1974.

$$FACTOR_\ell = \frac{(INDEXB + ANFAC * \ell)}{INDEXA} \quad . .(15)$$

in which
$FACTOR_\ell$ = inflation factor in year
INDEXA = index for June 1974 (different for construction and operation and maintenance)
INDEXB = index for base or initial year of study
ANFAC = annual increase in cost index
ℓ = planning year, 1,2,..,L

Wastewater quantities

The quantity of wastewater entering each treatment plant is determined each planning year on the basis of population projections. The per capita wastewater load is based on peak flow needs by multiplying the average flow by a peak flow factor. Population data are required for each plant either in present use or future use. The quantity of wastewater for each plant for each year is given by the following relationship:

$$Q_{j\ell} = POP_{j\ell}\ (GPDCAP)\ (f) \quad . \; . \; . \; . \; . (16)$$

in which

$Q_{j\ell}$ = quantity of wastewater to plant j in year ℓ

$POP_{j\ell}$ = population served by plant j in year ℓ

GPDCAP = gpd/capita of wastewater flow

f = peak flow factor

and:

$j = 1,2,..,J$

$\ell = 1,2,..,L$

Time phased treatment levels

State and federal regulations are establishing minimum effluent standards to be met by all treatment plants. These will be enacted at different points in time and will set the minimum treatment level that will be required by all treatment plants, regardless of the alternative treatment systems being analyzed.

$$QUAL_{\ell} = \text{minimum treatment level required by all treatment plants in year} \quad . \; . (17)$$

in which

$\ell = 1,2,..,L$

Feasible paths

The model is loaded with data for several alternative treatment schemes consisting of various combinations of individual, combined, or regional treatment plants by storing a '1' in memory to indicate which trunk sewers connecting plants will be used and in which direction. These data are used to build a 0-1 integer matrix for each alternative. The output destination node for each treatment plant discharging treated effluent is represented by the number of treatment plants, n, in the system plus 1. Likewise, the input source node for each treatment plant receiving wastewater from the sewerage collection system is set equal to the treatment plant node number, j. The link matrix is defined below.

$$P_{jkm} = \begin{cases} 1 & \text{(feasible path)} \\ 0 & \text{(nonfeasible path)} \end{cases} \quad . \; . \; . \; . \; . (18)$$

in which

P_{jkm} = 0-1 integer feasible path matrix

and

$j = 1,2,..,J$

$k = 1,2,..,J+1$

$m = 1,2,..,M$

Input-output matrices

The input and output matrices are built from the matrix given by Equation 18. The output matrix is set equal to the feasible path matrix since each plant has only one output node.

$$OUT_{jkm} = P_{jkm} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . (19)$$

in which

OUT_{jkm} = output matrix from plant j to destination k for alternative m

P_{jkm} = 0-1 integer feasible path matrix

and

$j = 1,2,..,J \; (j \neq k)$

$k = 1,2,..,J+1$

$m = 1,2,..,M$

The input matrix has to be built by an iteration process since the sewerage from several areas may be transported by trunk sewer to plant j. The input matrix is set equal to the feasible path matrix to establish the initial conditions for the iteration.

$$IN_{ijm} = P_{jkm} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . (20)$$

in which

IN_{ijm} = input matrix from several sources i to plant j for alternative m

P_{jkm} = 0-1 integer feasible path matrix

and:

$i = 1,2,..,J$

$j = 1,2,..,J$

$k = 1,2,..,J$

$m = 1,2,..,M$

The first step of the iteration is to find the output path, k, from node j by finding an integer '1' in the output matrix (Equation 19). By iteration, an integer '1' is entered into the input matrix for each input node, i, that contributes wastewater to plant j.

$$\text{if } OUT_{jkm} = 1, \text{ then } n = k \quad . \; . \; . \; . \; . \; . \; . (21)$$

$$\text{if } IN_{ijm} = 1, \text{ then } IN_{inm} = 1 \quad . \; . \; . \; . \; . \; . (22)$$

in which

OUT_{jkm} = output matrix from plant j to destination k for alternative m

IN_{ijm} = input matrix from several sources i to plant j for alternative m

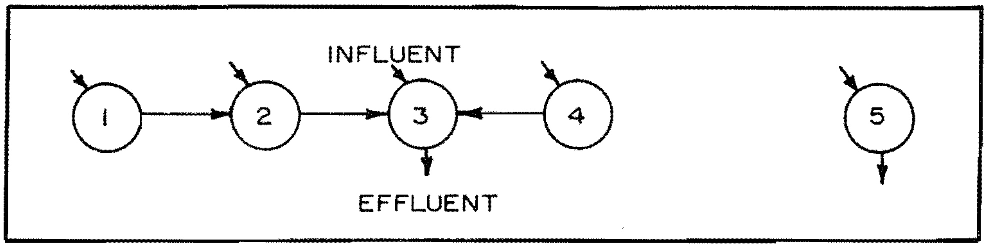


Figure 6. Sample treatment system.

Table 3. Input-output matrix.

ALT m	PLANT j	LEVEL $MTREAT_{jm}$	INPUT					OUTPUT					
			1	2	3	4	5	1	2	3	4	5	6
1	1	0	1	0	0	0	0	0	1	0	0	0	0
1	2	0	1	1	0	0	0	0	0	1	0	0	0
1	3	2	1	1	1	1	0	0	0	0	0	0	1
1	4	0	0	0	0	1	0	0	0	1	0	0	0
1	5	1	0	0	0	0	1	0	0	0	0	0	1

and

i = 1,2,. ,J
j = 1,2,. ,J
k = 1,2,. ,J+1
m = 1,2,. ,M
n = temporary index to indicate which plant j is receiving wastewater

Steps 21 and 22 are repeated for each plant j and then the whole process is repeated again and again until the matrix contains sufficient integer '1' to denote all input which contribute wastewater to each plant j. The number of iterations is equal to 1 less than the longest number of paths to any one plant. This process is repeated for each alternative m. An example of a treatment system and the related input-output matrices are shown in Figure 6 and Table 3.

Treatment levels

Several treatment levels or standard treatment plant schemes will be defined to meet various water quality standards. For each alternative treatment system, each plant has its own required treatment levels. These are entered along with the feasible path data but do not affect the input-output matrices.

$$MTREAT_{jm} = \text{treatment level of plant } j \text{ for alternative } m \quad . . (23)$$

in which

j = 1,2,. ,J
m = 1,2,. ,M

Construction time lag

There is period of time required between the decision to build, expand, or upgrade a treatment plant and the actual operation of the plant. This time lag requires that the decisions to modify the plant be based on conditions at some time in the future equal to time lag.

$$LAGP = \text{construction time lag for treatment plants, yrs} \quad . . . . . . (24)$$

Quantity collected

The quantity of wastewater collected at each treatment plant is determined by the use of the input matrix (Equation 20) and the projected quantities of wastewater (Equation 16).

$$COL_{j\ell m} = \sum_{i} (Q_{i\ell})(IN_{ijm}) \quad . . . . (25)$$

in which

$COL_{j\ell m}$ = total quantity of wastewater collected by plant j in year ℓ for alternative m
$Q_{i\ell}$ = quantity of wastewater to plant i in year ℓ
IN_{ijm} = input matrix from several sources i to plant j for alternative m

and:

i = 1,2,. ,J
j = 1,2,. ,J
ℓ = ℓ
m = m

This quantity does not necessarily imply that the treatment plant is treating the wastewater, only that this amount of wastewater passes through node j.

Quantity treated

The output matrix (Equation 19) determines which plants are operating. If an integer '1' is found in the k = J + 1 position, the plant will treat the wastewater collected by it (Equation 25). The quantity of water collected is that projected to be produced at some time in the future equal to the construction lag time.

$$TREAT_{j(\ell + LAGP)m} = COL_{j(\ell + LAGP)m}(OUT_{jkm}) \quad .(26)$$

in which

$TREAT_{j(\ell + LAGP)m}$ = quantity of wastewater to be treated by plant j in year ℓ + LAGP) for alternative m, mgd
$COL_{j(\ell + LAGP)m}$ = quantity of wastewater collected by plant j in year (ℓ + LAGP) for alternative m, mgd
OUT_{jkm} = output matrix from plant j to destination k for alternative m

and:

j = 1,2, . ,J
k = J+1
ℓ = ℓ
m = m
LAGP = construction lag time, yrs

Design index

Each existing treatment plant has a current level of treatment (Equation 8), and each alternative requires the same or another level (Equation 23). The cost of upgrading the treatment plants from one level to another is dependent upon these levels. The design index allows the selection of the proper cost equations. Assume the following conditions:

Existing level –	0	0	0	0	1	1	1	2	2	3
Required level –	1	2	3	4	2	3	4	3	4	4
$INDEX_{jm}$ –	1	2	3	4	5	6	7	8	9	10

$$\text{if } LTREAT_j = 0, \text{ then } INDEX_{jm} = MTREAT_{jm} \quad .(27)$$

$$\text{if } LTREAT_j = 1, \text{ then } INDEX_{jm} = MTREAT_{jm} + 3 \quad .(28)$$

$$\text{if } LTREAT_j = 2, \text{ then } INDEX_{jm} = MTREAT_{jm} + 5 \quad .(29)$$

$$\text{if } LTREAT_j = 3, \text{ then } INDEX_{jm} = MTREAT_{jm} + 7 \quad .(30)$$

in which

$LTREAT_j$ = existing treatment level of plant j
$INDEX_{jm}$ = design index
$MTREAT_{jm}$ = treatment level of plant j for alternative m

and:

j = 1,2, . ,J
m = 1,2, . ,M

Design period

The design of treatment plants is based on the interest rate (Equation 13) and the economy of scale, a_p. The value of a_p is dependent upon the design index. The following equation must be iterated about 25 times to obtain a reasonably accurate value for the design period (Equation 4).

$$t^* = \frac{LN\left[\frac{(t^*)(r_\ell)}{a_p} + 1.0\right]}{r_\ell} \quad . \; . \; . \; . \; . \; . \; .(31)$$

in which

t^* = optimum design period, yrs
r_ℓ = annual interest rate for year ℓ
a_p = economy of scale for cost equation

and:

ℓ = ℓ
p = design index, $INDEX_{jm}$

Annual increase

The required capacity of a treatment plant is compared to existing capacity to determine if expansion is needed. The quantity of capacity expansion is based on the linear growth of wastewater quantity for the design period (Equation 31). The annual growth rate is based on needs over a 20 year period.

$$D_{j\ell m} = \frac{COL_{j(\ell + 20)m} - COL_{j\ell m}}{20} \quad . \; . \; . \; . \; .(32)$$

in which

$D_{j\ell m}$ = annual increase in quantity of wastewater, mgd/yr
$COL_{j\ell m}$ = total quantity of wastewater collected by plant j in year ℓ for alternative m

and:

j = 1,2, . ,J
ℓ = ℓ
m = m

Capacity expansion

The expanded capacity of the treatment plant is given by the following equation.

$$CAPP_{j(\ell + 1)m} = TREAT_{j(\ell + LAGP)m} + (D_{j\ell m})(t^*) \quad . \; .(33)$$

in which

$CAPP_{j(\ell+1)m}$ = capacity of treatment plant j in year ℓ+1 for alternative m, mgd

$TREAT_{j(\ell+LAGP)m}$ = quantity of wastewater to be treated by plant j in year (ℓ + LAGP) for alternative m, mgd

$D_{j\ell m}$ = annual increase in quantity of wastewater, mgd/yr

t^* = optimum design period, yrs

and:

j = 1,2, . ,J
ℓ = ℓ
m = m
LAGP = construction lag time, yrs

Expansion costs

The costs of expanding and upgrading a treatment plant is given by the following equation.

$$CTP_{jm} = (FACTOR_{\ell})(k_p)(CAPP_{j(\ell+1)m} - CAPP_{j\ell m})^{a_p} \quad .(34)$$

in which

CTP_{jm} = cost of expanding and upgrading treatment plant j for alternative m, mil $

$FACTOR_{\ell}$ = inflation factor

k_p = cost coefficient

$CAPP_{j(\ell+1)m}$ = expanded capacity of treatment plant j in year (ℓ+1) for alternative m, mgd

$CAPP_{j\ell m}$ = existing capacity of treatment plant j in year ℓ for alternative m, mgd

a_p = economy of scale factor

and:

j = 1,2, . ,J
ℓ = ℓ
m = m
p = design index, $INDEX_{jm}$

Capital debt

The existing debt of each treatment plant was entered into the model to initialize the model. It was assumed that the cost of expanding the plant was distributed such that the debt was increased by 50 percent of CTP_{jm} this year and 50 percent next year.

$$DEBTP_{j\ell m} = DEBTP_{j\ell m} + (0.50)(CTP_{jm}) \quad . \; .(35)$$

$$DEBTP_{j(\ell+1)m} = DEBTP_{j\ell m} + (0.50)(CTP_{jm}) \quad . \; .(36)$$

in which

$DEBTP_{j\ell m}$ = capital debt of treatment plant j in year ℓ for alternative m, mil $

$DEBTP_{j(\ell+1)m}$ = capital debt of treatment plant j in year (ℓ+1) for alternative m, mil $

CTP_{jm} = cost of expanding and upgrading treatment plant j for alternative m, mil $

and:

j = 1,2, . ,J
ℓ = ℓ
m = m

Annual capital debt

The debt of the treatment plants is decreased annually by the amount of the capital recovery factor.

$$ANNP_{j\ell m} = DEBTP_{j(\ell-1)m}(CRF_{\ell}) \quad . \; . \; . \; .(37)$$

$$DEBTP_{j\ell m} = DEBTP_{j\ell m} - ANNP_{j\ell m} \quad . \; . \; . \; .(38)$$

in which

$ANNP_{j\ell m}$ = annual repayment of previous years capital debt for plant j in year ℓ for alternative m, mil $

$DEBTP_{j(\ell-1)m}$ = capital debt of treatment plant j in year (ℓ+1) for alternative m, mil $

$DEBTP_{j\ell m}$ = new capital debt of treatment plant j after addition of expansion costs and after subtraction of annual repayment, mil $

CRF_{ℓ} = capital recovery factor for treatment plants for year ℓ

and:

$j = 1,2,..,J$
$\ell = \ell$
$m = m$

Annual O & M

The annual operation and maintenance (O & M) costs are directly related to the quantity of wastewater being treated by the treatment plants.

$$OMP_{j\ell m} = (FACTOR_{\ell})(k_p)(TREAT_{j\ell m})^{\alpha_p} \quad . \; . (39)$$

in which

$OMP_{j\ell m}$ = annual O & M cost of treatment plant j in year ℓ for alternative m, mil $

$FACTOR_{\ell}$ = inflation factor for O & M

k_p = cost index for O & M cost equation

$TREAT_{j\ell m}$ = quantity of wastewater being treated by plant j in year ℓ for alternative m, mgd

α_p = economy of scale factor

and:

$j = 1,2,..,J$
$\ell = \ell$
$m = m$
$p =$ design index, $INDEX_{jm}$

Present worth

The present worth of the treatment plant consists of the present worth of the sum of the annual costs for capital repayment and for O & M.

$$PWP_{j\ell m} = \frac{ANNP_{j\ell m} + OMP_{j\ell m}}{(1.0 + r_{\ell})^{\ell-1}} \quad . \; . \; . \; . \; . (40)$$

in which

$PWP_{j\ell m}$ = present worth produced by plant j in year ℓ for alternative m, mil $
$ANNP_{j\ell m}$ = annual repayment of capital for plant j for debt incurred in previous year from year ℓ for alternative m, mil $
$OMP_{j\ell m}$ = annual O & M cost of treatment plant j in year ℓ for alternative m, mil $
r_{ℓ} = annual interest rate for year

and:

$j = 1,2,..,J$
$\ell = \ell$
$m = m$

Construction lag time

There is a period of time required between the decision to build or expand a trunk sewer and the actual operation of the trunk sewer. This time lag requires that the decisions to build the trunk sewer be based on conditions at some time in the future equal to the time lag.

LAGS = construction time lag for trunk sewers, yrs . . . . (41)

Trunk sewer flows

The quantity of wastewater flowing through any trunk sewer is equal to the amount of wastewater collected by plant j that is not treated according to Equation 26. The output matrix (Equation 19) is searched for an integer '1,' and the appropriate path, $X_{jk\ell m}$ is loaded with the quantity of wastewater collected by plant j.

$$\text{if } OUT_{jkm} = 1, \text{ then } r = k \quad . \; . \; . \; . \; . \; . \; . \; . (42)$$

$$X_{jr(\ell+LAGS)m} = COL_{j(\ell+LAGS)m} \quad . \; . \; . \; . \; . (43)$$

in which

OUT_{jkm} = output matrix

$X_{jr(\ell+LAGS)m}$ = quantity of wastewater transported by trunk sewer jr in year (ℓ+LAGS) for alternative m, mgd

$COL_{j(\ell+LAGS)m}$ = quantity of wastewater collected by plant j, but not treated, in year (ℓ+LAGS) for alternative m, mgd

and:

$j = j$
$k = 1,2,..,J+1 \; (j \neq k)$
$\ell = \ell$
$m = m$

Design period

The design period of trunk sewers is based on the interest rate (Equation 13) and the economy of scale, α_p. Although the parameters are different, the equation for optimal design period, t*, in trunk sewers is the same as Equation 31 for treatment plants.

Annual increase

The required capacity of the trunk sewer is compared with the existing capacity to determine if expansion is needed. Since treatment plants have only one output, the annual increase in wastewater flow is the same as it is for treatment plants.

$$\text{if } OUT_{jkm} = 1, \text{ then } r = k \quad \ldots\ldots\ldots (44)$$

$$DS_{jr\ell m} = D_{j\ell m} \quad \ldots\ldots\ldots\ldots\ldots (45)$$

in which

OUT_{jkm} = output matrix

$DS_{jr\ell m}$ = annual increase in quantity of trunk sewer flow, mgd/yr

$D_{j\ell m}$ = annual increase in quantity of wastewater, mgd/yr

and:

$j = j$

$k = 1,2,\ldots,J \; (j \neq k)$

$\ell = \ell$

$m = m$

Capacity expansion

The expansion of capacity of trunk sewers is given by the following equation.

$$CAPS_{jk(\ell+1)m} = X_{jk(\ell+LAGS)m} + (DS_{jk\ell m})(t^*) \quad \ldots (46)$$

in which

$CAPS_{jk(\ell+1)m}$ = expanded capacity of trunk sewer jk in year (ℓ+1) for alternative m, mgd

$X_{jk(\ell+LAGS)m}$ = quantity of wastewater to be transported by trunk sewer jk in year (ℓ +LAGS) for alternative m, mgd

$DS_{jk\ell m}$ = annual increase in quantity of trunk sewer flow, mgd/yr

t^* = optimum design period, yrs

and:

$j = 1,2,\ldots,J \; (j \neq k)$

$k = 1,2,\ldots,J$

$\ell = \ell$

$m = m$

Expansion costs

The cost of building or expanding a trunk sewer is dependent upon the length, slope, elevation difference, and capacity.

$$\begin{aligned} CTS_{jkm} = {} & (FACTOR_\ell)\,[(k_{12})(CAPS_{jk(\ell+1)m} \\ & - CAPS_{jk\ell m})^{a_{12}}\,(DIST_{jk}) \\ & + (k_{13})\,(CAPS_{jk(\ell+1)m} - CAPS_{jk\ell m})^{a_{13}} \\ & (NUMPS_{jk})| \quad \ldots\ldots\ldots\ldots (47) \end{aligned}$$

in which

CTS_{jkm} = cost of building or expanding trunk sewer jk for alternative m, mgd

$FACTOR_\ell$ = inflation factor

k_{12} = cost coefficient for constructing trunk sewer

$CAPS_{jk(\ell+1)m}$ = expanded capacity of trunk sewer jk in year (ℓ +1) for alternative m, mgd

$CAPS_{jk\ell m}$ = existing capacity of trunk sewer jk in year ℓ for alternative m, mgd

a_{12} = economy of scale for constructing trunk sewer

$DIST_{jk}$ = length of existing or proposed trunk sewer, mi

k_{13} = cost coefficient for constructing lift station

a_{13} = economy of scale for constructing lift station

$NUMPS_{jk}$ = number of lift stations for trunk sewer jk

and:

$j = 1,2,\ldots,J$

$k = 1,2,\ldots,J$

$\ell = \ell$

$m = m$

Capital debt

The existing debt of each trunk sewer was entered into the model to initialize the model. It was assumed that the cost of expanding the sewer was distributed such that the debt was increased by 50 percent of the CTS_{jkm} this year and 50 percent next year.

$$DEBTS_{jk\ell m} = DEBTS_{jk\ell m} + (0.50)(CTS_{jkm}) \quad . \quad . (48)$$

$$DEBTS_{jk(\ell+1)m} = DEBTS_{jk\ell m} + (0.50)(CTS_{jkm}) \quad . \quad . (49)$$

in which

$DEBTS_{jk\ell m}$ = capital debt of trunk sewer jk in year ℓ for alternative m, mil \$

$DEBTS_{jk(\ell+1)m}$ = capital debt for trunk sewer jk in year $(\ell+1)$ for alternative m, mil \$

CTS_{jkm} = cost of building or expanding trunk sewer jk for alternative m, mil \$

and

$j = 1,2,..J\ (j \neq k)$
$k = 1,2,..J$
$\ell = \ell$
$m = m$

Annual capital debt

The debt of the trunk sewer is decreased annually by the amount of the capital recovery factor.

$$ANNS_{jk\ell m} = DEBTS_{jk(\ell-1)m}(CRF_\ell) \quad . \quad . \quad . \quad . \quad . (50)$$

$$DEBTS_{jk\ell m} = DEBTS_{jk\ell m} - ANNS_{jk\ell m} \quad . \quad . \quad . \quad . (51)$$

in which

$ANNS_{jk\ell m}$ = annual repayment of previous year capital debt for trunk sewer jk in year ℓ for alternative m, mil \$

$DEBTS_{jk(\ell-1)m}$ = capital debt of trunk sewer jk in year $(\ell-1)$ for alternative m, mil \$

$DEBTS_{jk\ell m}$ = new capital debt of trunk sewer jk after the addition of expansion costs and after subtraction of annual repayment, mil \$

CRF_ℓ = capital recovery factor for treatment plants for year ℓ

and:

$j = 1,2,..J\ (j \neq k)$
$k = 1,2,..J$
$\ell = \ell$
$m = m$

Annual O & M

The annual O & M costs are directly related to the flow through the trunk sewer and to the pumping head.

$$OMS_{jk\ell m} = (FACTOR_\ell)[(k_{12})(X_{jk\ell m})^{a_{12}}(HEAD_{jk}) + (k_{13})(X_{jk\ell})^{a_{13}}](NUMPS_{jk}) \quad . \quad . \quad . \quad . \quad . (52)$$

in which

$OMS_{jk\ell m}$ = annual O & M cost of trunk sewer jk in year ℓ for alternative m, mil \$
$FACTOR_\ell$ = inflation factor for O & M
k_{12} = cost index for power cost of lift station
$X_{jk\ell m}$ = quantity of wastewater transported by trank sewer jk in year ℓ for alternative m, mgd
a_{12} = economy of scale for power cost of lift station
k_{13} = cost coefficient for O & M of lift station
a_{13} = economy of scale for O & M of lift station
$HEAD_{jk}$ = pumping head of lift station, ft
$NUMPS_{jk}$ = number of lift stations for trunk sewer jk

and:

$j = 1,2,..J\ (j \neq k)$
$k = 1,2,..J$
$\ell = \ell$
$m = m$

Present worth

The present worth of the trunk sewer consists of the present worth of the sum of the annual costs for capital repayment and for O & M.

$$PWS_{jk\ell m} = \frac{ANNS_{jk\ell m} + OMS_{jk\ell m}}{(1.0 + r_\ell)^{\ell-1}} \quad . \quad . \quad . \quad . \quad . (53)$$

in which

$PWS_{jk\ell m}$ = present worth produced by trunk sewer jk in year ℓ for alternative m, mil \$

$ANNS_{jk\ell m}$ = annual repayment of capital for trunk sewer jk for debt incurred in previous year from year ℓ for alternative m, mil \$

$OMS_{jk\ell m}$ = annual O & M cost of trunk sewer jk in year ℓ for alternative m, mil \$

r_{ℓ} = annual interest rate for year ℓ

and:

$j = 1,2,..,J \; (j \neq k)$

$k = 1,2,..,J$

$\ell = \ell$

$m = m$

Total present worth

A single value of present worth is required by the dynamic programming model for each alternative treatment scheme in each planning year. This is obtained by adding all of the present worth values for the treatment plants and trunk sewers of a single alternative. The present worths are measured with respect to the base year of the model.

$$TPTOW_{\ell m} \quad PWP_{j\ell m} + PWS_{jk\ell m} \quad . \; . \; . \; . \; . \; . (54)$$

in which

$TPTOW_{\ell m}$ = total present worth of all of the treatment plants and trunk sewers for alternative m in year ℓ, mil \$

$PWP_{j\ell m}$ = present worth of treatment plants for alternative m in year ℓ, mil \$

$PWS_{jk\ell m}$ = present worth of trunk sewers for alternative m in year ℓ, mil \$

and:

$j = 1,2,..,J \; (j \neq k)$

$k = 1,2,..,J$

$\ell = \ell$

$m = m$

Dynamic Programming Model Formulation

Consider the model configuration shown in Figure 7 in which each box represents an alternative treatment scheme. The model is divided into a number of stages, represented by the years T_0 through T_3, and into a number of states in each stage, represented by alternatives A through C. The principle of optimality (Bellman and Dryfus, 1962)

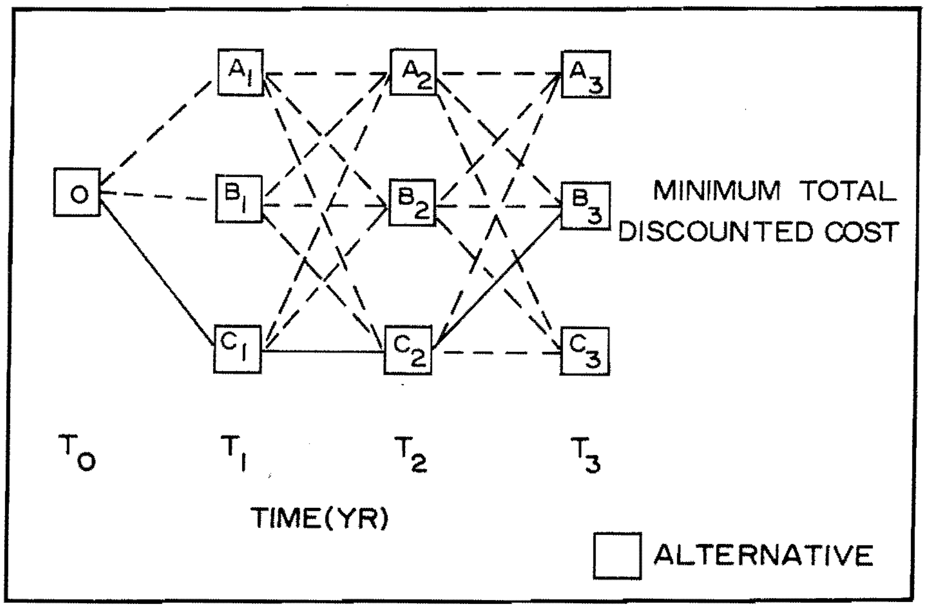


Figure 7. Dynamic programming formulation.

asserts that a state is reached by an optimal path—i.e., a path that minimizes the objective function over the transition from the initial state to the state in question—only if the prior state achieved at the previous stage was itself reached by a path that was optimal to that point. Application of this principle leads to a recursive equation in which for every possible state both the optimal value of the objective function and the previous optimal state can be determined successively from stage to stage. At the last stage one or more final states are achieved, from any of which an optimal path can be extended back to the original state.

The development of the recursive equation assumes that if S_m^ℓ represents the mth state within the ℓth stage, then the optimal, or in this case, the minimum cost path $C^*(I,S_m^\ell)$ from the initial state I to the state S_m^ℓ is given by:

$$C^*(I,S_m^\ell) = \underset{k = 1,2,..,M}{\text{Min}} \left[C(S_k^{\ell-1},S_m^\ell) + C^*(I,S_k^{\ell-1})\right] \quad \cdots\cdots\cdots (55)$$

in which

$S_k^{\ell-1}$ = state k in stage ℓ-1

M = number of possible states in stage ℓ-1

$C^*(I,S_k^{\ell-1})$ = minimum cost of getting from state I to state $S_k^{\ell-1}$

$C(S_k^{\ell-1},S_m^\ell)$ = cost of going from state $S_k^{\ell-1}$ to state S_m^ℓ

With this equation the optimal or minimum cost to go to any state within any stage can be calculated from known minimum costs in all possible states in the previous stage.

To solve a dynamic programming problem, the equation cited is used in a "forward pass" from the initial stage to the final stage. In the forward pass the minimum costs of going from the initial state to every possible state in every stage are calculated from each stage to the next. In addition, the previous state associated with the optimal cost to the state in question is noted and stored. At the completion of the forward pass, the desirable final state of the system is selected from among the possible states in the final stage. This is normally the one that produced the lowest total discounted cost.

When the optimum final state and its corresponding cost have thus been determined, the previous state associated with the minimum cost in the final state is taken to be the optimal state at the next-to-final stage. This process is then repeated successively for each stage in a "backward pass" from the final to the initial stage. At the completion of the backward pass the succession of optimal states thus determined defines the optimal path from the initial to the final state. Over this path the previously determined cost of going from the initial to the final state is obtained. Most uses of dynamic programming end at this point, but in this model another forward pass along the optimal path is necessary to recalculate all of the desired parameters of the system. These were not retained on the first pass because of the high cost of computer storage.

Application of this technique has been shown in Figure 7 and is illustrated in the following discussion. The first box at time T_0 represents the initial system of treatment plants in the base year. The other boxes represent alternatives A, B, and C in any given year. Starting with the initial system at T_0, the annual cost of using alternative A_1 in year T_1 is determined. This includes the costs of building, expanding, or upgrading the treatment plants or the trunk sewers, and the cost of operation and maintenance of the entire system. The annual costs are converted to a present worth value at the base year, and are stored with alternative A_1. This process is repeated for alternatives B_1 and C_1. In year T_2, the costs, capacities, and treatment levels are determined for alternative A_2 by considering A_1 as the initial condition. The present worth of this treatment scheme in the base year, T_0, is added to the present worth stored with A_1 and then stored with A_2. Likewise, the costs, capacities, and treatment levels are determined for A_2 using B_1 and C_1 as the initial conditions. The alternative in T_1 that results in the lowest total discounted cost at A_2 is stored with A_2 as its optimum back path. The optimum costs, capacities, and treatment levels are also stored with A_2. This process is repeated for each alternative in year T_2, and for each remaining year of the planning period.

Once the analysis of the last planning year has been completed, the alternative in that year that has the lowest cumulative discounted cost, is selected as the best optimum alternative of those considered. In Figure 7 in year T_3 this is B_3. The optimum path from year T_0 to year T_3 is obtained by determining the optimum back path of alternative B_3 in year T_3; this is C_2. From C_2 the optimum back path is C_1, and so on. The process is repeated until year T_0 is reached. Having determined the optimum combination of alternatives through time, the forward pass from year T_0 to year T_3 is repeated for that path to determine all the required parameters for each year.

DEVELOPMENT OF MODEL PARAMETERS

The application of any model to a wastewater treatment system requires that the chosen parameters be valid for real life problems. The parameters and the factors affecting the parameters that were considered in this model were as follows: Population projections, wastewater quantity and quality, stream and effluent standards, pollution removal efficiencies, treatment level classifications, cost indices, interest rates, economies of scale and cost coefficients for capital and for operation and maintenance costs. The data were obtained or calculated from available literature and summarized in the desired formats. These parameters reflect national averages and can be adjusted to any desired part of the country.

Population Projections

The first step in the evaluation of the wastewater needs of an area is the determination of the population projections. A number of population forecasting techniques have been used, including: (1) Graphical projections; (2) mathematical projections; (3) ratio and correlation methods; (4) growth composition analysis; and (5) employment forecasts. The latter three methods may offer somewhat greater reliability than methods (1) and (2) (McJunkin, 1964). The data for this study will be obtained from previously published sources.

Wastewater Quantities

The expected load for a treatment system, or the wastewater quantity, is generally predicted by its relationship to population projections, which are subject to many variable factors. The per capita contribution to wastewater flow is often given as 100 gpd per capita, and the peak flow which governs design may be 225 percent of this figure. With the variability of these parameters, the future demands for the treatment capacity may show a uniform rate of increase, an increasing rate of increase, or a decreasing rate of increase. For this reason, a capacity expansion model is usually restricted to an uniformly increasing quantity of wastewater (Rachford, Scarto, and Tchobanoglous, 1969). In this model projected populations, and hence wastewater quantities, can be entered at any number of years in the planning period. Straight lines are then calculated between these points, resulting in a piecewise linear population projection. Alternative futures can be easily analyzed by changing the population projection at intermediate years.

Wastewater Quality

The quality of a municipal wastewater is generally considered to be constant in any given area. Exceptions are due to infiltration of storm waters, increased use of home grinding units, and changes in quality of the industrial contribution. If the quality decreases or if the discharge requirements are made stricter, the cost coefficients for treatment plant expansions or upgrading would have to be increased. Typical values of influent quality of a medium strength domestic sewage are shown in Table 4.

Table 4. Domestic sewage quality.[a]

Suspended solids, mg/l	250
Grease & oil, mg/l	100
BOD_5, mg/l	200
COD, mg/l	500
Total Nitrogen, mg/l	50
Total Phosphorus, mg/l	12
Coliform, 100 ml	10

[a] Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973b).

Stream and Effluent Standards

Effluents from wastewater treatment plants eventually are reused for another purpose. This may be as industrial or irrigation waters, or for fishing, recreation, or drinking waters. The State of Utah and the Federal Government have defined stream and effluent standards to protect the environment and the welfare of the people. Most streams in the State of Utah are now classified as Class 'C' waters. This requires that the river water not be degraded below this level. A federal timetable has been established for all dischargers to meet required effluent standards. In Utah, the check points are at 1977 and 1980. A summary of these standards is shown in Table 5.

Wastewater Treatment Sequence

There are a large number of unit processes available today to be considered in the design of a wastewater treatment system. Most require a certain degree of prior treatment of wastewaters before they can be used. Even then, many of the units have limited ranges of flow rates in which economical

Table 5. Water quality for beneficial uses and state standards.[a,b,c]

Constituent	Drinking	Recreation (contact)	Industrial	Irrigation	Fisheries	Class "C"		Class "D"	Effluent Standards	
						Recommended	Mandatory		1977	1980
Alkalinity	120	---	< 150	---	---	---	---	---	---	---
Hardness	---	---	< 250	---	---	---	---	---	---	---
Arsenic (As)	---	---	---	---	---	0.01	0.05	---	---	---
Barium (Ba)	---	---	---	---	---	---	1.0	---	---	---
Cadmium (Cd)	---	---	---	---	---	---	0.01	---	---	---
Chloride (Cl)	250	---	< 250	100	---	250	---	---	---	---
Chromium (Cr)	---	---	---	---	---	---	0.05	---	---	---
Copper (Cu)	---	---	---	---	---	1.0	---	---	---	---
Cyanide (CN)	---	---	---	---	---	0.01	0.02	---	---	---
Fluoride (F)	---	---	---	---	---	1.0	2.0	---	---	---
Iron (Fe)	---	---	---	---	---	0.3	---	---	---	---
Lead (Pb)	---	---	---	---	---	---	0.05	---	---	---
Manganese (Mn)	---	---	---	---	---	0.05	---	---	---	---
Nitrate (NO_3)	45	---	---	400	0.05	45	---	---	---	---
Phenols	---	---	---	---	---	0.001	---	---	---	---
Selenium (Se)	---	---	---	---	---	---	0.01	---	---	---
Silver (Ag)	---	---	---	---	---	---	0.05	---	---	---
Sulfate (SO_4)	250	---	---	190	---	250	---	---	---	---
Zinc (Zn)	---	---	---	---	---	5.0	---	---	---	-
Phosphate (P)	2	---	---	---	0.01	---	---	---	---	--
Total Dissolved Solids (TDS)	500	---	1000	1500	2000	500	---	---	---	---
Suspended Solids (SS)	0	20	---	---	25	---	---	---	25	10
Dissolved Oxygen (DO)	7.5	> 6.5	> 5	---	> 5	---	5.5	---	---	---
BOD_5	0	< 1.5	< 5	---	< 1.5	---	< 5	< 25	< 25	< 10
Coliform - Total[d]	< 50	1000/100	---	---	<500/100	5000/100	---	5000/100	2000/100	200/100
- Fecal	---	---	---	---	---	2000/100	---	---	200/100	20/100
Turbidity	5	10	50	---	50	---	---	---	---	---
Temperature	---	---	---	---	73 F	---	---	---	---	---
pH	6.5 - 8.5	---	6.5 - 9.0	---	6.5 - 8.5	6.5 - 8.5	---	6.5 - 9.0	6.5 - 9.0	6.5 - 9.0
Oil and Grease	---	---	---	---	---	undetectable	---	---	---	---

[a] Concentration in mg/l.

[b] Maximum concentrations.

[c] Sources: Utah State Division of Health, 1965; Public Health Service, 1962; California State Water Resources Control Board, 1963; Utah State Water Pollution Committee, 1974.

[d] MPN per 100 ml.

operation is possible. The flow chart in Figure 8 represents the relative locations and purposes of each unit process. The feasible combinations of processes will depend upon the type of influent being treated and the required effluent quality.

Pollution Removal Efficiencies

A comparison of the treatment efficiencies of several types of treatment plants and advanced waste treatment unit processes is shown in Table 6. The values are subject to many variables but do provide an initial basis for planning wastewater treatment systems. These are overall values that require that the proper pretreatment of the wastewater is performed prior to the unit in question.

Treatment Level Classifications

There are a number of possible configurations of unit processes to meet specific treatment needs. Some are more suitable for a given flow rate and influent concentration than others. Many of the unit processes have required influent qualities that limit the number of possible configurations.

Using a typical medium strength domestic sewage (Table 4), a series of treatment processes can be defined to achieve various effluent qualities. One such combination is shown in Figure 9 where four levels of treatment and the related effluent qualities have been defined for the State of Utah. The existing secondary treatment plants are considered the lowest acceptable treatment level, and the other levels are suggested for planning purposes. A detailed engineering analysis would still have to be undertaken before the selection of the actual processes. All of the treatment plant configurations also receive chlorination of the effluent.

Cost Indices

The costs associated with the construction and operation of wastewater treatment plants and trunk

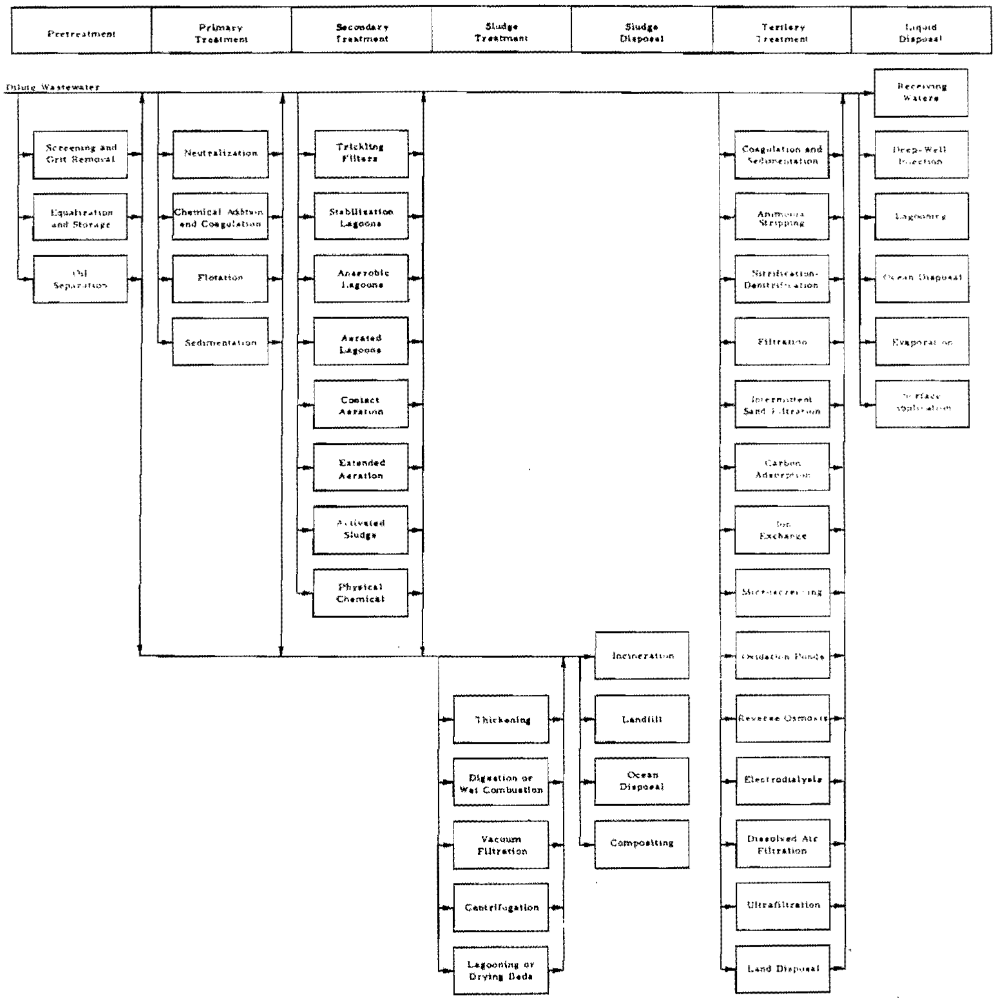


Figure 8. **Wastewater sequence and process substitution diagram.**

sewers have always been difficult to estimate for planning purposes. Since the data must be gathered from several different sources, usually based on widely different time periods, it was necessary to adjust the cost data to June 1974. Several different indices were considered and three were chosen.

The Engineering New Record's Construction Cost Index (ENR-C) was not suitable for comparing costs in wastewater treatment plants because it is weighted too heavily in favor of the cost of common labor. A treatment plant has a considerable amount of equipment and piping that require skilled labor. Both the ENR Building Cost Index (ENR-B) and the Federal Water Pollution Control Administration's Sewage Treatment Plant Construction Cost Index (WPC-STP) are considered to give a more realistic representation of the increase in construction costs with time. Since the latter index is no longer being produced, the ENR-B Cost Index was used for the construction costs of the wastewater treatment plants.

The Federal Water Pollution Control Administration Sewer Construction Cost Index (WPC-S) was used to adjust the costs for trunk sewers to June 1974. However, lift stations on the sewer lines relate more closely to the ENR-B Cost Index.

The operation and maintenance data are generally affected by the cost of labor. The U.S. Department of Labor's tabulation of the Average Earnings for Nonsupervisory Workers in Water,

Table 6. Treatment capabilities for various types of wastewater treatment units.

