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Development of a Dynamic Programming Model for the Regionalization and Staging of Wastewater Treatment Plants

Stanley L. Klemetson

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

by

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June 1975
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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 publicly 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 meet 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
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.
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; Haines, 1971; Haines, 1972a; Haines, 1972b; and Haines, 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 Moner (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 techniques 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.

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

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 Monsen (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.

Shull 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.

Shull and DeFilippi (1970) used dynamic programming to identify the optimal 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.

Lieberman and Marks (1968) applied Bals 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 (Haines, 1972a; Haines, 1972b; and Haines, 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.

\[
C(X) = k (X)^a \quad (k > 0; 0 < a < 1) \quad \ldots (1)
\]

in which
- \( C(X) \) = present cost
- \( k \) = cost coefficient
- \( X \) = increment of size, \( D_t \)
- \( a \) = economies of scale

The present worth of adding \( D_t \) units of capacity over an infinite number of periods of equal time \( t \) is given by

\[
C(D_t) = \frac{k (D_t)^a}{1 - e^{rt}} \quad \ldots \ldots \ldots \ldots \ldots \ldots (2)
\]

in which
- \( C(D_t) \) = present worth of discounted future costs
- \( r \) = discount factor or interest rate
- \( t \) = time period between additions, yr

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

\[
\frac{d}{dt} \left[ \log C(D_t) \right] = \frac{a}{D_t} \cdot \frac{r}{1 - e^{rt}} = 0 \quad \ldots (3)
\]

Hereafter, optimal values of \( t \) and \( C(D_t) \) 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 \( a \) and \( r \) alone (Singh and Lonnquist, 1972). By varying the values of \( a \), \( r \), and \( t^* \) in Equation 4, the relationships shown in Figure 2 were developed.

\[
t^* = \frac{\ln \left( \frac{t^* \cdot r + 1}{a} \right)}{r} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)
\]

in which
- \( t^* \) = optimum design period, yr
- \( r \) = annual interest rate
- \( a \) = economies of scale

Rachford, Scarto, and Tchobanoglous (1969) point out that increasing the economies of scale, indicated by decreasing the value of \( a \), will result in an increased plant size to achieve optimality, while increasing the interest rate decreases the optimum time, \( t^* \), and size, \( D_t^* \).
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).²

<table>
<thead>
<tr>
<th>Number</th>
<th>Equation Type</th>
<th>Derived Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(C(x) = k(x)^a)</td>
<td>(a = \frac{rx}{e^{rt} - 1})</td>
</tr>
<tr>
<td>2</td>
<td>(C(x) = a + kx^a)</td>
<td>(a = \frac{2rx}{e^{rt} - 1})</td>
</tr>
<tr>
<td>3</td>
<td>(C(x) = ax + kx^a)</td>
<td>(a = \frac{3rx}{e^{rt} - 1})</td>
</tr>
<tr>
<td>4</td>
<td>(C(x) = a + bx + kx^a)</td>
<td>(a = \frac{3rx}{e^{rt} - 1})</td>
</tr>
</tbody>
</table>

²\(x = Dt\).

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
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 probabilistic 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).
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 year's debt. The capital debt remaining was reduced by this amount. The annual operation and
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
- \( \xi \) = 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

\[
\text{Input} - \text{Output} = 0 \quad (5)
\]

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.

- \( \text{CAP}_{j} \) = capacity of treatment plant \( j \), mgd . \( (6) \)
- \( \text{DEBT}_{j} \) = capital debt of treatment plant \( j \), mil $ \quad (7) \)
Figure 5. Input and output at a node (after Lynn, Logan, and Chames, 1962).

\[ ELEV_j = \text{elevation of treatment plant } j, \text{ ft} \quad \text{(8)} \]

\[ \text{LTREAT}_j = \text{treatment level of plant } j \quad \text{(9)} \]

in which

\[ j = 1,2, \ldots , J \]

**Trunk sewer parameters**

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

\[ \text{CAPS}_{jk} = \text{capacity of trunk sewer } jk, \text{ mgd} \quad \text{(10)} \]

\[ \text{DEBTS}_{jk} = \text{capital debt of trunk sewer } jk, \text{ mil } \$ \quad \text{(11)} \]

\[ \text{DIST}_{jk} = \text{length of trunk sewer } jk, \text{ ft} \quad \text{(12)} \]

in which

\[ j = 1,2, \ldots , J \]

\[ k = 1,2, \ldots , J+1 \]

**Interest rates**

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

\[ r_\ell = R + \text{ANRATE } * \ell \quad \text{(13)} \]

in which

\[ r_\ell = \text{annual rate of interest in year } \ell \]

\[ R = \text{annual rate of interest in base year} \]

\[ \text{ANRATE} = \text{annual increase in the rate of interest} \]

\[ \ell = \text{planning year, } 1,2, \ldots , L \]

**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.

\[ \text{CRF}_\ell = \frac{r_\ell (1.0 + r_\ell)^{\text{PER}}}{(1.0 + r_\ell)^{\text{PER}} - 1} \quad \text{(14)} \]

in which

\[ \text{CRF}_\ell = \text{capital recovery factor in year } \ell \]

(Note: will be different for plants and sewers)

\[ \text{PER} = \text{capital return period (e.g., 20 years for treatment plants and 50 years for trunk sewers)} \]

\[ r_\ell = \text{annual rate of interest in year } \ell \]

**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.

\[ \text{FACTOR}_\ell = \frac{(\text{INDEX}_B + \text{ANFAC } * \ell)}{\text{INDEX}_A} \quad \text{(15)} \]

in which

\[ \text{FACTOR}_\ell = \text{inflation factor in year } \ell \]

\[ \text{INDEX}_A = \text{index for June 1974 (different for construction and operation and maintenance)} \]

\[ \text{INDEX}_B = \text{index for base or initial year of study} \]

\[ \text{ANFAC} = \text{annual increase in cost index} \]

\[ \ell = \text{planning year, } 1,2, \ldots , L \]
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:

\[ Q_{jt} = \text{POP}_{jt} \cdot (\text{GPDCAP}) \cdot f \]  

where:
- \( Q_{jt} \) = quantity of wastewater to plant \( j \) in year \( t \)
- \( \text{POP}_{jt} \) = population served by plant \( j \) in year \( t \)
- \( \text{GPDCAP} \) = gpd/capita of wastewater flow
- \( f \) = peak flow factor

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.

\[ \text{QUAL}_t = \text{minimum treatment level required by all treatment plants in year } t \]  

in which:
- \( t \) = 1, 2, \ldots, \( L \)

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.

\[ P_{jkm} = \begin{cases} 1 & \text{(feasible path)} \\ 0 & \text{(nonfeasible path)} \end{cases} \]  

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.

\[ \text{OUT}_{jkm} = P_{jkm} \]  

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

\[ \text{IN}_{ijm} = P_{jkm} \]  

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 \( j \).

\[ \text{if } \text{OUT}_{jkm} = 1, \text{ then } n = k \]  

\[ \text{if } \text{IN}_{ijm} = 1, \text{ then } \text{IN}_{inm} = 1 \]  

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.

\[ \text{OUT}_{jkm} = P_{jkm} \]  

in which:
- \( \text{OUT}_{jkm} \) = output matrix from plant \( j \) to destination \( k \) for alternative \( m \)
- \( P_{jkm} \) = 0-1 integer feasible path matrix
- \( j = 1, 2, \ldots, J \)
- \( k = 1, 2, \ldots, J+1 \)
- \( m = 1, 2, \ldots, M \)

in which:
- \( \text{IN}_{ijm} \) = input matrix from several sources \( i \) to plant \( j \) for alternative \( m \)
- \( P_{jkm} \) = 0-1 integer feasible path matrix
- \( i = 1, 2, \ldots, J \)
- \( j = 1, 2, \ldots, J \)
- \( k = 1, 2, \ldots, J \)
- \( m = 1, 2, \ldots, M \)
Figure 6. Sample treatment system.