Treatment Type	BOD_5		COD		S.S.		Turbidity	P		N		References
	mg/l[a]	%Removal	mg/l	%Removal	mg/l	%Removal	JTU	mg/l	%Removal	mg/l	%Removal	
Primary & Secondary[b]												
Waste Stabilization Lagoon	30-60	70	-	-	30-60	70	-	-	-	15^d	20-30	f
Extended Aeration	20-20	80-90	-	-	10	95	-	-	10-20	15^d	20-30	f
	20			-	35	-	-	-	-	-	-	g
Primary Sedimentation	120	45	-	-	75	70	-	-	-	-	-	f
		25-40	-	-	-	40-70	-	-	-	-	-	h
High Rate Trickling Filters	40	80	-	-	20-30	90	-	-	10-20	15^d	20-30	f
Single Stage	-	60-85	-	-	-	-	-	-	-	-		h
Two Stage	-	80-95	-	-	-	-	-	-	-	-	-	h
Standard Rate Trickling Filters	20-30	85	-	-	10-12	95	-	5^e	50	10^d	30-40	f
	-	80-95	-	-	-	80-90	-	-	-	-	-	h
High Rate Activated Sludge	30-50	75	-	-	20-25	90	-	-	10-20	10^d	20-30	f
Standard Rate Activated Sludge	15-20	90	-	-	20-25	90	-	8^e	20	10^d	30-40	f
	-	85-95	-	-	-	85-95		-	-	-		h
Physical-Chemical	10-15	93	-	-	10-20	90	-	1.5^e	85	4.6^d	75	f
Tertiary[c]												
Intermittent Sand Filtration	3-5	-	-	-	0-3	-	-	-	-	-	-	g
	-	90-95	-	-	-	85-95	-	-	-		-	h
Chemical Precipitation	-	50-75	-	-	-	70-90	-	-	-		-	h
Chemical Treatment (Solids contact)	2.9-5	-	17	-	0-7	-	0.2-2.9	0.08-0.9	-	5-10.7	-	g
Granular or Mixed Media Filtration w/Chem.	3.1-5.8	-	13-17	-	0-5	-	0.2-10	0.5	-	5	-	g
Sand Filtration - Deep Bed	4-12	94-98	-	-	5-7	96-98	-	2.5^e	98	-	-	f
Chemical Coagulation and	4-12	94-98	-	-	5-7	96-98	-	2.5^e	98	-	-	f
Sand Filtration	2-3	-	26	-	2-5	-	0.8-3.5	0.15-1.5	-	-	-	g
Microbial Denitrification	-	-	-	-	-	-	-	-	-	4^d	60-95	f
Ammonia Stripping/B. P. Chlorination (10 mg Cl per 1.0 mg NH_3)	1-3	98	-	-	-	-	-	-	-	4^d	85-98	f
Carbon Adsorption	2-10	95-99	-	-	1-3	98	-	-	-	-	-	f
	1.0	-	10-12	-	0.6	-	1.2	0.3	-	6.6	-	g
Microscreening	4-12	94-98	-	-	2-6	97-99	-	-	-	-	-	f
	3	-	6	-	5	-	-	-	-	-	-	g
Ion Exchange	-	-		-	-	-	-	-	-	5^d	80-90	f
	-	-	3.7	-	-	-	0.0	8.8^e		4.2^d	-	g
Reverse Osmosis	1-2	99	-	-	<1	99+	-	$<1^e$	98+	$<1^d$	95-99	f
	-	-	0-1.0	-	-	-	0.27	3.5^e	-	0.2^d	-	g
Electrodialysis	1-2	99	-	-			-	6^e	30-50	10^d	30-50	f
	-	-	8.0	-	-	-	-	7.8^e	-	8.2^d	-	g
Dissolved Air Flotation	-	-	3	-	6	-	-	-	-	-	-	g
Ultrafiltration	<1	-	20	-	0	-	<0.1	-	-	-	-	g
Land Dispersal/Ground Drains	1-2	99	-	-	0-2	99	-	$0.5-1.0^e$	90	17^d	5-15	f

[a] mg/l of constituent remaining in effluent.

[b] Values based on typical raw sewage influent (Table 4).

[c] Overall effluent quality and removals when process is preceded by primary and secondary treatment.

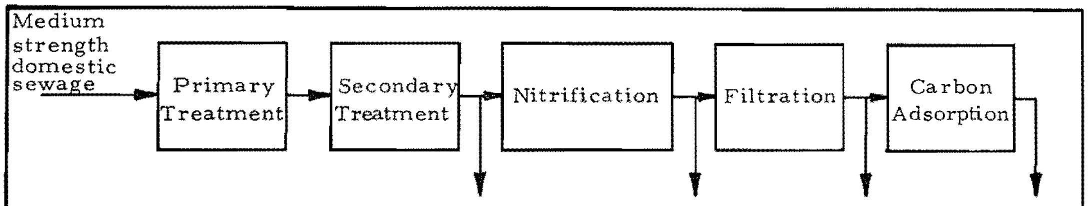
[d] NO_3

[e] PO_4

[f] Templeton, Linke, and Alsup Consulting Engineers (1973).

[g] Middlebrooks et al. (1971).

[h] Utah State Division of Health (1965).



Treatment Level	1	2	3	4
Suspended Solids, mg/l	35	20	15	10
Turbidity, JTU	20	15	10	5
Grease & Oil, mg/l	12	8	2	1
BOD_5, mg/l	25	20	10	5
COD, mg/l	100	75	50	20
Nitrogen, mg/l	30	30	30	30
Phosphorus, mg/l	8	8	6	5
Coliform, MPN/100 ml	1000	240	2.2	2.2
Toxicants				
Survival, %	33	40	80	90
TL_M, %	80	90	100 +	100 +
Toxicity Conc., TU	1.25	1.1	0.8	0.6

Figure 9. Estimated effluent quality from wastewater treatment process chains (adapted from Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973b).

Steam, and Sanitary Systems was used to adjust the O & M costs to the base year of June 1974.

The cost indices are presented in Figure 10 and are tabulated in Table 7. Some of the indices were reported on the 1967 = 100 basis, but these were adjusted to the base years shown. These indices are projected into the future to indicate the rate of inflation in the construction and operation and maintenance costs of treatment plants and trunk sewers.

Interest Rates

The cost of borrowing money to finance wastewater treatment plants has been increasing with time but not at the rate that inflation in construction and operation and maintenance cost have during the past decades. There has been a trend in recent years to finance this construction by the use of revenue bonds rather than general obligation bonds. A graph of the yearly averages of municipal bond yield index for the past 25 years is shown in Figure 11 and tabulated in Table 8.

The United States Environmental Protection Agency has proposed that an interest or discount rate of 7 percent per year be used for all cost effectiveness analysis of wastewater treatment systems (Environmental Protection Agency, 1973). This rate will be changed along with changes in the interest rate used for water resources projects (Water Resources Council, 1973).

The amortization period varies with the type of structure, but a period of 20 years for treatment plants, 50 years for trunk sewers, and 10 years for lift stations is often used. The revenues collected for the wastewater treatment plant facilities are generally in the form of a per capita service charge levied on the consumer. As such, they are somewhat independent of the capacity of the plant and are not relevant to the decision-making process. The revenues do affect the financing of the projects, but this is beyond the scope of this model.

Cost Equations

The cost versus quantity relationship for the construction and the operation and maintenance costs of wastewater treatment plants and trunk sewers was given by several authors (Tables 9 and 10) to be as shown in Equation 56.

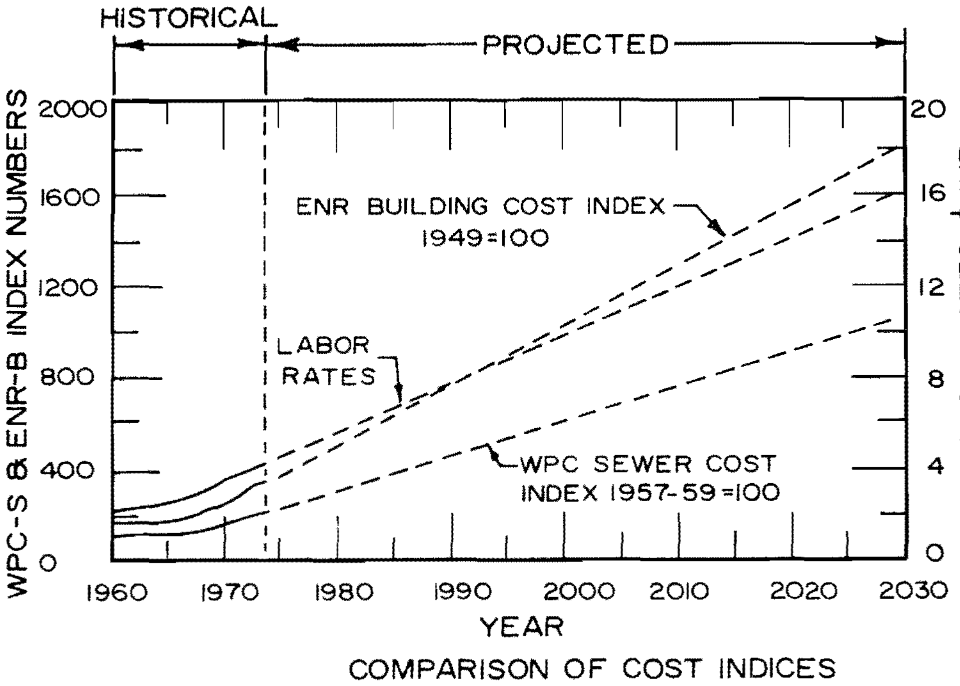


Figure 10. Comparison of cost indices.

Table 7. Cost indices.

Year	Labor[a] Rates $/hr	WPC Construction Cost Index[b]		Engineering New Record Cost Index[c]			
		WTP 1957-59[d]	Sewers 1957-59	Building		Construction	
				1913	1949	1913	1949
1958	2.00	101.50	100.42	521.09	148.13	757.31	158.77
1959	2.07	103.65	104.78	548.35	155.87	795.16	166.70
1960	2.17	104.96	106.22	561.02	159.48	826.64	173.29
1961	2.27	105.83	108.19	570.17	162.07	850.38	178.28
1962	2.33	106.99	109.72	579.57	164.75	872.90	182.99
1963	2.38	108.52	113.07	589.90	167.69	897.48	188.44
1964	2.44	110.54	115.10	612.22	174.03	935.42	196.09
1965	2.54	112.57	117.31	625.84	177.90	971.14	203.58
1966	2.68	116.92	121.18	656.31	186.56	1028.65	215.64
1967	2.82	120.28	125.36	675.17	191.92	1072.02	224.73
1968	3.00	n.a.[e]	130.50	700.67	199.17	1154.18	241.96
1969	3.24	n.a.	139.78	798.26	226.91	1284.96	269.37
1970	3.52	n.a.	150.93	830.14	235.98	1368.66	286.72
1971	3.74	n.a.	168.36	944.31	268.43	1575.05	330.19
1972	3.97	n.a.	186.91	1048.37	297.83	1760.78	368.35
1973	4.18	n.a.	201.07	1137.76	323.23	1896.13	396.69
1974	4.36	n.a.	211.66	1199.20	340.66	1993.47	417.05

[a] U.S. Labor Statistics Bureau (1974).

[b] Federal Water Pollution Control Administration (1967) and U.S. Department of Commerce (1974).

[c] Engineering New Record (1974).

[d] Year in which cost index equal to 100.

[e] Not available.

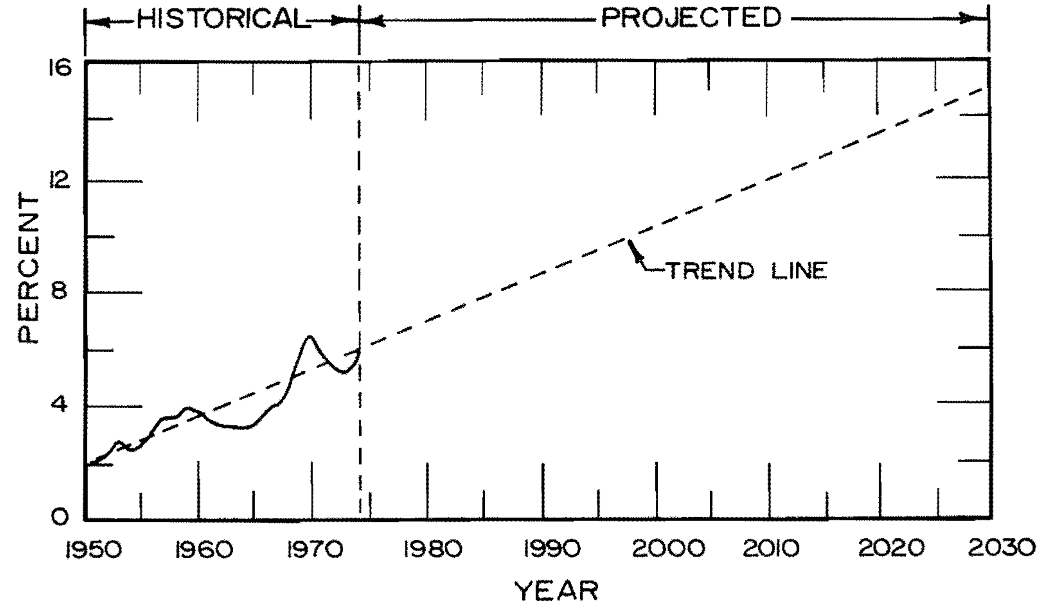


Figure 11. Yearly averages of municipal bond yield indices.

Table 8. Municipal bond yield indices.[a]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Avg
1950	2.08	2.06	2.07	2.08	2.07	2.09	2.09	1.90	1.88	1.82	1.79	1.77	1.98
1951	1.62	1.61	1.87	2.05	2.09	2.22	2.18	2.04	2.05	2.08	2.07	2.10	2.00
1952	2.10	2.04	2.07	2.01	2.05	2.10	2.12	2.22	2.33	2.42	2.40	2.40	2.19
1953	2.47	2.54	2.61	2.63	2.73	2.99	2.99	2.89	2.88	2.72	2.62	2.59	2.72
1954	2.50	2.39	2.38	2.47	2.49	2.48	2.31	2.23	2.29	2.32	2.29	2.33	2.37
1955	2.39	2.42	2.45	2.43	2.41	2.48	2.62	2.67	2.63	2.56	2.55	2.71	2.53
1956	2.64	2.58	2.69	2.88	2.86	2.75	2.78	2.94	3.07	3.14	3.38	3.44	2.93
1957	3.40	3.26	3.32	3.33	3.52	3.75	3.75	3.91	3.90	3.79	3.76	3.47	3.60
1958	3.32	3.37	3.45	3.31	3.25	3.26	3.45	3.74	3.96	3.94	3.84	3.84	3.56
1959	3.87	3.85	3.76	3.84	3.97	4.04	4.04	3.96	4.13	3.99	3.94	4.05	3.95
1960	4.13	3.97	3.87	3.84	3.85	3.78	3.72	3.53	3.53	3.59	3.46	3.45	3.73
1961	3.44	3.33	3.38	3.44	3.38	3.53	3.53	3.55	3.54	3.46	3.44	3.49	3.46
1962	3.32	3.28	3.19	3.08	3.09	3.24	3.30	3.31	3.18	3.03	3.03	3.12	3.18
1963	3.12	3.18	3.11	3.11	3.15	3.27	3.29	3.22	3.27	3.32	3.41	3.34	3.23
1964	3.23	3.17	3.32	3.29	3.21	3.20	3.18	3.20	3.25	3.26	3.18	3.15	3.22
1965	3.06	3.10	3.18	3.17	3.19	3.26	3.26	3.25	3.36	3.42	3.47	3.56	3.27
1966	3.52	3.63	3.72	3.59	3.68	3.77	3.94	4.17	4.11	3.97	3.93	3.83	3.82
1967	3.58	3.56	3.60	3.66	3.92	3.99	4.05	4.03	4.15	4.31	4.36	4.49	3.98
1968	4.34	4.39	4.56	4.41	4.56	4.56	4.36	4.31	4.47	4.56	4.68	4.91	4.51
1969	4.95	5.10	5.34	5.29	5.47	5.83	5.84	6.07	6.35	6.21	6.37	6.91	5.81
1970	6.80	6.57	6.14	6.55	7.02	7.06	6.69	6.33	6.45	6.55	6.20	5.71	6.51
1971	5.70	5.55	5.44	5.65	6.14	6.22	6.31	5.95	5.52	5.24	5.30	5.36	5.70
1972	5.25	5.33	5.30	5.45	5.26	5.37	5.39	5.29	5.36	5.20	5.03	5.03	5.27
1973	5.05	5.12	5.30	5.16	5.12	5.15	5.39	5.47	5.11	5.05	5.17	5.12	5.18
1974	5.20	5.19	5.36	5.67	5.96	n.a.[b]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

[a] Standard & Poor's Corporation (1974).

[b] Not available.

Table 9. A comparison of cost equations for treatment plant unit processes.

References	Techniques used to take different processes into consideration	Variables used to account size	Equation format	Index and value reported by reference		Index used	
						ENR - B 1949	Labor Rates
Smith, 1968	Separate equation for each process and treatment plant	Flow	$Y = k X^{\alpha}$	20 Region WPC-STP Index 1957-59 = 100	119.11	191.92	2.82
Templeton, Linke, and Alsup Consulting Engineers (1973)	Tabulation of costs for each process for several plant sizes	Flow	$Y = k X^{\alpha}$	20 Region ENR - C Index 1913 = 100	1800	304.46	4.04
Logan et al., 1962	Separate equation for each process and treatment plant	Flow	$Y = k X^{\alpha}$	20 Region ENR - C Index 1913 = 100	812	159.17	2.17
Michel, 1970	Separate equation for each process	Population equivalent flow	$Y = k X^{\alpha}$	None 1965-67 Data	-	186.56	2.68
Berthouex, 1972	Economies of scale, α, for construction for plants only	Flow	$Y = k X^{\alpha}$	None	-	-	-
Rowan, Jenkins, and Howells, 1961	Separate equation for each process	Population flow	$\ln Y = \frac{1}{a + b \ln X}$	None 1955-58 Data	-	148.13	2.00
Michel, 1969	Separate equation for each process	Pop., flow man-hr/wk	$\ln Y = \frac{1}{a + b \ln X}$	None 1965-68 Data	-	186.56	2.68
Shah and Reid, 1970	Separate equation for each process	P.E., flow	$\ln Y = b_o + \Sigma b_i \ln X_i$	WPC-STP Index 1957-59 = 100	100	148.13	2.00

Table 10. A comparison of cost equations for trunk sewers, force mains, and lift stations.

References	Unit	Variables used to account for size	Equation format	Index and value reported by reference		Index used		
						ENR-B 1949	WPC-S 1957-59	Labor Rates
Engineering-Science, Inc., 1970	Trunk sewers	Diameter	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	1300	-	141.42	3.28
Bauer, 1962	Trunk sewers	Diameter	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	1000	-	120.80	2.62
Spencer, 1958	Trunk sewers	Flow	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	692.13	-	91.78	1.83
Classen & Voigt, 1973	Trunk sewers	Population	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	1368.66	-	150.93	3.52
Dawes, 1970	Force Mains	Diameter	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	935.42	-	115.10	2.44
Engineering-Science, Inc., 1970	Force Mains	Diameter	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	1300	-	141.42	3.28
Linaweaver & Clark, 1964	Force Mains	Diameter	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	877	-	110.24	2.34
Engineering-Science, Inc., 1970	Lift Station	Flow	$Y = k X^{\alpha}$	ENR - C Index 1913 = 100	1300	229.56	-	-
Benjes, 1960	Lift Station	Flow	$Y = k X^{\alpha}$	ENR - B Index 1913 = 100	555.18	157.81	-	-
Engineering-Science, Inc., 1970	Lift Station - O&M	Flow	$Y = k X^{\alpha} H + k' X^{\alpha'}$	ENR - C Index 1913 = 100	1300	-	-	3.28

$$Y = k X^{\alpha} (0 < \alpha < 1) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; (56)$$

in which

Y = total cost of an item of capacity X, \$ for treatment plants and lift stations, and \$/mi for trunk sewers
k = cost coefficient
X = capacity, mgd
α = economies of scale

The power costs for lift stations and pumping of wastewater through force mains require a cost equation with added variables. For lift stations this equation is shown below.

$$Y = k X^{\alpha} H (0 < \alpha < 1) \quad . \; . \; . \; . \; . \; . \; . \; (57a)$$

in which

Y = cost of pumping a flow of X to a height of H, \$
k = cost coefficient
X = flow rate, mgd
α = economy of scale
H = effective pumping head, ft

The values of k and α in Equations 56 and 57 should not be used without consideration of the factors included and omitted by the different people originally reporting the costs. However, this is not always possible and small variations in the values will not affect the results of the analysis significantly unless they are very close. This points to the need to make a detailed engineering cost estimate after the preliminary selection of treatment alternatives has been made.

Economies of Scale

When there are large economies of scale, represented by a small value of α, there is incentive to provide extra capacity for future growth. The relationship between cost and capacity is shown in Figure 12.

The selection of the appropriate economies of scale, α, is essential to the production of a valid model. In general, α has a range of 0.5 to 0.9 in most wastewater treatment plants and lift stations, and about 0.3 for most trunk sewers.

It is difficult to accurately determine the economy of scale factor and the cost coefficients for a composite system such as a treatment plant because each type of equipment and process has its own characteristics. However, the general cost function of the overall facility is the weighted average of each components costs. The total cost of the combined system can be described by Equation 57 and the method of calculating the composite economy of scale is presented in Equation 58.

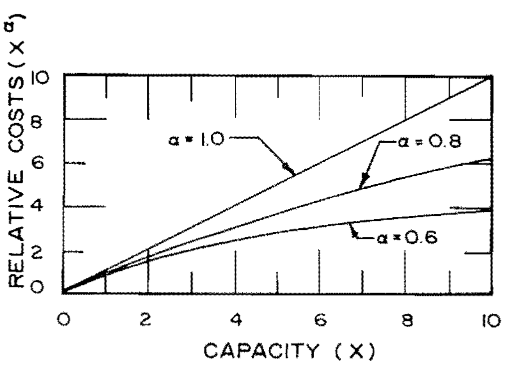


Figure 12. Effects of the economies of scale.

$$\text{Total cost} = \text{cost of component A} + \text{cost of component B} + \ldots \quad . \; . \; . \; . \; (57b)$$

$$1.0\, X^{\alpha_0} = \sum_i P_i X^{\alpha_i} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (58)$$

in which

X = capacity rating, mgd
P_i = percent of the total cost contributed by process i, fraction
α_0 = composite economies of scale
α_i = process economies of scale

This equation can be solved for α as a close approximation of the overall economy of scale within the range of the individual equations. There are several limitations to this method based on the different optimum values of each unit and the limited ranges at which parallel or duplicate units may be added (Berthouex, 1972).

Treatment Plant Cost Equations

The coefficients for several types of treatment plants and advanced waste treatment unit processes are shown in Table 11. The cost coefficients were adjusted by the use of the cost indices (Table 7). These values may vary 20 to 30 percent plus or minus of the true value depending upon the similarities of the plants, construction conditions, and range of the capacities used in the extrapolations by the authors.

Treatment Alternatives

The cost of upgrading a treatment plant is dependent in part on what the initial and final treatment levels are. Using the four treatment levels

Table 11. Coefficients for wastewater treatment plant cost equation $Y = kX^{a}$.

Units	Valid Range (mgd)	Construction Costs			O & M Costs			References
		a	Original Data $k \times 10^{-3}$	Adjusted June '74 $k \times 10^{-3}$	a	Original Data $k \times 10^{-3}$	Adjusted June '74 $k \times 10^{-3}$	
Primary Treatment Plants	1 - 100	0.700	350	643	0.813	16.4	25.4	Smith, 1968
	0.1 - 100	0.755	315	706	0.873	13.3	24.7	Logan et al., 1962
	0.1 - 10	0.55	-	-	-	-		Berthouex, 1972
	0.1 - 10	-	-	-	0.587	21.4	34.5	Michel, 1970
with Oxidation Ponds	0.1 - 1.0	-	-	-	0.154	[illegible]	19.5	Michel, 1970
Waste Stabilization Ponds	0.1 - 2.5	-	-	-	0.554	[illegible]	[illegible]	Michel, 1970
	0.1 - 10	0.5[illegible]	-	-			-	Berthouex, 1972
Standard Rate Trickling Filter Plants	1 - 100	0.690	495	909	[illegible]	[illegible]	[illegible]	Smith, 1968
	0.1 - 100	0.830	430	964	0.744	15.9	35.0	Logan et al., 1962
	0.1 - 2.5	-	-	-	0.573	17.1	27.8	Michel, 1970
	0.1 - 20	0.60	-	-	-	-	-	Berthouex, 1972
High Rate Trickling Filter Plants	0.1 - 100	0.592	526	1179	0.717	17.3	35.8	Logan et al., 1962
	0.1 - 3	-	-	-	0.621	20.0	32.5	Michel, 1970
	0.1 - 20	0.60	-	-	-	-	-	Berthouex, 1972
with Oxidation Ponds	0.1 - 2.5	-	-	-	0.712	13.6	22.4	Michel, 1970
Extended Aeration	0.1 - 2.5	-	-	-	0.621	23.2	37.7	Michel, 1970
Contact Aeration	0.1 - 2.5	-	-	-	0.553	23.7	38.6	Michel, 1970
Activated Sludge Plants	1 - 100	0.780	550	1010	0.756	31.4	48.5	Smith, 1968
	0.1 - 100	0.771	597	1338	0.757	24.3	48.8	Logan et al., 1962
	0.1 - 10	-	-	-	0.730	31.9	51.9	Michel, 1970
	0.1 - 100	0.77	-	-	-	-	-	Berthouex, 1972
Tertiary Treatment								
Chlorination of Secondary Effluent	1 - 100	0.658	15	27.5	0.900	3.3	5.1	Smith, 1968
Ammonia Stripping	1 - 3	0.335	90	165	0.691	5.8	9.0	Smith, 1968
	3 - 5	0.637	130	239	0.912	4.2	6.4	Smith, 1968
	5 - 100	0.878	180	331	0.971	4.0	6.2	Smith, 1968
Microbial Denitrification	1 - 100	[illegible]	189	217	0.689	13.0	14.0	Templeton, Linke, and Alsup Consulting Engineers, 1973
Coagulation and Sedimentation	1 - 100	0.899	51	94	0.920	3.8	5.9	Smith, 1968
Phosphate Precipitation with Recalcination	1 - 100	0.583	179	206	0.927	28.0	30.2	Templeton, Linke, and Alsup Consulting Engineers, 1973
Rapid Sand Filtration	1 - 100	0.662	90	165	0.637	21.9	33.9	Smith, 1968
	1 - 100	0.657	168	193	0.636	15.0	60.6	Templeton, Linke, and Alsup Consulting Engineers, 1973
Granular Carbon Adsorption with - no regeneration	1 - 100	0.630	380	698	0.724	36.5	56.4	Smith, 1968
- regeneration	1 - 100	0.661	525	604	0.669	55.0	59.4	Templeton, Linke, and Alsup Consulting Engineers, 1973
Microstraining of Secondary Effluent	1 - 100	0.902	55	101	0.900	2.9	4.5	Smith, 1968
Electrodialysis	1 - 100	0.712	490	900	0.870	43.1	66.6	Smith, 1968
Ion Exchange	1 - 100	0.916	263	302	0.914	55.0	59.4	Templeton, Linke, and Alsup Consulting Engineers, 1973
Oxidation Ponds	1 - 10	0.725	32	37	0.477	4.0	4.3	Templeton, Linke, and Alsup Consulting Engineers, 1973
Mechanical Aerators with Algae Stripping	1 - 10	0.634	13	15	0.362	1.0	1.1	Templeton, Linke, and Alsup Consulting Engineers, 1973

shown in Figure 9, a set of ten combinations of treatment levels was defined. The selection of the proper cost equation will be made by the use of the design index developed in Equations 27 through 30. These combinations are presented in Table 12. The initial treatment level '0' indicates that a new treatment plant must be built to the upgraded level shown. While all ten values of the design index are required for the selection of the proper construction costs, only the first four are necessary for the operation and maintenance costs. This is because the operation and maintenance costs apply to the entire plant and not just the expanded or upgraded portion.

In Table 13 are shown the selected unit processes necessary to meet the treatment level requirements of Figure 9. From this list the costs of the treatment process chains were developed. Since these costs reflect primarily new construction, the activated sludge plant was chosen to represent secondary treatment. Data were not found that completely represent the costs of the nitrification step. There are several possible ways to achieve biological nitrification in wastewater. The simplest is to increase the mean cell time and aeration rate of the activated sludge basin, and the second is to add an additional nitrification basin and clarifier. The latter

Table 12. **Design index selection of treatment alternatives.**

Design Index	1	2	3	4	5	6	7	8	9	10
Treatment Levels										
Initial	0	0	0	0	1	1	1	2	2	3
Final	1	2	3	4	2	3	4	3	4	4

method provides better nitrification, but also costs a great deal more. It was decided that an average of these costs could be approximately represented by the ammonia stripping costs.

Wastewater Transportation Cost Equations

The cost of transporting wastewater between treatment plants often determines whether or not it is feasible to combine plants or build a regional plant. Some of the factors affecting this cost are the cost of pipe, cost of lift stations, transmission distance, slope of terrain, cost of right-of-way, and operation and maintenance costs. Hydraulic considerations, such as minimum and maximum velocities in the pipes determine the allowable flow.

Little data are available on the general costs of trunk sewers and lift stations as a function of their capacity. Most of the source of data used diameter of pipe rather than flow capacity as the variable in the cost equation. These were converted to the form shown in Table 14.

A combination of gravity trunk sewers and lift stations will be used for the cost equations in the model. The trunk sewer will be sloped to achieve a minimum of 2.5 fps. When the depth becomes excessive, a lift station will lift the wastewater to the desired elevation for gravity flow to continue. The following composite cost equations will be used.

Construction costs for gravity trunk sewers:

$$Y = 127\, X^{0.390} \qquad \ldots\ldots\ldots\ldots (59)$$

in which

Y = cost of construction of sewer, $1000/mi

X = capacity, mgd

Construction costs for lift stations:

$$Y = 128\, X^{0.615} \qquad \ldots\ldots\ldots\ldots (60)$$

in which

Y = cost of construction of lift station, $1000

X = capacity, mgd

O & M costs of lift station:

$$Y = 0.0288\, X^{0.897} H + 1.80\, X^{0.644} \qquad \ldots (61)$$

in which

Y = total operation and maintenance cost, electrical power + general, $1000

X = capacity, mgd

H = pumping head, ft

Cost Graphs

The cost equations presented in Table 13 for wastewater treatment plant alternatives, and Equations 59, 60, and 61 for trunk sewers and lift stations are present in graph form in Figures 13 through 18.

Table 13. Coefficients for wastewater treatment process chain cost equation Y[a] $= k X^{\alpha}$.

Design Level	Treatment Level		Treatment Type	Construction Costs				O & M Costs			
				α		k x 10^{-3}		α		k x 10^{-3}	
	Initial[b]	Final		Range	Average	Range	Average	Range	Average	Range	Average
Treatment Process Units											
a	-	-	Activated Sludge Plant	.77-.78	.775	1010-1338	1174	.756-.757	.756	48.5-48.8	48.6
b	-	-	Nitrification	.878	.878	331	331	.971	.971	6.2	6.2
c	-	-	Filtration	.662-.657	.660	165-193	179	.636-.637	.636	33.9-60.6	47.2
d	-	-	Carbon Adsorption	.630-.661	.646	604-698	651	.669-.724	.696	56.4-59.4	57.9
e	-	-	Chlorination	.658	.658	27.5	27.5	.900	.900	5.1	5.1
Treatment Process Chains											
1	0	1	a, e	-	.773	-	1201	-	.775	-	53.7
2	0	2	a, b, e	-	.800	-	1532	-	.805	-	59.9
3	0	3	a, b, c, e	-	.789	-	1712	-	.746	-	107
4	0	4	a, b, c, d, e	-	.758	-	2362	-	.730	-	165
5	1	2	b, e	-	.867	-	358	-	.942	-	11.3
6	1	3	b, c, e	-	.817	-	538	-	.738	-	58.5
7	1	4	b, c, d, e	-	.740	-	1188	-	.718	-	116
8	2	3	c, e	-	.660	-	206	-	.681	-	52.3
9	2	4	c, d, e	-	.649	-	858	-	.689	-	110
10	3	4	d, e	-	.646	-	678	-	.722	-	63.0

[a] Y in dollars, X in mgd.

[b] Initial treatment level = 0 indicates complete new treatment plant to be built.

Table 14. Coefficients for trunk sewer, force main, and lift station cost equations Y[a] = k X^{α}.

Units	Valid Range (mgd)	Construction Costs			O & M Costs			References
		α	Original Data	Adjusted June '74	α	Original Data	Adjusted June '74	
			$k \times 10^{-3}$	$k \times 10^{-3}$		k	k	
Gravity Trunk Sewers	20 - 500	0.359	192[b]	287	-	-	-	Engineering-Sci., Inc., 1970
	1 - 3000	0.50	40[b]	70.0	-	-	-	Bauer, 1962
	0.1 - 100	0.268	30.9	71.3	-	-	-	Spencer, 1958
	0.1 - 15	0.309	55.6	78.0	-	-	-	Classen & Voigt, 1973
Force Mains	0.1 - 50	0.45	39.9[b]	73.4	-	-	-	Dawes, 1970
	0.1 - 200	0.463	69.0[b]	103	-	-	-	Engineering-Sci., Inc., 1970
	0.1 - 1000	0.483	43.4[b]	83.3	-	-	-	Linaweaver & Clark, 1964
Lift Stations	0.1 - 500	0.685	94.0	140	0.897[c]	28.8 H	32.3 H	Engineering-Sci., Inc., 1970
					0.644[c]	1800	2393	
	1 - 50	0.50	53.8	116	-	-	-	Benjes, 1960

[a] Y = \$/mi, X = mgd.

[b] $D = 11;36\ X^{0.3745}$, $n = 0.015$, $S = 0.003$, $V = 2.65$ fps (American Society of Civil Engineers, 1970, Figure 22).

[c] Composite cost equation, $Y = k X^{\alpha} H + k' X^{\alpha'}$; Y = \$/mi, X = mgd, and H = feet of head.

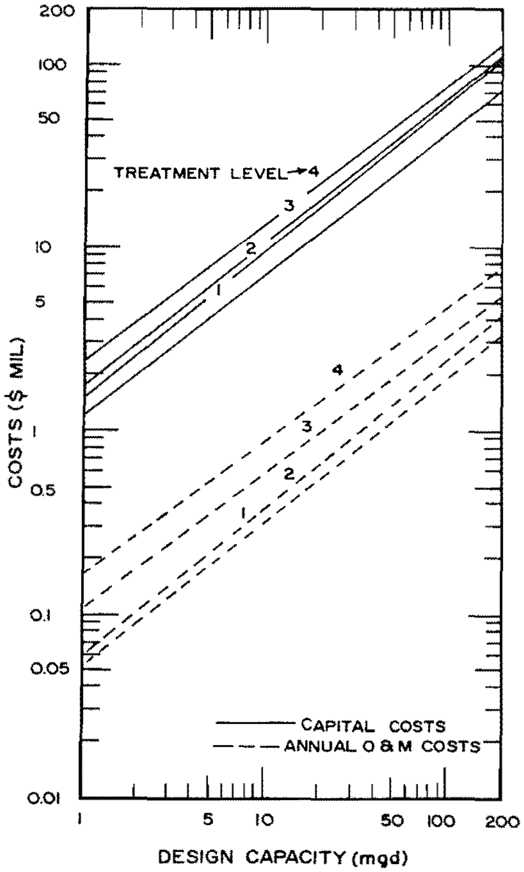


Figure 13. Capital and annual O&M costs vs design capacity to build a new wastewater treatment plant, adjusted to June 1974.

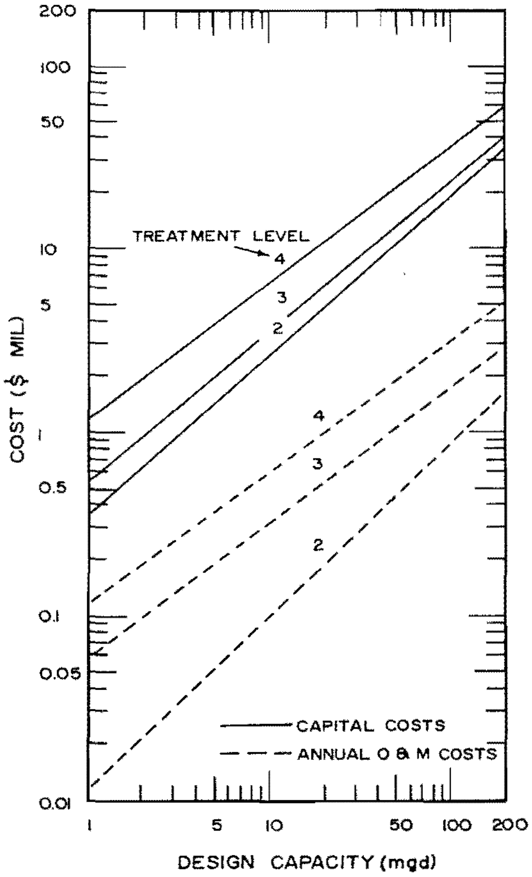


Figure 14. Capital and annual O&M costs vs design capacity to upgrade level '1' wastewater treatment plant, adjusted to June 1974.

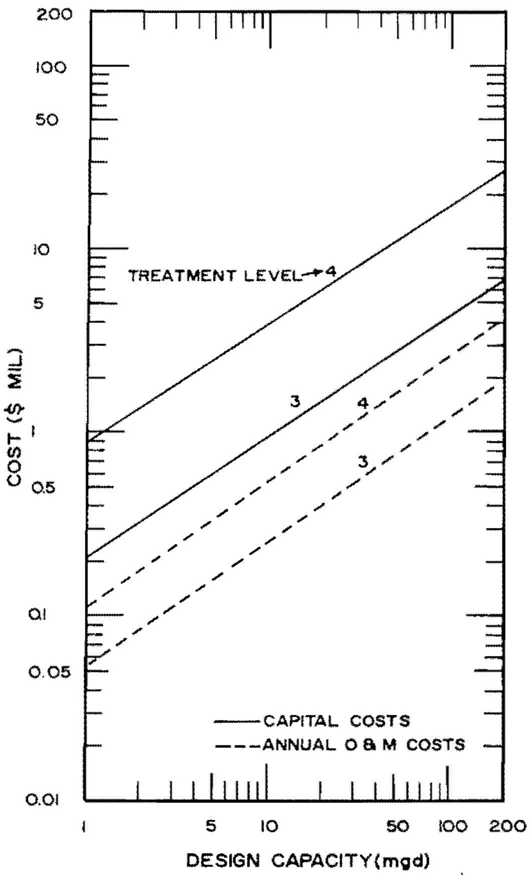


Figure 15. Capital and annual O&M costs vs design capacity to upgrade level '2' wastewater treatment plant, adjusted to June 1974.

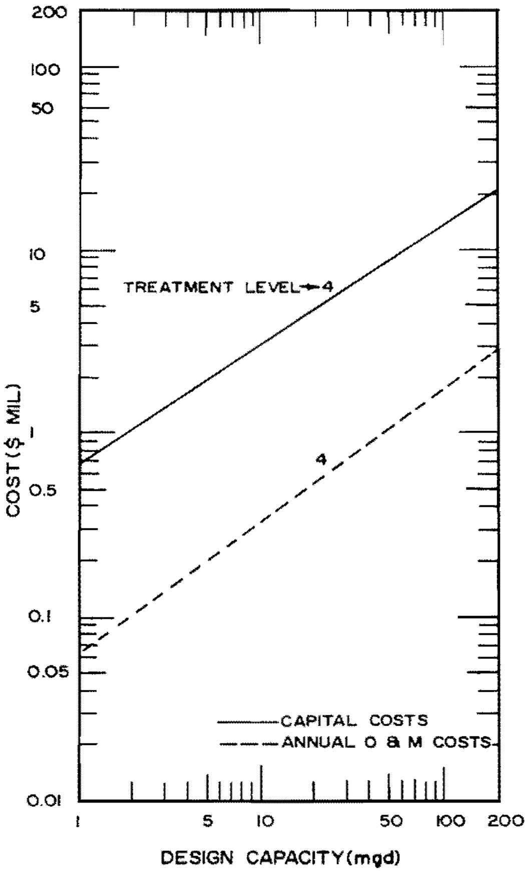


Figure 16. Capital and annual O&M costs vs design capacity to upgrade level '3' wastewater treatment plant, adjusted to June 1974.

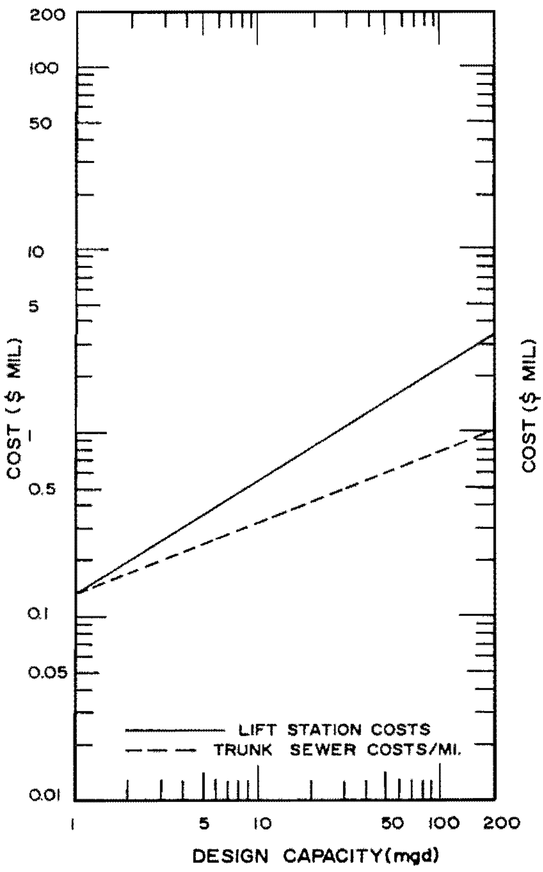


Figure 17. Capital costs of lift stations and trunk sewers vs design capacity, adjusted to June 1974.

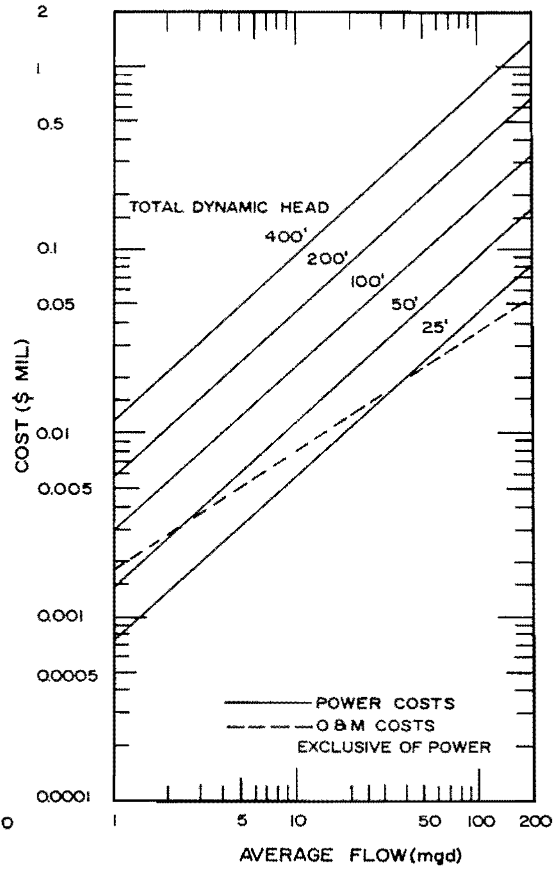


Figure 18. Annual O&M costs of lift station vs average flow, adjusted to June 1974.

APPLICATION OF MODEL TO THE LOWER JORDAN RIVER REGION

The application of the Wastewater Treatment Optimization Model (WTOM) is necessary to verify the performance of the model under real conditions. The Lower Jordan River region along the Wasatch Mountains in Salt Lake and southern Davis Counties, Utah, was chosen as the study area. Considerable data have previously been collected about the wastewater treatment needs of this region, thereby providing a good data base for the application of the model. The application of this model to any other region would require that the appropriate input data be gathered for that region.

Wastewater Treatment Plants

There are eight treatment plants in Salt Lake County and one in Davis County that discharge effluent into the Jordan River in sufficient quantity to be considered in this study. The general distribution of these plants along the Jordan River are indicated in Figure 19. All of the plants, except the Sandy Wastewater Treatment Plant, treat to level 1 with trickling filters. The Sandy plant uses activated sludge.

A summary of the loading and performance data for the wastewater treatment plants is presented in Table 15. There is sufficient treatment capacity in the region to meet the current needs, however, three of the plants, Murray, Tri-Community, and Sandy, are currently overloaded.

Population Projections

The need for planning of wastewater treatment systems is emphasized by the ever increasing population growths over time shown in Table 16. High and low projections were needed for sensitivity analysis of the population projections and its effect on the decision process. The populations were used to calculate the wastewater treatment quantities of the plants.

Wastewater Quantity Projections

The quantities of wastewater projected for each plant in the study area are presented in Table 17. The quantities were obtained from monthly operating summary sheets of each treatment plant, and calculated from population projections and present water usages.

Wastewater Treatment Systems

The use of the model requires that each treatment plant, both existing and proposed, be given an identification number as shown in Figure 20. These numbers are used in all references to a given treatment plant. The length of economically feasible trunk sewers between these treatment plants was determined by plotting on a 1:24000 topographic map, and measuring the distance in feet. These data are reported in Table 18.

Model Input Data

A user's manual for the operation of the model is presented in Appendix A. The required input card formats are presented in that manual. The required input data for this study of the Lower Jordan River Region were obtained from material and data presented previously in this report or developed as otherwise indicated on the following tables. The data required are as follows: Model control parameters, cost equation coefficients, treatment plant characteristics, feasible connecting trunk sewers, population or wastewater projections, and the treatment alternatives.

Model control parameters

Two types of data are required. The first is the control parameters that actually control how the model is to operate. These are described in detail in the user's manual found in Appendix A. The other type of data affects the economic analysis of the model and is presented in Table 19. The variations in the annual increase values reflect alternative future conditions, and were used for the sensitivity analysis of the model.

Cost equation coefficients

The cost coefficients presented in Table 20 determine the costs of expanding and/or upgrading treatment plants, trunk sewers, and lift stations. The selection of the appropriate set of coefficients for treatment plants is controlled by the design index, which ranges from 1 to 10. The remaining parameters are for trunk sewers and lift stations.

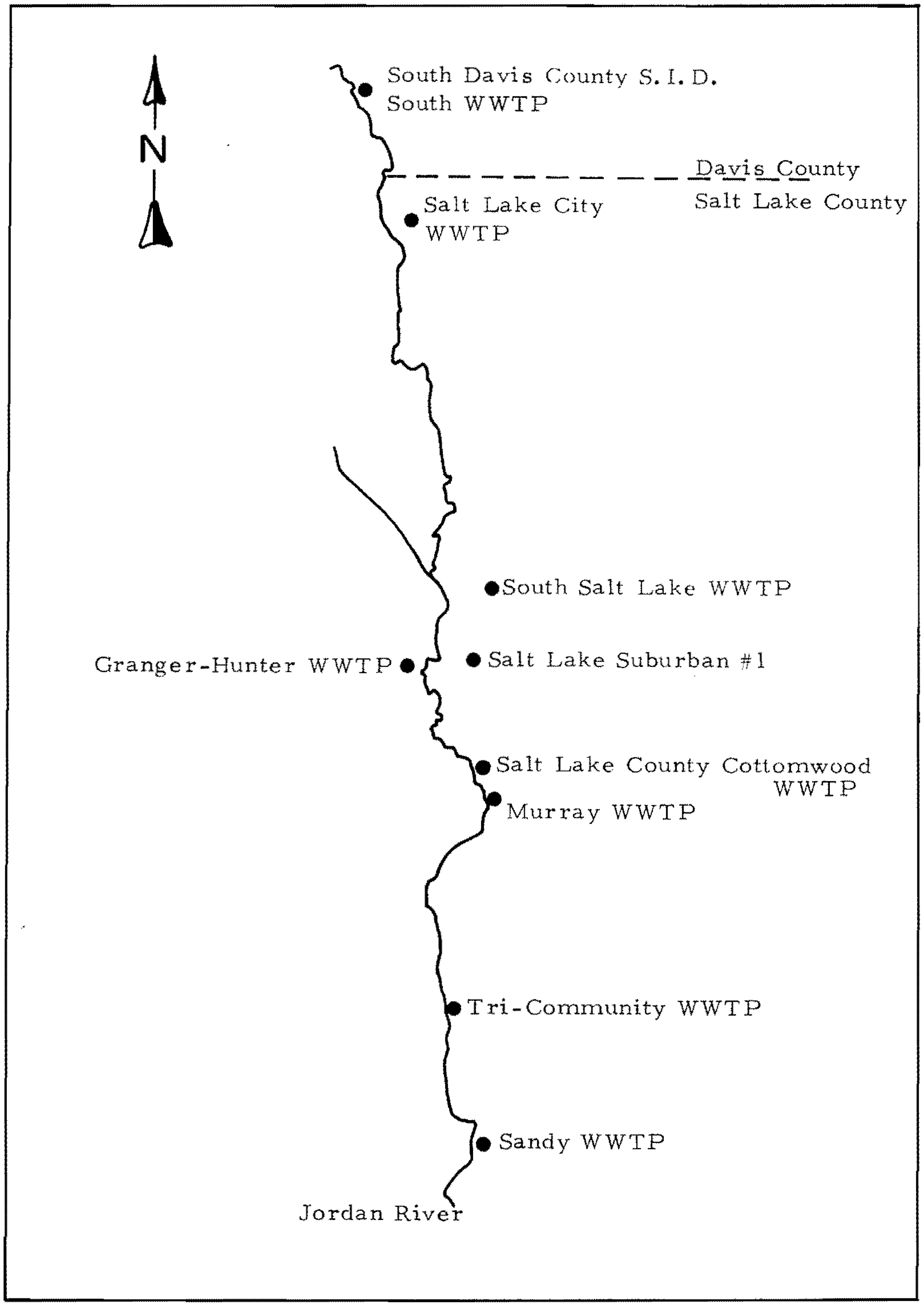


Figure 19. Lower Jordan River wastewater treatment facilities.

Table 15. Treatment plants on Lower Jordan River—1972 loading and actual performance.[a]

No.	Wastewater Treatment Plant	Year Operation Began	Type of Plant[b]	Present Design Capacity (mgd)	Flow (mgd)		BOD mg/l		Suspended Solids mg/l		Settleable Solids mg/l		BOD lbs/day		Suspended Solids lbs/day		Settleable Solids lbs/day	
					Avg.	Peak	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
	DAVIS COUNTY																	
1	South Davis County S. I. D. South Plant	1962	TF	2.27	1.39	1.49	182	24	193	9	1.1	0.1	2,100	277	2,237	104	13	1.2
	SALT LAKE COUNTY																	
2	Salt Lake City	1965	TF	45.0	33.4	35.8	130	23	124	33	3.6	0.2	36,168	6,390	34,540	9,192	1,002	55.7
3	South Salt Lake City	1954	TF	4.55	3.69	4.35	170	19	180	8	4.3	0.1	5,250	597	5,539	246	132	3.1
4	Salt Lake City S. S. D. # 1	1955	TF	16.0	11.69	14.0	173	24	182	10	6.0	0.1	16,840	2,330	17,744	975	545	9.7
5	Granger-Hunter Imp. Dist.	1959	TF	7.3	6.13	6.75	203	25	227	9	8.3	0.1	10,760	1,350	11,605	460	424	5.1
6	Salt Lake County Cottonwood	1958	TF	8.0	5.3	5.9	124	29	143	13	5.3	0.1	5,470	1,280	6,320	575	234	4.4
7	Murray City	1953	TF	4.0	2.4	4.3	262	30	270	10	4.8	0.1	5,230	599	5,404	200	96	2.0
8	Tri-Community (Midvale)	1956	TF	3.6	3.78	5.46	152	24	159	10	5.7	0.1	4,790	775	5,012	315	180	3.2
9	Sandy City	1962	AS	1.5	1.73	2.07	175	22	-	-	7.3	0.1	2,520	320	-	-	105	1.4
	Salt Lake County Sub-total			89.95	68.12	78.63												
	Lower Jordan River Total			92.22	69.51	80.12												

[a] Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973a), Table 6-2.

[b] TF - Trickling filter, AS - Activated sludge.

Table 16. Present and projected populations.[a]

No.	Wastewater Treatment Plant	(Census) 1970	(Estimate) 1974 (0)[c]	1978 (4)	1985 (11)	1995 (21)	(Low)[b] 2024 (50)	(Middle) 2024 (50)	(High)[b] 2024 (50)
	DAVIS COUNTY								
1	South Davis County								
	S. I. D. South Plant								
	North Salt Lake	2,143	2,972	3,800	4,700	5,700			
	Unincorporated	7,600	8,250	8,900	10,200	11,900			
	Sub-total	9,743	11,222	12,700	14,900	17,600	17,400	25,400	31,800
	SALT LAKE COUNTY								
2	Salt Lake City	174,870	188,367	201,864	215,361	242,356	219,200	320,600	401,700
3	South Salt Lake City								
	Chesterfield								
	Sub-total	11,821	14,802	17,783	20,764	26,726	30,100	44,000	55,100
4	Salt Lake City S. S. D. #1	86,092	93,918	101,744	105,404	113,581			
	Taylorsville-Bennion	19,092	22,546	26,000	33,200	46,745			
	Sub-total	105,184	116,464	127,744	138,604	160,326	152,700	223,300	279,800
5	Granger-Hunter Imp. Dist.								
	Kearns								
	Sub-total	49,374	63,450	77,526	91,602	119,755	137,700	201,500	252,000
6	Salt Lake County Cottonwood	34,416	43,025	51,634	60,243	77,462	87,100	127,400	159,600
7	Murray City	21,308	26,646	31,984	37,322	48,000	54,000	79,000	99,000
8	Tri-Community								
	Midvale	7,499	7,999	8,499	8,999	10,000			
	West Jordan	5,473	7,978	10,483	12,988	18,000			
	S. L. C. S. S. D. #2	6,823	3,460	10,098	11,733	15,000			
	S. L. C. S. I. D. #1	13,763	20,130	26,497	32,384	45,600			
	Sub-total	33,557	44,567	55,577	66,584	88,600	104,200	152,400	190,900
9	Sandy City	4,943	5,354	5,765	6,176	7,000			
	Sandy Suburban	7,432	9,884	12,334	14,784	19,682			
	Sub-total	12,377	15,238	18,099	20,960	26,682	29,600	43,300	54,200
	Salt Lake County Sub-total	442,907	514,059	528,211	651,440	789,907	814,600	1,191,500	1,492,300
	Lower Jordan River Total	452,650	523,780	594,911	666,340	801,507	832,000	1,216,900	1,524,100

[a] Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973a) up to 1995, straight line projection to 2024.

[b] Estimated from Bishop et al. (1974).

[c] Year of data.

Table 17. Average flows of wastewater treatment plants, mgd.[a]

No.	Wastewater Treatment Plant	Present Design Capacity (mgd)	(Estimate) 1974 (0)[b]	1978 (4)	1985 (11)	1995 (21)	(Low) 2024 (50)	(Middle) 2024 (50)	(High) 2024 (50)
	DAVIS COUNTY								
1	South Davis County								
	S. I. D. South Plant								
	North Salt Lake								
	Unincorporated								
	Sub-total	2.27	1.4	1.7	1.9	2.3	2.3	3.3	4.2
	SALT LAKE COUNTY								
2	Salt Lake City	45.0	34.1	37.0	40.0	43.5	39.3	57.5	72.1
3	South Salt Lake City	4.55	3.6	4.2	4.9	5.9			
	Chesterfield		0.4	0.8	1.3	1.9			
	Sub-total		4.0	5.0	6.2	7.8	8.8	12.8	16.1
4	Salt Lake City S. S. D. #1	16.0	9.7	10.3	11.0	12.0			
	Taylorsville-Bennion		2.4	3.0	3.7	4.7			
	Sub-total		12.1	13.3	14.7	16.7	15.9	23.3	29.1
5	Granger-Hunter Imp. Dist.	7.3	4.4	5.8	7.3	9.5			
	Kearns		2.2	2.8	3.6	4.7			
	Sub-total		6.6	8.6	10.9	14.2	16.3	23.9	29.9
6	Salt Lake County Cottonwood	8.0	5.7	7.5	9.1	13.0	14.6	21.4	26.8
7	Murray City	4.0	2.6	3.2	3.7	4.6	5.2	7.6	9.5
8	Tri-Community	3.6							
	Midvale		1.5	1.6	1.7	1.8			
	West Jordan		1.2	1.6	2.2	2.9			
	S. L. C. S. S. D. #2		1.3	1.5	1.9	2.4			
	S. L. C. S. I. D. #1		0	3.7	5.0	7.3			
	Sub-total		4.0	8.4	10.8	14.4	16.9	24.8	31.0
9	Sandy City	1.5	0.7	0.9	1.0	1.1			
	Sandy Suburban		1.2	1.8	2.2	2.9			
	Sub-total		1.9	2.7	3.2	4.0	4.4	6.5	8.1
	Salt Lake County Sub-total	89.4	71.0	85.7	98.6	118.2	121.4	177.8	222.6
	Lower Jordan River Total	92.22	72.4	87.4	100.5	120.5	123.7	181.1	226.8

[a] Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973a) up to 1995; values in 2024 based on population projections and estimated.

[b] Year of data.

Treatment plant data

The characteristics of the existing and proposed treatment plants are required to initialize the model. These plants do not have to be entered into the model in sequential order as the model will store their real number and assign a new number to them. The dynamic programming section of the model uses present worth as the control parameter in the selection of the optimum set of alternatives; therefore, the selection of the appropriate value for the capital debt of the plants is quite important. The elevation of the treatment plant is used to calculate the slope and pumping heads on the trunk sewers between the plants. The name of the treatment plant is output by the model as a listing of the input data for the treatment plants. This provides an easy correlation between plant number and names. These data are presented in Table 21.

Feasible connecting trunk sewers

There are a large number of possible trunk sewers between treatment plants, however, many of them would not be considered economically desirable. The set of feasible sewers presented in Figure 20 and Table 22 were selected to represent the feasible treatment systems. The length of the trunk sewer affects the construction costs and lift station requirements. A minimum slope of the trunk sewer was defined in the control parameters section, and this was used to determine if the flow would be gravity or if lift stations were required. The existing capacity and capital debt set the initial conditions for the model.

Population input data

The population data can be entered for any or all points during the planning period. However, both the initial and final population values must be entered. Since the proposed regional plant does not serve any population area directly, it does not have to be entered. The zero value data for that plant will automatically be generated. These input data are shown in Table 23.

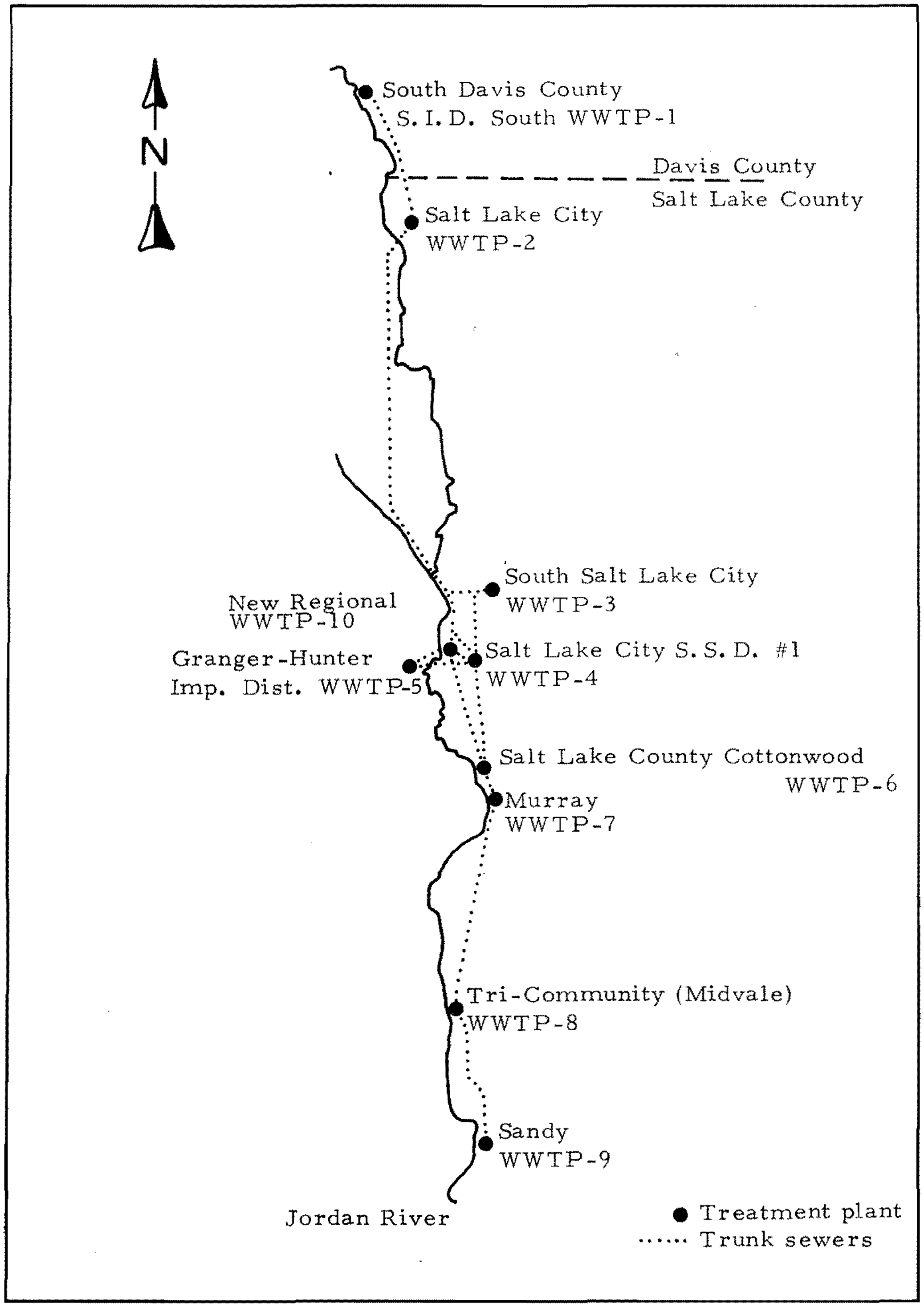


Figure 20. Feasible connecting trunk sewers.

Table 18. Trunk sewer lengths, ft.[a]

To From	1	2	3	4	5	6	7	8	9	10
1	-	12,500	-	-	-	-	-	-	-	-
2	12,500	-	38,300	41,700	-	-	-	-	-	40,300
3	-	38,300	-	7,800	-	-	-	-	-	9,400
4	-	41,700	7,800	-	5,800	9,300	-	-	-	2,400
5	-	-	-	5,800	-	-	-	-	-	3,600
6	-	-	-	9,300	-	-	2,800	-	-	10,200
7	-	-	-	-	-	2,800	-	18,600	-	-
8	-	-	-	-	-	-	18,600	-	13,200	-
9	-	-	-	-	-	-	-	13,200	-	-
10	-	40,300	9,400	2,400	3,600	10,200	-	-	-	-

[a] Plotted and scaled on 1:24000 scale topographic maps.

Wastewater quantity input data

Wastewater quantities can be entered directly into the model in place of the population projections if the appropriate control parameter on card 2 of the control cards (see Appendix A) is activated. This option might be used in cases where population does not have a constant relationship to wastewater quantity.

Treatment alternatives

There are a large number of possible combinations of treatment plants and trunk sewers, however, since this section is only to test the model, 40 alternatives were prepared for study. The first group of 20 includes all nine treatment plants and one proposed regional plant on the Lower Jordan River. The last 20 alternatives include only the plants located in Salt Lake County. These were included to account for the political constraints of county boundaries.

These alternatives were additionally analyzed for the effect of the proposed 1977 and 1980 Utah State effluent standards. The model also has the capability to apply any time phased effluent standards to the individual treatment plants if the assimilative capacity of the river were to be used by any of the treatment plants.

Table 19. Selection of model parameters.

Parameter	1974 Values	Annual Increase		
		Low	Projected	High
Capital recovery period for treatment plants, yr.	20.0	-	-	-
Capital recovery period for trunk sewers, yr.	50.0	-	-	-
Capital recovery period for lift stations, yr.	10.0	-	-	-
Construction lag time, yr.	2	-	-	-
Annual rate of interest	0.0600	0.0	0.001675	0.003
Gpd/capita of wastewater flow	100.0	-	-	-
Peak flow factor (for population projections only)	2.25	-	-	-
Peak flow factor (for wastewater flow projections only)	1.25	-	-	-
Minimum slope of trunk sewer, -ft/1000 ft.	-0.100	-	-	-
Average pumping head of lift stations, ft	25.0	-	-	-
ENR-B Index for treatment plant and lift station costs	340.66	10.0	26.17	40.0
WPC-S or EPA-S Index for sewer construction costs	211.66	10.0	15.184	30.0
Labor cost index for O&M and power costs	4.36	0.10	0.21	0.30
Time phased treatment levels, 1977	2	-	-	-
1980	4	-	-	-

Table 20. **Input data for cost equation coefficients[a] - $y = k X^{a}$.**

Design Index	Treatment Level		Construction Costs		O & M Costs	
	Initial	Final	k	a	k	a
1	0	1	1.2010	0.7730	0.0537	0.7750
2	0	2	1.5320	0.8000	0.0599	0.8050
3	0	3	1.7120	0.7890	0.1070	0.7460
4	0	4	2.3620	0.7580	0.1650	0.7300
5	1	2	0.3580	0.8670	0.0133	0.9420
6	1	3	0.5380	0.8170	0.0585	0.7380
7	1	4	1.1880	0.7400	0.1160	0.7180
8	2	3	0.2060	0.6600	0.5230	0.6810
9	2	4	0.8580	0.6490	0.1100	0.6890
10	3	4	0.6780	0.6460	0.6300	0.7220
11	-	-	0.1270[b]	0.3900[b]	0.0018[c]	0.6640[c]
12	-	-	0.1280[d]	0.6150[d]	0.0288[e]	0.8970[e]

[a] Total cost, y, in mil \$; quantity, X, in mgd.

[b] Trunk sewer construction cost, mil \$/mile.

[c] Lift station overall O & M cost, excluding power costs.

[d] Lift station construction costs.

[e] Lift station power costs - $y = 10^{-3} k X^{a} H$; H is pumping head in ft.

The 40 alternatives were initially analyzed individually over time to determine the total present worth of that alternative by its use for 20 years. Four alternatives were selected from both the Salt Lake County and Lower Jordan River Region groups for final comparison by the dynamic programming model. The best combination of alternatives was selected by the model and the annual costs and the list of expansion projects were obtained.

A sensitivity analysis was run for one alternative by adjusting the amount of the annual increase in interest rates, ENR-building cost index, EPA-sewer cost index, and labor rate index. The economic effects of high and low population projections and variation in the value of the peak flow factor were also determined. An additional seven alternatives were analyzed to evaluate the effects of inflation on the selection of the best alternative.

Table 21. **Treatment plant input data.**

Plant No.	Capacity (mgd)	Capital Debt[a] (mil \$)	Elevation (ft)	Treatment Level	Name of Treatment Plant (36 letter limit)
1	2.27	0.3064	4214	1	South Davis Co. S.I.D. South Plant
2	45.0	3.2259	4213	1	Salt Lake City
3	4.55	0.5591	4230	1	South Salt Lake City
4	16.0	0.1138	4238	1	Salt Lake City S.S.D. #1
5	7.3	0.3715	4250	1	Granger-Hunter Imp. Dist.
6	8.0	0.3514	4246	1	Salt Lake County Cottonwood
7	4.0	0	4243	1	Murray City
8	3.6	0.0990	4277	1	Tri-Community (Midvale)
9	1.5	0.3111	4300	1	Sandy City
10	0	0	4236	0	New Regional Plant @ 900 W 3100 S

[a] Estimated using construction cost equations adjusted to year built, and applying straight line depreciation.

Table 22. Input data feasible connecting trunk sewers.

Origin j	Destination k	Length (ft)	Capacity (mgd)	Debt (mil $)
1	2	12,500	0	0
2	1	12,500	0	0
2	3	38,300	0	0
2	4	41,700	0	0
2	10	40,300	0	0
3	2	38,300	0	0
3	4	7,800	0	0
3	10	9,400	0	0
4	2	41,700	0	0
4	3	7,800	0	0
4	5	5,800	0	0
4	6	9,300	0	0
4	10	2,400	0	0
5	4	5,800	0	0
5	10	3,600	0	0
6	4	9,300	0	0
6	7	2,800	0	0
6	10	10,200	0	0
7	6	2,800	0	0
7	8	18,600	0	0
8	7	18,600	0	0
8	9	13,200	0	0
9	8	13,200	0	0
10	2	40,300	0	0
10	3	9,400	0	0
10	4	2,400	0	0
10	5	3,600	0	0
10	6	10,200	0	0

Treatment alternative input data

Maps of the treatment alternatives for the Lower Jordan River Region and the Salt Lake County area are shown in Figures 21 and 22, respectively. The treatment levels shown reflect the current or near future treatment levels. Since the model is capable of enforcing higher treatment levels on each individual plant and at different points in time, it may be desirable to set the plants at the current level and have them upgraded as required by the time phased effluent standards.

The treatment plant alternatives are shown with no flow requirements, but the model is capable of accepting both low flow and high flow limitations. When a plant exceeds either limit during the dynamic programming phase of the model, an arbitrary value of one billion dollars is added to the present worth total to prohibit that alternatives selection as an optimum alternative. This value is removed at a later year if the condition is changed. A capacity limit indicator on the printout is also used to indicate this condition.

The data from the maps (Figures 21 and 22) are presented in the proper form for computer input in Tables 24 and 25. The exact format requirements are discussed in the user's manual in Appendix A.

Results of Model Runs

All of the alternatives were analyzed individually to determine the present worth value of each alternative. The 20 year total present worth values were used to select the optimum alternatives. The four alternatives that produced the lowest present worth values were selected for further analysis. In Tables 26 and 27 are presented the annual costs and present worths, both with effluent standards and without standards, for the Lower Jordan River Region and the Salt Lake Regions, respectively.

The selected alternatives were analyzed by the dynamic programming portion of the model to determine if there would be any interaction between the alternatives. At the end of the planning period, the alternatives were ranked on the basis of present worth. The rankings for the Lower Jordan River Region and the Salt Lake County Region are shown in Tables 28 and 29, respectively. This also contains a detailed listing of which alternatives were optimum during each year of the planning period. One of the more important features of the model is the listing of quality-capacity expansion projects. In Tables 30 and 31, the required projects are lised for the 1st optimal treatment sequence for both the regions.

Sensitivity analysis

A sensitivity analysis was run on alternative 8 to provide information about the effect of variations in the data on the present worth value. The results are summarized in Table 32. The data are also plotted in Figures 23 and 24. A relative index was used in Figure 23 so that effects of the interest rate and cost indexes could be plotted on the same figure. The true value is equal to the relative index divided by the value shown with each parameter.

The seven additional alternative treatment schemes shown in Figure 25 were analyzed to determine the effect of inflation on the selection of the best alternative. The existing debt was set equal to zero and interest rate was held constant. Three effluent quality schedules based on the federal requirements were used. A summary of the model parameters for the sensitivity analysis are presented in Table 33. The results of the model runs are shown in Table 34.

Table 23. Wastewater flow projections with population or wastewater data.

Year	Time Period	Wastewater Treatment Plant Numbers 1	2	3	4	5	6	7	8	9
		Population Projections								
1974	0	11,222	188,367	14,802	116,464	63,450	43,025	26,646	44,567	15,238
1978	4	12,700	201,864	17,783	127,744	77,526	51,634	31,984	55,577	18,099
1985	11	14,900	215,361	20,764	138,604	91,602	60,243	37,322	66,584	20,960
1995	21	17,600	242,356	26,726	160,326	119,755	77,462	48,000	88,600	26,682
2024 (L)[a]	50	17,400	219,200	30,100	152,700	137,700	87,100	54,000	104,200	29,600
2024 (M)	50	25,400	320,600	44,000	223,300	201,500	127,400	79,000	152,400	43,300
2024 (H)[a]	50	31,800	401,700	55,100	279,800	252,000	159,600	99,000	190,900	54,200
		Average Flows of Wastewater Treatment Plants, mgd								
1974	0	1.4	34.1	4.0	12.1	6.6	5.7	2.6	4.0	1.9
1978	4	1.7	37.0	5.0	13.3	8.6	7.5	3.2	8.4	2.7
1985	11	1.9	40.0	6.2	14.7	10.9	9.1	3.7	10.8	3.2
1995	21	2.3	43.5	7.8	16.7	14.2	13.0	4.6	14.4	4.0
2024 (L)[a]	50	2.3	39.3	8.8	15.9	16.3	14.6	5.2	16.9	4.4
2024 (M)	50	3.3	57.5	12.8	23.3	23.9	21.4	7.6	24.8	6.5
2024 (H)[a]	50	4.2	72.1	16.1	29.1	29.9	26.8	9.5	31.0	8.1

[a] Assume a straight line projection between 1974 and 2024.

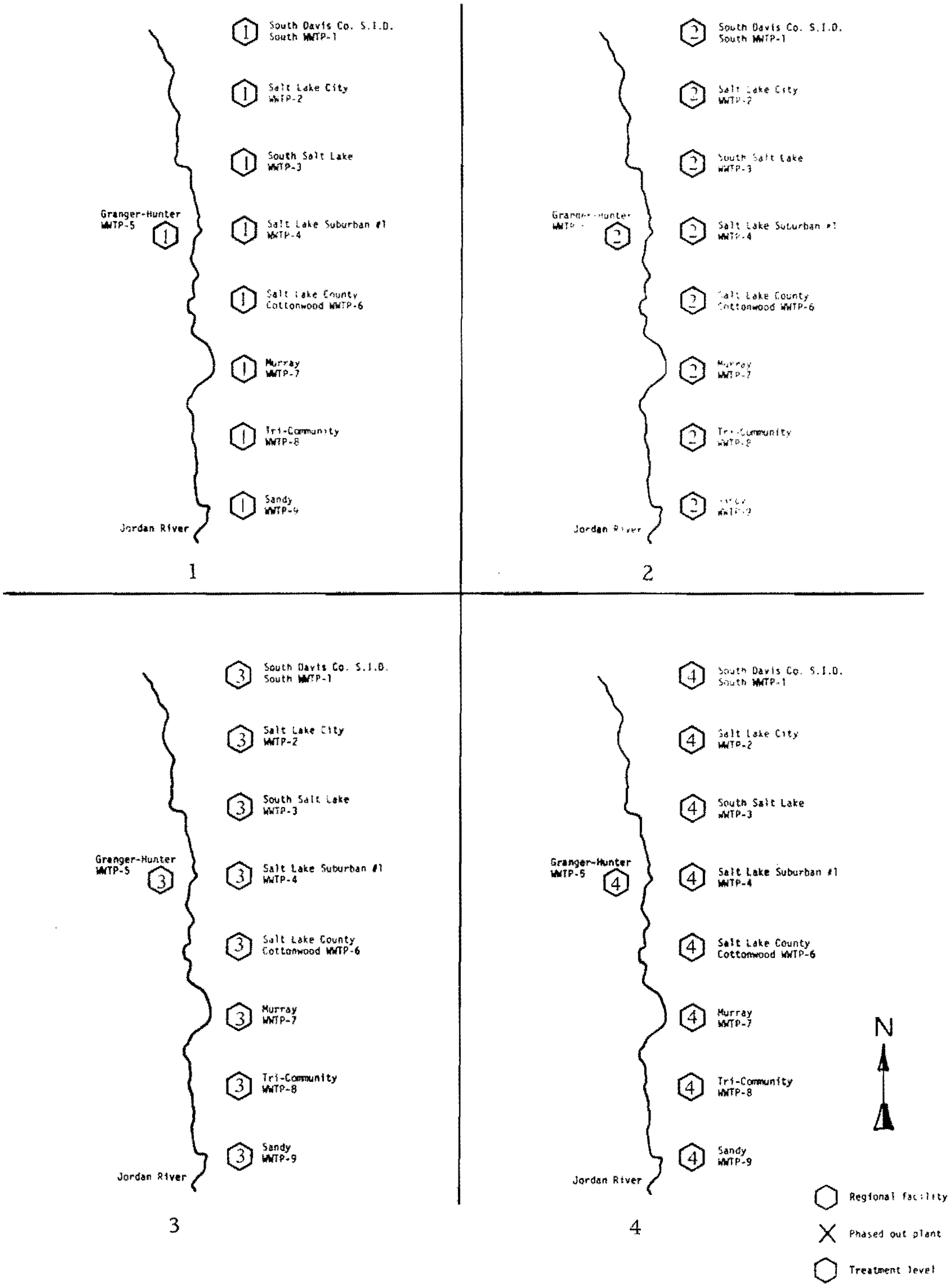


Figure 21. Lower Jordan River conceptual wastewater treatment alternatives.

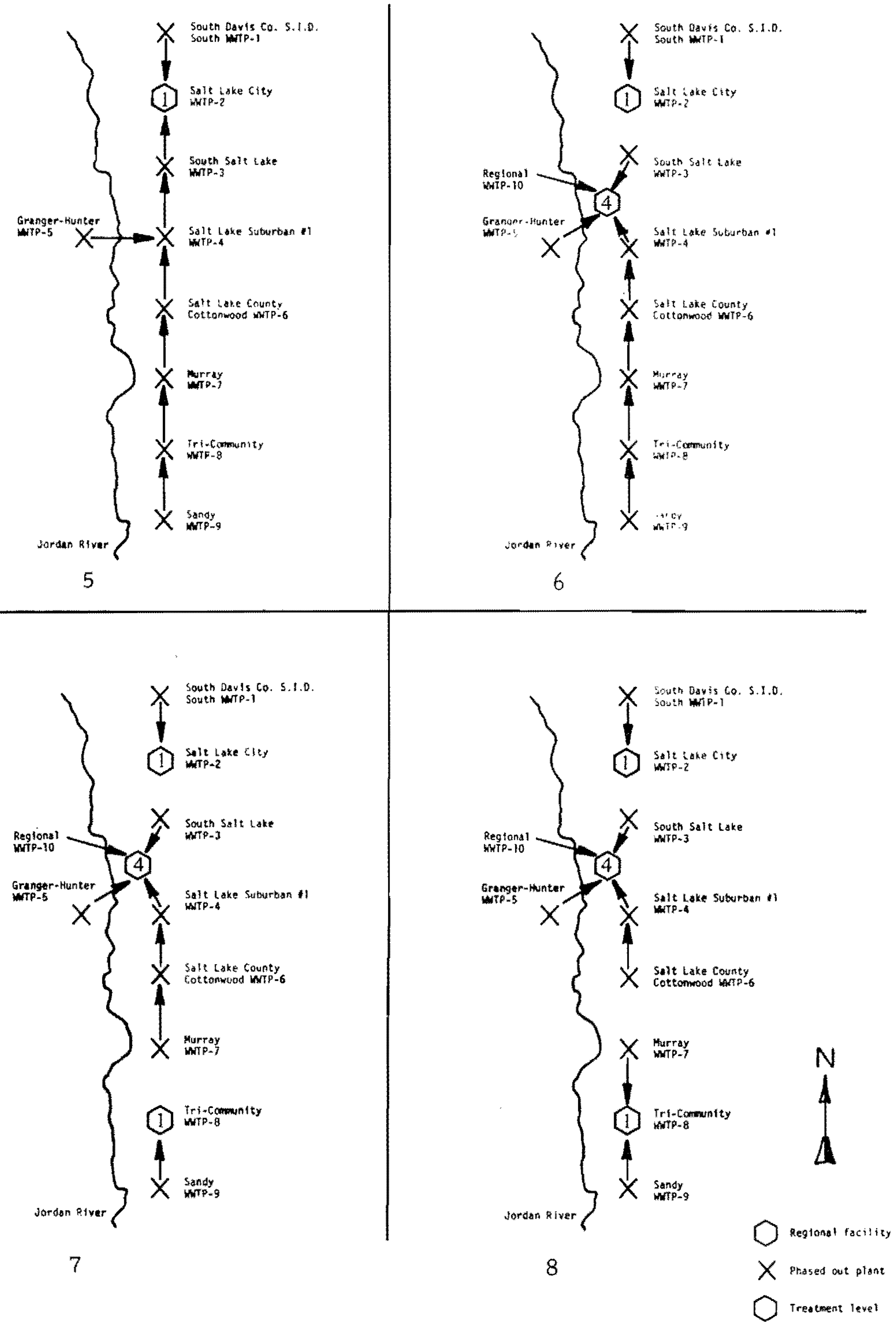


Figure 21. Continued.

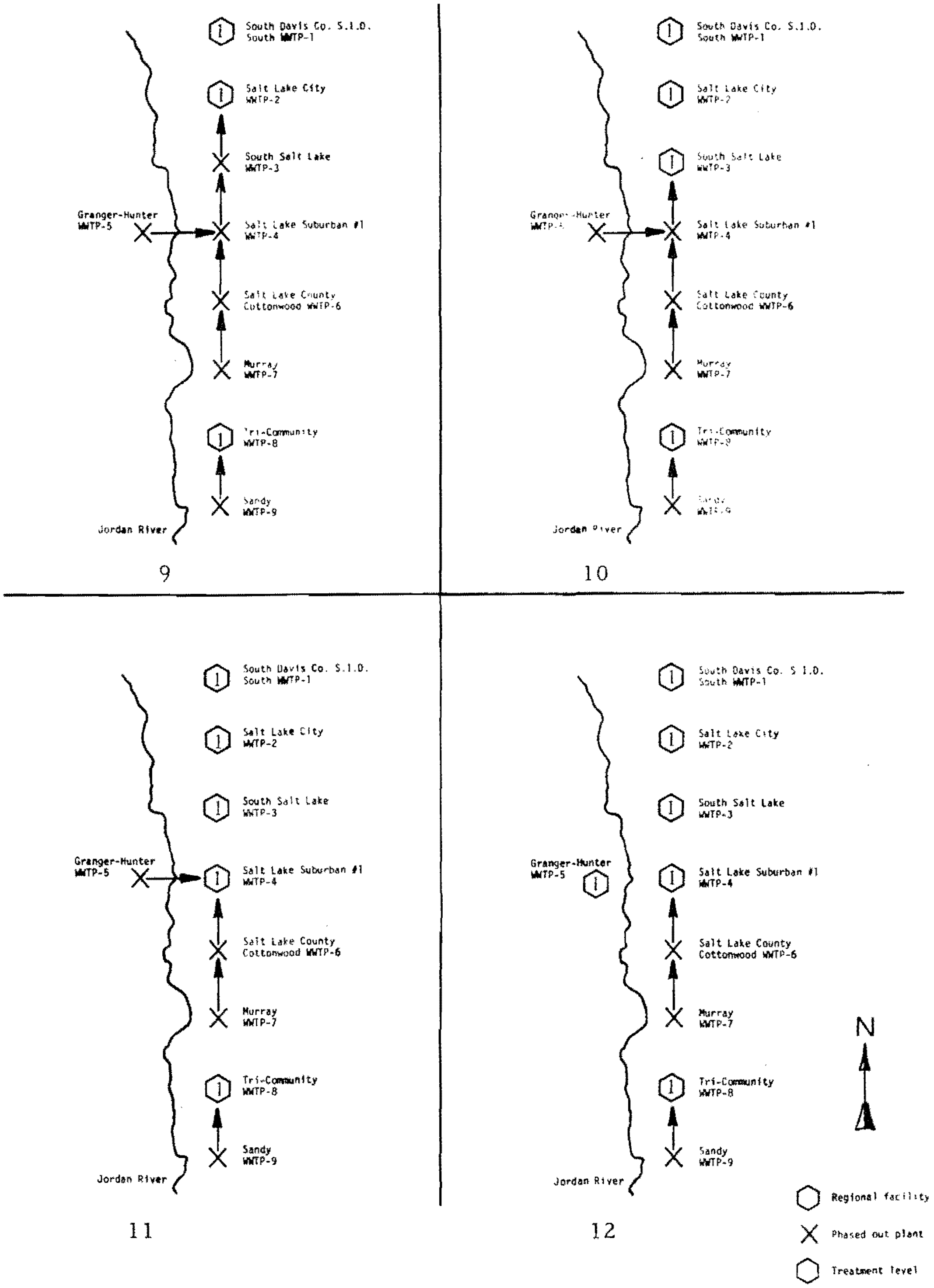
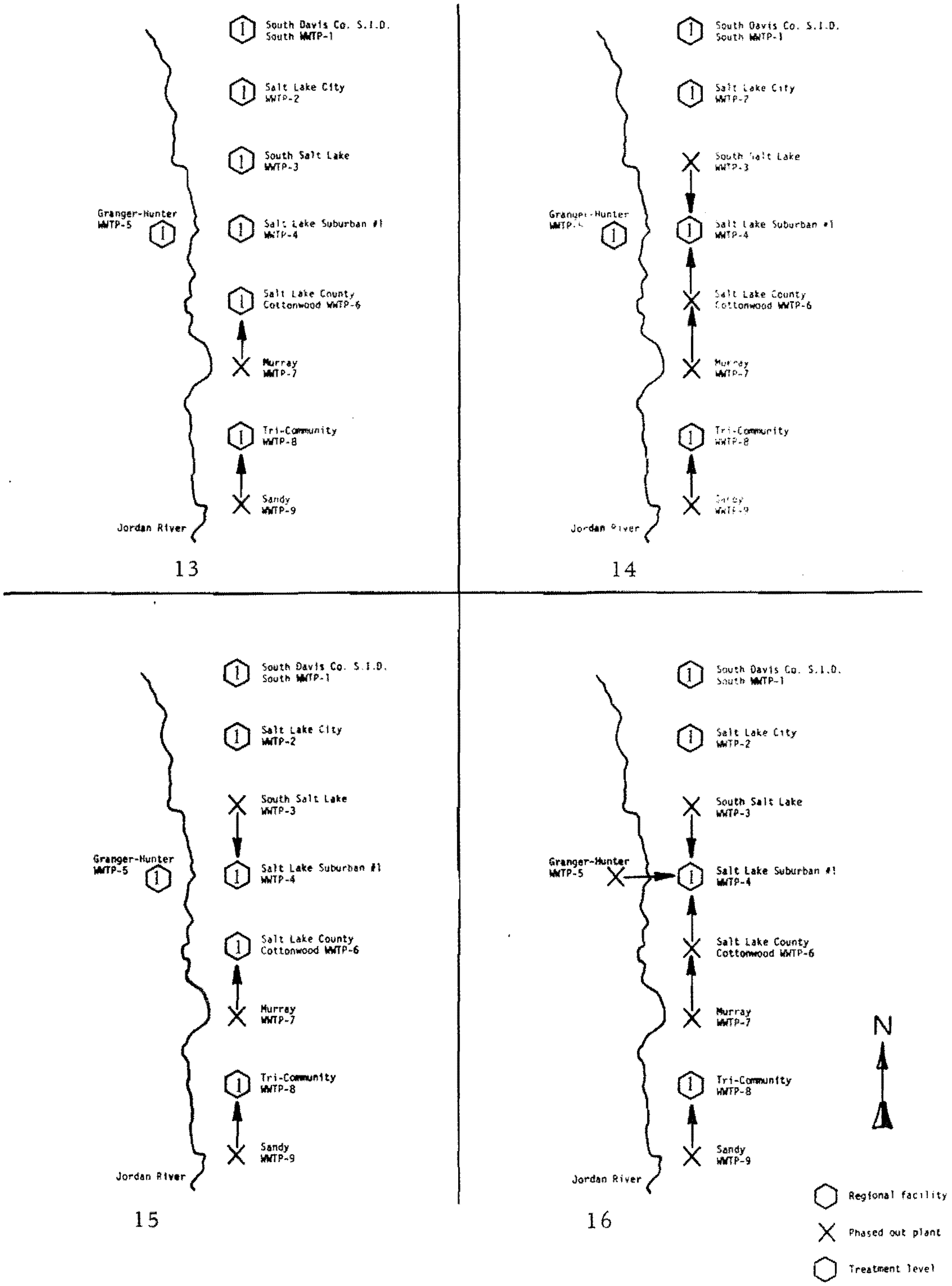


Figure 21. Continued.