Table 3. Input-output matrix.

<table>
<thead>
<tr>
<th>ALT m</th>
<th>PLANT j</th>
<th>LEVEL</th>
<th>MTREAT jm</th>
<th>INPUT 1 2 3 4 5</th>
<th>OUTPUT 1 2 3 4 5 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
<td>1 0 0 0 0</td>
<td>0 1 0 0 0 0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td></td>
<td>1 1 0 0 0</td>
<td>0 0 1 0 0 0</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
<td>1 1 1 1 0</td>
<td>0 0 0 0 0 1</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td></td>
<td>0 0 0 1 0</td>
<td>0 0 1 0 0 0</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>1</td>
<td></td>
<td>0 0 0 0 1</td>
<td>0 0 0 0 0 1</td>
</tr>
</tbody>
</table>

and

\[ i = 1, 2, \ldots, J \]
\[ j = 1, 2, \ldots, J \]
\[ k = 1, 2, \ldots, J + 1 \]
\[ m = 1, 2, \ldots, M \]
\[ n = \text{temporary index to indicate which plant j is receiving wastewater} \]

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 = treatment level of plant \( j \) for alternative \( m \) \( \ldots (23) \)

in which

\[ j = 1, 2, \ldots, J \]
\[ m = 1, 2, \ldots, M \]

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.

\[ \text{LAGP} = \text{construction time lag for treatment plants, yrs} \ldots (24) \]

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).

\[ \text{COL}_{ijm} = \sum_i Q_{il} (IN_{ijm}) \ldots \ldots (25) \]

in which

\[ \text{COL}_{ijm} = \text{total quantity of wastewater collected by plant j in year } \& \text{ for alternative } m \]
\[ Q_{il} = \text{quantity of wastewater to plant i in year } \& \]
\[ \text{IN}_{ijm} = \text{input matrix from several sources i to plant j for alternative m} \]

and:

\[ i = 1, 2, \ldots, J \]
\[ j = 1, 2, \ldots, J \]
\[ \& = \& \]
\[ m = m \]
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.

\[
\text{TREAT}_{jk}(\ell + \text{LAGP})m = \text{CO}_j(\ell + \text{LAGP})m(\text{OUT})_{jkm}.
\]

in which

\[
\text{TREAT}_{jk}(\ell + \text{LAGP})m = \text{quantity of wastewater to be treated by plant } j \text{ in year } \ell + \text{LAGP} \text{ mgd}
\]

\[
\text{CO}_j(\ell + \text{LAGP})m = \text{quantity of wastewater collected by plant } j \text{ in year } \ell + \text{LAGP} \text{ mgd}
\]

\[
\text{OUT}_{jkm} = \text{output matrix from plant } j \text{ to destination } k \text{ for alternative } m
\]

and:

\[
j = 1,2, \ldots, J
\]

\[
k = J + 1
\]

\[
\ell = \ell
\]

\[
m = m
\]

\[
\text{LAGP} = \text{construction lag time, yrs}
\]

**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 2 2 3
- Required level
  - 1 2 3 4 2 3 4 4
- INDEX
  - 1 2 3 4 5 6 7 8 9 10

if \( \text{LTREAT}_{j\ell} = 0 \), then \( \text{INDEX}_{jm} = \text{MTREAT}_{jm} \).

if \( \text{LTREAT}_{j\ell} = 1 \), then \( \text{INDEX}_{jm} = \text{MTREAT}_{jm} + 3 \).

if \( \text{LTREAT}_{j\ell} = 2 \), then \( \text{INDEX}_{jm} = \text{MTREAT}_{jm} + 5 \).

if \( \text{LTREAT}_{j\ell} = 3 \), then \( \text{INDEX}_{jm} = \text{MTREAT}_{jm} + 7 \).

in which

\[
\text{LTREAT}_{j\ell} = \text{existing treatment level of plant } j
\]

\[
\text{INDEX}_{jm} = \text{design index}
\]

\[
\text{MTREAT}_{jm} = \text{treatment level of plant } j \text{ for alternative } m
\]

and:

\[
j = 1,2, \ldots, J
\]

\[
m = 1,2, \ldots, M
\]

**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).

\[
t^* = \frac{\ln \left( \frac{\left( \frac{(t^*)^{(t^*)}}{r_{\ell}} \right) + 1.0}{a_p} \right)}{r_{\ell}}
\]

in which

\[
t^* = \text{optimum design period, yrs}
\]

\[
r_{\ell} = \text{annual interest rate for year } \ell
\]

\[
a_p = \text{economy of scale for cost equation}
\]

and:

\[
\ell = \ell
\]

\[
p = \text{design index, INDEX}_{jm}
\]

**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.

\[
D_{j\ell m} = \frac{\text{CO}_j(\ell + 20m) - \text{CO}_j(\ell m)}{20}
\]

in which

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

\[
\text{CO}_j(\ell m) = \text{total quantity of wastewater collected by plant } j \text{ in year } \ell \text{ for alternative } m
\]

and:

\[
j = 1,2, \ldots, J
\]

\[
\ell = \ell
\]

\[
m = m
\]

**Capacity expansion**

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

\[
\text{CAP}_{j\ell m} = \text{TREAT}_{j(\ell + \text{LAGP})m} + \left( D_{j\ell m} \right) (t^*)
\]
CAP_{j(m+1)} = \text{capacity of treatment plant } j \text{ in year } (m+1) \text{ for alternative } m, \text{ mgd}

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

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

t^* = \text{optimum design period, yrs}

\text{and: } 
\begin{align*}
 j & = 1, 2, \ldots, J \\
\ell & = \ell \\
m & = m \\
\text{LAGP} & = \text{construction lag time, yrs}
\end{align*}

Expansion costs

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

CTP_{jm} = (\text{FACTOR}_{\ell}(k_p)(\text{CAP}_{j(\ell+1)m} - \text{CAP}_{j\ell m}k_p \cdot (34)

in which

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

\text{FACTOR}_{\ell} = \text{inflation factor}

k_p = \text{cost coefficient}

\text{CAP}_{j(\ell+1)m} = \text{expanded capacity of treatment plant } j \text{ in year } (\ell+1) \text{ for alternative } m, \text{ mgd}

\text{CAP}_{j\ell m} = \text{existing capacity of treatment plant } j \text{ in year } \ell \text{ for alternative } m, \text{ mgd}

\alpha_p = \text{economy of scale factor}

\text{and: } 
\begin{align*}
 j & = 1, 2, \ldots, J \\
\ell & = \ell \\
m & = m \\
p & = \text{design index, INDEX}_{jm}
\end{align*}

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.