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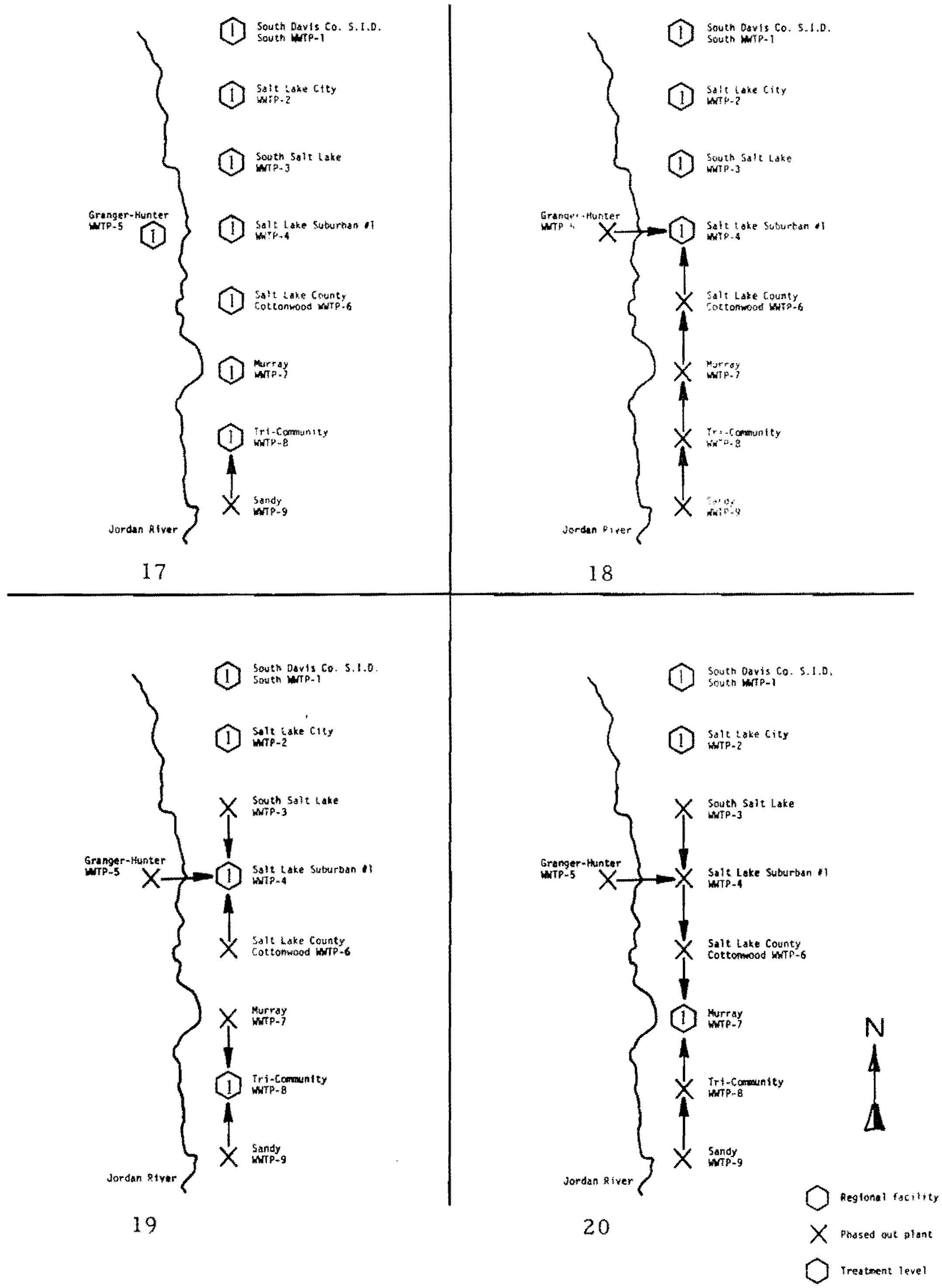

Figure 21. Continued.

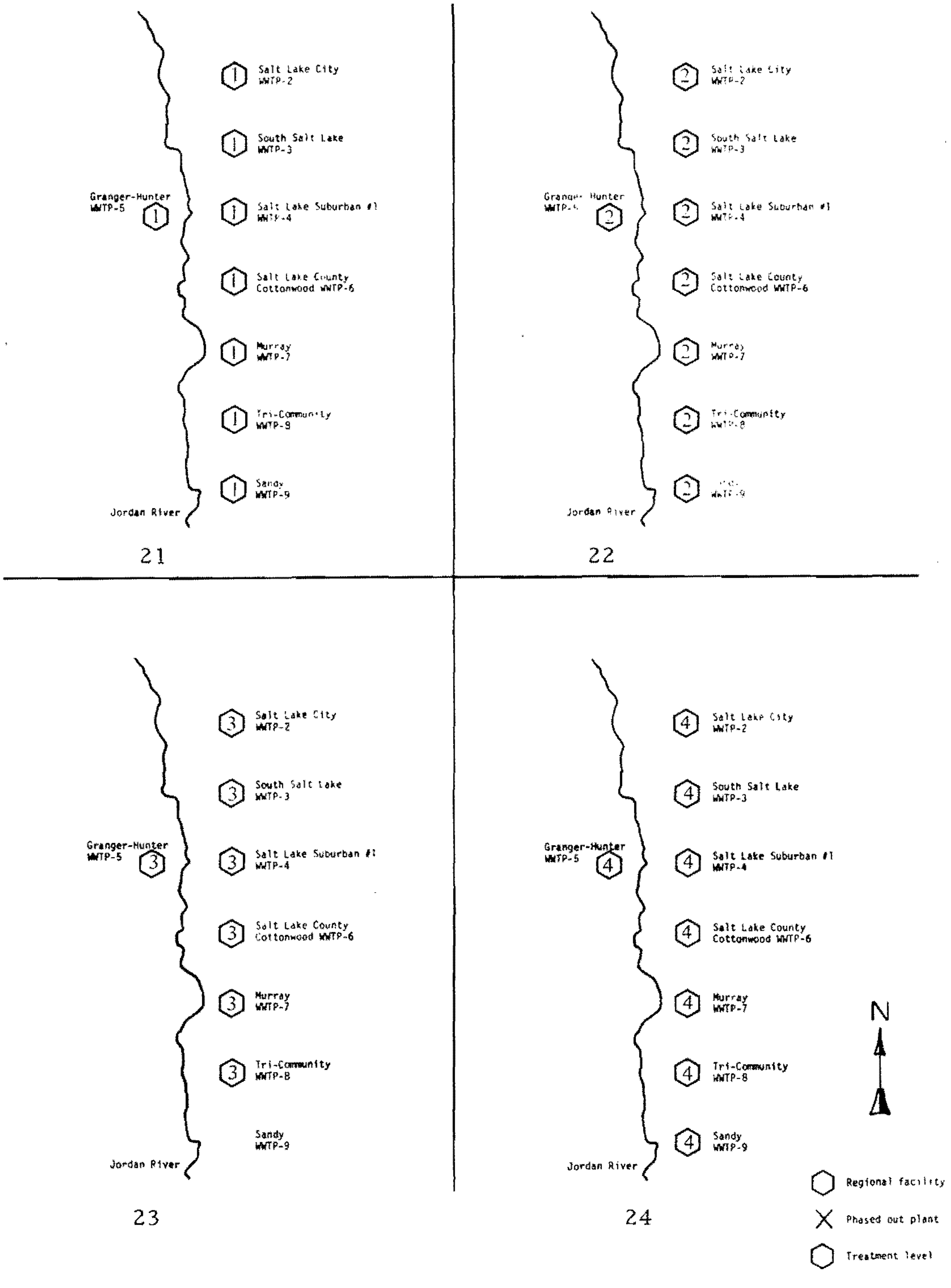

Figure 22. Salt Lake County conceptual wastewater treatment alternatives.

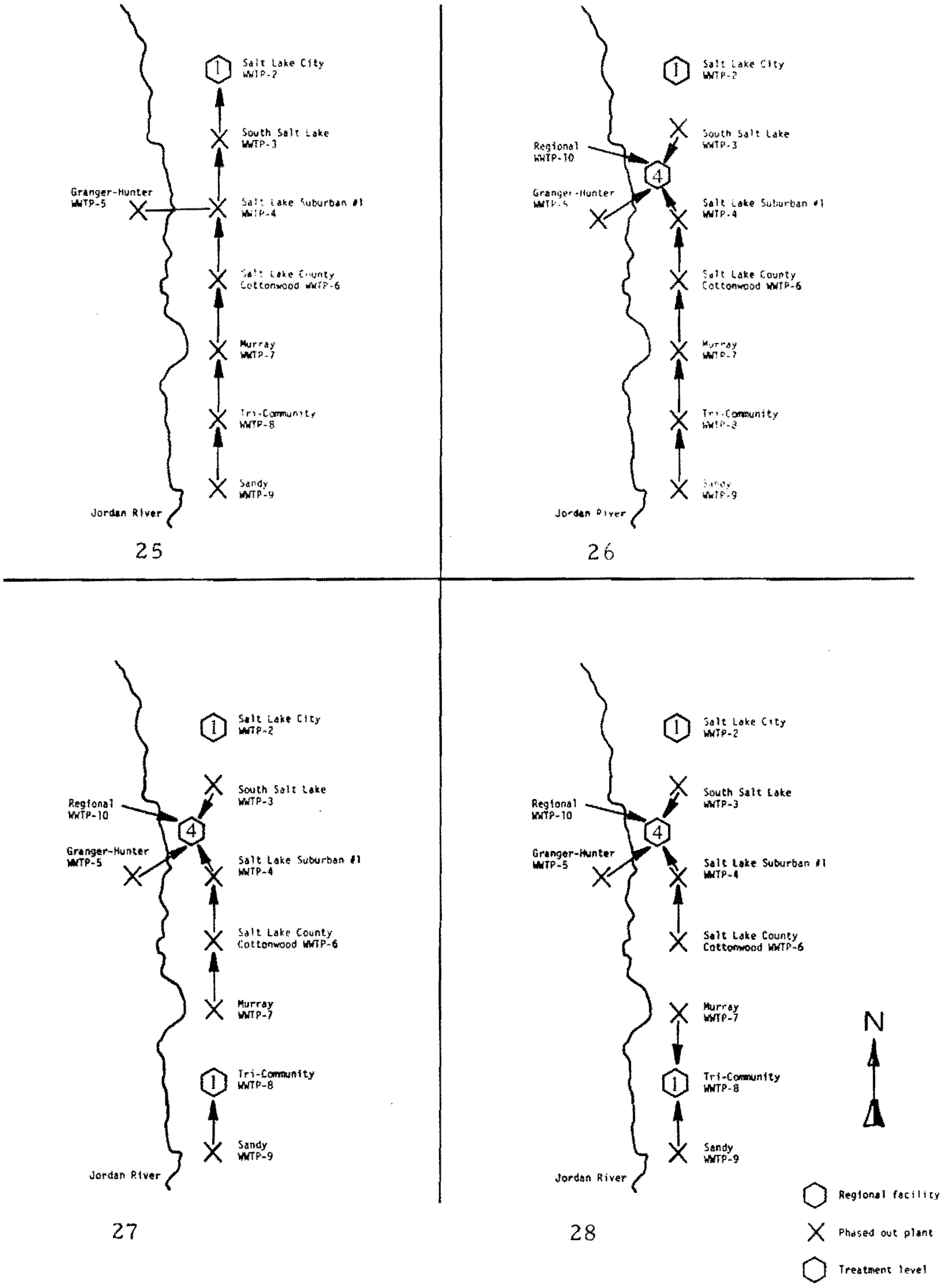

Figure 22. Continued.

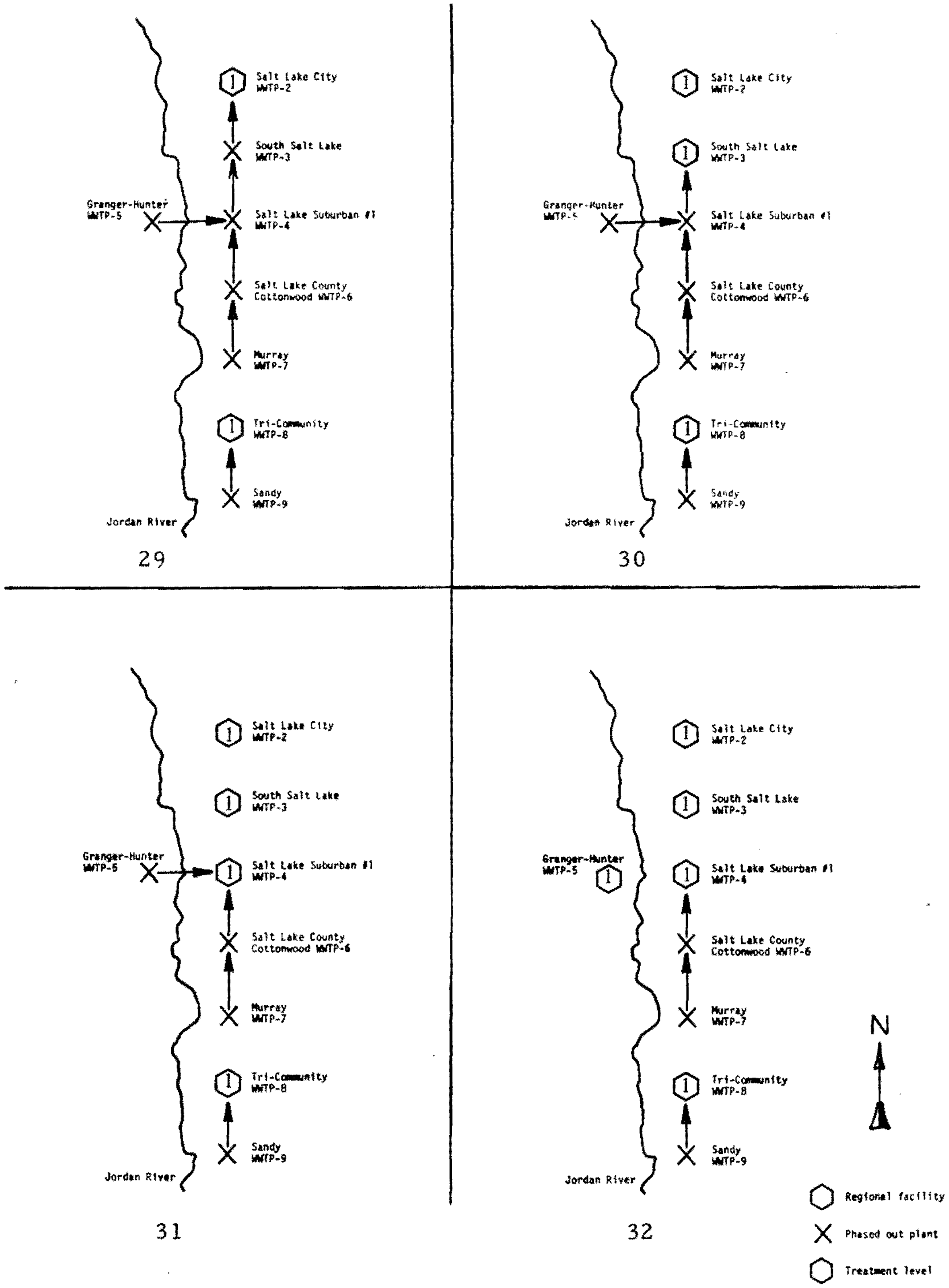

Figure 22. Continued.

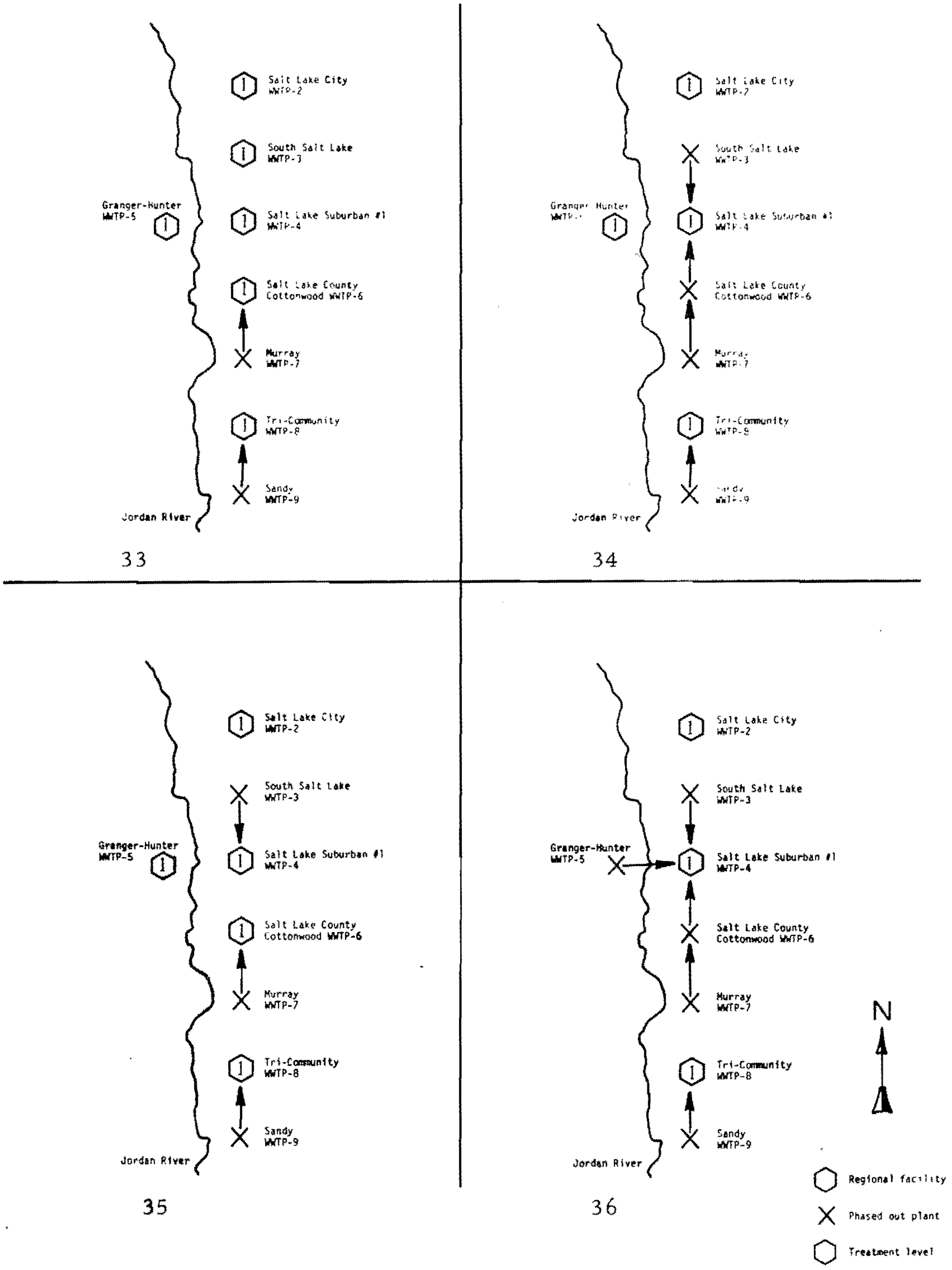

Figure 22. Continued.

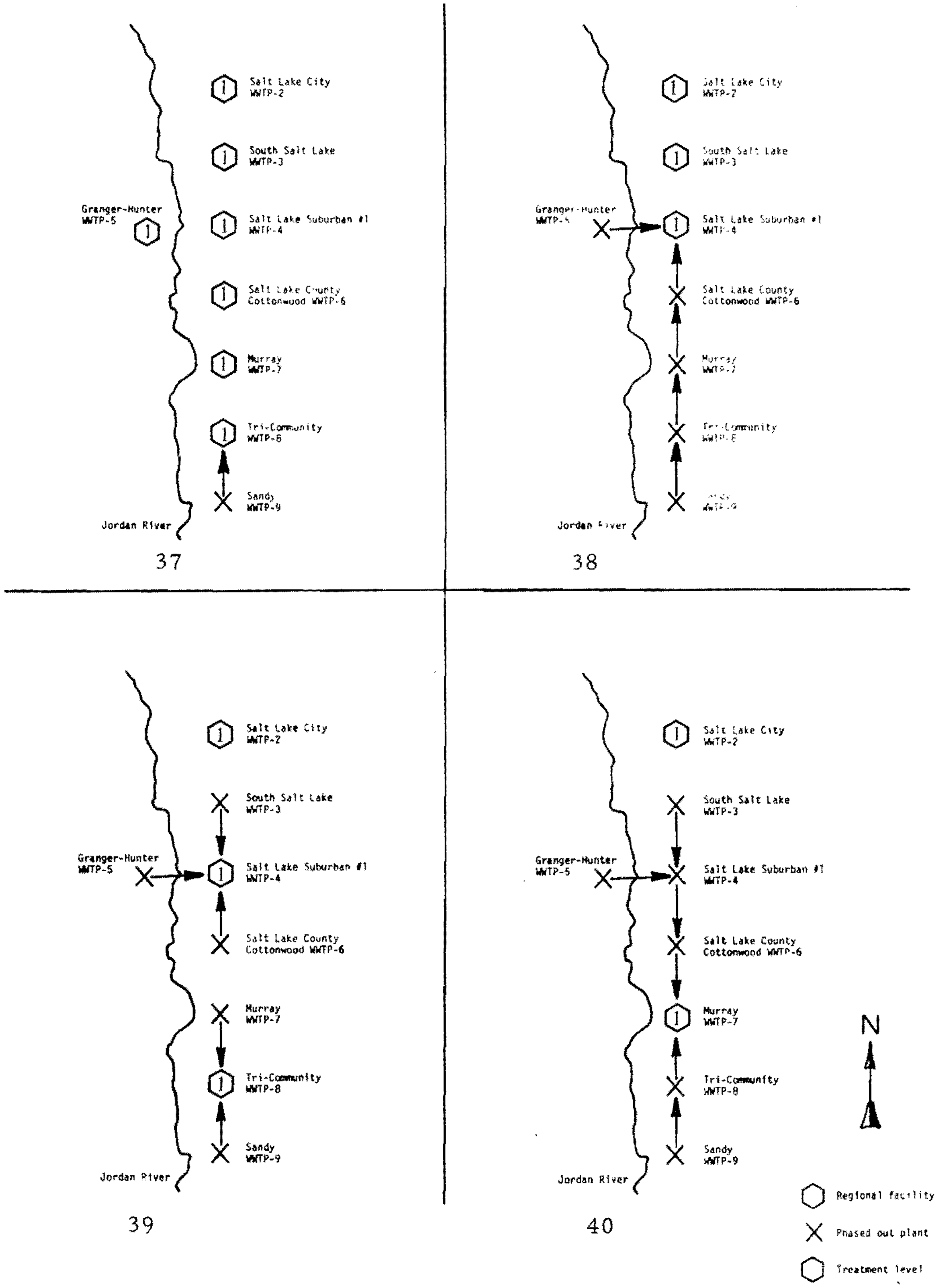

Figure 22. Continued.

Table 24. Input data for the Lower Jordan River wastewater treatment alternatives.

Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level
1	1	1	1	6	1	2		11	1	1	1	16	1	1	1
1	2	2	1	6	2	2	1	11	2	2	1	16	2	2	1
1	3	3	1	6	3	10		11	3	[illegible]	1	16	3	4	
1	4	4	1	6	4	10		11	4	4	1	16	4	4	1
1	5	5	1	6	5	10		11	5	4		16	5	4	
1	6	6	1	6	6	4		11	6	4		16	6	4	
1	7	7	1	6	7	[illegible]		11	7	6		16	7	6	
1	8	8	1	6	8	7		11	8	8	1	16	8	8	1
1	9	9	1	6	9	8		11	9	8		16	9	8	
				6	10	10	4								
2	1	1	2	7	1	2		12	1	1	1	17	1	1	1
2	2	2	2	7	2	2	1	12	2	2	1	17	2	2	1
2	3	3	2	7	3	10		12	3	3	1	17	3	3	1
2	4	4	2	7	4	10		12	4	4	1	17	4	4	1
2	5	5	2	7	5	10		12	5	5	1	17	5	5	1
2	6	6	2	7	6	4		12	6	4		17	6	6	1
2	7	7	2	7	7	6		12	7	6		17	7	7	1
2	8	8	2	7	8	8	1	12	8	8	1	17	8	8	1
2	9	9	2	7	9	8		12	9	8		17	9	8	
				7	10	10	4								
3	1	1	3	8	1	2		13	1	1	1	18	1	1	1
3	2	2	3	8	2	2	1	13	2	2	1	18	2	2	1
3	3	3	3	8	3	10		13	3	3	1	18	3	3	1
3	4	4	3	8	4	10		13	4	4	1	18	4	4	1
3	5	5	3	8	5	10		13	5	5	1	18	5	4	
3	6	6	3	8	6	4		13	6	6	1	18	6	4	
3	7	7	3	8	7	8		13	7	6		18	7	6	
3	8	8	3	8	8	8	1	13	8	8	1	18	8	7	
3	9	9	3	8	9	8		13	9	8		18	9	8	
				8	10	10	4								
4	1	1	4	9	1	1	1	14	1	1	1	19	1	1	1
4	2	2	4	9	2	2	1	14	2	2	1	19	2	2	1
4	3	3	4	9	3	2		14	3	4		19	3	4	
4	4	4	4	9	4	3		14	4	4	1	19	4	4	1
4	5	5	4	9	5	4		14	5	5	1	19	5	4	
4	6	6	4	9	6	4		14	6	4		19	6	4	
4	7	7	4	9	7	6		14	7	6		19	7	8	
4	8	8	4	9	8	8	1	14	8	8	1	19	8	8	1
4	9	9	4	9	9	8		14	9	8		19	9	8	
5	1	2		10	1	1	1	15	1	1	1	20	1	1	1
5	2	2	1	10	2	2	1	15	2	2	1	20	2	2	1
5	3	2		10	3	3	1	15	3	4		20	3	4	
5	4	3		10	4	3		15	4	4	1	20	4	6	
5	5	4		10	5	4		15	5	5	1	20	5	4	
5	6	4		10	6	4		15	6	6	1	20	6	7	
5	7	6		10	7	6		15	7	6		20	7	7	1
5	8	7		10	8	8	1	15	8	8	1	20	8	7	
5	9	8		10	9	8		15	9	8		20	9	8	

Table 25. Input data for the Salt Lake County wastewater treatment alternatives.

Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level	Alternative	Origin	Destination	Treatment Level
21	2	2	1	26	2	2	1	31	2	2	1	36	2	2	1
21	3	3	1	26	3	10		31	3	3	1	36	3	4	
21	4	4	1	26	4	10		31	4	4	1	36	4	4	1
21	5	5	1	26	5	10		31	5	4		36	5	4	
21	6	6	1	26	6	4		31	6	4		36	6	4	
21	7	7	1	26	7	6		31	7	6		36	7	6	
21	8	8	1	26	8	7		31	8	8	1	36	8	8	1
21	9	9	1	26	9	8		31	9	8		36	9	8	
				26	10	10	4								
22	2	2	2	27	2	2	1	32	2	2	1	37	2	2	1
22	3	3	2	27	3	10		32	3	3	1	37	3	3	1
22	4	4	2	27	4	10		32	4	4	1	37	4	4	1
22	5	5	2	27	5	10		32	5	5	1	37	5	5	1
22	6	6	2	27	6	4		32	6	4		37	6	6	1
22	7	7	2	27	7	6		32	7	6		37	7	7	1
22	8	8	2	27	8	8	1	32	8	8	1	37	8	8	1
22	9	9	2	27	9	8		32	9	8		37	9	8	
				27	10	10	4								
23	2	2	3	28	2	2	1	33	2	2	1	38	2	2	1
23	3	3	3	28	3	10		33	3	3	1	38	3	3	1
23	4	4	3	28	4	10		33	4	4	1	38	4	4	1
23	5	5	3	28	5	10		33	5	5	1	38	5	4	
23	6	6	3	28	6	4		33	6	6	1	38	6	4	
23	7	7	3	28	7	8		33	7	6		38	7	6	
23	8	8	3	28	8	8	1	33	8	8	1	38	8	7	
23	9	9	3	28	9	8		33	9	8		38	9	8	
				28	10	10	4								
24	2	2	4	29	2	2	1	34	2	2	1	39	2	2	1
24	3	3	4	29	3	2		34	3	4		39	3	4	
24	4	4	4	29	4	3		34	4	4	1	39	4	4	1
24	5	5	4	29	5	4		34	5	5	1	39	5	4	
24	6	6	4	29	6	4		34	6	4		39	6	4	
24	7	7	4	29	7	6		34	7	6		39	7	8	
24	8	8	4	29	8	8	1	34	8	8	1	39	8	8	1
24	9	9	4	29	9	8		34	9	8		39	9	8	
25	2	2	1	30	2	2	1	35	2	2	1	40	2	2	1
25	3	2		30	3	3	1	35	3	4		40	3	4	
25	4	3		30	4	5		35	4	4	1	40	4	6	
25	5	4		30	5	4		35	5	5	1	40	5	4	
25	6	4		30	6	4		35	6	6	1	40	6	7	
25	7	6		30	7	6		35	7	6		40	7	7	1
25	8	7		30	8	8	1	35	8	8	1	40	8	7	
25	9	8		30	9	8		35	9	8		40	9	8	

Table 26. Wastewater treatment system costs for the Lower Jordan River Region.

Alternative No.	With Effluent Standards[a]				Without Effluent Standards[a]			
	20 yr Annual Costs		20 yr Present Worths		20 yr Annual Costs		20 yr Present Worths	
	Total (mil $)	Average (mil $)	Total[b] (mil $)	Average (mil $)	Total (mil $)	Average (mil $)	Total (mil $)	Average (mil $)
1	471.06	23.55	228.88	11.44	189.48	9.47	97.63	4.88
2	471.06	23.55	228.88	11.44	257.93	12.90	134.78	6.74
3	439.13	21.96	216.02	10.80	342.17	17.11	175.27	8.76
4	485.24	24.26	246.56	12.33	485.24	24.26	246.56	12.33
5	311.12	15.56	156.56[c]	7.83	149.73	7.49	79.80	3.99
6	355.19	17.76	180.11[c]	9.00	282.40	14.12	145.80	7.29
7	384.51	19.26	193.55	9.68	273.84	13.69	141.59	7.08
8	390.71	19.54	196.49	9.82	268.84	13.44	139.23	6.96
9	353.07	17.65	176.14[c]	8.81	162.17	8.11	85.97	4.30
10	392.03	19.60	193.78	9.69	171.17	8.56	89.87	4.49
11	402.37	20.12	197.18	9.86	170.61	8.53	88.55	4.43
12	429.60	21.48	209.94	10.50	179.28	8.96	92.88	4.64
13	451.39	22.57	219.94	11.00	184.96	9.25	95.55	4.78
14	416.19	20.81	204.60	10.23	176.35	8.82	92.07	4.60
15	439.48	21.97	215.35	10.77	182.77	9.14	95.15	4.75
16	388.23	19.41	191.49	9.57	167.37	8.37	87.58	4.38
17	462.15	23.10	224.75	11.24	187.06	9.35	96.44	4.82
18	374.02	18.70	183.87	9.19	161.76	8.09	84.10	4.20
19	394.25	19.71	194.51	9.73	170.41	8.52	89.23	4.46
20	363.60	18.18	180.47[c]	9.02	162.52	8.13	85.55	4.28

[a] Proposed effluent standards for State of Utah. Treatment level 2, 1977; treatment level 4, 1980.

[b] Values used to select best treatment alternatives.

[c] Alternatives selected for further study.

Table 27. Wastewater treatment system costs for the Salt Lake County Region.

Alternative No.	With Effluent Standards[a]				Without Effluent Standards[a]			
	20 yr Annual Costs		20 yr Present Worths		20 yr Annual Costs		20 yr Present Worths	
	Total (mil $)	Average (mil $)	Total[b] (mil $)	Average (mil $)	Total (mil $)	Average (mil $)	Total (mil $)	Average (mil $)
21	454.47	22.72	220.89	11.04	183.27	9.16	94.42	4.72
22	454.47	22.72	220.89	11.04	249.95	12.50	130.60	6.53
23	423.84	21.19	208.55	10.43	330.67	16.53	169.39	8.47
24	468.22	23.41	237.92	11.90	468.22	23.41	237.92	11.90
25	304.31	15.21	152.97[c]	7.65	145.49	7.27	77.46	3.87
26	348.60	17.43	176.48[c]	8.82	278.26	13.91	143.29	7.16
27	377.92	18.90	189.92	9.50	269.71	13.48	139.08	6.95
28	384.12	19.21	192.85	9.64	264.70	13.23	136.73	6.84
29	336.49	16.82	168.15	8.41	155.96	7.80	82.76	4.14
30	375.33	18.77	185.72	9.28	164.97	8.25	86.66	4.33
31	385.79	19.29	189.19	9.46	164.40	8.22	85.34	4.27
32	413.02	20.65	201.94	10.10	173.08	8.65	89.67	4.48
33	434.81	21.74	211.94	10.60	178.76	8.94	92.34	4.62
34	399.60	19.98	196.61	9.83	170.15	8.51	88.86	4.44
35	422.90	21.14	207.36	10.37	176.56	8.83	91.94	4.60
36	371.65	18.58	183.50	9.17	161.17	8.06	84.37	4.22
37	445.57	22.28	216.75	10.84	180.86	9.04	93.23	4.66
38	357.43	17.87	175.87[c]	8.79	155.55	7.78	80.89	4.04
39	377.66	18.88	186.51	9.33	164.21	8.21	86.02	4.30
40	347.02	17.35	172.48[c]	8.62	156.32	7.82	82.34	4.12

[a] Proposed effluent standards for State of Utah. Treatment level 2, 1977; Treatment level 4, 1980.

[b] Values used to select best treatment alternatives.

[c] Alternatives selected for further study.

Table 28. Optimal treatment sequences for the Lower Jordan River Region.

Year	Period	1st	2nd	3rd	4th
1975	1	5	5	5	5
1976	2	5	5	5	5
1977	3	5	5	5	5
1978	4	5	5	5	5
1979	5	5	5	5	5
1980	6	5	5	5	5
1981	7	5	5	5	5
1982	8	5	5	5	5
1983	9	5	5	5	5
1984	10	5	5	5	5
1985	11	5	5	5	5
1986	12	5	5	5	5
1987	13	5	5	5	5
1988	14	5	5	5	5
1989	15	5	5	5	5
1990	16	5	5	5	5
1991	17	5	5	5	5
1992	18	5	5	5	5
1993	19	5	5	5	5
1994	20	6	20	9	5
Total Present Worth[a]		153.80	154.78	155.58	155.61

[a] mil $.

Discussion of Results

While these are just a few of the possible alternatives that could be considered, they do give an idea how the model is to be operated. The model is able to analyze the expansion costs of a large number of alternatives at a low computer cost. The average computer processor time for analyzing ten alternatives over a 20 year period was about 20 seconds. The time for the dynamic programming portion of the model for analyzing four alternatives over a 20 year period was about 30 seconds.

Preliminary selection

Twenty alternatives were analyzed for both the Lower Jordan River Region and the Salt Lake County Region. The results of these runs were presented in Tables 26 and 27. Effluent standards are generally considered to be mandatory, but it is important to realize the cost of these standards. In the alternatives that provided the lowest total cost over 20 years, alternatives 5 and 25, the imposed effluent standards doubled the cost of the treatment system that would have been required without these standards. This points to the need to investigate the possibilities of using the stream for the assimilative capacity that it does have. This does not imply that the river is to be degraded to an unusable level, but rather that its capacity should not be wasted either.

Optimization results

Having made a preliminary selection of the alternatives, four alternatives were analyzed in the dynamic programming portion of the model to determine if there was any interaction between them. The data presented in Tables 28 and 29 allow the comparison of these alternatives. Generally, one alternative will become the optimum path into which all of the alternatives intersect. This is true because the alternative which provides the least cost solution to the treatment system analysis also becomes the least cost path used by all of the alternatives in the dynamic programming portion of the model.

The introduction of minimum and maximum capacity constraints on the treatment plants can cause a new least cost path to be chosen during the planning period. In this case, all of the alternatives would switch to include this alternative in their least cost path.

Table 29. Optimal treatment sequences for the Salt Lake Region.

Year	Period	1st	2nd	3rd	4th
1975	1	25	25	25	25
1976	2	25	25	25	25
1977	3	25	25	25	25
1978	4	25	25	25	25
1979	5	25	25	25	25
1980	6	25	25	25	25
1981	7	25	25	25	25
1982	8	25	25	25	25
1983	9	25	25	25	25
1984	10	25	25	25	25
1985	11	25	25	25	25
1986	12	25	25	25	25
1987	13	25	25	25	25
1988	14	25	25	25	25
1989	15	25	25	25	25
1990	16	25	25	25	25
1991	17	25	25	25	25
1992	18	25	25	25	25
1993	19	25	25	25	25
1994	20	26	40	38	25
Total Present Worth[a]		150.36	151.33	151.39	152.18

[a] mil $.

Table 30. **Quality-capacity expansion projects for the Lower Jordan River Region for 1st optimal treatment sequence.**

Year	Origin J	Destination K	Capacity, mgd		Treatment Level		Capital Debt, mil $		
			Existing	Proposed	Existing	Proposed	Existing	Expansion	Total
1975	1	2	0.00	6.15			0.0000	1.0759	1.0759
1975	2		45.00	188.34	1	2	3.2259	96.2314	99.4573
1975	3	2	0.00	196.79			0.0000	7.7467	7.7467
1975	4	3	0.00	186.67			0.0000	1.5455	1.5455
1975	5	4	0.00	46.34			0.0000	0.6675	0.6675
1975	6	4	0.00	89.13			0.0000	1.3812	1.3812
1975	7	6	0.00	59.83			0.0000	2.0628	2.0628
1975	8	7	0.00	41.68			0.0000	2.0537	2.0537
1975	9	8	0.00	6.57			0.0000	0.7091	0.7091
1978	2		188.34	188.34	2	4	82.3133	33.5968	115.9100

Quantity-capacity expansion projects

The required construction projects for any alternative treatment scheme, as shown in Figures 31 and 32, (Appendix A), can be produced. All of the dates represent the time that the design and construction process needs to be started if the plant or trunk sewer is to be completed and operational by the required date. The length of time was determined by the construction lag period. Origin J represents a treatment plant and destination K represents a trunk sewer between plant J and plant K. The proposed capacities and treatment levels provide information for the detailed engineering analysis that must be done before the results of the model can be applied. The capital debt information provides an approximate value of the projects. This listing of projects allows planning to be done before the need becomes evident.

Sensitivity analysis

The variation of the parameters in the model and the related effects on the total present worth value are shown in Table 32 and Figures 23 and 24. The EPA sewer construction cost index caused little effect on the present worth value of alternative 8. On the other hand, the labor rates, reflecting operation and maintenance costs, greatly affected the present worths. Interest rates caused a significant decrease in the present worth because of the decreasing value of money with time as the interest rates go up. Projected populations and the peak flow factor have a significant effect on the values of the present worth, but

Table 31. **Quality-capacity expansion projects for the Salt Lake County Region for 1st optimal treatment sequence.**

Year	Origin J	Destination K	Capacity, mgd		Treatment Level		Capital Debt, mil $		
			Existing	Proposed	Existing	Proposed	Existing	Expansion	Total
1975	2		45.00	184.21	1	2	3.2259	94.2024	97.4283
1975	3	2	0.00	196.79			0.0000	7.7467	7.7467
1975	4	3	0.00	186.67			0.0000	1.5455	1.5455
1975	5	4	0.00	46.34			0.0000	0.6675	0.6675
1975	6	4	0.00	89.13			0.0000	1.3812	1.3812
1975	7	6	0.00	59.83			0.0000	2.0628	2.0628
1975	8	7	0.00	41.68			0.0000	2.0537	2.0537
1975	9	8	0.00	6.57			0.0000	0.7091	0.7091
1978	2		184.21	184.21	2	4	80.6293	33.1172	113.7465

Table 32. Sensitivity analysis of model.[a]

Annual Increase in Parameter	Present Worth (mil $)	Value of Parameter	Present Worth (mil $)
Interest Rate		Population Projections	
0.0	210.18		
0.0010	201.69	High	217.07
0.001675[b]	196.43	Projected[b]	196.42
0.00255	190.10	Low	170.82
0.0040	180.73	Peak Flow Factor	
ENR-B		1.0	109.23
0.0	188.78	1.5	142.84
10.0	191.70	2.25[b]	196.43
20.0	194.62	2.5	213.56
26.17[b]	196.43		
30.0	197.54		
40.0	200.46		
EPA-S			
0.0	196.27		
10.0	196.37		
15.184[b]	196.43		
20.0	196.47		
30.0	196.57		
Labor Rates			
0.0	161.60		
0.10	178.18		
0.21[b]	196.43		
0.30	211.35		
0.40	227.94		

[a] Using alternative No. 8.

[b] Projected values used for all runs.

may have little effect on the decision process of selecting between alternatives, because it is applied equally to all alternatives. It is possible that population could increase faster in one area while the other areas are slower, but the planning period is short enough to compensate for these irregularities.

The inflation of the construction and operating costs, as shown in Table 34, have a significant effect on the present worth of each alternative. However, the ranking of each alternative on the basis of present worth remained the same both with and without inflation. Some variations in ranking were noted when total annual costs were used as the basis of selection. In general, consideration of inflation is required to determine the true cost of an alternative but it may not be required for the selection of the best alternative since all of the alternatives experience the same inflation rates. The decision on whether or not to consider inflation in the model will depend upon whether the alternatives experience expansion requirements at similar points in time or at widely different points in time.

Other applications

The model was limited to four treatment levels, but it could be easily modified to include many more combinations of levels. Some possible additions include land spreading of effluents and different treatment methods developed by a changing technology. The model contains sufficient flexibility to be adapted to the needs of most users with only minor changes.

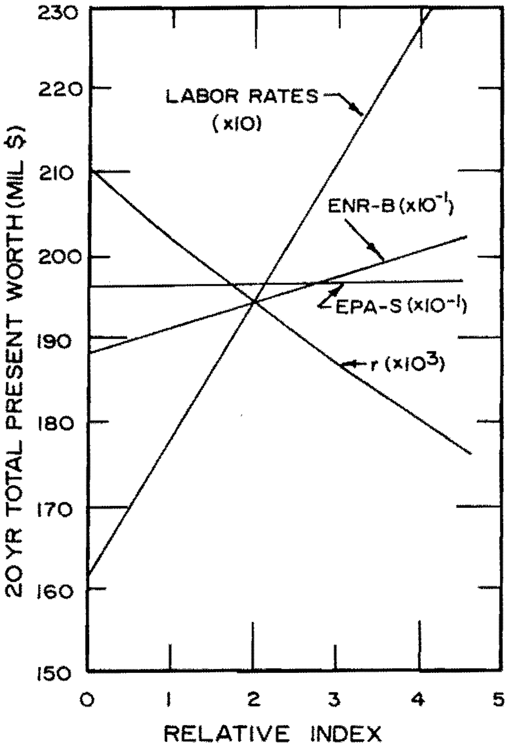

Figure 23. Effects of rates of increase of parameters on present worth values of alternative 8.

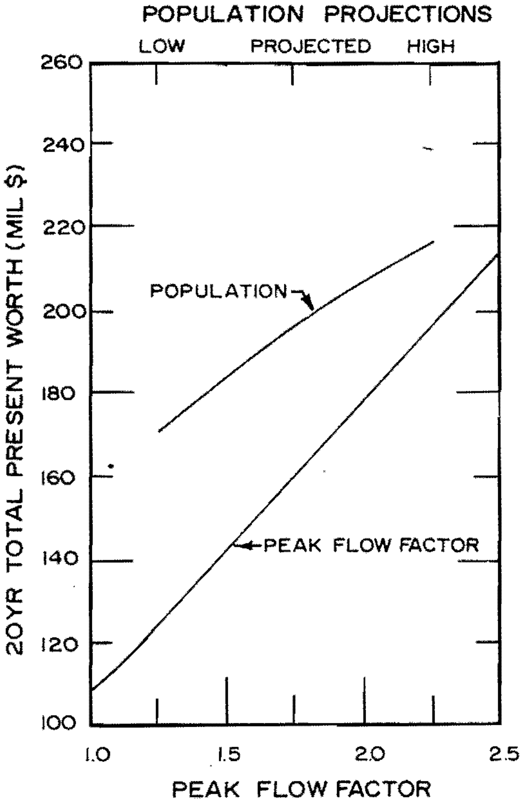

Figure 24. Effects of parameter variation on present worth values of alternative 8.

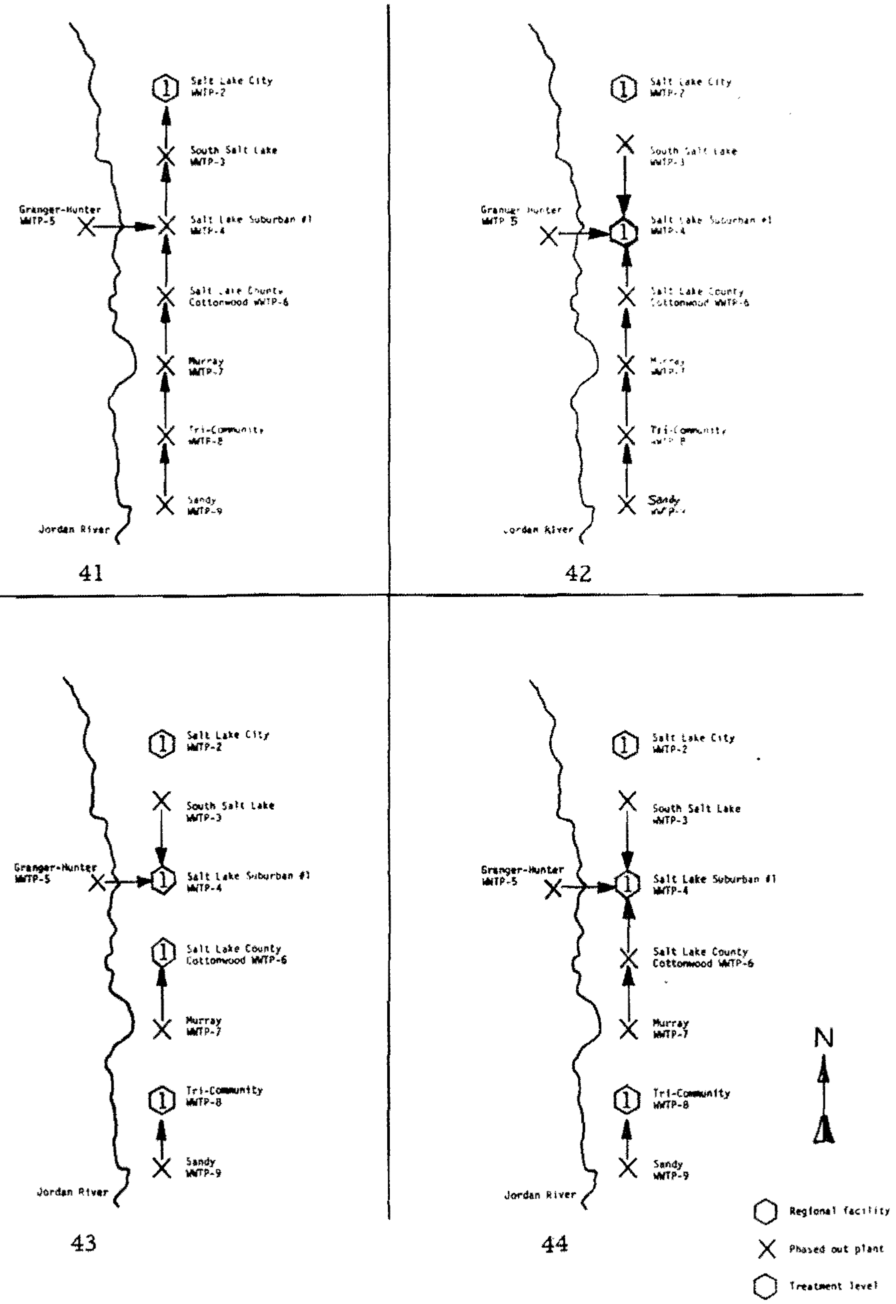

Figure 25. Salt Lake County conceptual wastewater treatment alternatives for sensitivity analysis.

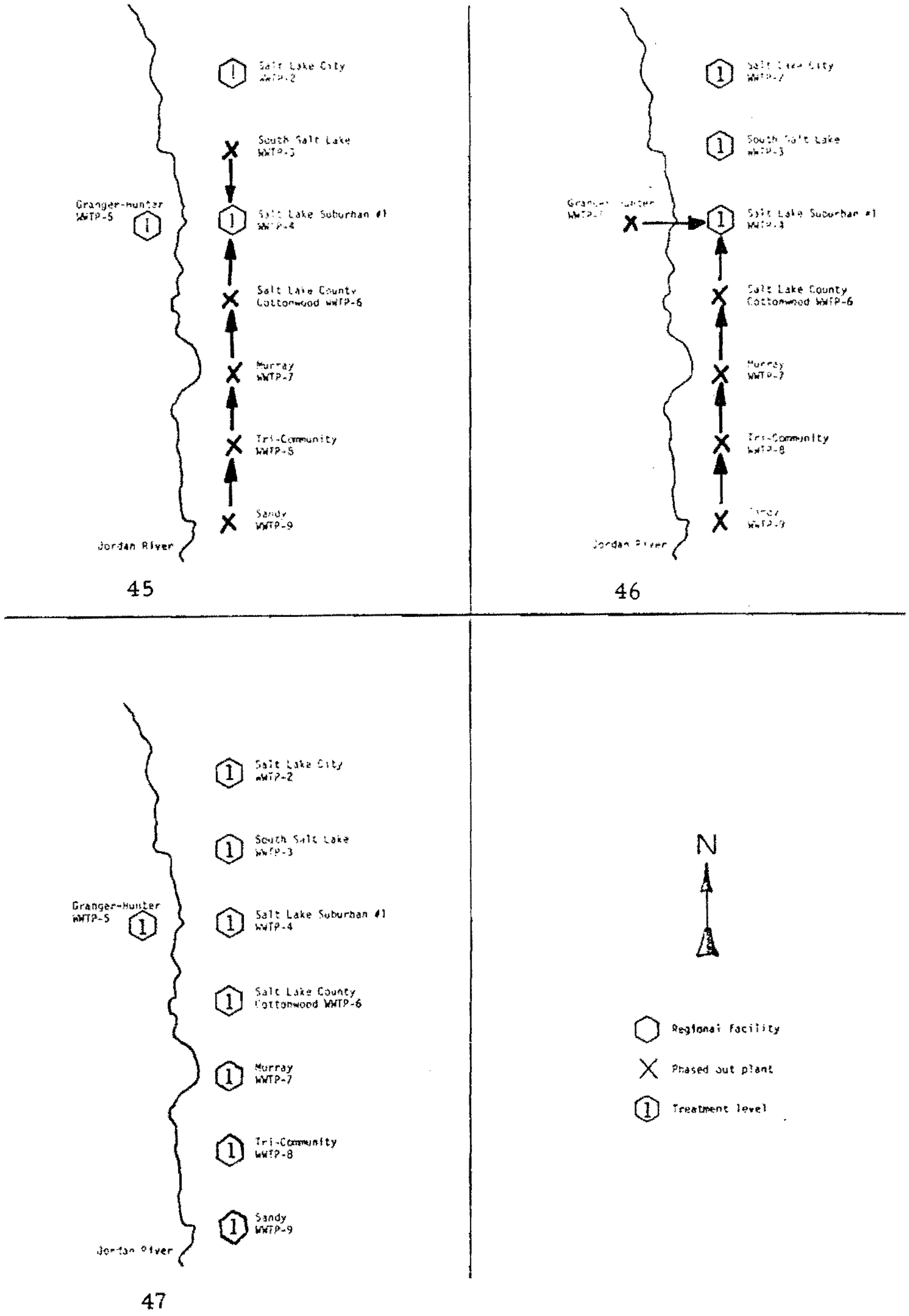

Figure 25. Continued.

Table 33. Model parameters for sensitivity analysis.

Parameter	1974 Values	Annual Increase With Inflation
Capital recovery period for treatment plants, yr.	30.0	-
Capital recovery period for trunk sewers, yr.	60.0	-
Capital recovery period for lift stations, yr.	30.0	-
Construction lag time, yr.	2.0	-
Annual rate of interest	0.0687	0
Gpd/capita of wastewater flow	100.0	-
Peak flow factor	1.0	-
Minimum slope of trunk sewer, -ft/1000 ft	-0.10	-
Average pumping head of lift stations, ft	25.0	-
ENR-B Index for treatment plant and lift station costs	340.66	26.17
WPC-S or EPA-S Index for sewer construction costs	211.66	15.184
Labor cost index for O & M and power costs	4.36	0.21
Time phased treatment levels, 1977	2	-
1980	3	-
1983	4	-

Table 34. Effects of inflation on wastewater treatment systems costs.[a]

Alternative No.	With Infilation[b]				Without Infilation			
	20 yr Annual Costs		20 yr Present Worths		20 yr Annual Costs		20 yr Present Worths	
	Total (mil $)	Average (mil $)	Total (mil $)	Average (mil $)	Total (mil $)	Average (mil $)	Total (mil $)	Average (mil $)
				EFFLUENT LEVEL 2[c]				
41	141.88	7.09	75.87	3.79	111.57	5.58	62.43	3.12
42	143.51	7.18	75.67[d]	3.78	110.17	5.51	61.08[d]	3.05
43	158.04	7.90	83.03	4.15	120.63	6.03	66.71	3.34
44	152.09	7.60	80.09	4.00	116.51	5.83	64.54	3.23
45	150.45	7.52	79.18	3.96	115.18	5.76	63.77	3.19
46	147.70	7.38	77.75	3.89	113.07	5.65	62.62	3.13
47	167.10	8.35	84.76	4.24	122.02	6.10	65.58	3.28
				EFFLUENT LEVELS 2,3				
41	170.19	8.51	88.48[d]	4.42	129.90	6.50	70.91[d]	3.54
42	180.27	9.01	92.02	4.60	133.90	6.70	72.04	3.60
43	205.05	10.25	103.89	5.19	150.95	4.75	80.69	4.03
44	194.28	9.71	98.83	4.94	143.74	7.19	77.10	3.86
45	192.08	9.60	97.67	4.88	142.04	7.10	76.17	3.81
46	188.16	9.41	95.73	4.79	139.18	6.96	74.67	3.73
47	225.46	11.27	110.53	5.53	159.50	7.98	82.79	4.14
				EFFLUENT LEVELS 2,3,4				
41	203.49	10.17	101.55[d]	5.08	149.74	7.49	78.90[d]	3.95
42	221.47	11.07	108.21	5.41	158.46	7.92	81.95	4.10
43	255.54	12.78	123.73	6.19	181.06	9.05	92.83	4.64
44	240.40	12.02	116.95	5.85	171.23	8.56	88.19	4.41
45	237.71	11.89	115.60	5.78	169.24	8.46	87.14	4.35
46	232.72	11.64	113.24	5.66	165.75	8.29	85.39	4.27
47	287.81	14.39	134.89	6.74	196.46	9.82	97.62	4.88

[a] Salt Lake County Plants, no existing plant debt.

[b] Annual increases of cost indexes, interest rate constant.

[c] Required effluent levels–1977 - level 2, 1980 - level 3, 1983 - level 4.

[d] Minimum cost alternative.

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APPENDICES

Appendix A

User's Manual

Wastewater Treatment Optimization Model--WTOM

Purpose of model

The dynamic programming model was developed to be used as a planning tool by regional and local planners, governmental agencies, and consulting firms. It provides information on the sequential expansion, upgrading, and regionalization of wastewater treatment plants at a minimum total discounted future cost. The required input data are the projected populations, the per capita contribution of wastewater, the peak flow factor, wastewater treatment plant and trunk sewer data, interest rates, cost indices, and cost coefficients. The economic effects of several alternative future conditions on the treatment needs of a region can then be analyzed.

Model options

The model contains several optional modes of operation and also the ability to suppress several of the output formats.

IEDIT. The edit data are used primarily for the debugging of the model, but does provide detailed information on the mathematical operations of the model. It produces a large volume of data for each year, and is not recommended for general use in the operation of the model. Definitions of all of the headings are presented in Table 35, and a sample output listing of the edit data is presented in Figure 26.

ILIST. The list data provide an annual summary of the capacity, capital debt, expansion costs, annual costs, and present worth values for each treatment plant and trunk sewer for each alternative. A sample output listing is presented in Figure 27.

IPW. This output provides the present worth values and the optimum back path for each alternative for each year. It is these values which were used in the dynamic programming portion of the model to select the optimum path. A listing is shown in Figure 28.

IRANK. This output provides the ranking of the final alternatives on the basis of their total accumulated present worth values in the final planning year. A sample listing is shown in Figure 29.

NRANK. The number of ranking data to be printed indicates how many of the final alternatives will be listed. This output provides the record of the present worth values over the entire planning period for the path that produced the given total values of final present worth. A sample listing is shown in Figure 30.

NALTPR. Up to this point all of the data output were produced by the dynamic programming portion of the model. NALTPR indicates the number of alternatives listed under the ranking data, Figure 29, for which a detailed analysis is desired. The latter portion of the model, that is under the control of this index, recalculates all of the costs along the optimum path previously selected, and produces the output that follows. A summary of annual costs is also printed with this option. A sample listing of this output is shown in Figure 31.

IPROJ. This option provides a listing of all the quality and capacity expansion projects required by an alternative or by the alternatives on the optimum path calculated by the dynamic programming portion of the model. A sample listing is presented in Figure 32.

IANUAL. This output produces a detailed output listing of the annual operations of each treatment plant and trunk sewer. If an item is not used, the data are not printed. The index indicates how many years these data are to be printed. A sample listing is shown in Figure 33.

NONDYN. This option allows an individual alternative to be suboptimized over the planning period. The dynamic programming portion of the model is bypassed, and all the annual costs of the alternative under consideration are calculated. The number of alternatives to be analyzed by this method is controlled by the NALTPR option, and the same output listings are produced.

Table 35. Definitions of column headings.

Heading	Definition
ANNUAL	Annual repayment of previous years capital debt, mil $.
BACK	Alternative in previous year that provided the minimum total present worth cost to provide alternative M this year.
CAPAC	Capacity of treatment plant or trunk sewer, mgd.
CAP LIMIT	Indicates when a capacity constraint has been exceeded. A '0' is the normal condition, a '1' indicates a minimum capacity, and a '2' indicates that a maximum capacity has been exceeded.
DEBT	Existing capital debt of the facility, mil $.
DEMAND	Annual increase in the quantity of wastewater, mgd.
DESIGN	Design capacity of the facility, mgd.
DESIGN INDEX	Indicates which cost coefficients were used to calculate construction and O & M costs of treatment plants.
EXISTING	Existing capacity of the facility, mgd.
EXPANSION	Construction cost of proposed expansion, mil $.
FLOW	Quantity of wastewater treated by treatment plant or transported by trunk sewer in year L, mgd.
FLOWL	Quantity of wastewater treated by treatment plant or transported by trunk sewer in year L plus the construction lag time. This quantity used for design of future facilities.
J	Wastewater treatment plant number.
K	Destination of trunk sewer from plant J to plant K.
L	Index of year with L = 1 for the initial year of study.
LIFT STATIONS	Number of lift stations required by trunk sewer.
M	Alternative treatment system be considered.
MB	Alternative in previous year that provided the minimum total present worth cost to provide alternative M this year.
O & M	Annual operation and maintenance costs, mil $.
OPTVAL	Cumulative total present worth going from the initial year to the present year.
TOTAL	Total capital debt equals existing capital debt minus annual repayment plus cost of expansion, mil $.
TSTAR	Design period of facility, yr.
VALUE	Present worth value of alternative M in year L, mil $.

Input data formats

The card formats and definitions of the required data for the model are presented in Table 36. Some of the parameters and their output listings are discussed in more detail in the following sections.

Sample outputs

Control parameters. The control parameters used to operate the model and control the economic conditions are listed for each run. A sample of this output is shown in Figure 34. The listing of card type and column simplify the process of making runs under varying conditions.

Cost coefficients. The costs of treating and transporting wastewater are represented in general by the equation - $y = k X^{a}$. Ten treatment options are available as shown in Table 37. The '0' level indicates the construction of a new treatment plant. Four levels of treatment are possible. The definition of these levels will change with changing technology.

The first ten (10) rows of model output record, shown in Figure 35, represent these ten treatment

```
LIST DATA - RUN   3

OPTIMUM ALTERNATIVES

  L    M   MB    J    K        CAPAC      DEBT     ANNUAL   EXPANSION    TOTAL      VALUE      OPTVAL
                                MGD      MIL $     MIL $      MIL $     MIL $      MIL $      MIL $


  2    5    5    1              2.27    0.3064    0.0267     0.0000    0.2797
  2    5    5    1    2         4.59    0.0000    0.0000     0.5839    0.5839

  2    5    5    2            188.34    3.2259    0.2812    96.2314   99.1760

  2    5    5    3              4.55    0.5591    0.0487     0.0000    0.5104
  2    5    5    3    2       196.79    0.0000    0.0000     7.7467    7.7467

  2    5    5    4             16.00    0.1138    0.0099     0.0000    0.1039
  2    5    5    4    3       186.67    0.0000    0.0000     1.5455    1.5455
```

Figure 26. Edit data listing.

```
EDIT DATA - RUN   3

                                                                                              ANNUAL PRESENT WORTH DATA

L  M MB  J  K  CAP    FLOW    FLOWL  DEMAND   TSTAR  DESIGN    LIFT   EXISTING DESIGN     DEBT   EXPANSION  ANNUAL    O & M     VALUE
              LIMIT    MGD     MGD     MGD     MGD   INDEX  STATIONS    MGD      MGD     MIL $     MIL $    MIL $     MIL $     MIL $

2  5  5  1       0    0.00    0.00  0.0000    0.00     5                 2.27     2.27   0.3064    0.0000   0.0252    0.0000    0.0252
         1  2         2.61    2.77  0.0676   26.90              0        0.00     4.59   0.0000    0.5839   0.0000    0.0000    0.0000
2  5  5  2       0  121.85  129.85  2.9244   20.00     5                45.00   188.34   3.2259   96.2314   0.2651    2.1942    2.4593
2  5  5  3       0    0.00    0.00  0.0000    0.00     5                 4.55     4.55   0.5591    0.0000   0.0459    0.0000    0.0459
         3  2        76.10   82.42  2.2874   50.00              0        0.00   196.79   0.0000    7.7467   0.0000    0.0000    0.0000
2  5  5  4       0    0.00    0.00  0.0000    0.00     5                16.00    16.00   0.1138    0.0000   0.0094    0.0000    0.0094
         4  3        72.60   78.59  2.1616   50.00              0        0.00   186.67   0.0000    1.5455   0.0000    0.0000    0.0000
2  5  5  5       0    0.00    0.00  0.0000    0.00     5                 7.30     7.30   0.3715    0.0000   0.0305    0.0000    0.0305
         5  4        15.07   16.65  0.5938   50.00              0        0.00    46.34   0.0000    0.6675   0.0000    0.0000    0.0000
2  5  5  6       0    0.00    0.00  0.0000    0.00     5                 8.00     8.00   0.3514    0.0000   0.0289    0.0000    0.0289
         6  4        30.70   33.83  1.1060   50.00              0        0.00    89.13   0.0000    1.3812   0.0000    0.0000    0.0000
         7  6        20.53   22.69  0.7428   50.00              0        0.00    59.83   0.0000    0.3560   0.0000    0.0000    0.0000
2  5  5  8       0    0.00    0.00  0.0000    0.00     5                 3.60     3.60   0.0990    0.0000   0.0081    0.0000    0.0081
         8  7        14.24   15.80  0.5176   50.00              0        0.00    41.68   0.0000    2.0537   0.0000    0.0000    0.0000
2  5  5  9       0    0.00    0.00  0.0000    0.00     5                 1.50     1.50   0.3111    0.0000   0.0256    0.0000    0.0256
         9  8         3.59    3.91  0.0532   50.00              0        0.00     6.57   0.0000    0.7091   0.0000    0.0000    0.0000
                                                                                                                                11.0578

2  5  6  1       0    0.00    0.00  0.0000    0.00     5                 2.27     2.27   0.3064    0.0000   0.0252    0.0000    0.0252
         1  2         2.61    2.77  0.0676   50.00              0        0.00     6.15   0.0000    0.6546   0.0000    0.0000    0.0000
2  5  6  2       0  121.85  129.85  2.9244   20.00     5                45.00   188.34   3.2259   96.2314   0.2651    2.1942    2.4593
2  5  6  3       0    0.00    0.00  0.0000    0.00     5                 4.55     4.55   0.5591    0.0000   0.0459    0.0000    0.0459
         3  2        76.10   82.42  2.2874   50.00              0        0.00   196.79   0.0000    7.7467   0.0000    0.0000    0.0000
2  5  6  4       0    0.00    0.00  0.0000    0.00     5                16.00    16.00   0.1138    0.0000   0.0094    0.0000    0.0094
         4  3        72.60   78.59  2.1616   50.00              0        0.00   186.67   0.0000    1.5455   0.0000    0.0000    0.0000
2  5  6  5       0    0.00    0.00  0.0000    0.00     5                 7.30     7.30   0.3715    0.0000   0.0305    0.0000    0.0305
         5  4        15.07   16.65  0.5938   50.00              0        0.00    46.34   0.0000    0.6675   0.0000    0.0000    0.0000
2  5  6  6       0    0.00    0.00  0.0000    0.00     5                 8.00     8.00   0.3514    0.0000   0.0289    0.0000    0.0289
         6  4        30.70   33.83  1.1060   50.00              0        0.00    89.13   0.0000    1.3812   0.0000    0.0000    0.0000
         7  6        20.53   22.69  0.7428   50.00              0        0.00    59.83   0.0000    0.3560   0.0000    0.0000    0.0000
2  5  6  8       0    0.00    0.00  0.0000    0.00     5                 3.60     3.60   0.0990    0.0000   0.0081    0.0000    0.0081
```

Figure 27. List data.

alternatives. AK and ALPHA represent k and α for the construction cost equation and BK and BALPHA represent the operation and maintenance equation. AK(11) and ALPHA(11) represent the cost equation for trunk sewer construction costs per mile, and AK(12) and ALPHA(12) represent the construction costs of a lift station feeding the gravity trunk sewer. The quantity of flow, 'X,' is measured in million gallons per day (mgd). The operation and maintenance cost of the lift station are in two parts. BK(11) and BALPHA(11) represent the cost equation for the general operation and maintenance costs of a lift station, and BK(12) and BALPHA(12) represent the average cost of power for the lift station. The latter equation is represented by $y = k\,X^{\alpha}H$, where H is the pumping head. BK(12) is presented as k x 1000.0 to allow the use of the same format in the model. The cost equation in the model is adjusted to reflect this change in value.

Wastewater treatment plant data. The output listing of the treatment plant is shown in Figure 36. These data are also required for any proposed treatment plants. The plants do not have to enter into the model in any order, as the model stores their real number and assigns a sequential number to the inputed order.

Trunk sewer data. The data of the existing and proposed trunk sewer system is required (Figure 37). This includes the length, capacity, and existing debt. The values for pumping head and slope are calculated and presented along with this output.

Annual cost factors. The annual values of the interest rate, capital recovery factors, and inflation indices are output as shown in Figure 38. The interest rate and the cost indices are inputed as control data

```
PRESENT WORTH VALUES USED TO SELECT OPTIMUM PATH - RUN    3

L      M    BACK                VALUE            OPTVAL

2      5      5                2.6329            2.6329
2      6      5                1.4657            1.4657
2      9      5                2.9211            2.9211
2     20      5                3.0550            3.0550

3      5      5               11.6497           14.2826
3      6      6               12.1783           13.6440
3      9      9               12.4591           15.3802
3     20     20               11.3754           14.4305

4      5      5               10.5348           24.8174
4      6      6               14.7065           28.3505
4      9      9               11.2768           26.6570
4     20     20               11.2842           25.7147
```

Figure 28. Present worth values for each alternative.

```
RANKING OF FINAL ALTERNATIVES - RUN

SEQUENCE ALTERNATIVE          OPTVAL

    1          6             96.7633
    2         20             98.1765
    3          9             99.3225
    4          5             99.3637
```

Figure 29. Ranking of final alternatives.

as shown in Figure 34. These are used to calculate the values of Figure 38.

Population projection data. Population data can be entered for any number of points in the planning period. The computer calculates a straight line between these values and fills in any holes in the data. The initial year of the study is presented as period '0' and the fifth year as year '5.' Planning periods up to 50 years can be used. A sample output is shown in Figure 39.

Wastewater quantities. Quantities of wastewater produced in each area are calculated from per capita contributions and peak flow factors. These results are presented in Figure 40.

Time-phased treatment levels. State and federal regulations of effluent quality have established a timetable for the upgrading of treatment plants. This schedule is entered into the computer to require the upgrading of treatment plants at given points in time. These data are presented along with the wastewater quantities in Figure 40. Individual plants can also be given timed treatment levels. A sample listing of this output is shown in Figure 41.

Trunk sewer alternative path table. The last section of input data provides information about which trunk sewers and treatment plants are being used for each alternative. Each trunk sewer used is indicated by noting the alternative, m; the origin, j; and the destination, k, on the data card. If a treatment plant is treating its and others wastewater, the destination, k, is set equal to the origin, j. This is converted in the output table to a '1' in the last column. The input table indicates all areas which supply wastewater to a given plant by the use of a '1.' This table is shown in Figure 42. The required treatment levels are also indicated.

Operation instructions

Card sequence. The input cards must be in the order indicated on the card format, Table 36. Cards with '99' in columns 1 and 2 are required after the trunk sewer data, card 8; the population data, card 9; the time phased treatment level data, cards 10 and 11; and the trunk sewer feasible path data, card 12.

Card layout. In the figure below is the pictorial layout of the cards and data. The control cards will vary with type of computer.

```
NUMBER     1  RANKING OF ALTERNATIVES - RUN    3

 YEAR      L      M          VALUE          OPTVAL
                             MIL $           MIL $

 1974      1      5         0.0000          0.0000
 1975      2      5         2.6329          2.6329
 1976      3      5        11.6497         14.2826
 1977      4      5        10.5348         24.8174
 1978      5      5         9.5343         34.3517
 1979      6      5        13.4484         47.8001
 1980      7      5        12.2567         60.0567
 1981      8      5        11.1835         71.2402
 1982      9      5        10.2169         81.4571
 1983     10      5         9.3459         90.8031
 1984     11      6         5.9602         96.7633
```

Figure 30. Annual listing of present worths for one alternative.

```
SUMMARY OF ANNUAL COSTS - RUN   3 - 1

                      CAPITAL        DEBT          O & M        TOTAL        P.W.
YEAR  ALTERNATIVE      TOTAL        ANNUAL        ANNUAL       ANNUAL       ANNUAL
           M          MIL $         MIL $         MIL $        MIL $        MIL $
----  -----------    -------       -------       ------       ------       ------

1975       5          4.8728        0.4654        2.3468       2.8122       2.6509
1976       5        108.2919       10.0545        3.2402      13.2947      11.7949
1977       5         98.9652        9.3267        3.4689      12.7956      10.6674
1978       5         90.3255        8.6398        3.7044      12.3442       9.6551
1979       5        112.8393       11.0829        7.4221      18.5050      13.5581
1980       5        102.6124       10.2269        7.8050      18.0319      12.3562
1981       5         93.1887        9.4238        8.1946      17.6184      11.2735
1982       5         84.5172        8.6715        8.5908      17.2623      10.2981
1983       5         76.5493        7.9679        8.9936      16.9614       9.4192
1984       6         69.2384        7.3109        4.3761      11.6871       6.0321

                                                             141.3128      97.7056
```

Figure 31. Summary of annual costs.

```
QUALITY - CAPACITY EXPANSION PROJECTS - RUN   3 - 1

YEAR  ORIGIN  DESTINATION        CAPACITY, MGD       TREATMENT LEVEL              CAPITAL DEBT, MIL $
        J          K          EXISTING    PROPOSED  EXISTING  PROPOSED     EXISTING   EXPANSION        TOTAL
----  ------  -----------     --------    --------  --------  --------     --------   ---------        -----

1975    1          2             0.00        6.15                            0.0000      1.0759       1.0759
1975    2                       45.00      188.34       1         2          3.2259     96.2314      99.4573
1975    3          2             0.00      196.79                            0.0000      7.7467       7.7467
1975    4          3             0.00      186.67                            0.0000      1.5455       1.5455
1975    5          4             0.00       46.34                            0.0000      0.6675       0.6675
1975    6          4             0.00       89.13                            0.0000      1.3812       1.3812
1975    7          6             0.00       59.83                            0.0000      2.0626       2.0626
1975    8          7             0.00       41.68                            0.0000      2.0537       2.0537
1975    9          8             0.00        6.57                            0.0000      0.7091       0.7091
1976    2                      188.34      188.34       2         4         82.3133     33.5968     115.9100
1984    3         10             0.00       11.41                            0.0000      2.0154       2.0154
1984    4         10             0.00      157.90                            0.0000      0.7139       0.7139
1984    5         10             0.00       52.48                            0.0000      0.6969       0.6969
1984   10          .             0.00      149.01       0         4          0.0000    185.4021     185.4021
```

Figure 32. Quality-capacity expansion projects.

Table 36. Listing of input card parameters.

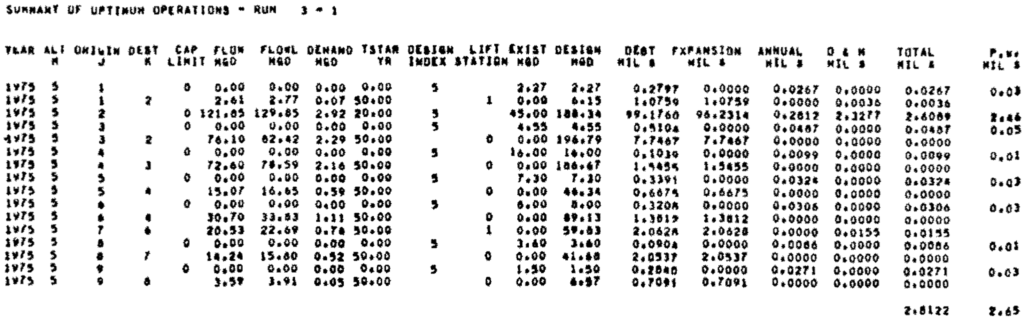
Card	Column	Name	Definition	Eq	Ref	Units
1	1-2	IRUN	Run number			
2	1-2	NUMPLT	Number of existing and proposed treatment plants (max - 10)			
	9-10	NUMYR	Number of planning years (max - 50)			
	17-18	NUMALT	Number of alternative plans (max - 10)			
	25-28	NYEAR	Initial year of study			
	33-34	IFLOW	Flow projections: 1 - wastewater, 0 - population			
	41-42	ITSTAR	Design period: 1 - optimal, 0 - capital recovery period			
3	1-2	IEDIT	Number of years that edit data is printed			
	9-10	ILIST	Number of years that list data is printed			
	17-18	IPW	Number of years that present worth data is printed for optimum alternatives			
	25-26	IRANK	Print ranking of alternatives at end of planning period: 1 - yes, 0 - no			
	33-34	NRANK	Number of alternatives for which annual present worths are to be printed			
	41-42	NALTPR	Number of alternatives to be analyzed in detail in terms of annual costs			
	49-50	IPROJ	Print list of quality-capacity expansion projects: 1 - yes, 0 - no			
	57-58	IANUAL	Number of years that summary of optimum operations is printed			
	65-66	NONDYN	Bypass dynamic programming portion and suboptimize individual alternatives: 1 - yes, 0 - no			
4	1-4	PERP	Capital recovery period of treatment plants	PER	(14)	yr
	9-10	PERS	Capital recovery period of trunk sewers	PER	(14)	yr
	17-20	PERL	Capital recovery period of lift stations	PER	(14)	yr
	25-26	LAG	Construction lag time	LAGP	(24)	yr
	33-40	RATE	Annual rate of interest in base year	R	(13)	dec
	41-48	ANRATE	Annual increase in the rate of interest	ANRATE	(13)	dec
	49-56	GPDCAP	Gpd/capita of wastewater flow	GPDCAP	(16)	gal
	57-64	PEAK	Peak flow factor	f	(16)	
	65-72	SLOPEM	Minimum slope of gravity sewer			ft/1000 ft
	73-80	HEAD	Average pumping head of lift station	H	(61)	ft
5	1-8	PINDA	ENR-B cost index for construction of treatment plants and lift stations in base year of cost data	INDEXA	(15)	
	9-16	PINDB	ENR-B cost index for initial year of study	INDEXB	(15)	
	17-24	PINDF	Annual increase in ENR-B index	ANFAC	(15)	
	25-32	SINDA	WPC-S or EPA-S cost index for trunk sewers for the base year of cost data	INDEXA	(15)	

Table 36. Continued.

Card	Column	Name	Definition	Eq	Ref	Units
	33-40	SINDB	WPC-S or EPA-S cost index for initial year of study	INDEXB	(15)	
	41-48	SINDF	Annual increase in WPC-S or EPA-S cost index	ANFAC	(15)	
	49-56	OMINDA	Labor rates or other O & M cost index for base year of cost data	INDEXA	(15)	
	57-64	OMINDB	Labor rates or other O & M cost index for initial year of study	INDEXB	(15)	
	65-72	OMINDF	Annual increase in labor rates or other O & M index	ANFAC	(15)	
6	1-8	AK(i)	Cost coefficient of capital costs: Treatment plants, i = 1, . . , 10: trunk sewers, i = 11; and lift station, i = 12	k_i	(56)	mil $
	9-16	ALPHA(i)	Economy of scale of capital costs: Treatment plants, i = 1, . . , 10; trunk sewers, i = 11; and lift stations, i = 12	α_i	(56)	
	17-24	BK(i)	Cost coefficients of O & M costs: Treatment plants, i = 1, . . , 10: lift station, i = 11; and lift station power i = 12 (Note: Power costs are given as 10^3 times true cost)	k_i	(56)	mil $
	25-32	BALPHA(i)	Economy of scale of O & M costs: Treatment plants, i = 1, . . , 10; lift station, i = 11; and lift station power, i = 12	α_i	(56)	
7	1-2	j	Treatment plant number			
	9-16	CAPP(j)	Capacity of treatment plant	$CAPP_j$	(6)	mgd
	17-24	DEBTP(j)	Capital debt of treatment plant j	$DEBTP_j$	(7)	mil $
	25-32	ELEV(j)	Elevation of treatment plant j			ft
	33-34	LTREAT(j)	Level of treatment at plant j	$LTREAT_j$		
	41-72	BNAME(j, i)	Name of treatment plant j			
8	1-2	j	Origin of trunk sewer, plant j			
	9-10	k	Destination of trunk sewer, plant k			
	17-24	DIST(j, k)	Length of trunk sewer	$DIST_{jk}$	(12)	ft
	25-32	CAPS(j, k)	Capacity of trunk sewer	$CAPS_{jk}$	(9)	mgd
	33-40	DEBTS(j, k)	Debt of trunk sewer	$DEBTS_{jk}$	(10)	mil $
9	1-2	j	Number of treatment plant j			
	9-10	n	Year of population data. Use '0' for initial year of study, and '1' for next year			
	17-28	POP(j, n)	Population projected for plant or area j in the nth year of the study. All points of time, except first and last are optional. Wastewater quantities can be used in place of population by setting IFLOW = 1	$POP_{j\ell}$	(16)	
10	1-2	n	The number of the year in which a state or federal effluent standard level will be enacted. Use n = 0 for initial year of study			

Table 36. Continued.

Card	Column	Name	Definition	Eq	Ref	Units
	9-10	LQUAL(n)	Treatment level required for effluent standard	$QUAL_\ell$	(17)	
11	1-2	n	Time period			
	9-10	j	Treatment plant number			
	17-18	LQUALJ(n, j)	Treatment level required for plant j in period n			
12		IPATH(j,k,m)	Alternative paths from plant j to plant k for alternative m. Set j = k if treatment plant is being used	P_{jkm}	(18)	
	1-2	m				
	9-10	j				
	17-18	k				
	25-26	MTREAT(j,m)	Treatment level required by alternative m for plant j	$MTREAT_{jm}$	(23)	
	33-40	CAPMIN(j,m)	Minimum allowable flow allowed by alternative m for plant j. If this limit is exceeded, the CAP LIMIT index is set equal to 1, and a value of 10^9 is added to the present worth in the dynamic programming portion			mgd
	41-48	CAPMAX(j, m)	Maximum allowable flow from plant j. If this limit is exceeded, the CAP LIMIT index will be set equal to 2, or an alternate trunk sewer will handle the excess flow			mgd



```
SUMMARY OF OPTIMUM OPERATIONS - RUN   3 - 1

YEAR ALT ORIGIN DEST  CAP  FLOW  FLOWL DEMAND TSTAR DESIGN  LIFT EXIST DESIGN   DEBT  EXPANSION  ANNUAL   O & M   TOTAL       P.W.
      M     J      K LIMIT MGD    MGD   MGD     YR  INDEX STATION MGD    MGD   MIL $    MIL $    MIL $   MIL $   MIL $       MIL $

1975  5     1          0   0.00   0.00  0.00  0.00     5          2.27   2.27  0.2797   0.0000   0.0267  0.0000  0.0267      0.03
1975  5     1      2       2.61   2.77  0.07 50.00          1     0.00   6.15  1.0759   1.0759   0.0000  0.0036  0.0036
1975  5     2          0 121.85 129.85  2.92 20.00     5         45.00 188.34 99.1760  96.2314   0.2812  2.3277  2.6089      2.46
1975  5     3          0   0.00   0.00  0.00  0.00     5          4.55   4.55  0.5104   0.0000   0.0487  0.0000  0.0487      0.05
1975  5     3      2      76.10  82.42  2.29 50.00          0     0.00 196.79  7.7467   7.7467   0.0000  0.0000  0.0000
1975  5     4          0   0.00   0.00  0.00  0.00     5         16.00  16.00  0.1030   0.0000   0.0099  0.0000  0.0099      0.01
1975  5     4      3      72.60  78.59  2.16 50.00          0     0.00 186.67  1.5455   1.5455   0.0000  0.0000  0.0000
1975  5     5          0   0.00   0.00  0.00  0.00     5          7.30   7.30  0.3391   0.0000   0.0324  0.0000  0.0324      0.03
1975  5     5      4      15.07  16.65  0.59 50.00          0     0.00  46.34  0.6675   0.6675   0.0000  0.0000  0.0000
1975  5     6          0   0.00   0.00  0.00  0.00     5          8.00   8.00  0.3208   0.0000   0.0306  0.0000  0.0306      0.03
1975  5     6      4      30.70  33.83  1.11 50.00          0     0.00  89.13  1.3812   1.3812   0.0000  0.0000  0.0000
1975  5     7      6      20.53  22.69  0.78 50.00          1     0.00  59.83  2.0628   2.0628   0.0000  0.0155  0.0155
1975  5     8          0   0.00   0.00  0.00  0.00     5          3.60   3.60  0.0904   0.0000   0.0086  0.0000  0.0086      0.01
1975  5     8      7      14.24  15.80  0.52 50.00          0     0.00  41.68  2.0537   2.0537   0.0000  0.0000  0.0000
1975  5     9          0   0.00   0.00  0.00  0.00     5          1.50   1.50  0.2840   0.0000   0.0271  0.0000  0.0271      0.03
1975  5     9      8       3.59   3.91  0.05 50.00          0     0.00   6.97  0.7091   0.7091   0.0000  0.0000  0.0000

                                                                                                                 2.8122      2.65
```

Figure 33. Summary of optimum operations.

```
CONTROL PARAMETERS - RUN   3

                                                                 CARD     COL

         3 - RUN NUMBER                                            1      1- 2

        10 - NUMBER OF EXISTING AND PROPOSED PLANTS                2      1- 2
        10 - NUMBER OF PLANNING YEARS                              2      9-10
         4 - NUMBER OF ALTERNATIVE PLANS                           2     17-18
      1974 - INITIAL YEAR OF STUDY                                 2     25-28
         0 - FLOWS FROM, 1 - WASTEWATER, 0 - POPULATION            2     33-34
         0 - DESIGN PERIOD, 1 - OPTIMAL, 0 - CAP. REC. PERIOD      2     41-42

         1 - NUMBER OF YEARS THAT EDIT DATA IS PRINTED             3      1-2
         1 - NUMBER OF YEARS THAT LIST DATA IS PRINTED             3      9-10
         1 - PRINT PRESENT WORTH DATA, 1 - YES, 0 - NO             3     17-18
         1 - PRINT RANKING, 1 - YES, 0 - NO                        3     25-26
         1 - NUMBER OF ANNUAL LISTINGS OF PRESENT WORTH            3     33-34
         1 - NUMBER OF ALTERNATIVES ANALYSED FOR ANNUAL COSTS      3     41-42
         1 - PRINT QUALITY-CAPACITY PROJECTS, 1 - YES, 0 - NO      3     49-50
         1 - NUMBER OF YEARS OF SUMMARY OF OPTIMUM OPERATION       3     57-58
         0 - OPTIMIZE INDIVIDUAL ALTERNATIVES, 1 - YES, 0 - NO     3     65-66

      20.0 - CAPITAL RECOVERY PERIOD FOR TREATMENT PLANTS,YR       4      1-4
      50.0 - CAPITAL RECOVERY PERIOD FOR TRUNK SEWERS,YR           4      9-12
      10.0 - CAPITAL RECOVERY PRERIOD FOR LIST STATIONS,YR         4     17-20
         2 - CONSTRUCTION LAG TIME,YR                              4     25-28
    0.0600 - ANNUAL RATE OF INTEREST                               4     33-40
  0.001675 - ANNUAL RATE OF INCREASE OF INTEREST                   4     41-48
   100.000 - GPD/CAPITA OF WASTEWATER FLOW                         4     49-56
     2.250 - PEAK FLOW FACTOR                                      4     57-64
   -0.1000 - MINIMUM SLOPE OF TRUNK SEWER, -FT/1000 FT             4     65-72
     25.00 - AVERAGE PUMPING HEAD OF LIFT STATIONS,FT              4     72-80

  340.6600 - ENR-B INDEX FOR COST DATA                             5      1- 8
  340.6600 - ENR-B INDEX FOR STUDY YEAR                            5      9-16
   26.1700 - ANNUAL INCREASE OF ENR-B INDEX                        5     17-24
  211.6600 - WPC-S INDEX FOR COST DATA                             5     25-32
  211.6600 - WPC-S INDEX FOR STUDY YEAR                            5     33-40
   15.1840 - ANNUAL INCREASE OF WPC-S INDEX                        5     41-48
    4.3600 - O & M INDEX FOR COST DATA                             5     49-56
    4.3600 - O & M INDEX FOR STUDY YEAR                            5     57-64
    0.2100 - ANNUAL INCREASE OF O & M INDEX                        5     65-72
```

Figure 34. Control parameters.