\text{DEBTP}_{j\ell m} = \text{DEBTP}_{j\ell m} + (0.50)(\text{CTP}_{jm}) \ldots (35)

\text{DEBTP}_{j(\ell+1)m} = \text{DEBTP}_{j\ell m} + (0.50)(\text{CTP}_{jm}) \ldots (36)

in which

\text{DEBTP}_{jm} = \text{capital debt of treatment plant } j \text{ in year } \ell \text{ for alternative } m, \text{ mil }$

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

\text{CTP}_{jm} = \text{cost of expanding and upgrading treatment plant } j \text{ for alternative } m, \text{ mil }$

\text{and: } 
\begin{align*}
 j & = 1, 2, \ldots, J \\
\ell & = \ell \\
m & = m
\end{align*}

Annual capital debt

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

\text{ANNP}_{j\ell m} = \text{DEBTP}_{j(\ell-1)m} \cdot \text{CRF}_{\ell} \ldots \ldots (37)

\text{DEBTP}_{j(\ell+1)m} = \text{DEBTP}_{j\ell m} - \text{ANNP}_{j\ell m} \ldots \ldots (38)

in which

\text{ANNP}_{jm} = \text{annual repayment of previous years capital debt for plant } j \text{ in year } \ell \text{ for alternative } m, \text{ mil }$

\text{DEBTP}_{j\ell m} = \text{capital debt of treatment plant } j \text{ in year } \ell \text{ for alternative } m, \text{ mil }$

\text{DEBTP}_{j(\ell+1)m} = \text{new capital debt of treatment plant } j \text{ after addition of expansion costs and after subtraction of annual repayment, mil }$

\text{CRF}_{\ell} = \text{capital recovery factor for treatment plants for year } \ell$
and:  
\[ j = 1,2, \ldots, J \]
\[ k = k \]
\[ m = m \]

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.

\[ \text{OMP}_{jkm} = (\text{FACTOR}_j)(k_p)(\text{TREAT}_{jkm})^{\text{INDEX}_{jm}} \]  

in which

\[ \text{OMP}_{jkm} \] = annual O & M cost of treatment plant j in year \( t \) for alternative m, mil $
\[ \text{FACTOR}_j \] = inflation factor for O & M
\[ k_p \] = cost index for O & M cost equation
\[ \text{TREAT}_{jkm} \] = quantity of wastewater being treated by plant j in year \( t \) for alternative m, mgd
\[ \alpha_p \] = economy of scale factor
and:
\[ j = 1,2, \ldots, J \]
\[ k = k \]
\[ m = m \]
\[ p = \text{design index, INDEX}_{jm} \]

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.

\[ \text{PWP}_{jkm} = \frac{\text{ANNP}_{jkm} + \text{OMP}_{jkm}}{(1+r)^t-1} \]  

in which

\[ \text{PWP}_{jkm} \] = present worth produced by plant j in year \( t \) for alternative m, mil $
\[ \text{ANNP}_{jkm} \] = annual repayment of capital for plant j for debt incurred in previous year from year \( t \) for alternative m, mil $
\[ \text{OMP}_{jkm} \] = annual O & M cost of treatment plant j in year \( t \) for alternative m, mil $
\[ r \] = annual interest rate for year

and:
\[ j = 1,2, \ldots, J \]
\[ k = k \]
\[ m = m \]

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 decision to build the trunk sewer be based on conditions at some time in the future equal to the time lag.

\[ \text{LAGS} = \text{construction time lag for trunk sewers, yes} \ldots \ldOTS

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, \( X_{jkm} \), is loaded with the quantity of wastewater collected by plant j.

\[ \text{if} \ OUT_{jkm} = 1, \text{then} \ r = k \]  

\[ X_{j(k + \text{LAGS})m} = X_{j(\text{LAGS})m} \]  

in which

\[ \text{OUT}_{jkm} \] = output matrix
\[ X_{j(k + \text{LAGS})m} \] = quantity of wastewater transported by trunk sewer jr in year (k + LAGS) for alternative m, mgd
\[ X_{j(\text{LAGS})m} \] = quantity of wastewater collected by plant j, but not treated, in year (k + LAGS) for alternative m, mgd
and:
\[ j = j \]
\[ k = 1,2, \ldots, J + 1 \] (j ≠ 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, \( \alpha_p \). 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.

\[
\text{if } \text{OUT}_{jkm} = 1, \text{ then } r = k \quad \quad \quad \quad \quad (44)
\]

\[
\text{DS}_{j\ell m} = D_{j\ell m} \quad \quad \quad \quad \quad (45)
\]

in which

\[
\text{OUT}_{jkm} = \text{output matrix}
\]

\[
\text{DS}_{j\ell m} = \text{annual increase in quantity of trunk sewer flow, mgd/yr}
\]

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

and:

\[
\begin{align*}
j & = j \\
k & = 1, 2, \ldots, J (j \neq k) \\
\ell & = \ell \\
m & = m
\end{align*}
\]

Capacity expansion

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

\[
\text{CAPS}_{jk(\ell+1)m} = X_{jk(\ell+LAGS)m} + (\text{DS}_{j\ell m})(t^*) \quad (46)
\]

in which

\[
\begin{align*}
\text{CAPS}_{jk(\ell+1)m} & = \text{expanded capacity of trunk sewer } jk \text{ in year } (\ell+1) \text{ for alternative } m, \text{ mgd} \\
X_{jk(\ell+LAGS)m} & = \text{quantity of wastewater to be transported by trunk sewer } jk \text{ in year } (\ell+LAGS) \text{ for alternative } m, \text{ mgd} \\
\text{DS}_{j\ell m} & = \text{annual increase in quantity of trunk sewer flow, mgd/yr} \\
t^* & = \text{optimum design period, yrs}
\end{align*}
\]

Expansion costs

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

\[
\text{CTS}_{jkm} = (\text{FACTOR}_{\ell})(k_{12})(\text{CAPS}_{jk(\ell+1)m} - \text{CAPS}_{jk}\ell m)^{a_{12}} (\text{DIST}_{jk})
\]

\[
+ (k_{13})(\text{CAPS}_{jk(\ell+1)m} - \text{CAPS}_{jk\ell m})^{a_{13}} (\text{NUMPS}_{jk})
\]

(47)

in which

\[
\begin{align*}
\text{CTS}_{jkm} & = \text{cost of building or expanding trunk sewer } jk \text{ for alternative } m, \text{ mgd} \\
\text{FACTOR}_{\ell} & = \text{inflation factor} \\
k_{12} & = \text{cost coefficient for constructing trunk sewer} \\
\text{CAPS}_{jk(\ell+1)m} & = \text{expanded capacity of trunk sewer } jk \text{ in year } (\ell+1) \text{ for alternative } m, \text{ mgd} \\
\text{CAPS}_{jk\ell m} & = \text{existing capacity of trunk sewer } jk \text{ in year } \ell \text{ for alternative } m, \text{ mgd} \\
\alpha_{12} & = \text{economy of scale for constructing trunk sewer} \\
\text{DIST}_{jk} & = \text{length of existing or proposed trunk sewer, mi} \\
\text{CAPS}_{jk(\ell+LAGS)m} & = \text{quantity of wastewater to be transported by trunk sewer } jk \text{ in year } (\ell+LAGS) \text{ for alternative } m, \text{ mgd} \\
k_{13} & = \text{cost coefficient for constructing lift station} \\
\alpha_{13} & = \text{economy of scale for constructing lift station} \\
\text{NUMPS}_{jk} & = \text{number of lift stations for trunk sewer } jk
\end{align*}
\]

and:

\[
\begin{align*}
j & = 1, 2, \ldots, J \\
k & = 1, 2, \ldots, J \\
\ell & = \ell \\
m & = m
\end{align*}
\]
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$_{jk, m}$ this year and 50 percent next year.

$$DEBTS_{jk, t} = DEBTS_{jk, t-1} + 0.50 \times CTS_{jk, m} \quad \text{(48)}$$

$$DEBTS_{jk, (t+1)} = DEBTS_{jk, t} + 0.50 \times CTS_{jk, m} \quad \text{(49)}$$

in which

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

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

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

and

$$j = 1, 2, \ldots, J \text{ (j } \neq k)$$

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

$$\xi = \xi$$

$$m = m$$

Annual capital debt

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

$$ANNS_{jk, t} = DEBTS_{jk, t-1} \times CRF_{\xi} \quad \text{(50)}$$

$$DEBTS_{jk, t} = DEBTS_{jk, t} - ANNS_{jk, t} \quad \text{(51)}$$

in which

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

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

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

$$CRF_{\xi} = \text{capital recovery factor for treatment plants for year } \xi$$

and:

$$j = 1, 2, \ldots, J \text{ (j } \neq k)$$

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

$$\xi = \xi$$

$$m = m$$

Annual O & M

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

$$OMS_{jk, t} = (\text{FACTOR}_{\xi} \times k_{12} \times X_{jk, t} \times a_{12} \times (\text{HEAD}_{jk}) + (k_{13} \times X_{jk, t} \times a_{13} \times \text{NUMPS}_{jk}) \quad \text{(52)}$$

in which

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

$$\text{FACTOR}_{\xi} = \text{inflation factor for O & M}$$

$$k_{12} = \text{cost index for power cost of lift station}$$

$$X_{jk, t} = \text{quantity of wastewater transported by trunk sewer } jk \text{ in year } t \text{ for alternative } m, \text{ mgd}$$

$$a_{12} = \text{economy of scale for power cost of lift station}$$

$$k_{13} = \text{cost coefficient for O & M of lift station}$$

$$a_{13} = \text{economy of scale for O & M of lift station}$$

$$\text{HEAD}_{jk} = \text{pumping head of lift station, ft}$$

$$\text{NUMPS}_{jk} = \text{number of lift stations for trunk sewer } jk$$

and:

$$j = 1, 2, \ldots, J \text{ (j } \neq k)$$

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

$$\xi = \xi$$

$$m = m$$

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.

$$PWS_{jk, t} = \frac{ANNS_{jk, t} + OMS_{jk, t}}{(1.0 + r_{\xi}^{-1}) \quad \text{(53)}}$$
in which

\[ PWS_{jk}^m \] present worth produced by trunk sewer \( jk \) in year \( \tau \) for alternative \( m \), mil $ \\

\[ ANNS_{jk}^m \] annual repayment of capital for trunk sewer \( jk \) for debt incurred in previous year from year \( \tau \) for alternative \( m \), mil $ \\

\[ OMS_{jk}^m \] annual O & M cost of trunk sewer \( jk \) in year \( \tau \) for alternative \( m \), mil $ \\

\[ r_\tau \] annual interest rate for year \( \tau \) \\

and:

\[ j = 1,2, \ldots, J (j \neq k) \] \\
\[ k = 1,2, \ldots, J \] \\
\[ \tau = \tau \] \\
\[ m = m \]

**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.

**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.](image-url)
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 state 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 \( S_k^g \) represents the \( m \)th state within the \( g \)th stage, then the optimal, or in this case, the minimum cost path \( C^*(I, S_k^g) \) from the initial state 1 to the state \( S_k^g \) is given by:

\[
C^*(I, S_k^g) = \min_{k=1,2, \ldots, M} \{ C(S_k^{g-1}, S_k^g) + C^*(I, S_k^{g-1}) \}
\]

in which

\[
\begin{align*}
S_k^{g-1} & = \text{state } k \text{ in stage } g-1 \\
M & = \text{number of possible states in stage } g-1 \\
C^*(I, S_k^{g-1}) & = \text{minimum cost of getting from state } I \text{ to state } S_k^{g-1} \\
C(S_k^{g-1}, S_k^g) & = \text{cost of going from state } S_k^{g-1} \text{ to state } S_k^g
\end{align*}
\]

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, \( T_1 \), 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 \( A_3 \) using \( B_1 \) and \( C_1 \) as the initial conditions. The alternative in \( T_3 \) 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 \( T_3 \), 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 \( B_2 \). 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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids, mg/l</td>
<td>250</td>
</tr>
<tr>
<td>Grease &amp; oil, mg/l</td>
<td>100</td>
</tr>
<tr>
<td>BOD₅, mg/l</td>
<td>200</td>
</tr>
<tr>
<td>COD, mg/l</td>
<td>500</td>
</tr>
<tr>
<td>Total Nitrogen, mg/l</td>
<td>50</td>
</tr>
<tr>
<td>Total Phosphorus, mg/l</td>
<td>12</td>
</tr>
<tr>
<td>Coliform, 100 ml</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4. Domestic sewage quality. a

aTempleton, 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

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Drinking</th>
<th>Recreational (contact)</th>
<th>Industrial</th>
<th>Irrigation</th>
<th>Fisheries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water</td>
<td>Water</td>
<td>Water</td>
<td>Water</td>
<td>Water</td>
</tr>
<tr>
<td>Alkaliinity</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Ascorbic Acid (AA)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Cyanide (CN)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Nitrate (NO₃)</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Phosphate (P)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Suspended Solids (SS)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Dissolved Oxygen (DO)</td>
<td>&gt; 6.5</td>
<td>&gt; 6.5</td>
<td>&gt; 6.5</td>
<td>&gt; 6.5</td>
<td>&gt; 6.5</td>
</tr>
<tr>
<td>BOD₅</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>COD - Total</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>Carbon - Total</td>
<td>1000/100</td>
<td>1000/100</td>
<td>1000/100</td>
<td>1000/100</td>
<td>1000/100</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.5</td>
<td>6.5-8.5</td>
<td>6.5-8.5</td>
<td>6.5-8.5</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>Oil and Grease</td>
<td>undetectable</td>
<td>undetectable</td>
<td>undetectable</td>
<td>undetectable</td>
<td>undetectable</td>
</tr>
</tbody>
</table>

*Concentration in mg/L.

**Maximum concentration.


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.