Table 37. Design index selection of treatment alternatives.

Design index	1	2	3	4	5	6	7	8	9	10
Treatment levels										
Initial	0	0	0	0	1	1	1	2	2	3
Final	1	2	3	3	2	3	4	3	4	4

```
COST EQUATION COEFFICIENTS - RUN    3

            CONSTRUCTION COSTS, MIL $                              O & M COSTS, MIL $

    COL -  1-8              COL -  9-16               COL - 17-24             COL - 25-32

1.2010 - AK( 1)         0.7730 - ALPHA( 1)        0.0537 - BK( 1)         0.7750 - BALPHA( 1)
1.5320 - AK( 2)         0.8000 - ALPHA( 2)        0.0599 - BK( 2)         0.8050 - BALPHA( 2)
1.7120 - AK( 3)         0.7890 - ALPHA( 3)        0.1070 - BK( 3)         0.7460 - BALPHA( 3)
2.3620 - AK( 4)         0.7580 - ALPHA( 4)        0.1650 - BK( 4)         0.7300 - BALPHA( 4)
0.3580 - AK( 5)         0.8670 - ALPHA( 5)        0.0133 - BK( 5)         0.9420 - BALPHA( 5)
0.5380 - AK( 6)         0.8170 - ALPHA( 6)        0.0585 - BK( 6)         0.7380 - BALPHA( 6)
1.1880 - AK( 7)         0.7400 - ALPHA( 7)        0.1160 - BK( 7)         0.7180 - BALPHA( 7)
0.2060 - AK( 8)         0.6600 - ALPHA( 8)        0.5230 - BK( 8)         0.6810 - BALPHA( 8)
0.8580 - AK( 9)         0.6490 - ALPHA( 9)        0.1100 - BK( 9)         0.6890 - BALPHA( 9)
0.6780 - AK(10)         0.6460 - ALPHA(10)        0.6300 - BK(10)         0.7220 - BALPHA(10)
0.1270 - AK(11)         0.3900 - ALPHA(11)        0.0018 - BK(11)         0.6640 - BALPHA(11)
0.1280 - AK(12)         0.6150 - ALPHA(12)        0.0288 - BK(12)         0.8970 - BALPHA(12)
```

Figure 35. Output listing of cost equation coefficients.

```
TREATMENT PLANT INPUT DATA - RUN    3

PLANT  CAPACITY     DEBT   ELEVATION  TREATMENT LEVEL        NAME
  J       MGD      MIL-$       FT

  1       2.27    0.3064   4214.00           1            SOUTH DAVIS COUNTY - SOUTH WWTP
  2      45.00    3.2259   4213.00           1            SALT LAKE CITY
  3       4.55    0.5591   4230.00           1            SOUTH SALT LAKE CITY
  4      16.00    0.1138   4238.00           1            SALT LAKE CITY S.S.D. #1
  5       7.30    0.3715   4250.00           1            GRANGER-HUNTER
  6       8.00    0.3514   4246.00           1            SALT LAKE COUNTY COTTONWOOD
  7       4.00    0.0000   4243.00           1            MURRAY
  8       3.60    0.0990   4277.00           1            TRI-COMMUNITY
  9       1.50    0.3111   4300.00           1            SANDY
 10       0.00    0.0000   4236.00           0            NEW REGIONAL WWTP
```

Figure 36. Output listing of wastewater treatment plant data.

```
TRUNK SEWER INPUT DATA AND CALCULATED PARAMETERS - RUN    3

FROM  TO  DISTANCE   CAPACITY        DEBT      HEAD     SLOPE
 J     K     FT         MGD         MIL-$       FT    FT/1000 FT


 1     2   12500.00     0.00       0.0000     -1.00    -0.0800
 2     1   12500.00     0.00       0.0000      1.00     0.0800
 2     3   38300.00     0.00       0.0000     17.00     0.4439
 2     4   41700.00     0.00       0.0000     25.00     0.5995
 2    10   40300.00     0.00       0.0000     23.00     0.5707
 3     2   38300.00     0.00       0.0000    -17.00    -0.4439
 3     4    7800.00     0.00       0.0000      8.00     1.0256
 3    10    9400.00     0.00       0.0000      6.00     0.6383
 4     2   41700.00     0.00       0.0000    -25.00    -0.5995
 4     3    7800.00     0.00       0.0000     -8.00    -1.0256
 4     5    5800.00     0.00       0.0000     12.00     2.0690
 4     6    9300.00     0.00       0.0000      8.00     0.8602
 4    10    2400.00     0.00       0.0000     -2.00    -0.8333
 5     4    5800.00     0.00       0.0000    -12.00    -2.0690
 5    10    3600.00     0.00       0.0000    -14.00    -3.8889
 6     4    9300.00     0.00       0.0000     -8.00    -0.8602
 6     7    2800.00     0.00       0.0000     -3.00    -1.0714
 6    10   10200.00     0.00       0.0000    -10.00    -0.9804
 7     6    2800.00     0.00       0.0000      3.00     1.0714
 7     8   18600.00     0.00       0.0000     34.00     1.8280
 8     7   18600.00     0.00       0.0000    -34.00    -1.8280
 8     9   13200.00     0.00       0.0000     23.00     1.7424
 9     8   13200.00     0.00       0.0000    -23.00    -1.7424
10     2   40300.00     0.00       0.0000    -23.00    -0.5707
10     3    9400.00     0.00       0.0000     -6.00    -0.6383
10     4    2400.00     0.00       0.0000      2.00     0.8333
10     5    3600.00     0.00       0.0000     14.00     3.8889
10     6   10200.00     0.00       0.0000     10.00     0.9804
```

Figure 37. Output listing of trunk sewer data.

```
ANNUAL COST FACTORS - RUN    3

YEAR   INTEREST    CRF       CRF       CRF          BUILDING      SEWER        O & M
         RATE      STP      SEWER  LIFT STATION   COST FACTOR  COST FACTOR  COST FACTOR

1974    0.0600    0.0872    0.0634    0.1359         1.0000       1.0000       1.0000
1975    0.0617    0.0884    0.0649    0.1369         1.0768       1.0717       1.0482
1976    0.0634    0.0896    0.0664    0.1380         1.1536       1.1435       1.0963
1977    0.0650    0.0908    0.0679    0.1391         1.2305       1.2152       1.1445
1978    0.0667    0.0920    0.0695    0.1402         1.3073       1.2870       1.1927
1979    0.0684    0.0932    0.0710    0.1413         1.3841       1.3587       1.2408
1980    0.0701    0.0944    0.0725    0.1424         1.4609       1.4304       1.2890
1981    0.0717    0.0957    0.0740    0.1435         1.5378       1.5022       1.3372
1982    0.0734    0.0969    0.0756    0.1446         1.6146       1.5739       1.3853
1983    0.0751    0.0981    0.0771    0.1457         1.6914       1.6456       1.4335
1984    0.0768    0.0994    0.0787    0.1469         1.7682       1.7174       1.4817
```

Figure 38. Output listing of annual cost factors.

```
POPULATION DATA - RUN    3

                                                      PLANT NUMBER
PERIOD   YEAR      1         2          3         4          5         6         7         8          9        10

  0      1974   11222.   188367.    14802.   116464.    63450.    43025.    26646.    44567.    15238.        0.
  1      1975   11592.   191741.    15547.   119284.    66969.    45177.    27981.    47320.    15953.        0.
  2      1976   11961.   195116.    16293.   122104.    70488.    47330.    29315.    50072.    16669.        0.
  3      1977   12331.   198490.    17038.   124924.    74007.    49482.    30650.    52825.    17384.        0.
  4      1978   12700.   201864.    17783.   127744.    77526.    51634.    31984.    55577.    18099.        0.
  5      1979   13014.   203792.    18209.   129295.    79537.    52864.    32747.    57149.    18508.        0.
  6      1980   13329.   205720.    18635.   130847.    81548.    54094.    33509.    58722.    18916.        0.
  7      1981   13643.   207648.    19061.   132398.    83559.    55324.    34272.    60294.    19325.        0.
  8      1982   13957.   209577.    19486.   133950.    85569.    56553.    35034.    61867.    19734.        0.
  9      1983   14271.   211505.    19912.   135501.    87580.    57783.    35797.    63439.    20143.        0.
 10      1984   14586.   213433.    20338.   137053.    89591.    59013.    36559.    65012.    20551.        0.
 11      1985   14900.   215361.    20764.   138604.    91602.    60243.    37322.    66584.    20960.        0.
 12      1986   15170.   218061.    21360.   140776.    94417.    61965.    38390.    68786.    20932.        0.
 13      1987   15440.   220760.    21956.   142948.    97233.    63687.    39458.    70987.    20904.        0.
 14      1988   15710.   223460.    22553.   145121.   100048.    65409.    40525.    73189.    20877.        0.
 15      1989   15980.   226159.    23149.   147293.   102863.    67131.    41593.    75390.    20849.        0.
 16      1990   16250.   228859.    23745.   149465.   105679.    68853.    42661.    77592.    20821.        0.
 17      1991   16520.   231558.    24341.   151637.   108494.    70574.    43729.    79794.    20793.        0.
 18      1992   16790.   234258.    24937.   153809.   111309.    72296.    44797.    81995.    20765.        0.
 19      1993   17060.   236957.    25534.   155982.   114124.    74018.    45864.    84197.    20738.        0.
 20      1994   17330.   239657.    26130.   158154.   116940.    75740.    46932.    86398.    20710.        0.
 21      1995   17600.   242356.    26726.   160326.   119755.    77462.    48000.    88600.    20682.        0.
 22      1996   17869.   245054.    27322.   162498.   122574.    79184.    49069.    90800.    21462.        0.
 23      1997   18138.   247752.    27917.   164669.   125393.    80906.    50138.    93000.    22242.        0.
 24      1998   18407.   250450.    28513.   166841.   128211.    82628.    51207.    95200.    23022.        0.
 25      1999   18676.   253148.    29109.   169012.   131030.    84350.    52276.    97400.    23802.        0.
 26      2000   18945.   255846.    29704.   171184.   133849.    86072.    53345.    99600.    24582.        0.
 27      2001   19214.   258544.    30300.   173355.   136668.    87794.    54414.   101800.    25362.        0.
 28      2002   19483.   261242.    30896.   175527.   139487.    89516.    55483.   104000.    26142.        0.
 29      2003   19752.   263941.    31491.   177698.   142305.    91238.    56552.   106200.    26921.        0.
 30      2004   20021.   266639.    32087.   179870.   145124.    92960.    57621.   108400.    27701.        0.
```

Figure 39. Output listing of population data.

```
WASTEWATER FLOWS TO PLANTS IN MGD - RUN    3

PERIOD   YEAR     TIME PHASED                                         PLANT NUMBER
                TREATMENT LEVEL      1        2        3        4        5        6        7        8        9       10

  0      1974          1           2.52    42.38     3.33    26.20    14.28     9.68     6.00    10.03     3.43     0.00
  1      1975          1           2.61    43.14     3.50    26.84    15.07    10.16     6.30    10.65     3.59     0.00
  2      1976          1           2.69    43.90     3.67    27.47    15.86    10.65     6.60    11.27     3.75     0.00
  3      1977          2           2.77    44.66     3.83    28.11    16.65    11.13     6.90    11.89     3.91     0.00
  4      1978          2           2.86    45.42     4.00    28.74    17.44    11.62     7.20    12.50     4.07     0.00
  5      1979          2           2.93    45.65     4.10    29.09    17.90    11.89     7.37    12.86     4.16     0.00
  6      1980          4           3.00    46.29     4.19    29.44    18.35    12.17     7.54    13.21     4.26     0.00
  7      1981          4           3.07    46.72     4.29    29.79    18.80    12.45     7.71    13.57     4.35     0.00
  8      1982          4           3.14    47.15     4.38    30.14    19.25    12.72     7.88    13.92     4.44     0.00
  9      1983          4           3.21    47.59     4.48    30.49    19.71    13.00     8.05    14.27     4.53     0.00
 10      1984          4           3.28    48.02     4.58    30.84    20.16    13.28     8.23    14.63     4.62     0.00
 11      1985          4           3.35    48.46     4.67    31.19    20.61    13.55     8.40    14.98     4.72     0.00
 12      1986          4           3.41    49.06     4.81    31.67    21.24    13.94     8.64    15.48     4.71     0.00
 13      1987          4           3.47    49.67     4.94    32.16    21.88    14.33     8.88    15.97     4.70     0.00
 14      1988          4           3.53    50.28     5.07    32.65    22.51    14.72     9.12    16.47     4.70     0.00
 15      1989          4           3.60    50.89     5.21    33.14    23.14    15.10     9.36    16.96     4.69     0.00
 16      1990          4           3.66    51.49     5.34    33.63    23.78    15.49     9.60    17.46     4.68     0.00
 17      1991          4           3.72    52.10     5.48    34.12    24.41    15.88     9.84    17.95     4.68     0.00
 18      1992          4           3.78    52.71     5.61    34.61    25.04    16.27    10.08    18.45     4.67     0.00
 19      1993          4           3.84    53.32     5.75    35.10    25.68    16.65    10.32    18.94     4.67     0.00
 20      1994          4           3.90    53.92     5.88    35.58    26.31    17.04    10.56    19.44     4.66     0.00
 21      1995          4           3.96    54.53     6.01    36.07    26.94    17.43    10.80    19.94     4.65     0.00
 22      1996          4           4.02    55.14     6.15    36.56    27.58    17.82    11.04    20.43     4.83     0.00
 23      1997          4           4.08    55.74     6.28    37.05    28.21    18.20    11.28    20.93     5.00     0.00
 24      1998          4           4.14    56.35     6.42    37.54    28.85    18.59    11.52    21.42     5.18     0.00
 25      1999          4           4.20    56.96     6.55    38.03    29.48    18.98    11.76    21.92     5.36     0.00
 26      2000          4           4.26    57.57     6.68    38.52    30.12    19.37    12.00    22.41     5.53     0.00
 27      2001          4           4.32    58.17     6.82    39.00    30.75    19.75    12.24    22.91     5.71     0.00
 28      2002          4           4.38    58.78     6.95    39.49    31.38    20.14    12.48    23.40     5.88     0.00
 29      2003          4           4.44    59.39     7.09    39.98    32.02    20.53    12.72    23.90     6.06     0.00
 30      2004          4           4.50    59.99     7.22    40.47    32.65    20.92    12.96    24.39     6.23     0.00
```

Figure 40. Wastewater quantitites and time-phased treatment levels.

```
INDIVIDUAL TREATMENT PLANT TIME PHASED TREATMENT LEVELS - RUN   3

PERIOD   YEAR                                       PLANT NUMBER
                   1       2       3       4       5       6       7       8       9      10

  0      1974      1       1       1       1       1       1       1       1       1       1
  1      1975      1       1       1       1       1       1       1       1       1       1
  2      1976      1       1       1       1       1       1       1       1       1       1
  3      1977      1       1       1       1       1       1       1       1       1       1
  4      1978      1       1       1       1       1       1       1       1       1       1
  5      1979      1       1       1       1       1       1       1       1       1       1
  6      1980      1       1       1       1       1       1       1       1       1       1
  7      1981      1       1       1       1       1       1       1       1       1       1
  8      1982      1       1       1       1       1       1       1       1       1       1
  9      1983      1       1       1       1       1       1       1       1       1       1
 10      1984      1       1       1       1       1       1       1       1       1       1
 11      1985      1       1       1       1       1       1       1       1       1       1
 12      1986      1       1       1       1       1       1       1       1       1       1
 13      1987      1       1       1       1       1       1       1       1       1       1
 14      1988      1       1       1       1       1       1       1       1       1       1
 15      1989      1       1       1       1       1       1       1       1       1       1
 16      1990      1       1       1       1       1       1       1       1       1       1
 17      1991      1       1       1       1       1       1       1       1       1       1
 18      1992      1       1       1       1       1       1       1       1       1       1
 19      1993      1       1       1       1       1       1       1       1       1       1
 20      1994      1       1       1       1       1       1       1       1       1       1
 21      1995      1       1       1       1       1       1       1       1       1       1
 22      1996      1       1       1       1       1       1       1       1       1       1
 23      1997      1       1       1       1       1       1       1       1       1       1
 24      1998      1       1       1       1       1       1       1       1       1       1
 25      1999      1       1       1       1       1       1       1       1       1       1
 26      2000      1       1       1       1       1       1       1       1       1       1
 27      2001      1       1       1       1       1       1       1       1       1       1
 28      2002      1       1       1       1       1       1       1       1       1       1
 29      2003      1       1       1       1       1       1       1       1       1       1
 30      2004      1       1       1       1       1       1       1       1       1       1
```

Figure 41. Individual plant time-phased treatment levels.

```
TRUNK SEWER ALTERNATIVE PATH TABLE - RUN   3

ALT PLANT TREATMENT  MIN CAP  MAX CAP   ALT                    INPUT                                     OUTPUT
            LEVEL      MGD      MGD    PATH   1  2  3  4  5  6  7  8  9  10     1  2  3  4  5  6  7  8  9  10  11

 5    1       0       0.00    999.99          1  0  0  0  0  0  0  0  0  0      0  1  0  0  0  0  0  0  0  0   0
 5    2       1       0.00    999.99          1  1  1  1  1  1  1  1  1  0      0  0  0  0  0  0  0  0  0  0   1
 5    3       0       0.00    999.99          0  0  1  1  1  1  1  1  1  0      0  1  0  0  0  0  0  0  0  0   0
 5    4       0       0.00    999.99          0  0  0  1  1  1  1  1  1  0      0  0  1  0  0  0  0  0  0  0   0
 5    5       0       0.00    999.99          0  0  0  0  1  0  0  0  0  0      0  0  0  1  0  0  0  0  0  0   0
 5    6       0       0.00    999.99          0  0  0  0  0  1  1  1  1  0      0  0  0  1  0  0  0  0  0  0   0
 5    7       0       0.00    999.99          0  0  0  0  0  0  1  1  1  0      0  0  0  0  0  1  0  0  0  0   0
 5    8       0       0.00    999.99          0  0  0  0  0  0  0  1  1  0      0  0  0  0  0  0  1  0  0  0   0
 5    9       0       0.00    999.99          0  0  0  0  0  0  0  0  1  0      0  0  0  0  0  0  0  1  0  0   0
 5   10       0       0.00    999.99          0  0  0  0  0  0  0  0  0  1      0  0  0  0  0  0  0  0  0  0   0

 6    1       0       0.00    999.99          1  0  0  0  0  0  0  0  0  0      0  1  0  0  0  0  0  0  0  0   0
 6    2       1       0.00    999.99          1  1  0  0  0  0  0  0  0  0      0  0  0  0  0  0  0  0  0  0   1
 6    3       0       0.00    999.99          0  0  1  0  0  0  0  0  0  0      0  0  0  0  0  0  0  0  0  1   0
 6    4       0       0.00    999.99          0  0  0  1  0  1  1  1  1  0      0  0  0  0  0  0  0  0  0  1   0
 6    5       0       0.00    999.99          0  0  0  0  1  0  0  0  0  0      0  0  0  0  0  0  0  0  0  1   0
 6    6       0       0.00    999.99          0  0  0  0  0  1  1  1  1  0      0  0  0  1  0  0  0  0  0  0   0
 6    7       0       0.00    999.99          0  0  0  0  0  0  1  1  1  0      0  0  0  0  0  1  0  0  0  0   0
 6    8       0       0.00    999.99          0  0  0  0  0  0  0  1  1  0      0  0  0  0  0  0  1  0  0  0   0
 6    9       0       0.00    999.99          0  0  0  0  0  0  0  0  1  0      0  0  0  0  0  0  0  1  0  0   0
 6   10       4       0.00    999.99          0  0  1  1  1  1  1  1  1  1      0  0  0  0  0  0  0  0  0  0   1

 9    1       1       0.00    999.99          1  0  0  0  0  0  0  0  0  0      0  0  0  0  0  0  0  0  0  0   1
 9    2       1       0.00    999.99          0  1  1  1  1  1  1  0  0  0      0  0  0  0  0  0  0  0  0  0   1
 9    3       0       0.00    999.99          0  0  1  1  1  1  1  0  0  0      0  1  0  0  0  0  0  0  0  0   0
 9    4       0       0.00    999.99          0  0  0  1  1  1  1  0  0  0      0  0  1  0  0  0  0  0  0  0   0
 9    5       0       0.00    999.99          0  0  0  0  1  0  0  0  0  0      0  0  0  1  0  0  0  0  0  0   0
 9    6       0       0.00    999.99          0  0  0  0  0  1  1  0  0  0      0  0  0  1  0  0  0  0  0  0   0
 9    7       0       0.00    999.99          0  0  0  0  0  0  1  0  0  0      0  0  0  0  0  1  0  0  0  0   0
 9    8       1       0.00    999.99          0  0  0  0  0  0  0  1  1  0      0  0  0  0  0  0  0  0  0  0   1
 9    9       0       0.00    999.99          0  0  0  0  0  0  0  0  1  0      0  0  0  0  0  0  0  1  0  0   0
 9   10       0       0.00    999.99          0  0  0  0  0  0  0  0  0  1      0  0  0  0  0  0  0  0  0  0   0

20    1       1       0.00    999.99          1  0  0  0  0  0  0  0  0  0      0  0  0  0  0  0  0  0  0  0   1
20    2       1       0.00    999.99          0  1  0  0  0  0  0  0  0  0      0  0  0  0  0  0  0  0  0  0   1
20    3       0       0.00    999.99          0  0  1  0  0  0  0  0  0  0      0  0  0  1  0  0  0  0  0  0   0
20    4       0       0.00    999.99          0  0  1  1  1  0  0  0  0  0      0  0  0  0  0  1  0  0  0  0   0
20    5       0       0.00    999.99          0  0  0  0  1  0  0  0  0  0      0  0  0  1  0  0  0  0  0  0   0
20    6       0       0.00    999.99          0  0  1  1  1  1  0  0  0  0      0  0  0  0  0  0  1  0  0  0   0
20    7       1       0.00    999.99          0  0  1  1  1  1  1  1  1  0      0  0  0  0  0  0  0  0  0  0   1
20    8       0       0.00    999.99          0  0  0  0  0  0  0  1  1  0      0  0  0  0  0  0  1  0  0  0   0
20    9       0       0.00    999.99          0  0  0  0  0  0  0  0  1  0      0  0  0  0  0  0  0  1  0  0   0
20   10       0       0.00    999.99          0  0  0  0  0  0  0  0  0  1      0  0  0  0  0  0  0  0  0  0   0
```

Figure 42. Alternative trunk sewer path table.

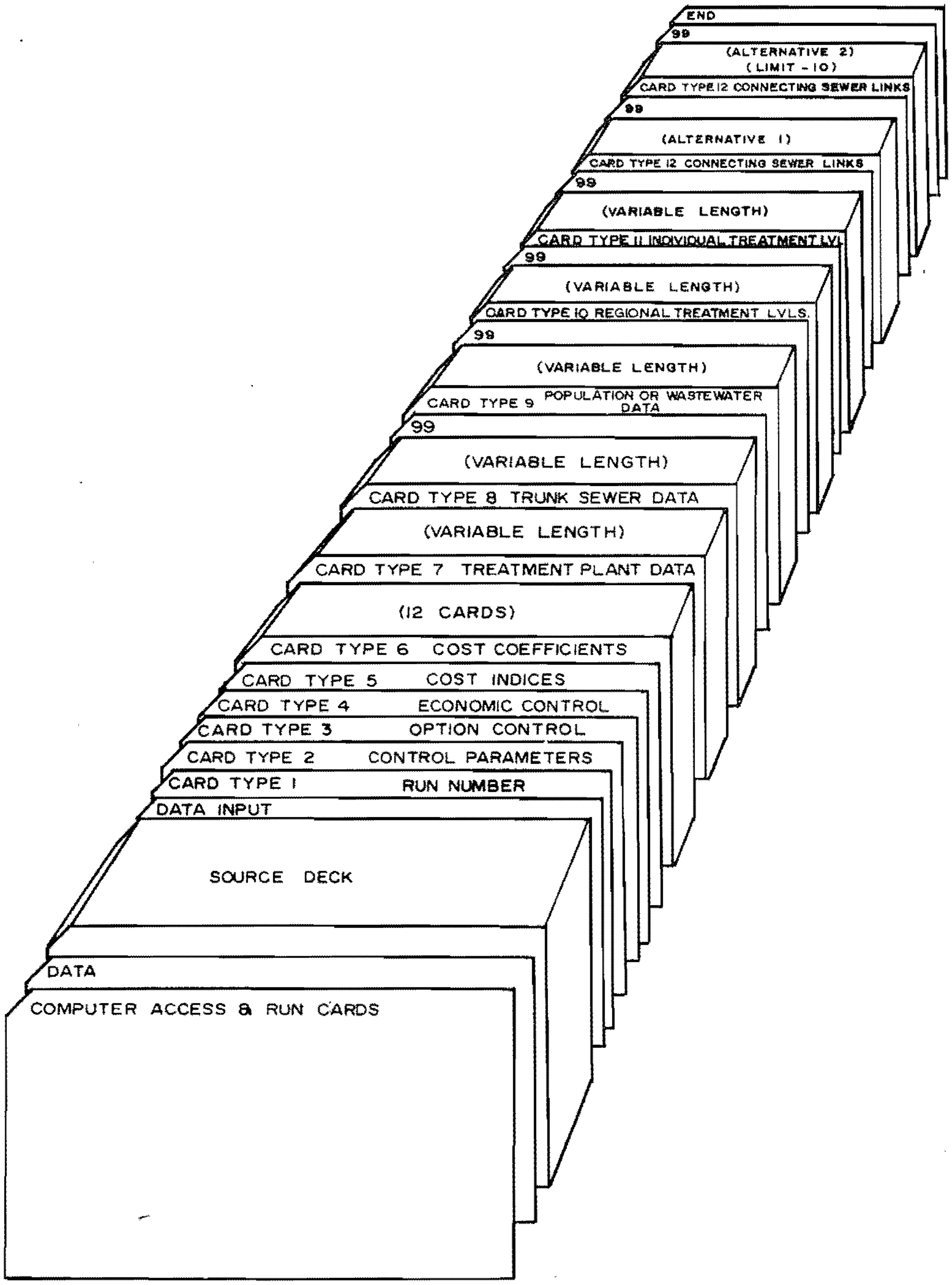
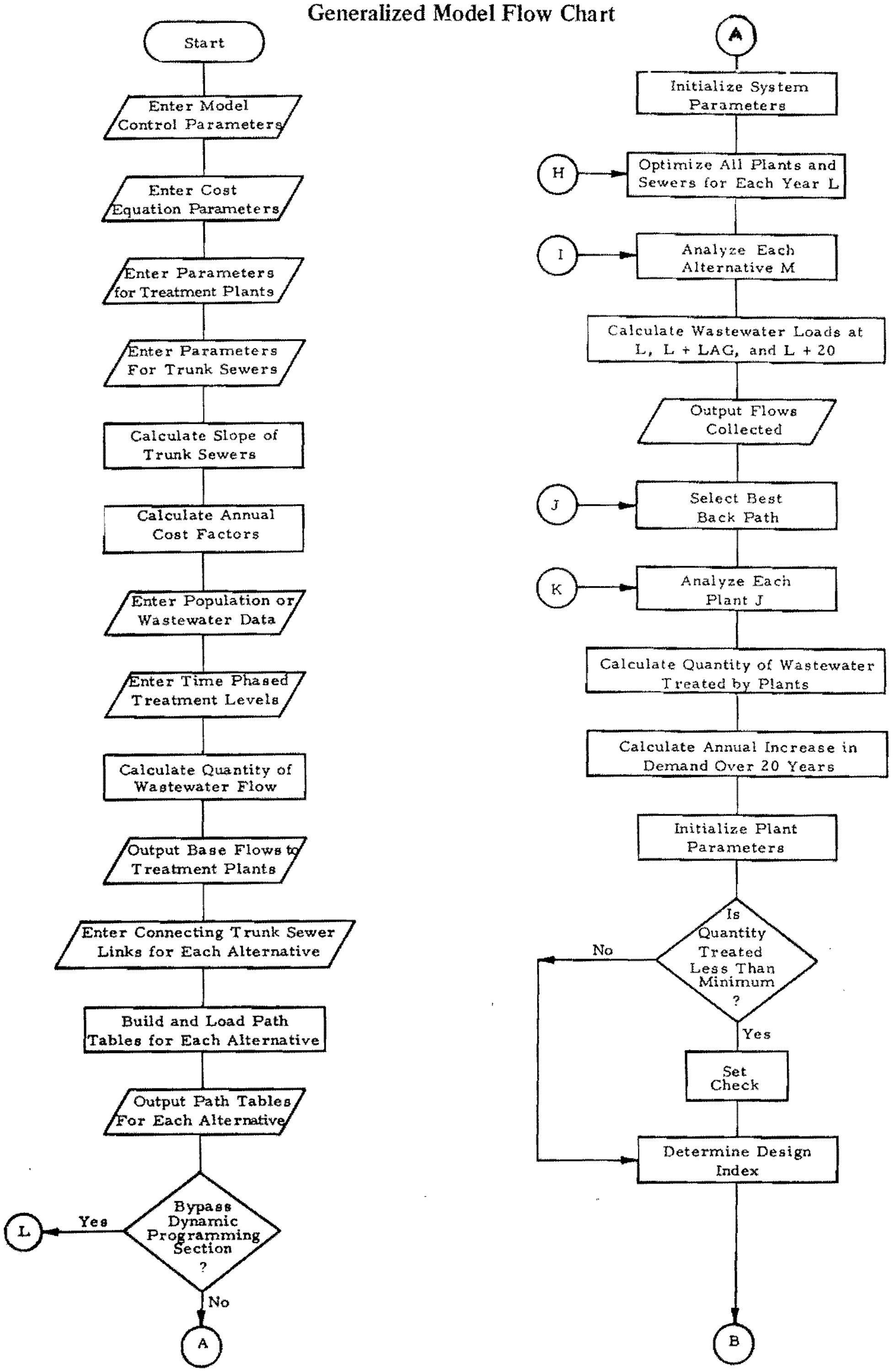
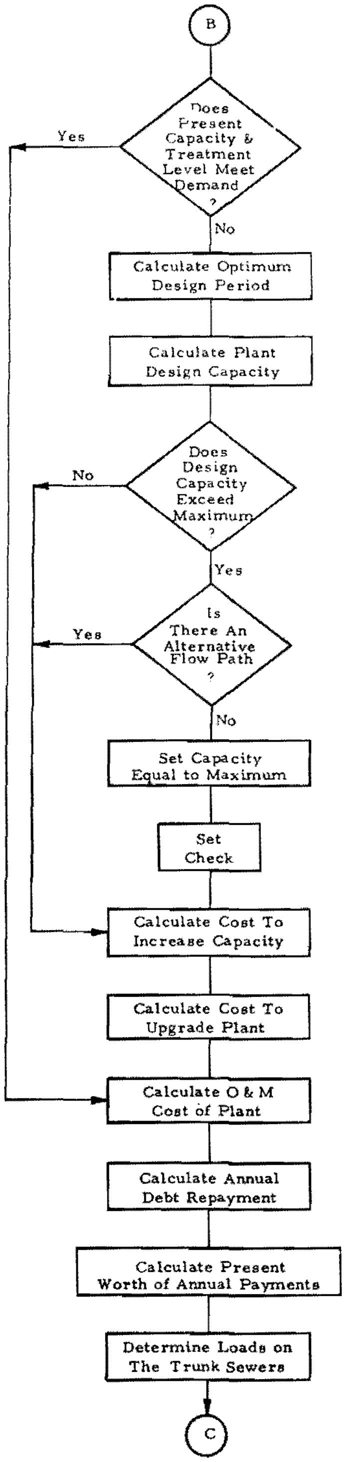


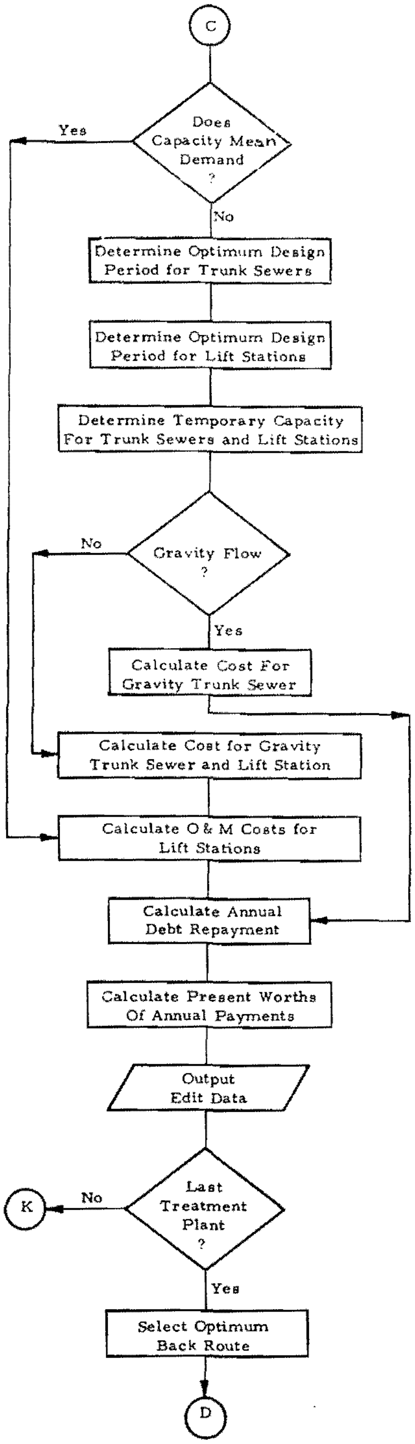
Figure 43. Pictorial layout of input cards.

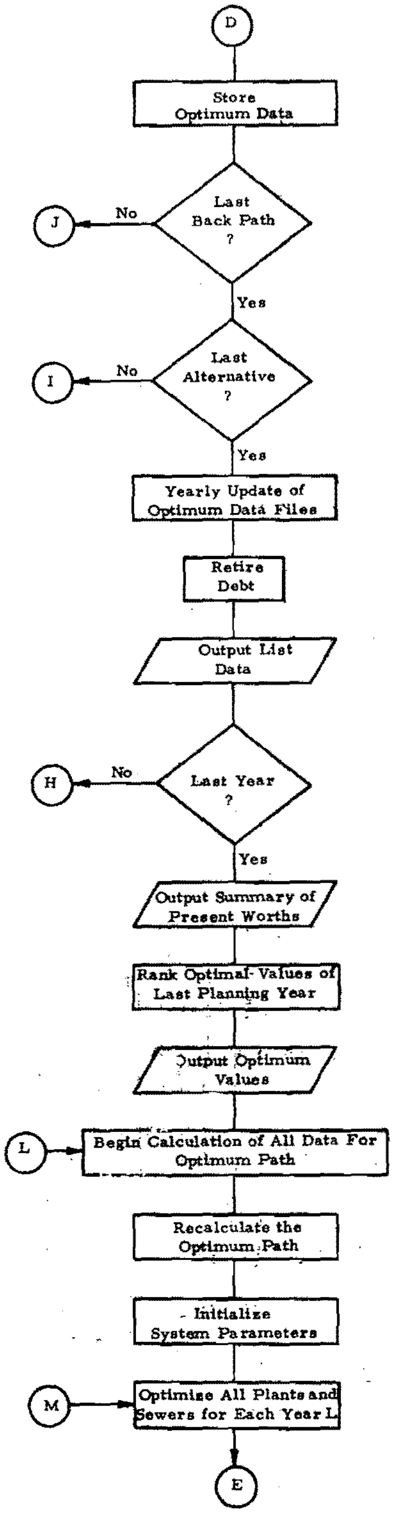
Appendix B

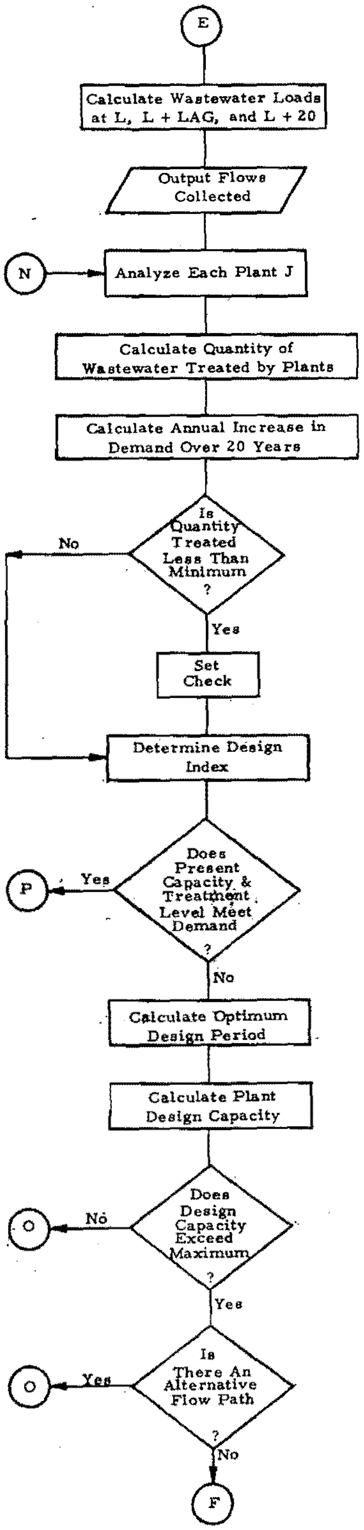
Generalized Model Flow Chart

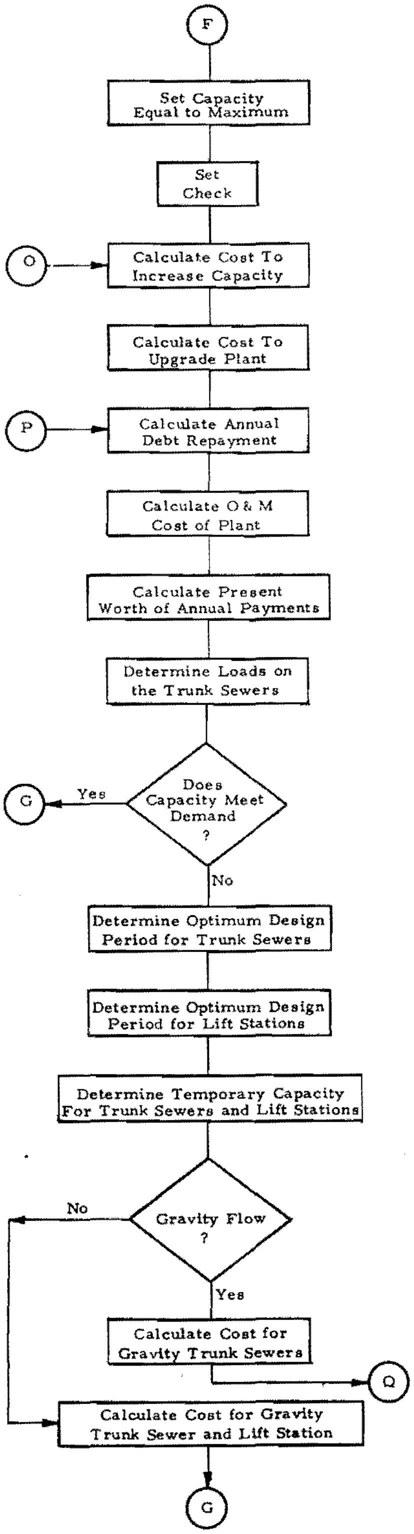


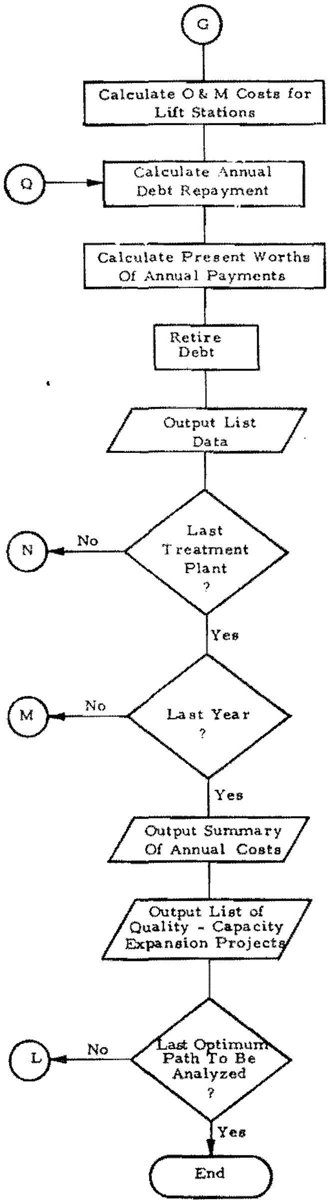

B
Does Present Capacity & Treatment Level Meet Demand ?
Yes
No
Calculate Optimum Design Period
Calculate Plant Design Capacity
Does Design Capacity Exceed Maximum ?
No
Yes
Is There An Alternative Flow Path ?
Yes
No
Set Capacity Equal to Maximum
Set Check
Calculate Cost To Increase Capacity
Calculate Cost To Upgrade Plant
Calculate O & M Cost of Plant
Calculate Annual Debt Repayment
Calculate Present Worth of Annual Payments
Determine Loads on The Trunk Sewers
C


C
Does Capacity Mean Demand ?
Yes
No
Determine Optimum Design Period for Trunk Sewers
Determine Optimum Design Period for Lift Stations
Determine Temporary Capacity For Trunk Sewers and Lift Stations
Gravity Flow ?
No
Yes
Calculate Cost For Gravity Trunk Sewer
Calculate Cost for Gravity Trunk Sewer and Lift Station
Calculate O & M Costs for Lift Stations
Calculate Annual Debt Repayment
Calculate Present Worths Of Annual Payments
Output Edit Data
Last Treatment Plant ?
No
K
Yes
Select Optimum Back Route
D


D
Store Optimum Data
Last Back Path ?
No
J
Yes
Last Alternative ?
No
I
Yes
Yearly Update of Optimum Data Files
Retire Debt
Output List Data
Last Year ?
No
H
Yes
Output Summary of Present Worths
Rank Optimal Values of Last Planning Year
Output Optimum Values
L
Begin Calculation of All Data For Optimum Path
Recalculate the Optimum Path
Initialize System Parameters
M
Optimize All Plants and Sewers for Each Year L
E


E
Calculate Wastewater Loads at L, L + LAG, and L + 20
Output Flows Collected
N
Analyze Each Plant J
Calculate Quantity of Wastewater Treated by Plants
Calculate Annual Increase in Demand Over 20 Years
Is Quantity Treated Less Than Minimum ?
No
Yes
Set Check
Determine Design Index
Does Present Capacity & Treatment Level Meet Demand ?
Yes
P
No
Calculate Optimum Design Period
Calculate Plant Design Capacity
Does Design Capacity Exceed Maximum ?
No
O
Yes
Is There An Alternative Flow Path ?
Yes
O
No
F