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Process Water</th>
<th>Pollutant</th>
<th>COD</th>
<th>S.S.</th>
<th>Turbidity</th>
<th>N</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary &amp; Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste Stabilization Lagoon</td>
<td>10-20</td>
<td>70</td>
<td>-</td>
<td>10-20</td>
<td>70</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Extended Aeration</td>
<td>20-20</td>
<td>80-90</td>
<td>-</td>
<td>10-20</td>
<td>90</td>
<td>-</td>
<td>10-20</td>
</tr>
<tr>
<td>Primary Sedimentation</td>
<td>120</td>
<td>15</td>
<td>-</td>
<td>10-20</td>
<td>15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High Rate Trickling Filters</td>
<td>40</td>
<td>100</td>
<td>-</td>
<td>10-20</td>
<td>100</td>
<td>-</td>
<td>10-20</td>
</tr>
<tr>
<td>Single Stage</td>
<td>60</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Two Stage</td>
<td>80</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Standard Rate Trickling Filters</td>
<td>20-30</td>
<td>95</td>
<td>-</td>
<td>10-20</td>
<td>95</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>High Rate Activated Sludge</td>
<td>30-50</td>
<td>75</td>
<td>-</td>
<td>20-25</td>
<td>75</td>
<td>-</td>
<td>10-20</td>
</tr>
<tr>
<td>Standard Rate Activated Sludge</td>
<td>15-20</td>
<td>70</td>
<td>-</td>
<td>20-25</td>
<td>70</td>
<td>-</td>
<td>10-20</td>
</tr>
<tr>
<td>Physical-Chemical</td>
<td>10-15</td>
<td>95</td>
<td>-</td>
<td>10-20</td>
<td>95</td>
<td>-</td>
<td>1.5</td>
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<tr>
<td>Tertiary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermittent Sand Filtration</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chemical Precipitation</td>
<td>50</td>
<td>70</td>
<td>-</td>
<td>70</td>
<td>70</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>Chemical Treatment (Shallow contact)</td>
<td>6.5</td>
<td>5</td>
<td>-</td>
<td>5</td>
<td>90</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Granular or Mixed Media</td>
<td>1</td>
<td>1-1.5</td>
<td>-</td>
<td>15</td>
<td>15</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Filtration w/Chem.</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sand Filtration - Deep Bed</td>
<td>4.2</td>
<td>94-96</td>
<td>-</td>
<td>5</td>
<td>95</td>
<td>-</td>
<td>98</td>
</tr>
<tr>
<td>Chemical Coagulation and Sand Filtration</td>
<td>4.2</td>
<td>94-96</td>
<td>-</td>
<td>5</td>
<td>95</td>
<td>-</td>
<td>98</td>
</tr>
<tr>
<td>Microbial Denitrification</td>
<td>2-3</td>
<td>20</td>
<td>-</td>
<td>5</td>
<td>10</td>
<td>-</td>
<td>3-1.5</td>
</tr>
<tr>
<td>Aflomias Stripping (R. P.)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Clarification, 10 mg Cl per L</td>
<td>1.0-10</td>
<td>95-99</td>
<td>-</td>
<td>1-3</td>
<td>98</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carbon Adsorption</td>
<td>1.0</td>
<td>10-12</td>
<td>-</td>
<td>0.6</td>
<td>1.2</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>Micronozzle Tower</td>
<td>4.12</td>
<td>94-98</td>
<td>-</td>
<td>2.4</td>
<td>97</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Ion Exchange</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reverse Osmosis</td>
<td>1-2</td>
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<td>-</td>
<td>1-4</td>
<td>95</td>
<td>-</td>
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<td>Electrolysis</td>
<td>1-1.5</td>
<td>99</td>
<td>-</td>
<td>0-2.0</td>
<td>99</td>
<td>-</td>
<td>0.27</td>
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<tr>
<td>Dissolved Air Flotation</td>
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<td>Ultrafiltration</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Land Disposal/Ground Drains</td>
<td>11-12</td>
<td>99</td>
<td>-</td>
<td>0-3</td>
<td>99</td>
<td>-</td>
<td>0.5-1.6</td>
</tr>
</tbody>
</table>

*mg/l of constituent remaining in effluents.

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

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

hCOD

Templeton, Link, and Alsup Consulting Engineers (1971).

Middlebrooks et al. (1973).

Utah State Division of Health (1966).
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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Labor Rates $/hr</th>
<th>WPC Construction Cost Index</th>
<th>Engineering New Record Cost Index</th>
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**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.\(^a\)

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<th>Year</th>
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<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
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\(^a\) Standard & Poor's Corporation (1974).
\(^b\) Not available.
Table 9. A comparison of cost equations for treatment plant unit processes.

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<th>Equation format</th>
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Table 10. A comparison of cost equations for trunk sewers, force mains, and lift stations.

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<td>Trunk sewers</td>
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in which

\[ Y = k X^a \] (56)

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.

\[ Y = k X^a H (0 < a < 1) \] (57a)

The values of \( k \) and \( a \) 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 \( a \), 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, \( a \), is essential to the production of a valid model. In general, \( a \) 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 component's 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.

\[ \text{Total cost} = \text{cost of component } A + \text{cost of component } B + \ldots \] (57b)

\[ 1.0 X^{a_0} = \sum P_i X_i^a \] (58)

in which

- \( X \) = capacity rating, mgd
- \( P_i \) = percent of the total cost contributed by process \( i \), fraction
- \( a_0 \) = composite economies of scale
- \( a_i \) = process economies of scale

This equation can be solved for \( a \) 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.
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.

<table>
<thead>
<tr>
<th>Design Index</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Levels</td>
<td>Initial</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

The 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:

$$ Y = 127 X^{0.390} $$

in which

- $Y$ = cost of construction of sewer, $\$1000/\text{mi}$
- $X$ = capacity, mgd

#### Construction costs for lift stations:

$$ Y = 128 X^{0.615} $$

in which

- $Y$ = cost of construction of lift station, $\$1000$
- $X$ = capacity, mgd

#### O & M costs of lift station:

$$ Y = 0.0288 X^{0.897} H + 1.80 X^{0.644} $$

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 $Y = kX^2$.

<table>
<thead>
<tr>
<th>Design Level</th>
<th>Treatment Type</th>
<th>Construction Costs</th>
<th>O &amp; M Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$a$</td>
<td>$k \times 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Average</td>
</tr>
<tr>
<td>Treatment Process Units</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Final</td>
<td>Activated Sludge Plant</td>
<td>.77-.78</td>
<td>.775</td>
</tr>
<tr>
<td>a</td>
<td>-</td>
<td>-</td>
<td>Nitrification</td>
</tr>
<tr>
<td>b</td>
<td>-</td>
<td>-</td>
<td>Filtration</td>
</tr>
<tr>
<td>c</td>
<td>-</td>
<td>-</td>
<td>Carbon Adsorption</td>
</tr>
<tr>
<td>d</td>
<td>-</td>
<td>-</td>
<td>Chlorination</td>
</tr>
<tr>
<td>e</td>
<td>-</td>
<td>-</td>
<td>Activated Sludge Plant</td>
</tr>
<tr>
<td>Treatment Process Chains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>a, e</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2</td>
<td>a, b, c</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>3</td>
<td>a, b, c, e</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>4</td>
<td>a, b, c, d, e</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2</td>
<td>b, c</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>3</td>
<td>b, c, e</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>4</td>
<td>b, c, d, e</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>3</td>
<td>c, e</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>4</td>
<td>c, d, e</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>3</td>
<td>d, e</td>
</tr>
</tbody>
</table>

$a$ 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 $Y^a = k X^a$.

<table>
<thead>
<tr>
<th>Units</th>
<th>Valid Range (mgd)</th>
<th>Original Data</th>
<th>Adjusted June '74</th>
<th>Original Data</th>
<th>Adjusted June '74</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$k \times 10^{-3}$</td>
<td>$k \times 10^{-3}$</td>
<td>$k$</td>
<td>$k$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity Trunk Sewers</td>
<td>20 - 500</td>
<td>0.359</td>
<td>192$^b$</td>
<td>287</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1 - 3000</td>
<td>0.50</td>
<td>40$^b$</td>
<td>70.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1 - 100</td>
<td>0.268</td>
<td>30.9</td>
<td>71.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1 - 15</td>
<td>0.309</td>
<td>55.6</td>
<td>78.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Force Mains</td>
<td>0.1 - 50</td>
<td>0.45</td>
<td>39.9$^b$</td>
<td>73.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1 - 200</td>
<td>0.463</td>
<td>69.0$^b$</td>
<td>103</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.1 - 1000</td>
<td>0.483</td>
<td>43.4$^b$</td>
<td>83.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lift Stations</td>
<td>0.1 - 500</td>
<td>0.685</td>
<td>94.0</td>
<td>140</td>
<td>0.897$^c$</td>
<td>28.8 H</td>
</tr>
<tr>
<td></td>
<td>1 - 50</td>
<td>0.50</td>
<td>53.8</td>
<td>116</td>
<td>0.644$^c$</td>
<td>1800</td>
</tr>
</tbody>
</table>

$^a Y = \$/mi, X = mgd.$

$^b D = 11.36 \times 0.3745, n = 0.015, S = 0.003, V = 2.65 \text{ fps (American Society of Civil Engineers, 1970, Figure 22).}$

$^c$ Composite cost equation, $Y = k X^a H + k' X^{a'}$; $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 'I' 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.\(^{a}\)

<table>
<thead>
<tr>
<th>No.</th>
<th>Wastewater Treatment Plant</th>
<th>Year Operation Began</th>
<th>Type of Plant</th>
<th>Present Design Capacity (mgd)</th>
<th>Flow (mgd)</th>
<th>BOD mg/l</th>
<th>Suspended Solids mg/l</th>
<th>Settleable Solids mg/l</th>
<th>BOD lbs/day</th>
<th>Suspended Solids lbs/day</th>
<th>Settleable Solids lbs/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South Davis County</td>
<td>1962</td>
<td>TF</td>
<td>2.27</td>
<td>1.39</td>
<td>1.49</td>
<td>182</td>
<td>24</td>
<td>193</td>
<td>9</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>Salt Lake City</td>
<td>1965</td>
<td>TF</td>
<td>35.0</td>
<td>13.1</td>
<td>15.8</td>
<td>130</td>
<td>23</td>
<td>124</td>
<td>33</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>South Salt Lake City</td>
<td>1954</td>
<td>TF</td>
<td>4.55</td>
<td>3.69</td>
<td>4.35</td>
<td>170</td>
<td>19</td>
<td>180</td>
<td>8</td>
<td>4.3</td>
</tr>
<tr>
<td>4</td>
<td>Salt Lake City S.S.D. #1</td>
<td>1955</td>
<td>TF</td>
<td>16.0</td>
<td>11.69</td>
<td>14.0</td>
<td>173</td>
<td>24</td>
<td>182</td>
<td>10</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>Granger-Hunter Imp. Dist.</td>
<td>1959</td>
<td>TF</td>
<td>7.4</td>
<td>6.43</td>
<td>6.73</td>
<td>203</td>
<td>25</td>
<td>227</td>
<td>9</td>
<td>8.3</td>
</tr>
<tr>
<td>6</td>
<td>Salt Lake County Cottonwood</td>
<td>1958</td>
<td>TF</td>
<td>5.0</td>
<td>5.1</td>
<td>5.9</td>
<td>124</td>
<td>29</td>
<td>143</td>
<td>13</td>
<td>5.3</td>
</tr>
<tr>
<td>7</td>
<td>Murray City</td>
<td>1953</td>
<td>TF</td>
<td>4.0</td>
<td>2.4</td>
<td>4.3</td>
<td>262</td>
<td>30</td>
<td>270</td>
<td>10</td>
<td>4.8</td>
</tr>
<tr>
<td>8</td>
<td>Tri-Community (Midvale)</td>
<td>1956</td>
<td>TF</td>
<td>3.6</td>
<td>1.78</td>
<td>5.46</td>
<td>192</td>
<td>24</td>
<td>159</td>
<td>10</td>
<td>5.7</td>
</tr>
<tr>
<td>9</td>
<td>Sandy City</td>
<td>1962</td>
<td>AS</td>
<td>1.5</td>
<td>1.73</td>
<td>2.07</td>
<td>175</td>
<td>22</td>
<td>-</td>
<td>7.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\(\text{a}\) Templeton, Linke, and Alsup Consulting Engineers and Engineering-Science, Inc. (1973a), Table 6-2.

\(\text{b}\) TF = Trickling filter, AS = Activated sludge.
<table>
<thead>
<tr>
<th>No.</th>
<th>Wastewater Treatment Plant</th>
<th>(Census)</th>
<th>(Estimate)</th>
<th>(Low)</th>
<th>(Middle)</th>
<th>(High)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(0)</td>
<td>(4)</td>
<td>(11)</td>
<td>(21)</td>
<td>(50)</td>
</tr>
<tr>
<td>1</td>
<td>DAVIS COUNTY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>South Davis County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S. I. D. South Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>North Salt Lake</td>
<td>2,143</td>
<td>2,972</td>
<td>3,800</td>
<td>4,700</td>
<td>5,700</td>
</tr>
<tr>
<td></td>
<td>Unincorporated</td>
<td>7,600</td>
<td>9,250</td>
<td>10,900</td>
<td>12,200</td>
<td>11,900</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>9,743</td>
<td>11,222</td>
<td>12,700</td>
<td>14,900</td>
<td>17,600</td>
</tr>
<tr>
<td></td>
<td>SALT LAKE COUNTY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Lake City</td>
<td>174,870</td>
<td>188,367</td>
<td>201,864</td>
<td>215,361</td>
<td>228,364</td>
</tr>
<tr>
<td>3</td>
<td>South Salt Lake City Chesterfield</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Lake City S. S. D. #1</td>
<td>85,392</td>
<td>93,918</td>
<td>101,744</td>
<td>105,404</td>
<td>108,951</td>
</tr>
<tr>
<td></td>
<td>Taylorsville-Bennington</td>
<td>19,092</td>
<td>22,546</td>
<td>26,000</td>
<td>30,300</td>
<td>34,745</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>104,484</td>
<td>116,464</td>
<td>127,744</td>
<td>135,644</td>
<td>143,696</td>
</tr>
<tr>
<td></td>
<td>Granger-Hunter Imp. Dist. Kearns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Sub-total</td>
<td>49,374</td>
<td>63,450</td>
<td>77,526</td>
<td>91,602</td>
<td>119,755</td>
</tr>
<tr>
<td>4</td>
<td>Salt Lake County Cottonwood</td>
<td>34,416</td>
<td>43,025</td>
<td>51,634</td>
<td>60,243</td>
<td>77,462</td>
</tr>
<tr>
<td>5</td>
<td>Murray City</td>
<td>21,308</td>
<td>26,646</td>
<td>31,984</td>
<td>37,322</td>
<td>48,000</td>
</tr>
<tr>
<td>6</td>
<td>Tri-Community</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Midvale</td>
<td>7,499</td>
<td>7,999</td>
<td>8,499</td>
<td>8,999</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>West Jordan</td>
<td>5,473</td>
<td>5,978</td>
<td>10,453</td>
<td>12,988</td>
<td>18,000</td>
</tr>
<tr>
<td></td>
<td>S. L. C. S. S. D. #2</td>
<td>6,823</td>
<td>8,460</td>
<td>10,098</td>
<td>11,733</td>
<td>15,000</td>
</tr>
<tr>
<td></td>
<td>S. L. C. S. I. D. #1</td>
<td>13,763</td>
<td>20,130</td>
<td>26,497</td>
<td>32,384</td>
<td>45,600</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>33,357</td>
<td>44,867</td>
<td>55,577</td>
<td>66,584</td>
<td>88,660</td>
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<tr>
<td>7</td>
<td>Sandy City</td>
<td>4,943</td>
<td>5,354</td>
<td>5,765</td>
<td>6,176</td>
<td>7,060</td>
</tr>
<tr>
<td></td>
<td>Sandy Suburban</td>
<td>7,432</td>
<td>9,884</td>
<td>12,334</td>
<td>14,784</td>
<td>19,682</td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>12,377</td>
<td>15,238</td>
<td>18,099</td>
<td>20,960</td>
<td>26,882</td>
</tr>
<tr>
<td>8</td>
<td>Salt Lake County Sub-total</td>
<td>442,907</td>
<td>514,059</td>
<td>528,211</td>
<td>651,440</td>
<td>789,907</td>
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<td>452,650</td>
<td>523,780</td>
<td>594,911</td>
<td>666,340</td>
<td>801,907</td>
</tr>
</tbody>
</table>