F
Set Capacity Equal to Maximum
Set Check
O
Calculate Cost To Increase Capacity
Calculate Cost To Upgrade Plant
P
Calculate Annual Debt Repayment
Calculate O & M Cost of Plant
Calculate Present Worth of Annual Payments
Determine Loads on the Trunk Sewers
Does Capacity Meet Demand ?
Yes
G
No
Determine Optimum Design Period for Trunk Sewers
Determine Optimum Design Period for Lift Stations
Determine Temporary Capacity For Trunk Sewers and Lift Stations
Gravity Flow ?
No
Yes
Calculate Cost for Gravity Trunk Sewers
Q
Calculate Cost for Gravity Trunk Sewer and Lift Station
G


G
Calculate O & M Costs for Lift Stations
Q
Calculate Annual Debt Repayment
Calculate Present Worths Of Annual Payments
Retire Debt
Output List Data
Last Treatment Plant ?
No
N
Yes
Last Year ?
No
M
Yes
Output Summary Of Annual Costs
Output List of Quality - Capacity Expansion Projects
Last Optimum Path To Be Analyzed ?
No
L
Yes
End

Appendix C

Program Listing

```
************************************************************************

      WASTEWATER TREATMENT OPTIMIZATION MODEL - WTOM

      BURROUGHS 6700  -  FORTRAN IV

      UTAH STATE UNIVERSITY

************************************************************************


FILE  5=WASTEIN
FILE  6=WASTEOUT
      DIMENSION AK(12), ALPHA(12), BK(12), BALPHA(12)
      DIMENSION IPLT(99), JPLT(11)
      DIMENSION CAPP(10), DEBTP(10), ELEV(10), LTREAT(10)
      DIMENSION ANAME(10,9), BNAME(9)
      DIMENSION DIST(10,11), CAPS(10,11), DEBTS(10,11), SHEAD(10,11),
     1 SLOPE(10,11)
      DIMENSION RETURN(51), CRFP(51), CRFS(51), CRFL(51)
      DIMENSION  FACCAP(51), FACSEW(51), FACOM(51)
      DIMENSION POP(10,71), LQUAL(71), QUANT(10,71)
      DIMENSION IPATH(10,11,10), NALT(10), MTREAT(10,10)
      DIMENSION IN(10,10,10), IOUT(10,11,10)
      DIMENSION TCAPP(10,2,10), TDEBTP(10,2,10)
      DIMENSION TCAPS(10,11,2,10), TDEBTS(10,11,2,10)
      DIMENSION ACAPP(10), ADEBTP(10), FDEBTP(10), LTTRET(10)
      DIMENSION CDEBTP(10), AOMP(10), MBACK(51,10)
      DIMENSION ABOMS(11)
      DIMENSION ACAPS(10,11), ADEBTS(10,11), FDEBTS(10,11)
      DIMENSION NUMLS(10,11)
      DIMENSION BOMS(11),      CDEBTS(11), BDEBTS(11), OPTVAL(51,10)
      DIMENSION VALUE(51,10), NUMINS(11), MALT(51), KALT(11)
      DIMENSION KYEAR(100), KORIGN(100), KDEST(100), CAP1(100),
     1 CAP2(100), KTRET1(100), KTRET2(100), EXDEBT(100), DEBTEX(100),
     2 TDEBT(100), NUMLSP(100)
      DIMENSION TOTCAP(51), TAN(51), TOM(51)
      DIMENSION  ANP(10), OMP(10), OMS(10,11), ANS(10,11)
      DIMENSION  DEBTPF(10,10), DEBTSF(10,11,10)
      DIMENSION LQUALJ(10,71), ICHECK(10,10,10)
      DIMENSION CAPMIN(10,10), CAPMAX(10,10)
      DIMENSION COLECT(10), COLLAG(10), FUTURE(10)
      DIMENSION IALT(10,10)
      DIMENSION LCHECK(10)
      DIMENSION TOTPW(71), ECAPS(11), KTREAT(10,2,10)
      EQUIVALENCE (IPATH,IOUT)
      EQUIVALENCE (POP,QUANT)
      DATA ASPACE/' '/
    1 FORMAT (I2)
    2 FORMAT ('1CONTROL PARAMETERS - RUN', I4// 64X, 'CARD', 4X, 'COL'/)
    3 FORMAT (3(I2, 6X), I4, 4X, 2(I2, 6X))
```

```
 4 FURMAT (8X, I4,' - RUN NUMBER', 41X, '1', 4X, '1- 2'///
  1 8X, I4, ' - NUMBER OF EXISTING AND PROPOSED PLANTS', 13X, '2',
  2 4X, '1- 2' /  8X, I4, ' - NUMBER OF PLANNING YEARS',  27X, '2',
  3 4X, '9-10'/  8X, I4, ' - NUMBER OF ALTERNATIVE PLANS', 24X, '2',
  4 3X, '17-18'/  8X, I4, ' - INITIAL YEAR OF STUDY', 30X, '2',
  5 3X, '25-28' / 8X, I4, ' - FLOWS FROM, 1 - WASTEWATER, 0 - POPULAT
  6ION', 9X, '2', 3X, '33-34' / 8X, I4, ' - DESIGN PERIOD, 1 - OPTIMA
  7L, 0 - CAP. REC. PERIOD', 3X, '2', 3X, '41-42' //)
 5 FURMAT (9(I2, 6X))
 6 FURMAT (8X, I4, ' - NUMBER OF YEARS THAT EDIT DATA IS PRINTED',
  110X, '3', 4X, '1-2' /  8X, I4, ' - NUMBER OF YEARS THAT LIST DATA
  2IS PRINTED', 10X, '3', 4X, '9-10' /  8X, I4, ' - PRINT PRESENT WOR
  3TH DATA, 1 - YES, 0 - NO',  10X, '3', 3X, '17-18' /
  4 8X, I4, ' - PRINT RANKING, 1 - YES, 0 - NO', 21X, '3', 3X, '25-26
  5' / 8X, I4, ' - NUMBER OF ANNUAL LISTINGS OF PRESENT WORTH',
  6 9X, '3', 3X, '33-34' / 8X,I4  ' - NUMBER OF ALTERNATIVES ANALYSED
  7 FOR ANNUAL COSTS', 3X, '3', 3X, '41-42' / 8X, I4, ' - PRINT QUALI
  8TY-CAPACITY PROJECTS, 1 - YES, 0 - NO', 3X, '3', 3X, '49-50' /
  9 8X, I4, ' - NUMBER OF YEARS OF SUMMARY OF OPTIMUM OPERATION', 4X,
  *'3', 3X, '57-58' / 8X, I4, ' - OPTIMIZE INDIVIDUAL ALTERNATIVES, 1
  1 - YES, 0 - NO', 2X, '3', 3X, '65-66' //)
 7 FURMAT ( 3(F4.1, 4X), I2, 6X, 6F8.4)
 8 FURMAT (8X, F4.1, ' - CAPITAL RECOVERY PERIOD FOR TREATMENT PLANTS
  1,YR', 4X, '4', 4X, '1-4' /  8X, F4.1, ' - CAPITAL RECOVERY PERIOD
  2FOR TRUNK SEWERS,YR', 8X, '4', 4X, '9-12', / 8X, F4.1, ' - CAPITAL
  3 RECOVERY PHERIOD FOR LIST STATIONS,YR', 6X, '4', 3X, '17-20' /
  4 8X, I4, ' - CONSTRUCTION LAG TIME,YR',  27X, '4', 3X, '25-28' /
  5 2X, F10.4, ' - ANNUAL RATE OF INTEREST', 28X, '4', 3X, '33-40' /
  6 2X, F10.6, ' - ANNUAL RATE OF INCREASE OF INTEREST', 16X, '4',
  7 3X, '41-48' / 2X, F10.3, ' - GPD/CAPITA OF WASTEWATER FLOW', 22X,
  8 '4', 3X, '49-56' / 2X, F10.3,  ' - PEAK FLOW FACTOR', 35X, '4',
  9 3X, '57-64' /  2X, F10.4, ' - MINIMUM SLOPE OF TRUNK SEWER, -FT/1
  *000 FT', 10X, '4', 3X, '65-72' / 2X, F10.2, ' - AVERAGE PUMPING HE
  1AD OF LIFT STATIONS,FT', 11X, '4', 3X, '72-80' //)
 9 FURMAT (9F8.4)
10 FORMAT (2X, F10.4, ' - ENR-B INDEX FOR COST DATA',  26X, '5',
  1 4X, '1- 8' /  2X, F10.4, ' - ENR-B INDEX FOR STUDY YEAR',  25X,
  2 '5', 4X,'9-16' /  2X, F10.4, ' - ANNUAL INCREASE OF ENR-B INDEX',
  3  21X, '5', 3X, '17-24' / 2X, F10.4, ' - WPC-S INDEX FOR COST DATA
  4 ', 25X, '5', 3X, '25-32' / 2X, F10.4, ' - WPC-S INDEX FOR STUDY Y
  5EAR', 25X, '5', 3X, '33-40' /2X, F10.4, ' - ANNUAL INCREASE OF WPC
  6-S INDEX',  21X, '5', 3X, '41-48' / 2X, F10.4, ' - O & M INDEX FOR
  7 COST DATA',  26X, '5', 3X, '49-56' /  2X, F10.4, ' - O & M INDEX
  8FOR STUDY YEAR',  25X, '5', 3X, '57-64' / 2X, F10.4, ' - ANNUAL IN
  9CREASE OF O & M INDEX',  21X, '5',3X, '65-72'//)
11 FORMAT ('1COST EQUATION COEFFICIENTS - RUN', I4 ///14X, 'CONSTRUCT
  1ION COSTS, MIL $', 33X, 'O & M COSTS, MIL $' /)
12 FURMAT (4F8.4)
13 FORMAT (9X, 'COL -  1-8' , 15X, 'COL -  9-16', 16X, 'COL - 17-24',
  1 16X, 'COL - 25-32' /)
14 FURMAT (2X, F10.4, ' - AK(', I2, ')', 6X, F10.4, ' - ALPHA(', I2,
  1 ')', 6X, F10.4, ' - BK(', I2, ')', 6X, F10.4, ' - BALPHA(', I2,
  2 ')' )
15 FORMAT ('1TREATMENT PLANT INPUT DATA - RUN ', I4//)
16 FURMAT (' PLANT  CAPACITY      DEBT   ELEVATION  TREATMENT LEVEL
  1    NAME')
17 FURMAT ('    J         MGD       MIL-$       FT'/)
18 FURMAT (I2, 6X, 3F8.4, I2, 6X, 9A4)
19 FURMAT (2X, I2, 2X, F8.2, 2X, F10.4, 2X, F8.2, 8X, I4, 10X, 9A4)
20 FURMAT (/' INVALID TREATMENT PLANT DATA, SEQ. NUM -', I4, '  DATA
  1- ', I2, 2X, F8.2, F8.4, F8.2, 2X, I2, 4X, 9A4/)
```

```
 25 FURMAT ('1TRUNK SEWER INPUT DATA AND CALCULATED PARAMETERS = RUN',
   1 I4//)
 26 FURMAT (' FROM  TO  DISTANCE  CAPACITY      DEBT    HEAD    SLOPE
   1')
 27 FURMAT ('    J     K      FT         MGD        MIL$      FT   FT/1000
   1FT'//)
 28 FURMAT (I2, 6X, I2, 6X, F8.2, F8.2, F12.4)
 29 FURMAT (I4, I5, F10.2,    F8.2,  2X, F10.4, F8. , F9.4)
 30 FURMAT (/' INVALID TRUNK SEWER DATA = ', 2X, I2, 2X, I2, 2X,
   1 2F10.2, F12.4/)
 35 FURMAT ('1 ANNUAL CUST FACTORS = RUN', I4 /)
 36 FURMAT ('  YEAR   INTEREST      CRF         CRF         CRF           BUI
   1LDING       SEWER          O & M')
 37 FURMAT ('              RATE         STP        SEWER  LIFT STATION  COST
   1FACTUR  COST FACTOR  COST FACTUR'/)
 38 FURMAT (2X,I4, F10.4, F10.4, F10.4, F10.4, 5X, F10.4, 3X,
   1 F10.4, 2X, F10.4)
 45 FURMAT (I2, 6X, I2, 6X, F12.0)
 46 FURMAT(/' INVALID POPULATION DATA = ', I4, 2X, I4, 2X, F10.2/)
 47 FURMAT (/' INVALID WASTEWATER QUANTITIES = ', I4, 2X, I4, 2X,
   1 F10.2/)
 48 FURMAT (3X,I2,4X,I4, *(F9.0))
 50 FURMAT ('1PUPULATIUN DATA = RUN ', I4//)
 51 FURMAT ( *A1, 'PLANT NUMBER')
 52 FORMAT (' PERIOD  YEAR', *(4X, I2, 3X) / )
 55 FURMAT (I2, 6X, I2)
 56 FURMAT (' INVALID TIME PHASED TREATMENT LEVEL PARAMETER = ', 2I6/)
 60 FURMAT ('1WASTEWATER FLOWS TU PLANTS IN MGD = RUN ', I4//)
 61 FURMAT (' PERIOD  YEAR    TIME PHASED  ', *A1, 'PLANT NUMBER')
 62 FURMAT (15X, 'TREATMENT LEVEL', *(4X, I2, 2X) /)
 63 FURMAT (3X, I2, 4X, I4, 8X, I2, 7X, *(F8.2) )
 64 FURMAT ( 3(I2, 6X))
 65 FURMAT (/' INVALID TIME PHASED TREATMENT LEVEL FOR TREATMENT PLANT
   1S =', 3(I4, 6X) / )
 66 FURMAT ('1INDIVIDUAL TREATMENT PLANT TIME PHASED TREATMENT LEVELS
   1= RUN', I4 //)
 67 FURMAT  (' PERIOD  YEAR', *A1, 'PLANT NUMBER')
 68 FURMAT (15X, *(4X, I2, 2X) / )
 69 FURMAT (3X, I2, 4X, I4, 2X, *(4X, I2, 2X) )
 70 FURMAT (I2, 6X, I2, 6X, I2, 6X, I2, 6X, 2F8.4)
 71 FURMAT (' INVALID TRUNK SEWER LINK DATA = ', I4, 2X, I4, 2X, I4,
   1 2X, I4, 2X, 2F10.2 /)
 75 FURMAT ('1TRUNK SEWER ALTERNATIVE PATH TABLE = RUN', I4 //)
 76 FURMAT (' ALT PLANT TREATMENT  MIN CAP  MAX CAP   ALT', *A1,
   1 'INPUT', *A1, 'OUTPUT')
 77 FURMAT (13X, 'LEVEL', 6X, 'MGD', 6X, 'MGD', 4X, 'PATH', *(I4),
   1 2X, *(I4) / )
 80 FORMAT (I3, 3X, I2, 6X, I2, 4X, F8.2, 1X, F8.2,  4X, I2,  1X,
   1 *(I4), 2X, *(I4) )
 82 FORMAT (I3, 3X, I2, 6X, I2, 4X, F8.2, 1X, F8.2,  4X, 2X,  1X,
   1 *(I4), 2X, *(I4) )
 90 FURMAT ('0')
 92 FORMAT ('1WASTEWATER FLOWS COLLECTED BY TREATMENT PLANTS, MGD,  RU
   1N = ', I4 //)
 93 FURMAT (' PERIOD  YEAR ALT', *A1, 'PLANT NUMBER')
 94 FURMAT (19X, *(4X, I2, 2X) / )
 95 FURMAT (3X, I2, 4X, I4, I4, 2X, *(F8.2) /)
101 FURMAT ('1EDIT DATA = RUN', I4// 104X, 'ANNUAL PRESENT WORTH DATA'
   *//)
102 FURMAT ('  L  M MB  J  K  CAP   FLOW   FLOWL  DEMAND  TSTAR  DESIG
   1N   LIFT   EXISTING DESIGN    DEBT    EXPANSION  ANNUAL    O & M
```

```
   2  VALUE')
103 FORMAT(16X, 'LIMIT   MGD    MGD     MGD    MGD   INDEX  STATIONS
   1 MGD      MGD     MIL $     MIL $      MIL $     MIL $     MIL $'//)
105 FORMAT (4I3, 5X, I2, 2F8.2, F8.4, F7.2, 4X, I2, 11X, F8.2,
   1 F8.2, 2F10.4, 3F9.4)
106 FORMAT (9X, 2I3, 4X, 2F8.2, F8.4, F7.2, 11X, I3, 3X, 2F8.2,
   1 2F10.4, 3F9.4)
107 FORMAT (114X, F16.4 /)
109 FORMAT ('1LIST DATA - RUN', I4 //)
110 FORMAT (' OPTIMUM ALTERNATIVES' //)
111 FORMAT ('   L   M  MB   J   K       CAPAC      DEBT     ANNUAL    EXPA
   1NSION   TOTAL       VALUE        OPTVAL')
112 FORMAT (27X, 'MGD', 5X, 'MIL $', 4X, 'MIL $', 6X, 'MIL $',
   15X, 'MIL $', 5X, 'MIL $', 6X, 'MIL $'/)
114 FORMAT (/4I4,7X,F8.2,4F10.4)
116 FORMAT (5I4,3X,F8.2,4F10.4)
117 FORMAT (71X,F10.4,F14.4)
119 FORMAT ('1 PRESENT WORTH VALUES USED TO SELECT OPTIMUM PATH - RUN'
   1 , I4/)
120 FORMAT ('   L     M   BACK                  VALUE           OPTVAL'/)
122 FORMAT (I4,I6,I6,4X,2F16.4)
123 FORMAT ('0')
124 FORMAT ('1RANKING OF FINAL ALTERNATIVES - RUN', I4//)
125 FORMAT (' SEQUENCE ALTERNATIVE        OPTVAL'/)
127 FORMAT (I6,4X,I6,2X,F16.4)
130 FORMAT ('1NUMBER ',I4,2X,'RANKING OF ALTERNATIVES - RUN', I4//)
131 FORMAT ('  YEAR     L      M                 VALUE           OPTVAL')
133 FORMAT(31X,'MIL $',11X, 'MIL $'/ )
135 FORMAT (I6,I6,I6,2X,2F16.4)
140 FORMAT ('1SUMMARY OF OPTIMUM OPERATIONS - RUN', I4, ' -', I2// )
141 FORMAT (' YEAR ALT ORIGIN DEST  CAP  FLOW  FLOWL DEMAND TSTAR DESI
   1GN  LIFT EXIST DESIGN   DEBT  EXPANSION  ANNUAL   O & M    TOTAL
   2     P.W.')
142 FORMAT ('         M      J     K  LIMIT MGD    MGD    MGD      YR  INDE
   1X STATION MGD    MGD    MIL $     MIL $      MIL $    MIL $     MIL $
   2     MIL $'/)
146 FORMAT (I5, I3, 3X, I3, 9X, I2, F7.2, F7.2, F6.2, F6.2, 4X,
   1 I2, 7X, F7.2, F7.2, F10.4, F9.4, F9.4, F8.4, F9.4, F9.2)
147 FORMAT (I5, I3, 3X, I3, 3X, I3, 41X, I3, F7.2, 7X, F10.4, 9X,
   1 F9.4, 8X, F9.4)
148 FORMAT (I5, I3, 3X, I3, 3X, I3, 5X, F7.2, F7.2, F6.2, F6.2, 10X,
   1 I3, F7.2, F7.2, F10.4, F9.4, F9.4, F8.4, F9.4)
150 FORMAT (/ 114X, F9.4, F9.2 / )
156 FORMAT ('1SUMMARY OF ANNUAL COSTS - RUN', I4, ' -', I2//)
158 FORMAT (24X, 'CAPITAL          DEBT           O & M          TOTAL
   1     P.W.')
160 FORMAT (' YEAR  ALTERNATIVE        TOTAL          ANNUAL         ANNU
   1AL          ANNUAL       ANNUAL')
161 FORMAT ('                M                MIL $          MIL $          MIL
   1$           MIL $        MIL $')
162 FORMAT (' ----  -----------        -------        -------        ----
   1--          ------       ------'//)
165 FORMAT (I5, 4X, I4, 6X, F12.4, 2X, F12.4, 2X, F12.4, 2X,
   1 F12.4, F12.4)
166 FORMAT (/ 61X, 2F12.4)
168 FORMAT ('1QUALITY - CAPACITY EXPANSION PROJECTS - RUN', I4, ' -',
   1 I2 //)
170 FORMAT (' YEAR  ORIGIN  DESTINATION                  CAPACITY, MGD
   1    TREATMENT LEVEL                   CAPITAL DEBT, MIL $')
171 FORMAT ('         J            K                 EXISTING       PROPOSE
   1D  EXISTING  PROPOSED       EXISTING      EXPANSION           TOTAL
```

```
     2')
  172 FORMAT (' ----  ------  -----------         --------       -------
     1-  --------  --------        --------     ---------          -----
     2'//)
  176 FORMAT (I5, I5, 19X, F12.2,4X, F12.2,5X, I4, 5X, I4, 6X, F12.4,
     1 3X, F12.4,3X, F12.4)
  178 FORMAT (I5, I5, 6X, I5, 8X, F12.2,4X, F12.2,18X,
     1 6X, F12.4,3X, F12.4,3X, F12.4)
C
C      READ IN CONTROL DATA
C
      READ (5,1) IRUN
      WRITE (6,2) IRUN
      READ(5,3) NUMPLT, NUMYR, NUMALT, NYEAR, IFLOW, ITSTAR
      WRITE (6,4) IRUN, NUMPLT, NUMYR, NUMALT, NYEAR, IFLOW, ITSTAR
      READ (5,5) IEDIT, ILIST, IPW, IRANK, NRANK, NALTPR, IPROJ,
     1 IANUAL, NONDYN
      WRITE (6,6) IEDIT, ILIST, IPW, IRANK, NRANK, NALTPR, IPROJ,
     1 IANUAL, NONDYN
      READ (5,7) PERP, PERS, PERL, LAG, RATE, ANRATE, GPDCAP, PEAK,
     1 SLOPEM, HEAD
      WRITE (6,8) PERP, PERS, PERL, LAG, RATE, ANRATE, GPDCAP, PEAK,
     1 SLOPEM, HEAD
      READ (5,9) PINDA, PINDB, PINDF, SINDA, SINDB, SINDF, OMINDA,
     1 OMINDB, OMINDF
      WRITE (6,10)PINDA, PINDB, PINDF, SINDA, SINDB, SINDF, OMINDA,
     1 OMINDB, OMINDF
      WRITE (6,11) IRUN
      READ (5,12)((AK(N), ALPHA(N), BK(N), BALPHA(N)), N = 1,12)
      WRITE (6,13)
      WRITE (6,14) ((AK(N), N, ALPHA(N), N, BK(N), N, BALPHA(N), N),
     1 N = 1,12)
C
C      ENTER PARAMETERS FOR WASTEWATER TREATMENT PLANTS
C
      WRITE (6,15) IRUN
      WRITE (6,16)
      WRITE (6,17)
      DO 202 I = 1, NUMPLT
      READ (5,18) J, C, D, E, L, (BNAME(K), K = 1,9)
      IF(I.GT.NUMPLT) GO TO 201
      IF(L.GT.4) GO TO 201
      IPLT(J) = I
      JPLT(I) = J
      CAPP(I) = C
      DEBTP(I) = D
      ELEV(I) = E
      LTREAT(I) = L
      DO 200 K = 1,9
      ANAME(I,K) = BNAME(K)
  200 CONTINUE
      WRITE (6,19) JPLT(I), CAPP(I), DEBTP(I), ELEV(I), LTREAT(I),
     1 (ANAME(I,K), K = 1,9)
      GO TO 202
  201 WRITE (6,20) I, J, C, D, E, L, (BNAME(K), K = 1,9)
  202 CONTINUE
C
C      ENTER PARAMETERS FOR TRUNK SEWER LINKS
C
      WRITE (6,25) IRUN
      WRITE (6,26)
```

```
      WRITE (6,27)
      DO 206 I = 1,999
      READ (5,28) J, K, CDIST, CCAPS, DDEBTS
      IF(J.EQ.99) GO TO 207
      IF(J.GT.99) GO TO 205
      IF(K.GT.99) GO TO 205
      IJ = IPLT(J)
      IF(IJ.EQ.0) GO TO 205
      IK = IPLT(K)
      IF(IK.EQ.0) GO TO 205
      DIST(IJ,IK) = CDIST
      CAPS(IJ,IK) = CCAPS
      DEBTS(IJ,IK) = DDEBTS
      SHEAD(IJ,IK) = ELEV(IK) - ELEV(IJ)
      SLOPE(IJ,IK) = (SHEAD(IJ,IK) / DIST(IJ,IK) ) * 1000.
      WRITE (6,29) JPLT(IJ), JPLT(IK), DIST(IJ,IK), CAPS(IJ,IK),
     1 DEBTS(IJ,IK), SHEAD(IJ,IK), SLOPE(IJ,IK)
      GO TO 206
  205 WRITE (6,30) J,K,CDIST,CCAPS, DDEBTS
  206 CONTINUE
  207 CONTINUE
C
C     DETERMINE ANNUAL FACTORS
C
      WRITE (6,35) IRUN
      WRITE (6,36)
      WRITE (6,37)
      RETURN(1) = RATE
      DO 210 L = 1, NUMYR + 1
      IF(L.EQ.1) GO TO 209
      RETURN(L) = RETURN(1) + ANRATE * (L-1)
  209 CONTINUE
      CRFP(L) = (RETURN(L) * ( 1.0 + RETURN(L)) ** PERP) /
     1(((1.0 + RETURN(L)) ** PERP)- 1.0)
      CRFS(L) = (RETURN(L) * (1.0 + RETURN(L)) ** PERS) /
     1(((1.0 + RETURN(L)) ** PERS)- 1.0)
      CRFL(L) = (RETURN(L) * ( 1.0 + RETURN(L)) ** PERL) /
     1(((1.0 + RETURN(L)) ** PERL)- 1.0)
      FACCAP(L) = (PINDB + PINDF * (L-1) ) / PINDA
      FACSEW(L) = (SINDB + SINDF * (L-1) ) / SINDA
      FACOM(L) = (OMINDB + OMINDF * (L-1) ) / OMINDA
      IYEAR = L + NYEAR - 1
      WRITE (6,38) IYEAR, RETURN(L), CRFP(L), CRFS(L), CRFL(L),
     1 FACCAP(L), FACSEW(L), FACOM(L)
  210 CONTINUE
C
C     ENTER POPULATION DATA
C     ENTER WASTEWATER QUANTITIES INSTEAD IF IPOP = 1
C
      DO 219 K = 1,999
      READ (5,45) J,N,POPUL
      IF(J.EQ.99) GO TO 220
      IF(N.GT.50) GO TO 215
      IF(J.LE.0) GO TO 215
      L = N + 1
      I = IPLT(J)
      IF(I.EQ.0) GO TO 215
      IF(I.GT.NUMPLT) GO TO 215
      POP(I,L) = POPUL
      LASTYR = N
      GO TO 219
```

```
  215 IF(IPOP.GE.1) GO TO 216
      WRITE (6,46) J, N, POPUL
      GO TO 219
  216 WRITE (6,47) J, N, POPUL
  219 CONTINUE
  220 CONTINUE
      DO 225 J = 1,NUMPLT
      IF(POP(J,1).EQ.0.0) GO TO 225
      DO 224 L = 1,70
      DO 223 N = L+1, 71
      IF(POP(J,N).EQ.0.0) GO TO 223
      ITIM = N-L
      POPQNT = (POP(J,N) - POP(J,L)) / ITIM
      DO 222 NUM = 1,ITIM - 1
      POP(J,L+1) = POP(J,L) + POPQNT
      L = L + 1
  222 CONTINUE
      GO TO 224
  223 CONTINUE
  224 CONTINUE
  225 CONTINUE
      IF(LASTYR.LE.0) LASTYR = NUMYR
      DO 228 J = 1,NUMPLT
      IF(POP(J,LASTYR+1).EQ.0.0) GO TO 228
      POPQNR = POP(J,LASTYR+1) - POP(J,LASTYR)
      DO 227 L = LASTYR+2, LASTYR+21
      POP(J,L) = POP(J,L-1) + POPQNT
  227 CONTINUE
  228 CONTINUE
C
C     LIST POPULATION INPUT DATA
C     DO NOT LIST IF WASTEWATER QUANTITIES ARE ENTERED INSTEAD OF POPULATIONS
C
      IF(IPOP.GE.1) GO TO 230
      WRITE (6,50) IRUN
      ISPACE = 6 * NUMPLT - 3
      WRITE (6,51)  ISPACE, (ASPACE, I = 1,ISPACE)
      WRITE (6,52) NUMPLT, (JPLT(I), I = 1,NUMPLT)
      DO 230 L = 1,NUMYR + 21
      IPER = L - 1
      IYEAR = NYEAR + L - 1
      WRITE(6,48) IPER, IYEAR, NUMPLT, (POP(J,L), J = 1,NUMPLT)
  230 CONTINUE
C
C     TIME PHASED TREATMENT LEVELS
C
      LQUAL(1) = 1
      DO 235 I = 1,99
      READ (5,55) N, LQ
      IF(N.EQ.99) GO TO 236
      IF(N.GT.50) GO TO 234
      IF(LQ.EQ.0) GO TO 234
      IF(LQ.GT.4) GO TO 234
      L = N + 1
      LQUAL(L) = LQ
      GO TO 235
  234 WRITE (6,56) N, LQ
  235 CONTINUE
  236 CONTINUE
      DO 240 L = 2,NUMYR + 21
      IF(LQUAL(L).EQ.0) LQUAL(L) = LQUAL(L-1)
```

```
  240 CONTINUE
C
C     CALCULATE FLOWS FROM POPULATION DATA
C
      IF(IPOP.GE.1) GO TO 246
      DO 246 J = 1,NUMPLT
      DO 244 L = 1,NUMYR + 21
      QUANT (J,L) = POP(J,L) * GPDCAP * PEAK / 1000000.0
  244 CONTINUE
  246 CONTINUE
      GO TO 249
C
C     CALCULATE FLOWS FROM WASTEWATER QUANTITIES
C
      DO 248 J = 1,NUMPLT
      DO 247 L = 1, NUMYR + 21
      QUANT(J,L) = POP(J,L) * PEAK
  247 CONTINUE
  248 CONTINUE
  249 CONTINUE
C
C     OUTPUT BASE FLOWS TO TREATMENT PLANTS
C
      WRITE (6,60) IRUN
      ISPACE = 4 * NUMPLT - 4
      WRITE (6,61) ISPACE, (ASPACE, I = 1,ISPACE)
      WRITE (6,62) NUMPLT, (JPLT(I), I = 1,NUMPLT)
      DO 250 L = 1,NUMYR + 21
      IPER = L - 1
      IYEAR = NYEAR + L - 1
      WRITE (6,63) IPER, IYEAR, LQUAL(L), NUMPLT, (QUANT(J,L), J = 1,
     1 NUMPLT)
      IF(L.NE.51) GO TO 250
      WRITE (6,60) IRUN
      WRITE (6,61) ISPACE, (ASPACE, I = 1,ISPACE)
      WRITE (6,62) NUMPLT, (JPLT(I), I = 1,NUMPLT)
  250 CONTINUE
C
C     ENTER TIME PHASED TREATMENT LEVELS FOR EACH PLANT  AS NEEDED
C
      DO 252 J = 1,NUMPLT
      DO 251 L = 1,NUMYR + 21
      LQUALJ(J,L) = 1
  251 CONTINUE
  252 CONTINUE
      DO 254 K = 1,999
      READ (5,64) N, J, LQ
      IF(N.EQ.99) GO TO 255
      IF(N.GT.50) GO TO 253
      IF(J.GT.NUMPLT) GO TO 253
      IF(J.LE.0) GO TO 253
      IF(LQ.EQ.0) GO TO 253
      IF(LQ.GT.4) GO TO 253
      L = N + 1
      I = IPLT(J)
      IF(I.LE.0) GO TO 253
      IF(I.GT.NUMPLT) GO TO 253
      LQUALJ(I,L) = LQ
      GO TO 254
  253 WRITE (6,65) N,J,LQ
  254 CONTINUE
```

```
  255 CONTINUE
      DO 257 I = 1,NUMPLT
      DO 256 L = 2, NUMYR + 21
      IF(LQUALJ(I,L).EQ.1) LQUALJ(I,L) = LQUALJ(I,L-1)
  256 CONTINUE
  257 CONTINUE
C
C     OUTPUT INDIVIDUAL TIME PHASED TREATMENT LEVELS
C
      WRITE (6,66) IRUN
      ISPACE = 4 * NUMPLT - 4
      WRITE (6,67) ISPACE, (ASPACE, I = 1, ISPACE)
      WRITE (6,68) NUMPLT, (JPLT(I), I = 1,NUMPLT)
      DO 258 L = 1, NUMYR + 21
      IPER = L - 1
      IYEAR = NYEAR + L - 1
      WRITE (6,69) IPER, IYEAR, NUMPLT, (LQUALJ(I,L),I = 1,NUMPLT)
  258 CONTINUE
C
C     ENTER ALTERNATIVE CONNECTING TRUNK SEWER LINKS
C
      DO 263 M = 1, NUMALT
  259 READ (5,70) MA, J, K, LT, AMIN, AMAX
      IF(AMAX.LE.0.0) AMAX = 999.99
      IF(MA.EQ.99) GO TO 263
      IF(MA.EQ.0) GO TO 261
      IF(J.EQ.0) GO TO 261
      IF(K.EQ.0) GO TO 261
      IF(LT.GT.4) GO TO 261
      IJ = IPLT(J)
      IF(IJ.EQ.0) GO TO 261
      IF(IJ.GT.NUMPLT) GO TO 261
      IK = IPLT(K)
      IF(J.EQ.K)  IK = NUMPLT + 1
      IF(IK.EQ.0) GO TO 261
      IF(IK.GT.NUMPLT + 1) GO TO 261
      NALT(M) = MA
      IF(IPATH(IJ,NUMPLT+1,M).EQ.1) GO TO 260
      MTREAT(IJ,M) = LT
      CAPMIN(IJ,M) = AMIN
      CAPMAX(IJ,M) = AMAX
  260 CONTINUE
      IPATH(IJ,IK,M) = 1
      GO TO 262
  261 WRITE (6,71) MA, J, K, LT, AMIN, AMAX
  262 GO TO 259
  263 CONTINUE
C
C     BUILD PATH TABLES FOR EACH ALTERNATIVE M
C     IN(I,J,M) = INPUT TABLE
C     IOUT(J,K,M) = OUTPUT TABLE (COMMON WITH IPATH(J,K,M)
C
      DO 266  M = 1,NUMALT
      DO 265  J = 1,NUMPLT
      DO 264  K = 1,NUMPLT
      IN(J,K,M) = IPATH(J,K,M)
      IF(J.NE.K) GO TO 264
      IN(J,K,M) = 1
  264 CONTINUE
  265 CONTINUE
  266 CONTINUE
```

```
C
C     LOAD INPUT TABLE WITH ALTERNATIVE DEMANDS
C
      DO 280 M = 1,NUMALT
      DO 279 L = 1,5
      DO 278 J = 1,NUMPLT
      IF(CAPMAX(J,M).LE.0.0) CAPMAX(J,M) = 999.99
      DO 272 K = 1,NUMPLT
C
C     FOR PLANT J FIND OUTPUT ROUTE, K NOT EQUAL J
C
      IF(K.EQ.J) GO TO 272
      IF(IOUT(J,K,M) .EQ. 1) GO TO 274
  272 CONTINUE
C
C     NO CHANGE FOR THIS J
C
      GO TO 278
C
C       N = DESTINATION OF WASTE LOADS
C
  274 N = K
      IF(IOUT(J,NUMPLT+1,M).NE.1) GO TO 275
      IALT(J,M) = K
      IOUT(J,K,M) = 0
      IN(J,K,M) = 0
      GO TO 276
  275 CONTINUE
C
C     SEARCH NODE J FOR NUMBER = 1 AND TRANSFER TO NODE N OF INPUT TABLE
C
      DO 276 I = 1,NUMPLT
      IF(I.EQ.K) GO TO 276
      IF(IN(I,J,M).EQ.1) IN(I,N,M) = 1
  276 CONTINUE
  278 CONTINUE
  279 CONTINUE
  280 CONTINUE
C
C     OUTPUT  TABLES
C
      ISPACE = NUMPLT * 2 - 4
      LSPACE = NUMPLT * 4 - 2
      WRITE (6,75) IRUN
      WRITE (6,76) ISPACE, (ASPACE, I = 1,ISPACE), LSPACE,
     1 (ASPACE, I = 1, LSPACE)
      NUMOUT = NUMPLT + 1
      JPLT(NUMOUT) = NUMPLT + 1
      WRITE (6,77) NUMPLT, (JPLT(I), I=1,NUMPLT),  NUMOUT, (JPLT(I),
     1 I = 1,NUMOUT)
      DO 290 M = 1,NUMALT
      DO 286 IJ = 1, NUMPLT
      IK = IALT(IJ,M)
      IF(IK.LE.0) GO TO 284
      IF(IK.GT.NUMPLT) GO TO 284
      WRITE (6,80) NALT(M), JPLT(IJ), MTREAT(IJ,M), CAPMIN(IJ,M),
     1 CAPMAX(IJ,M), JPLT(IK), NUMPLT, (IN(I,IJ, M), I = 1, NUMPLT),
     2 NUMOUT, (IOUT(IJ, K, M), K = 1, NUMOUT)
      GO TO 286
  284 WRITE (6,82) NALT(M), JPLT(IJ), MTREAT(IJ,M), CAPMIN(IJ,M),
     1 CAPMAX(IJ,M),            NUMPLT, (IN(I,IJ, M), I = 1, NUMPLT),
```

```
     2 NUMOUT, (IOUT(IJ, K, M), K = 1, NUMOUT)
  286 CONTINUE
      WRITE (6,90)
  290 CONTINUE
C
C     BYPASS DYNAMIC PROGRAMMING SECTION OF MODEL
C
      IF(NONDYN.GE.1) GO TO 500
C
C     INITIALIZE SYSTEM PARAMETERS
C
      DO 306 M = 1,NUMALT
      MBACK(2,M) = 1
      VALUE(1,M) = 0.0
      OPTVAL(1,M) = 0.0
      DO 304 J = 1,NUMPLT
      TCAPP(J,1,M) = CAPP(J)
      TDEBTP(J,1,M) = DEBTP(J)
      KTREAT(J,1,M) = LTREAT(J)
      DO 302 K = 1,NUMPLT + 1
      TCAPS(J,K,1,M) = CAPS(J,K)
      TDEBTS(J,K,1,M) = DEBTS(J,K)
  302 CONTINUE
  304 CONTINUE
  306 CONTINUE
C
C     OPTIMIZE ALL PLANTS AND INTERCEPTORS FOR EACH YEAR L
C
      ADDVAL = 1000.
      DO 440 L = 2,NUMYR + 1
      DO 400 M = 1,NUMALT
      TEMPA = 99999999999.
C
C     DETERMINE LOAD ON PLANTS AT L, L + LAG, AND L + 20
C
      DO 307 J = 1, NUMPLT
      COLECT(J) = 0.0
      COLLAG(J) = 0.0
      FUTURE(J) = 0.0
  307 CONTINUE
      DO 309 J = 1,NUMPLT
      DO 308 I = 1, NUMPLT
      COLECT(J) = COLECT(J) + QUANT(I,L) * IN(I,J,M)
      COLLAG(J) = COLLAG(J) + QUANT(I,L+LAG) * IN(I,J,M)
      FUTURE(J) = FUTURE(J) + QUANT(I,L+20) * IN(I,J,M)
  308 CONTINUE
  309 CONTINUE
C
C     ADD EXCESS FLOWS FROM PLANTS WITH MAXIMUMS CAPACITIES
C
      DO 310 J = 1, NUMPLT
      IF(IOUT(J,NUMPLT+1,M).NE.1) GO TO 310
      K = IALT(J,M)
      IF(K.EQ.0) GO TO 310
      IF(K.GT.NUMPLT) GO TO 310
      Q = COLECT(J) - CAPMAX(J,M)
      IF(Q.LE.0.0) Q = 0.0
      QL = COLLAG(J) - CAPMAX(J,M)
      IF(QL.LE.0.0) QL = 0.0
      QF = FUTURE(J) - CAPMAX(J,M)
      IF(QF.LE.0.0) QF = 0.0
```

```
      COLECT(K) = COLECT(K) + Q
      COLLAG(K) = COLLAG(K) + QL
      FUTURE(K) = FUTURE(K) + QF
  310 CONTINUE
C
C     OUTPUT FLOWS COLLECTED AT TREATMENT PLANTS
C
      IF(IEDIT.LE.0) GO TO 312
      WRITE (6,92)  IRUN
      ISPACE = 4 * NUMPLT - 4
      WRITE (6,93) ISPACE, (ASPACE, I = 1, ISPACE)
      WRITE (6,94) NUMPLT, (JPLT(I), I = 1,NUMPLT)
      IPER = L - 1
      IYEAR = NYEAR + L - 1
      WRITE (6,95) IPER, IYEAR, NALT(M),NUMPLT,(COLECT(J),J=1,NUMPLT)
      IP = IPER + LAG
      IY = IYEAR + LAG
      WRITE (6,95) IP, IY, NALT(M), NUMPLT, (COLLAG(J), J = 1, NUMPLT)
      IP = IPER + 20
      IY = IYEAR + 20
      WRITE (6,95) IP, IY, NALT(M), NUMPLT, (FUTURE(J), J = 1,NUMPLT)
  312 CONTINUE
      IF(IEDIT.LE.0) GO TO 313
      WRITE (6,101) IRUN
      WRITE (6,102)
      WRITE (6,103)
  313 CONTINUE
C
C     SELECT BEST BACK PATH
C
      MBACK(L,M) = 1
      DO 390 MB = 1,NUMALT
      TVALUE = 0.0
C
C     FIND COSTS AND CAPACITY FOR  EACH TREATMENT PLANT
C
      DO 380 J = 1,NUMPLT
      TREAT = COLECT(J) * IOUT(J,NUMPLT + 1,M)
      TREATL = COLLAG(J) * IOUT(J,NUMPLT+1,M)
      ICHECK(J,M,MB) = 0
C
C     DETERMINE ANNUAL DEMAND OVER 20 YEARS
C
      DEMAND = (FUTURE(J) - COLECT(J)) / 20.0
      DEMP = DEMAND * IOUT(J,NUMPLT + 1, M)
C
C     INITIALIZE PARAMETERS
C
      ACAPP(J) = TCAPP(J,1,MB)
      ADEBTP(J) = TDEBTP(J,1,MB)
      FDEBTP(J) = 0.0
      LITRET(J) = KTREAT(J,1,MB)
      INDEX = 0
      ITREAT = MTREAT(J,MB)
      IF(LQUAL(L+LAG).GT.MTREAT(J,MB)) ITREAT = LQUAL(L+LAG)
      IF(LQUALJ(J, L + LAG).GT.ITREAT) ITREAT = LQUALJ(J,L+LAG)
      TSTAR = 0.0
      COSTA = 0.0
      COSTB = 0.0
C
C     CHECK TREATMENT PLANTS FOR MINIMUM FLOWS
```

```
C
      IF(TREATL.GE.CAPMIN(J,M)) GO TO 316
      IF(ICHECK(J,M,MB).EQ.1) GO TO 315
      ICHECK(J,M,MB) = 1
      TVALUE = TVALUE + ADDVAL
  315 CONTINUE
      GO TO 317
  316 CONTINUE
      IF(ICHECK(J,M,MB).NE.1) GO TO 317
      ICHECK(J,M,MB) = 0
      TVALUE = TVALUE - ADDVAL
  317 CONTINUE
C
C     DETERMINE DESIGN INDEX
C
      IF(ITREAT.LE.LTTRET(J)) GO TO 323
      GO TO (319, 320, 321) LTTRET(J)
  318 INDEX = ITREAT
      GO TO 322
  319 INDEX = ITREAT + 3
      GO TO 322
  320 INDEX = ITREAT + 5
      GO TO 322
  321 INDEX = ITREAT + 7
  322 CONTINUE
  323 CONTINUE
C
C     DOES PRESENT CAPACITY AND TREATMENT LEVEL OF PLANT MEET DEMAND?
C
      IF(TREATL.LE.0.0) GO TO 336
      IF(TREATL.LE.ACAPP(J).AND.ITREAT.LE.LTTRET(J)) GO TO 336
C
C     DETERMINE OPTIMUM DESIGN PERIOD FOR TREATMENT PLANTS
C
      TSTAR = PERP
      IF(ITSTAR.LE.0) GO TO 328
      IF(INDEX.LE.0) GO TO 328
      DO 327 ITIME = 1,25
      TSTAR = (ALOG((TSTAR * RETURN(L) / ALPHA(INDEX))+ 1.0))/RETURN(L)
  327 CONTINUE
  328 CONTINUE
      IF(TREATL.LT.ACAPP(J)) GO TO 332
      ACAPP(J) = TREATL + DEMP * TSTAR
C
C     CHECK TREATMENT PLANTS AGAINST MAXIMUM FLOWS
C
      IF(ACAPP(J).LE.CAPMAX(J,M)) GO TO 330
      ACAPP(J) = CAPMAX(J,M)
      IF(IALT(J,M).GE.1) GO TO 330
      IF(ICHECK(J,M,MB).EQ.2) GO TO 329
      ICHECK(J,M,MB) = 2
      TVALUE = TVALUE + ADDVAL
  329 CONTINUE
      GO TO 331
  330 CONTINUE
      IF(ICHECK(J,M,MB).NE.2) GO TO 331