Table 16. Present and projected populations.

aData from Templeton, Linke, and Alsop Consulting Engineers and Engineering Science, Inc. (1973a) up to 1995, straight line projection to 2024.

bEstimated from Bishop et al. (1974).

cYear of data.
Table 17. Average flows of wastewater treatment plants, mgd.a

<table>
<thead>
<tr>
<th>No.</th>
<th>Wastewater Treatment Plant</th>
<th>Present Design Capacity (mgd)</th>
<th>1972</th>
<th>1978</th>
<th>1985</th>
<th>1995</th>
<th>(Low)</th>
<th>(Middle)</th>
<th>(High)</th>
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<tr>
<td></td>
<td></td>
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<td>(50)</td>
<td>(50)</td>
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<tr>
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<td>South Davis County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.D. South Plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>North Salt Lake Unincorporated</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Salt Lake City</td>
<td>45.6</td>
<td>34.1</td>
<td>33.0</td>
<td>46.5</td>
<td>43.5</td>
<td>39.5</td>
<td>57.5</td>
<td>72.1</td>
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<tr>
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<td>South Salt Lake City</td>
<td>26.6</td>
<td>36.5</td>
<td>35.5</td>
<td>35.7</td>
<td>47.2</td>
<td>57.3</td>
<td>75.4</td>
<td>88.9</td>
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<tr>
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<td>Chesterfield</td>
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<td></td>
</tr>
<tr>
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<td>Sub-total</td>
<td>2.8</td>
<td>3.0</td>
<td>2.7</td>
<td>3.2</td>
<td>3.8</td>
<td>4.7</td>
<td>5.5</td>
<td>6.1</td>
</tr>
<tr>
<td>4</td>
<td>Salt Lake City S.S.D. #1</td>
<td>16.0</td>
<td>9.7</td>
<td>10.3</td>
<td>11.0</td>
<td>12.0</td>
<td>11.9</td>
<td>23.3</td>
<td>25.1</td>
</tr>
<tr>
<td></td>
<td>Taylorsville-Brigham</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>12.1</td>
<td>15.3</td>
<td>14.7</td>
<td>15.7</td>
<td>15.9</td>
<td>23.3</td>
<td>25.1</td>
<td>27.7</td>
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<tr>
<td>5</td>
<td>Granger-Hunter Imp. Dist.</td>
<td>7.3</td>
<td>4.4</td>
<td>5.8</td>
<td>7.3</td>
<td>9.5</td>
<td>10.3</td>
<td>12.3</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>Kearns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>6.4</td>
<td>5.0</td>
<td>7.8</td>
<td>10.0</td>
<td>12.3</td>
<td>16.0</td>
<td>23.9</td>
<td>28.9</td>
</tr>
<tr>
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<td>Salt Lake County Cottonwood</td>
<td>8.0</td>
<td>5.7</td>
<td>7.5</td>
<td>9.1</td>
<td>13.0</td>
<td>14.6</td>
<td>21.4</td>
<td>26.8</td>
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<tr>
<td>7</td>
<td>Murray City</td>
<td>4.0</td>
<td>2.6</td>
<td>3.2</td>
<td>4.7</td>
<td>7.6</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Tri-Community</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Midvale</td>
<td>1.5</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>West Jordan</td>
<td>1.2</td>
<td>1.6</td>
<td>2.2</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.L.C.S.S.D. #2</td>
<td>1.3</td>
<td>1.5</td>
<td>1.8</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S.L.C.S.S.D. #3</td>
<td>0.2</td>
<td>0.7</td>
<td>1.0</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>4.4</td>
<td>5.4</td>
<td>10.0</td>
<td>14.4</td>
<td>16.9</td>
<td>24.8</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sandy City</td>
<td>1.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sandy Suburban</td>
<td>1.2</td>
<td>1.8</td>
<td>2.2</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Sub-total</td>
<td>1.9</td>
<td>2.5</td>
<td>3.2</td>
<td>4.6</td>
<td>4.4</td>
<td>6.5</td>
<td>8.1</td>
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</tr>
<tr>
<td>10</td>
<td>Salt Lake County Sub-total</td>
<td>89.4</td>
<td>71.0</td>
<td>85.7</td>
<td>98.6</td>
<td>118.2</td>
<td>121.4</td>
<td>177.8</td>
<td>222.6</td>
</tr>
<tr>
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<td>Lower Jordan River Total</td>
<td>92.2</td>
<td>72.4</td>
<td>87.4</td>
<td>100.5</td>
<td>120.5</td>
<td>123.7</td>
<td>181.1</td>
<td>226.8</td>
</tr>
</tbody>
</table>

a Tempelton, 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.