      ICHECK(J,M,MB) = 0
      TVALUE = TVALUE - ADDVAL
  331 CONTINUE
C
C
```

```
C     DETERMINE THE COST TO INCREASE CAPACITY OF PLANT
C
      COSTA = 0.0
      IF(ACAPP(J).LE.TCAPP(J,1,MB)) GO TO 332
      IF(LTTRET(J).EQ.0) GO TO 332
      COSTA =(AK(LTTRET(J)) * (ACAPP(J) - TCAPP(J,1,MB)) **
     1 ALPHA(LTTRET(J)))* FACCAP(L)
  332 CONTINUE
C
C     DETERMINE COST OF UPGRADING TREATMENT PLANT
C
      IF(ITREAT.LE.LTTRET(J)) GO TO  336
      IF(INDEX.EQ.0) GO TO 336
      COSTB = (AK(INDEX) * (ACAPP(J)) ** ALPHA(INDEX))* FACCAP(L)
      LTTRET(J) = ITREAT
  336 CONTINUE
C
C     DETERMINE TEMPORARY FUTURE COST OF EXPANSION
C
      FDEBTP(J) = COSTA + COSTB
C
C     DETERMINE AMOUNT OF ANNUAL CAPITAL PAYMENT ON LAST YEARS DEBT
C
      CDEBTP(J) = ADEBTP(J) * CRFP(L-1)
C
C     CALCULATE O & M COSTS FOR TREATMENT PLANT
C
      AOMP(J) = 0.0
      IF(KTREAT(J,1,MB).EQ.0) GO TO 338
      AOMP(J) = BK(KTREAT(J,1,MB)) * (TREAT ** BALPHA(KTREAT(J,1,MB)))*
     1 FACOM(L)
  338 CONTINUE
C
C     DETERMINE THE TEMPORARY DISCOUNTED COSTS FOR DEBT AND O & M OF PLANT
C
      AVGRET = (RETURN(1) + RETURN(L)) / 2.0
      BDEBTP = CDEBTP(J) / ((1.0 + AVGRET) ** (L-1))
      BOMP = AOMP(J) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = TVALUE + BDEBTP + BOMP
      TPWP = (FDEBTP(J) * CRFP(L)) / ((1.0 + AVGRET) ** (L))
      TVALUE = TVALUE + TPWP
C
C     DETERMINE THE LOADS ON THE INTERCEPTORS
C
      IF(IALT(J,M).LE.0) GO TO 339
      KOUT = IALT(J,M)
      FLOW = COLECT(J) - CAPMAX(J,M)
      IF(FLOW.LE.0.0) FLOW = 0.0
      FLOWL = COLLAG(J) - CAPMAX(J,M)
      IF(FLOWL.LE.0.0) FLOWL = 0.0
      GO TO 341
  339 CONTINUE
      KOUT = NUMPLT + 1
      DO 340 K = 1,NUMPLT
      IF(K.EQ.J) GO TO 340
      IF(IOUT(J,K,M).EQ.1) KOUT = K
  340 CONTINUE
      FLOW = COLECT(J)
      FLOWL = COLLAG(J)
  341 CONTINUE
C
```

```
C      SINCE THE TREATMENT PLANTS HAVE ONLY ONE DISCHARGE ROUTE
C      OR A MAXIMUM CAPACITY, THE TRUNK SEWER HAS THE SAME VALUE
C      FOR DEMAND
C
       COSTS = 0.0
       TSTARS = 0.0
C
C      DOES CAPACITY OF TRUNK SEWER MEET DEMAND?
C
       DO 344 K = 1, NUMPLT
       ACAPS(J,K) = TCAPS(J,K,1,MB)
       ADEBTS(J,K) = TDEBTS(J,K,1,MB)
       FDEBTS(J,K) = 0.0
       BDEBTS(K) = 0.0
       BOMS(K) = 0.0
   344 CONTINUE
       IF(KOUT.EQ.NUMPLT+1) GO TO 358
       IF(FLOWL.LE.ACAPS(J,KOUT)) GO TO 351
C
C      DETERMINE OPTIMUM DESIGN PERIOD FOR TRUNK SEWERS
C
       TSTARS = PERS
       IF(ITSTAR.LE.0) GO TO 346
       DO 346 ITIME = 1,25
       TSTARS = (ALOG((TSTARS*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)
   346 CONTINUE
C
C      DETERMINE OPTIMUM DESIGN PERIOD FOR LIFT STATIONS
C
       TSTARL = PERL
       IF(ITSTAR.LE.0) GO TO 348
       DO 348 ITIME = 1,25
       TSTARL = (ALOG((TSTARL*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)
   348 CONTINUE
C
C      DETERMINE TEMPORARY CAPACITY OF INTERCEPTOR SEWER
C
       ACAPS(J,KOUT) = FLOWL + DEMAND * TSTARS
C
C      DETERMINE COST OF EXPANDING CAPACITY OF TRUNK SEWER
C      (INCLUDING DISTANCE AND ELEVATION DIFFERENCE)
C
       COSTS = 0.0
       IF(DEMAND.EQ.0.0) GO TO 358
       IF(SLOPE(J,KOUT).GT.SLOPEM) GO TO 350
C
C      GRAVITY FLOW
C
       COSTS =(AK(11) * (ACAPS(J,KOUT) - TCAPS(J,KOUT,1,MB)) ** ALPHA(11)
      1 * FACSEW(L)) * (DIST(J,KOUT) / 5280.0)
       GO TO 356
C
C      GRAVITY FLOW PLUS LIFT STATIONS
C
   350 CONTINUE
       PHEAD = SHEAD(J,KOUT) - (DIST(J,KOUT) * SLOPEM / 1000.0)
       IF(PHEAD.LE.0.0) PHEAD = 0.0
       NUMLS(J,KOUT) = (PHEAD / HEAD) + 0.5
       IF(NUMLS(J,K).LE.1) NUMLS(J,K) = 1
       COST1 = FACSEW(L)* (( AK(11) *(ACAPS(J,KOUT) - TCAPS(J,KOUT,1,MB))
      1 ** ALPHA(11))* (DIST(J,KOUT) / 5280.0) )
```

```
      COST2 = FACCAP(L)* (( AK(12) *(ACAPS(J,KOUT) - TCAPS(J,KOUT,1,MB))
     1 ** ALPHA(12)) * NUMLS(J,KOUT) )
      COSTS = COST1 + COST2
C
C     CALCULATE THE O & M COSTS OF THE TRUNK SEWER AND LIFT STATIONS
C
  351 AHEAD = 0.0
      IF(NUMLS(J,KOUT).LE.0) GO TO 352
      AHEAD = PHEAD / NUMLS(J,KOUT)
  352 CONTINUE
      ABOMS(KOUT)  = FACOM(L) * ((BK(11) * FLOW ** BALPHA(11)  +
     1 (BK(12) / 1000.0) * FLOW ** BALPHA(12) * AHEAD ) * NUMLS(J,KOUT))
C
C     DETERMINE TEMPORARY FUTURE COST OF TRUNK SEWER EXPANSION
C
  356 CONTINUE
      FDEBTS(J,KOUT) = COSTS
C
C     CALCULATE AMOUNT OF ANNUAL REPAYMENT OF CAPITAL FOR LAST YEARS DEBT
C
  358 CONTINUE
      DO 360 K = 1,NUMPLT
      CDEBTS(K) = ADEBTS(J,K) * CRFS(L-1)
  360 CONTINUE
C
C     DETERMINE THE TEMPORARY DISCOUNTED COSTS FOR DEBT AND O & M
C
      AVGRET = (RETURN(1) + RETURN(L)) / 2.0
      DO 362 K = 1,NUMPLT
      BDEBTS(K) =  CDEBTS(K) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = TVALUE + BDEBTS(K)
  362 CONTINUE
      IF(KOUT.EQ.NUMPLT + 1) GO TO 364
      BOMS(KOUT) = ABOMS(KOUT) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = TVALUE + BOMS(KOUT)
      TPWS = (FDEBTS(J,KOUT) * CRFS(L)) / ((1.0 + AVGRET) ** (L))
      TVALUE = TVALUE + TPWS
  364 CONTINUE
C
C     OUTPUT EDIT DATA
C
      IF(IEDIT.LE.0) GO TO 380
      TOTAL = BDEBTP + BOMP
      IF(TOTAL.LE.0.0.AND.FDEBTP(J).LE.0.0) GO TO 370
      WRITE(6,105) L,NALT(M),NALT(MB),JPLT(J),ICHECK(J,M,MB), TREAT,
     1 TREATL, DEMP, TSTAR, INDEX, TCAPP(J,1,MB), ACAPP(J), ADEBTP(J),
     2 FDEBTP(J), BDEBTP, BOMP, TOTAL
  370 TOTAL = 0.0
      DO 374 K = 1,NUMPLT
      TOTAL = BDEBTS(K) + BOMS(K)
      IF(TOTAL.LE.0.0.AND.FDEBTS(J,K).LE.0.0) GO TO 372
      WRITE (6,106) JPLT(J), JPLT(K), FLOW, FLOWL, DEMAND,
     1 TSTARS, NUMLS(J,K), TCAPS(J,K,1,MB), ACAPS(J,K), ADEBTS(J,K),
     2 FDEBTS(J,K), BDEBTS(K), BOMS(K), TOTAL
  372 TOTAL = 0.0
  374 CONTINUE
  380 CONTINUE
      IF(IEDIT.LE.0) GO TO 382
      WRITE(6,107) TVALUE
  382 CONTINUE
C
```

```
C     SELECT OPTIMUM BACK ROUTE
C
      TEMPB = OPTVAL(L-1,MB) + TVALUE
      IF(TEMPB.GE.TEMPA) GO TO 390
      TEMPA = TEMPB
      MBACK(L,M) = MB
      VALUE(L,M) = TVALUE
C
C     STORE OPTIMUM DATA
C
      DO 386 J = 1,NUMPLT
      TCAPP(J,2,M) = ACAPP(J)
      TDEBTP(J,2,M) = ADEBTP(J)
      DEBTPF(J,M) = FDEBTP(J)
      KTREAT(J,2,M) = LTTRET(J)
      DO 384 K = 1, NUMPLT + 1
      TCAPS(J,K,2,M) = ACAPS(J,K)
      TDEBTS(J,K,2,M) = ADEBTS(J,K)
      DEBTSF(J,K,M) = FDEBTS(J,K)
  384 CONTINUE
  386 CONTINUE
  390 CONTINUE
      TEMPR = 0.0
      DO 396 J = 1,NUMPLT
      TEMPR = TEMPR + (DEBTPF(J,M) * CRFP(L))/((1.0+AVGRET)**L)
      DO 394 K = 1,NUMPLT
      TEMPR = TEMPR + (DEBTSF(J,K,M)*CRFS(L))/((1.0+AVGRET)**L)
  394 CONTINUE
  396 CONTINUE
      VALUE(L,M) = VALUE(L,M) - TEMPR
      TEMPA = TEMPA - TEMPR
      OPTVAL(L,M) = TEMPA
  400 CONTINUE
C
C     YEARLY UPDATE OF OPTIMUM DATA FILES
C     RETIRE DEBT
C     OUTPUT DATA FOR THIS YEAR
C     LIST DATA
C
      IF(ILIST.LE.0) GO TO 421
      WRITE (6,109) IRUN
      WRITE (6,110)
      WRITE (6,111)
      WRITE (6,112)
      IPER = L - 1
  421 CONTINUE
      DO 428 M = 1,NUMALT
      DO 426 J = 1,NUMPLT
      TCAPP(J,1,M) = TCAPP(J,2,M)
      KTREAT(J,1,M) = KTREAT(J,2,M)
      ANNP = TDEBTP(J,2,M) * CRFP(L-1)
      TDEBTP(J,1,M) = TDEBTP(J,2,M) - ANNP + DEBTPF(J,M)
      IF(ILIST.LE.0) GO TO 422
      IF(TDEBTP(J,1,M).EQ.0.0) GO TO 422
      WRITE(6,114) L,NALT(M),NALT(MBACK(L,M)),JPLT(J),TCAPP(J,1,M),
     1 TDEBTP(J,2,M), ANNP, DEBTPF(J,M), TDEBTP(J,1,M)
  422 DO 424 K = 1,NUMPLT
      TCAPS(J,K,1,M) = TCAPS(J,K,2,M)
      ANNS = TDEBTS(J,K,2,M) * CRFS(L-1)
      TDEBTS(J,K,1,M) = TDEBTS(J,K,2,M) - ANNS + DEBTSF(J,K,M)
      IF(ILIST.LE.0) GO TO 424
```

```
      IF(TDEBTS(J,K,1,M) .EQ.0.0) GO TO 424
      WRITE(6,116) L,NALT(M),NALT(MBACK(L,M)),JPLT(J),JPLT(K),TCAPS(J,
     1K,1,M), TDEBTS(J,K,2,M), ANNS,DEBTSF(J,K,M),TDEBTS(J,K,1,M)
  424 CONTINUE
  426 CONTINUE
      IF(ILIST.LE.0) GO TO 428
      WRITE(6,117) VALUE(L,M), OPTVAL(L,M)
  428 CONTINUE
  430 CONTINUE
      IEDIT = IEDIT - 1
      ILIST = ILIST - 1
  440 CONTINUE
C
C     OUTPUT SUMMARY
C
      IF(IPW.LE.0) GO TO 452
      WRITE (6,119) IRUN
      WRITE (6,120)
      DO 450 L = 2, NUMYR    + 1
      DO 448 M = 1, NUMALT
      WRITE (6,122) L, NALT(M), NALT(MBACK(L,M)), VALUE(L,M),OPTVAL(L,M)
  448 CONTINUE
      WRITE (6,123)
  450 CONTINUE
  452 CONTINUE
C
C     RANK OPTIMAL VALUES OF LAST PLANNING YEAR
C
      DO 456 I = 1, NUMALT
      NUMINS(I) = I
  456 CONTINUE
      IF(NUMALT.LE.1) GO TO 463
      DO 462 NI = 1,NUMALT - 1
      I = NUMINS(NI)
      DO 460 NJ = NI + 1, NUMALT
      J = NUMINS(NJ)
      IF(OPTVAL(NUMYR+1,I).LE.OPTVAL(NUMYR+1,J)) GO TO 460
      NUMINS(NI) = J
      NUMINS(NJ) = I
      I = NUMINS(NI)
  460 CONTINUE
  462 CONTINUE
  463 CONTINUE
      IF(IRANK.LE.0) GO TO 470
      WRITE (6,124) IRUN
      WRITE (6,125)
      DO 470 N = 1, NUMALT
      M = NUMINS(N)
      WRITE (6,127) N, NALT(M), OPTVAL(NUMYR + 1, M)
  470 CONTINUE
C
C     OUTPUT OPTIMUM VALUES
C
      IF(NRANK.LE.0) GO TO 490
      DO 490 IOPT = 1,NRANK
      MALT(NUMYR + 1) = NUMINS(IOPT)
      M = MALT(NUMYR + 1)
      DO 480 N = 1,NUMYR
      L = NUMYR - N + 2
      M = MBACK(L,M)
      MALT(L-1) = M
```

```
  480 CONTINUE
      WRITE (6,130) IOPT, IRUN
      WRITE (6,131)
      WRITE (6,133)
      DO 486 L = 1,NUMYR + 1
      IPER = L
      IYEAR = L + NYEAR - 1
      M = MALT(L)
      WRITE(6,135) IYEAR,IPER,NALT(M),VALUE(L,M), OPTVAL(L,M)
  486 CONTINUE
  490 CONTINUE
C
C     CALCULATE ALL DATA FOR OPTIMUM PATH
C
  500 IF(NALTPR.LE.0) GO TO 670
      DO 670  MSUM = 1,NALTPR
C
C     RECALCULATE THE OPTIMUM PATH
C
      IF(NONDYN.GE.1) GO TO 511
      MALT(NUMYR + 1) = NUMINS(MSUM)
      M = MALT(NUMYR + 1)
      DO 510  N = 1,NUMYR
      L = NUMYR - N + 2
      M = MBACK(L,M)
      MALT(L-1) = M
  510 CONTINUE
      GO TO 513
  511 DO 512 LN = 1,NUMYR + 1
      MALT(LN) = MSUM
  512 CONTINUE
  513 CONTINUE
C
C     INITIALIZE SYSTEM PARAMETERS
C
      DO 516  J = 1,NUMPLT
      ACAPP(J) = CAPP(J)
      ADEBTP(J) = DEBTP(J)
      FDEBTP(J) = 0.0
      LTTRET(J) = LTREAT(J)
      COLECT(J) = 0.0
      COLLAG(J) = 0.0
      FUTURE(J) = 0.0
      LCHECK(J) = 0.0
      DO 514  K = 1,NUMPLT + 1
      ACAPS(J,K) = CAPS(J,K)
      ADEBTS(J,K) = DEBTS(J,K)
      FDEBTS(J,K) = 0.0
      NUMLS(J,K) = 0
  514 CONTINUE
  516 CONTINUE
      DO 520  N = 1,100
      KYEAR(N) = 0
      KORIGN(N) = 0
      KDEST(N) = 0
      CAP1(N) = 0.0
      CAP2(N) = 0.0
      KTRET1(N) = 0
      KTRET2(N) = 0
      EXDEBT(N) = 0.0
      DEBTEX(N) = 0.0
```

```
      TDEBT(N) = 0.0
      NUMLSP(N) = 0
  520 CONTINUE
      DO 526 L = 1,NUMYR + 1
      TOTCAP(L) = 0.0
      TAN(L) = 0.0
      TOM(L) = 0.0
      TOTPW(L) = 0.0
  526 CONTINUE
      N = 1
C
C     OPTIMIZE ALL PLANTS AND INTERCEPTORS FOR EACH YEAR L
C
      DO 650  L = 2,NUMYR + 1
      IPER = L - 1
      IYEAR = L + NYEAR - 1
      M = MALT(L)
      TVALUE = 0.0
      TANUAL = 0.0
C
C     DETERMINE LOAD ON PLANT AT L, L + LAG , AND L + 20
C
      DO 530 J = 1,NUMPLT
      COLECT(J) = 0.0
      COLLAG(J) = 0.0
      FUTURE(J) = 0.0
  530 CONTINUE
      DO 532 J = 1, NUMPLT
      DO 531 I = 1, NUMPLT
      COLECT(J) = COLECT(J) + QUANT(I,L) * IN(I,J,M)
      COLLAG(J) = COLLAG(J) + QUANT(I,L+LAG) * IN(I,J,M)
      FUTURE(J) = FUTURE(J) + QUANT(I,L+20) * IN(I,J,M)
  531 CONTINUE
  532 CONTINUE
C
C     ADD EXCESS FLOWS FROM PLANTS WITH MAXIMUM CAPACITIES
C
      DO 533 J = 1, NUMPLT
      IF(IOUT(J,NUMPLT+1,M).NE.1) GO TO 533
      K = IALT(J,M)
      IF(K.EQ.0) GO TO 533
      IF(K.GT.NUMPLT) GO TO 533
      Q = COLECT(J) - CAPMAX(J,M)
      IF(Q.LE.0.0) Q = 0.0
      QL = COLLAG(J) - CAPMAX(J,M)
      IF(QL.LE.0.0) QL = 0.0
      QF = FUTURE(J) - CAPMAX(J,M)
      IF(QF.LE.0.0) QF = 0.0
      COLECT(K) = COLECT(K) + Q
      COLLAG(K) = COLLAG(K) + QL
      FUTURE(K) = FUTURE(K) + QF
  533 CONTINUE
C
C     OUTPUT FLOWS COLLECTED AT TREATMENT PLANTS
C
      IF(IANUAL.LE.0) GO TO 534
      WRITE (6,92) IRUN
      ISPACE = 4 * NUMPLT - 4
      WRITE (6,93) ISPACE, (ASPACE, I = 1, ISPACE)
      WRITE (6,94) NUMPLT, (JPLT(I), I = 1,NUMPLT)
      WRITE (6,95) IPER, IYEAR, NALT(M),NUMPLT,(COLECT(J),J=1,NUMPLT)
```

```
      IP = IPER + LAG
      IY = IYEAR + LAG
      WRITE (6,95) IP, IY, NALT(M), NUMPLT, (COLLAG(J), J = 1, NUMPLT)
      IP = IPER + 20
      IY = IYEAR + 20
      WRITE (6,95) IP, IY, NALT(M), NUMPLT, (FUTURE(J), J = 1,NUMPLT)
  534 CONTINUE
      IF(IANUAL.LE.0) GO TO 535
      WRITE (6,140) IRUN, MSUM
      WRITE (6,141)
      WRITE (6,142)
  535 CONTINUE
C
C     FIND COSTS AND CAPACITY FOR  EACH TREATMENT PLANT
C
      DO 642  J = 1,NUMPLT
      TREAT = COLECT(J) * IOUT(J,NUMPLT+1,M)
      TREATL = COLLAG(J) * IOUT(J,NUMPLT+1,M)
      LPRES = LTTRET(J)
      TVALUE = 0.0
      COSTA = 0.0
      COSTB = 0.0
      FDEBTP(J) = 0.0
C
C     DETERMINE ANNUAL DEMAND OVER 20 YEARS
C
      DEMAND = (FUTURE(J) - COLECT(J)) / 20.0
      DEMP = DEMAND * IOUT(J,NUMPLT + 1, M)
C
C     CHECK TREATMENT PLANT FOR MINIMUM FLOWS
C
      IF(TREATL.GE.CAPMIN(J,M)) GO TO 538
      IF(LCHECK(J).EQ.1) GO TO 537
      LCHECK(J) = 1
  537 CONTINUE
      GO TO 539
  538 CONTINUE
      IF(LCHECK(J).NE.1) GO TO 539
      LCHECK(J) = 0
  539 CONTINUE
C
C     DETERMINE DESIGN INDEX
C
      INDEX = 0
      ITREAT = MTREAT(J,M)
      IF(LQUAL(L+LAG).GT.MTREAT(J,M)) ITREAT = LQUAL(L+LAG)
      IF(LQUALJ(J,L + LAG).GT.ITREAT) ITREAT = LQUALJ(J,L+LAG)
      IF(ITREAT.LE.LTTRET(J)) GO TO 550
      GO TO (542, 544, 546) LTTRET(J)
  540 INDEX = ITREAT
      GO TO 548
  542 INDEX = ITREAT + 3
      GO TO 548
  544 INDEX = ITREAT + 5
      GO TO 548
  546 INDEX = ITREAT + 7
  548 CONTINUE
  550 CONTINUE
C
C     DOES PRESENT CAPACITY AND TREATMENT LEVEL OF PLANT MEET DEMAND?
C
```

```
      ECAPP = ACAPP(J)
      TSTAR = 0.0
      IF(TREATL.LE.0.0) GO TO 572
      IF(TREATL.LE.ACAPP(J).AND.ITREAT.LE.LTTRET(J)) GO TO 572
C
C     DETERMINE OPTIMUM DESIGN PERIOD FOR TREATMENT PLANTS
C
      TSTAR = PERP
      IF(ITSTAR.LE.0) GO TO 555
      IF(INDEX.LE.0) GO TO 555
      DO 554  ITIME = 1,25
      TSTAR = (ALOG((TSTAR * RETURN(L))/ ALPHA(INDEX) + 1.0))/RETURN(L)
  554 CONTINUE
  555 CONTINUE
C
C     DETERMINE CAPACITY OF THE PLANT
C
      KYEAR(N) = IYEAR
      KORIGN(N) = J
      CAP1(N) = ACAPP(J)
      CAP2(N) = ACAPP(J)
      KTRET1(N) = LTTRET(J)
      KTRET2(N) = LTTRET(J)
      EXDEBT(N) = ADEBTP(J)
      DEBTEX(N) = 0.0
      TDEBT(N) = ADEBTP(J)
      COSTA = 0.0
      IF(TREATL.LT.ACAPP(J)) GO TO 556
      ACAPP(J) = TREATL + DEMP * TSTAR
      CAP2(N) = ACAPP(J)
  556 CONTINUE
C
C     CHECK TREATMENT PLANTS AGAINST MAXIMUM FLOWS
C
      IF(ACAPP(J).LE.CAPMAX(J,M)) GO TO 558
      ACAPP(J) = CAPMAX(J,M)
      CAP2(N) = ACAPP(J)
      IF(IALT(J,M).GE.1) GO TO 558
      IF(LCHECK(J).EQ.2) GO TO 557
      LCHECK(J) = 2
  557 CONTINUE
      GO TO 559
  558 CONTINUE
      IF(LCHECK(J).NE.2) GO TO 559
      LCHECK(J) = 0
  559 CONTINUE
C
C     DETERMINE THE COST TO INCREASE CAPACITY OF PLANT
C
      IF(ACAPP(J).LE.ECAPP) GO TO 564
      IF(LTTRET(J).EQ.0) GO TO 564
      COSTA = AK(LTTRET(J)) * (ACAPP(J) - CAP1(N)) **
     1 ALPHA(LTTRET(J)) * FACCAP(L)
  564 CONTINUE
  568 CONTINUE
C
C     DETERMINE COST OF UPGRADING TREATMENT PLANT
C
      IF(ITREAT.LE.LTTRET(J)) GO TO  570
      IF(INDEX.EQ.0) GO TO 570
      COSTB = (AK(INDEX) * (ACAPP(J)) ** ALPHA(INDEX))* FACCAP(L)
```

```
      KTRET2(N) = ITREAT
      LTTRET(J) = ITREAT
  570 CONTINUE
C
C     DETERMINE TEMPORARY FUTURE COST OF EXPANSION
C
      DEBTEX(N) = COSTA + COSTB
      TDEBT(N) = ADEBTP(J) + COSTA + COSTB
      FDEBTP(J) = COSTA + COSTB
      N = N + 1
C
C     DETERMINE AMOUNT OF ANNUAL CAPITAL PAYMENT ON LAST YEARS DEBT
C
  572 CONTINUE
      ANP(J) = ADEBTP(J) * CRFP(L-1)
      TAN(L) = TAN(L) + ANP(J)
C
C     CALCULATE O & M COSTS FOR TREATMENT PLANT
C
       OMP(J) = 0.0
      IF(LPRES.EQ.0) GO TO 575
      OMP(J) = BK(LPRES) * (TREAT ** BALPHA(LPRES)) * FACOM(L)
      TOM(L) = TOM(L) + OMP(J)
      TANUAL = TANUAL +  ANP(J) +  OMP(J)
  575 CONTINUE
C
C     DETERMINE DISCOUNTED COSTS FOR DEBT AND O & M OF PLANT
C
      AVGRET = (RETURN(1) + RETURN(L)) / 2.0
      BDEBTP = ANP(J) / ((1.0 + AVGRET) ** (L-1))
      BOMP = OMP(J) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = BDEBTP + BOMP
C
C     DETERMINE THE LOADS ON THE INTERCEPTORS
C
      IF(IALT(J,M).LE.0) GO TO 577
      KOUT = IALT(J,M)
      FLOW = COLECT(J) - CAPMAX(J,M)
      IF(FLOW.LE.0.0) FLOW = 0.0
      FLOWL = COLLAG(J) - CAPMAX(J,M)
      IF(FLOWL.LE.0.0) FLOWL = 0.0
      GO TO 579
  577 CONTINUE
      KOUT = NUMPLT + 1
      DO 578  K = 1,NUMPLT
      IF(K.EQ.J) GO TO 578
      IF(IOUT(J,K,M).EQ.1) KOUT = K
  578 CONTINUE
      FLOW = COLECT(J)
      FLOWL = COLLAG(J)
  579 CONTINUE
C
C     SINCE THE TREATMENT PLANTS HAVE ONLY ONE DISCHARGE ROUTE
C     OR A MAXIMUM CAPACITY, THE TRUNK SEWER HAS THE SAME VALUE
C     FOR DEMAND
C
      TSTARS = 0.0
      KALT(J) = KOUT
      KDEST(N) = 0
C
C     DOES CAPACITY OF TRUNK SEWER MEET DEMAND?
```

```
C
      DO 580 K = 1, NUMPLT
      FDEBTS(J,K) = 0.0
      BDEBTS(K) = 0.0
      BOMS(K) = 0.0
      ECAPS(K) = ACAPS(J,K)
      OMS(J,K) = 0.0
      ANS(J,K) = 0.0
  580 CONTINUE
      COSTS = 0.0
      IF(KOUT.EQ.NUMPLT+1) GO TO 596
      IF(FLOWL.LE.ACAPS(J,KOUT)) GO TO 589
C
C     DETERMINE OPTIMUM DESIGN PERIOD FOR TRUNK SEWERS
C
      TSTARS = PERS
      IF(ITSTAR.LE.0) GO TO 584
      DO 584  ITIME = 1,25
      TSTARS = (ALOG((TSTARS*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)
  584 CONTINUE
C
C     DETERMINE OPTIMUM DESIGN PERIOD FOR LIFT STATIONS
C
      TSTARL = PERL
      IF(ITSTAR.LE.0) GO TO 587
      DO 586  ITIME = 1,25
      TSTARL = (ALOG((TSTARL*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)
  586 CONTINUE
  587 CONTINUE
C
C     DETERMINE TEMPORARY CAPACITY OF TRUNK SEWER
C
      KYEAR(N) = IYEAR
      KORIGN(N) = J
      KDEST(N) = KOUT
      CAP1(N) = ACAPS(J,KOUT)
      NUMLSP(N) = 0
      EXDEBT(N) = ADEBTS(J,KOUT)
      DEBTEX(N) = 0.0
      TDEBT(N) = ADEBTS(J,KOUT)
      ACAPS(J,KOUT) = FLOWL + DEMAND * TSTARS
      CAP2(N) = ACAPS(J,KOUT)
C
C     DETERMINE COST OF EXPANDING CAPACITY OF TRUNK SEWER
C     (INCLUDING DISTANCE AND ELEVATION DIFFERENCE)
C
      COSTS = 0.0
      IF(DEMAND.EQ.0.0) GO TO 592
      IF(SLOPE(J,KOUT).GT.SLOPEM) GO TO 588
C
C     GRAVITY FLOW
C
      COSTS = (AK(11) * ((ACAPS(J,KOUT)-ECAPS(KOUT))** ALPHA(11))
     1 * FACSEW(L)) * (DIST(J,KOUT) / 5280.0)
      GO TO 592
C
C     GRAVITY FLOW PLUS LIFT STATIONS
C
  588 CONTINUE
      PHEAD = SHEAD(J,KOUT) - (DIST(J,KOUT) * SLOPEM / 1000.0)
      IF(PHEAD.LE.0.0) PHEAD = 0.0
```

```
      NUMLS(J,KOUT) = (PHEAD / HEAD) + 0.5
      IF(NUMLS(J,KOUT).LE.1) NUMLS(J,KOUT) = 1
      COST1 = FACSEW(L) * ((AK(11) * (ACAPS(J,KOUT) - ECAPS(KOUT))
     1 ** ALPHA(11))* (DIST(J,KOUT) / 5280.0) )
      COST2 = FACCAP(L) * ((AK(12) * (ACAPS(J,KOUT) - ECAPS(KOUT))
     1 ** ALPHA(12)) * NUMLS(J,KOUT) )
      COSTS = COST1 + COST2
C
C     DETERMINE FUTURE COST OF TRUNK SEWER EXPANSION
C
  592 CONTINUE
      FDEBTS(J,KOUT) = COSTS
      DEBTEX(N) = COSTS
      TDEBT(N) = ADEBTS(J,KOUT) + COSTS
      N = N + 1
C
C     CALCULATE THE O & M COSTS OF THE TRUNK SEWER AND LIFT STATIONS
C
  589 AHEAD = 0.0
      IF(NUMLS(J,KOUT).LE.0) GO TO 590
      AHEAD = PHEAD / NUMLS(J,KOUT)
  590 CONTINUE
      OMS(J,KOUT)  = FACOM(L) * ((BK(11) * FLOW ** BALPHA(11)  +
     1 (BK(12) / 1000.0) * FLOW ** BALPHA(12) * AHEAD ) * NUMLS(J,KOUT))
      TOM(L) = TOM(L) + OMS(J,KOUT)
      TANUAL = TANUAL +  OMS(J,KOUT)
C
C     CALCULATE AMOUNT OF ANNUAL REPAYMENT OF CAPITAL FOR LAST YEARS DEBT
C
  596 CONTINUE
      DO 597 K = 1,NUMPLT
      ANS(J,K) = ADEBTS(J,K) * CRFS(L-1)
  597 CONTINUE
  600 CONTINUE
C
C     TOTAL ANNUAL DEBT FOR CAPITAL
C
      DO 606 K = 1,NUMPLT
      TAN(L) = TAN(L) + ANS(J,K)
      TANUAL = TANUAL +  ANS(J,K)
  606 CONTINUE
C
C     DETERMINE THE DISCOUNTED COSTS FOR DEBT AND O & M
C
      AVGRET = (RETURN(1) + RETURN(L)) / 2.0
      DO 610 K = 1,NUMPLT
      BDEBTS(K) = ANS(J,K) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = TVALUE + BDEBTS(K)
  610 CONTINUE
      IF(KOUT.EQ.NUMPLT+1) GO TO 612
      BOMS(KOUT) = OMS(J,KOUT) / ((1.0 + AVGRET) ** (L-1))
      TVALUE = TVALUE + BOMS(KOUT)
  612 CONTINUE
C
C     RETIRE DEBT
C
      TOTCAP(L) = TOTCAP(L) + ADEBTP(J) - ANP(J)
      ADEBTP(J) = ADEBTP(J) - ANP(J) + FDEBTP(J)
      IF(ADEBTP(J).LE.0.0) ADEBTP(J) = 0.0
      DO 622  K = 1,NUMPLT
      TOTCAP(L) = TOTCAP(L) + ADEBTS(J,K) - ANS(J,K)
```

```
      ADEBTS(J,K) = ADEBTS(J,K) - ANS(J,K) + FDEBTS(J,K)
      IF(ADEBTS(J,K).LE.0.0) ADEBTS(J,K) = 0.0
  622 CONTINUE
C
C     LIST DATA
C
      IF(IANUAL.LE.0) GO TO 640
      TOTAL =  ANP(J) +  OMP(J)
      IF(FDEBTP(J).GT.0.0) GO TO 624
      IF(TOTAL.LE.0.0) GO TO 626
  624 CONTINUE
      WRITE(6,146)IYEAR,NALT(MALT(L)),JPLT(J),LCHECK(J),TREAT,TREATL,
     1 DEMP, TSTAR, INDEX, ECAPP, ACAPP(J), ADEBTP(J), FDEBTP(J),
     2 ANP(J), OMP(J), TOTAL, TVALUE
  626 TOTAL = 0.0
      DO 636  K = 1,NUMPLT
      TOTAL =  ANS(J,K) +  OMS(J,K)
      IF(FDEBTS(J,K).GT.0.0) GO TO 630
      IF(TOTAL.LE.0.0) GO TO 634
  630 CONTINUE
      IF(K.EQ.KOUT) GO TO 632
      WRITE (6,147) IYEAR, NALT(MALT(L)), JPLT(J), JPLT(K), NUMLS(J,K),
     1 ECAPS(K), ADEBTS(J,K), ANS(J,K), TOTAL
      GO TO 634
  632 WRITE (6,148) IYEAR, NALT(MALT(L)), JPLT(J), JPLT(K), FLOW,
     1 FLOWL, DEMAND,TSTARS,NUMLS(J,KOUT), ECAPS(KOUT),
     2 ACAPS(J,KOUT), ADEBTS(J,KOUT), FDEBTS(J,KOUT), ANS(J,KOUT),
     3 OMS(J,KOUT), TOTAL
  634 TOTAL = 0.0
  636 CONTINUE
  640 CONTINUE
      TOTPW(L) = TOTPW(L) + TVALUE
  642 CONTINUE
      IF(IANUAL.LE.0) GO TO 646
      WRITE (6,150) IANUAL, TOTPW(L)
  646 CONTINUE
      IANUAL = IANUAL - 1
  650 CONTINUE
C
C     SUMMARY OF ANNUAL COSTS
C
      TA = 0.0
      TP = 0.0
      WRITE (6,156) IRUN, MSUM
      WRITE (6,158)
      WRITE (6,160)
      WRITE (6,161)
      WRITE (6,162)
      TOTAL = 0.0
      DO 660 L = 2,NUMYR + 1
      IYEAR = NYEAR - 1 + L
      TOTAL = TAN(L) + TOM(L)
      TA = TA + TOTAL
      TP = TP + TOTPW(L)
      WRITE (6,165) IYEAR, NALT(MALT(L)), TOTCAP(L), TAN(L), TOM(L),
     1 TOTAL, TOTPW(L)
  660 CONTINUE
      WRITE (6,166) TA, TP
C
C     QUALITY - CAPACITY EXPANSION PROJECTS
C
```

```
      IF(IPROJ.NE.1) GO TO 670
      WRITE (6,168) IRUN, MSUM
      WRITE (6,170)
      WRITE (6,171)
      WRITE (6,172)
      NUMPRO = N
      DO 670  N = 1,NUMPRO - 1
      IF(KDEST(N).NE.0.0) GO TO 664
      WRITE (6,176) KYEAR(N), JPLT(KORIGN(N)), CAP1(N), CAP2(N),
     1 KTRET1(N), KTRET2(N), EXDEBT(N), DEBTEX(N), TDEBT(N)
      GO TO 670
  664 WRITE (6,178) KYEAR(N), JPLT(KORIGN(N)), JPLT(KDEST(N)), CAP1(N),
     1 CAP2(N), EXDEBT(N), DEBTEX(N), TDEBT(N)
  670 CONTINUE
      STOP
      END

*************************************************************************

 DATA WASTEIN

03
10       10       04       1974     00       00
01       01       01       01       01       01       01       01       00
20.0     50.0     10.0     02       0.060    .001675 100.0     2.25     -0.100   25.0
340.66   340.66   26.17    211.66   211.66   15.184   4.36     4.36     0.21
1.201    0.773    0.0537   0.775
1.532    0.800    0.0599   0.805
1.712    0.789    0.1070   0.746
2.362    0.758    0.1650   0.730
0.358    0.867    0.0133   0.942
0.538    0.817    0.0585   0.738
1.188    0.740    0.1160   0.718
0.206    0.660    0.523    0.681
0.858    0.649    0.1100   0.689
0.678    0.646    0.630    0.722
0.127    0.390    0.0018   0.664
0.128    0.615    0.0288   0.897
01       2.27     0.3064   4214.    01       SOUTH DAVIS COUNTY - SOUTH WWTP
02       45.0     3.2259   4213.    01       SALT LAKE CITY
03       4.55     0.5591   4230.    01       SOUTH SALT LAKE CITY
04       16.0     0.1138   4238.    01       SALT LAKE CITY S.S.D. #1
05       7.3      0.3715   4250.    01       GRANGER-HUNTER
06       8.0      0.3514   4246.    01       SALT LAKE COUNTY COTTONWOOD
07       4.0      0.0      4243.    01       MURRAY
08       3.6      0.0990   4277.    01       TRI-COMMUNITY
09       1.5      0.3111   4300.    01       SANDY
10       0.0      0.0      4236.    00       NEW REGIONAL WWTP
01       02       12500.   0.0      0.0
02       01       12500.   0.0      0.0
02       03       38300.   0.0      0.0
02       04       41700.   0.0      0.0
02       10       40300.   0.0      0.0
03       02       38300.   0.0      0.0
03       04       7800.    0.0      0.0
03       10       9400.    0.0      0.0
04       02       41700.   0.0      0.0
04       03       7800.    0.0      0.0
04       05       5800.    0.0      0.0
04       06       9300.    0.0      0.0
04       10       2400.    0.0      0.0
```

```
05         04         5800.     0.0        0.0
05         10         3600.     0.0        0.0
06         04         9300.     0.0        0.0
06         07         2800.     0.0        0.0
06         10         10200.    0.0        0.0
07         06         2800.     0.0        0.0
07         08         18600.    0.0        0.0
08         07         18600.    0.0        0.0
08         09         13200.    0.0        0.0
09         08         13200.    0.0        0.0
10         02         40300.    0.0        0.0
10         03         9400.     0.0        0.0
10         04         2400.     0.0        0.0
10         05         3600.     0.0        0.0
10         06         10200.    0.0        0.0
99
01         00         11222.
01         04         12700.
01         11         14900.
01         21         17600.
01         50         25400.
02         00         188367.
02         04         201864.
02         11         215361.
02         21         242356.
02         50         320600.
03         00         14802.
03         04         17783.
03         11         20764.
03         21         26726.
03         50         44000.
04         00         116464.
04         04         127744.
04         11         138604.
04         21         160326.
04         50         223300.
05         00         63450.
05         04         77526.
05         11         91602.
05         21         119755.
05         50         201500.
06         00         43025.
06         04         51634.
06         11         60243.
06         21         77462.
06         50         127400.
07         00         26646.
07         04         31984.
07         11         37322.
07         21         48000.
07         50         79000.
08         00         44567.
08         04         55577.
08         11         66584.
08         21         88600.
08         50         152400.
09         00         15238.
09         04         18099.
09         11         20960.
09         21         20682.
09         50         43300.
```

```
99
03         02
06         04
99
99
05         01         02
05         02         02         01
05         03         02
05         04         03
05         05         04
05         06         04
05         07         06
05         08         07
05         09         08
99
06         01         02
06         02         02         01
06         03         10
06         04         10
06         05         10
06         06         04
06         07         06
06         08         07
06         09         08
06         10         10         04
99
09         01         01         01
09         02         02         01
09         03         02
09         04         03
09         05         04
09         06         04
09         07         06
09         08         08         01
09         09         08
99
20         01         01         01
20         02         02         01
20         03         04
20         04         06
20         05         04
20         06         07
20         07         07         01
20         08         07
20         09         08
99

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