<table>
<thead>
<tr>
<th>To</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>12,500</td>
<td>-</td>
<td>38,300</td>
<td>41,700</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>40,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>38,300</td>
<td>7,800</td>
<td>5,800</td>
<td>9,300</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>41,700</td>
<td>7,800</td>
<td>5,800</td>
<td>9,300</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5,800</td>
<td></td>
<td>2,800</td>
<td>18,600</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>18,600</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,600</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,600</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>40,300</td>
<td>9,400</td>
<td>2,400</td>
<td>3,600</td>
<td>10,200</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1974 Values</th>
<th>Annual Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital recovery period for treatment plants, yr.</td>
<td>20.0</td>
<td>-</td>
</tr>
<tr>
<td>Capital recovery period for trunk sewers, yr.</td>
<td>50.0</td>
<td>-</td>
</tr>
<tr>
<td>Capital recovery period for lift stations, yr.</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td>Construction lag time, yr.</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Annual rate of interest</td>
<td>0.0600</td>
<td>0.0 0.001675</td>
</tr>
<tr>
<td>Gpd/capita of wastewater flow</td>
<td>100.0</td>
<td>-</td>
</tr>
<tr>
<td>Peak flow factor (for population projections only)</td>
<td>2.25</td>
<td>-</td>
</tr>
<tr>
<td>Peak flow factor (for wastewater flow projections only)</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>Minimum slope of trunk sewer, ft.</td>
<td>-0.100</td>
<td>-</td>
</tr>
<tr>
<td>Average pumping head of lift stations, ft</td>
<td>25.0</td>
<td>-</td>
</tr>
<tr>
<td>ENR-B Index for treatment plant and lift station costs</td>
<td>340.66</td>
<td>10.0 26.17 40.0</td>
</tr>
<tr>
<td>WPC-S or EPA-S Index for sewer construction costs</td>
<td>211.66</td>
<td>10.0 15.184 30.0</td>
</tr>
<tr>
<td>Labor cost index for O&amp;M and power costs</td>
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<td>0.10 0.21 0.30</td>
</tr>
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<td>Time phased treatment levels, 1977</td>
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</tr>
<tr>
<td></td>
<td>1980</td>
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</table>
Table 20. Input data for cost equation coefficients $a - y = k X^a$.

<table>
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<tr>
<th>Design Index</th>
<th>Treatment Level</th>
<th>Construction Costs</th>
<th>O &amp; M Costs</th>
</tr>
</thead>
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<tr>
<td></td>
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<td>k</td>
</tr>
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<td>1</td>
<td>1.2010</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1.5320</td>
</tr>
<tr>
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<td>0</td>
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<td>4</td>
<td>1.1880</td>
</tr>
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<td>4</td>
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<td>11</td>
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</tr>
<tr>
<td>12</td>
<td>-</td>
<td>-</td>
<td>0.1280d</td>
</tr>
</tbody>
</table>

aTotal cost, $y$, in mil $; quantity, $X$, in mgd.
bTrunk sewer construction cost, mil $/milc.$
cLift station overall O & M cost, excluding power costs.
dLift station construction costs.
eLift 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.

<table>
<thead>
<tr>
<th>Plant No.</th>
<th>Capacity (mgd)</th>
<th>Capital Debt (mil $)</th>
<th>Elevation (ft)</th>
<th>Treatment Level</th>
<th>Name of Treatment Plant (36 letter limit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.27</td>
<td>0.3064</td>
<td>4214</td>
<td>1</td>
<td>South Davis Co. S.I.D. South Plant</td>
</tr>
<tr>
<td>2</td>
<td>45.0</td>
<td>3.2259</td>
<td>4213</td>
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</tr>
<tr>
<td>3</td>
<td>4.55</td>
<td>0.5591</td>
<td>4230</td>
<td>1</td>
<td>South Salt Lake City</td>
</tr>
<tr>
<td>4</td>
<td>16.0</td>
<td>0.1138</td>
<td>4238</td>
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</tr>
<tr>
<td>5</td>
<td>7.3</td>
<td>0.3715</td>
<td>4250</td>
<td>1</td>
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</tr>
<tr>
<td>6</td>
<td>8.0</td>
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<td>4.0</td>
<td>0.0</td>
<td>4243</td>
<td>1</td>
<td>Murray City</td>
</tr>
<tr>
<td>8</td>
<td>3.6</td>
<td>0.0990</td>
<td>4277</td>
<td>1</td>
<td>Tri-Community (Midvale)</td>
</tr>
<tr>
<td>9</td>
<td>1.5</td>
<td>0.3111</td>
<td>4300</td>
<td>1</td>
<td>Sandy City</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
<td>4236</td>
<td>0</td>
<td>New Regional Plant @ 900 W 3100 S</td>
</tr>
</tbody>
</table>

aEstimated using construction cost equations adjusted to year built, and applying straight line depreciation.
Table 22. Input data feasible connecting trunk sewers.

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<th>Capacity (mgd)</th>
<th>Debt (mil $)</th>
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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 listed 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.

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<th>Wastewater Treatment Plant Numbers</th>
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<tr>
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\(^a\) Assume a straight line projection between 1974 and 2024.

Average Flows of Wastewater Treatment Plants, mgd

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Figure 21. Lower Jordan River conceptual wastewater treatment alternatives.
Figure 21. Continued.
Figure 21. Continued.
Figure 21. Continued.
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.

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61
Table 25. Input data for the Salt Lake County wastewater treatment alternatives.

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62
Table 26. Wastewater treatment system costs for the Lower Jordan River Region.

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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.

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<sup>b</sup> Values used to select best treatment alternatives.

<sup>c</sup> Alternatives selected for further study.
Table 28. Optimal treatment sequences for the Lower Jordan River Region.

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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 30 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.

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<td>1984</td>
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<td>1985</td>
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<td>1986</td>
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<td>1988</td>
<td>14</td>
<td>25</td>
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<td>1989</td>
<td>15</td>
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<td>1990</td>
<td>16</td>
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<td>1991</td>
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<td>1992</td>
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<td>25</td>
<td>25</td>
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<td>1993</td>
<td>19</td>
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</tr>
<tr>
<td>1994</td>
<td>20</td>
<td>26</td>
<td>40</td>
<td>38</td>
<td>25</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Origin</th>
<th>Destination</th>
<th>Capacity, mgd</th>
<th>Treatment Level</th>
<th>Capital Debt, mil $</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J</td>
<td>K</td>
<td>Existing</td>
<td>Proposed</td>
<td>Existing</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>2</td>
<td>0.00</td>
<td>6.15</td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>2</td>
<td>45.00</td>
<td>188.34</td>
<td>1 2</td>
<td>3.2259</td>
</tr>
<tr>
<td>1975</td>
<td>3</td>
<td>0.00</td>
<td>196.79</td>
<td>0.0000</td>
<td>7.7467</td>
</tr>
<tr>
<td>1975</td>
<td>4</td>
<td>0.00</td>
<td>186.67</td>
<td>0.0000</td>
<td>1.5455</td>
</tr>
<tr>
<td>1975</td>
<td>5</td>
<td>0.00</td>
<td>46.34</td>
<td>0.0000</td>
<td>0.6675</td>
</tr>
<tr>
<td>1975</td>
<td>6</td>
<td>0.00</td>
<td>89.13</td>
<td>0.0000</td>
<td>1.3812</td>
</tr>
<tr>
<td>1975</td>
<td>7</td>
<td>0.00</td>
<td>59.83</td>
<td>0.0000</td>
<td>2.0628</td>
</tr>
<tr>
<td>1975</td>
<td>8</td>
<td>0.00</td>
<td>41.68</td>
<td>0.0000</td>
<td>2.0537</td>
</tr>
<tr>
<td>1975</td>
<td>9</td>
<td>0.00</td>
<td>6.57</td>
<td>0.0000</td>
<td>0.7091</td>
</tr>
<tr>
<td>1975</td>
<td>10</td>
<td>0.00</td>
<td>188.34</td>
<td>2 3.2259</td>
<td>94.2024</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Origin</th>
<th>Destination</th>
<th>Capacity, mgd</th>
<th>Treatment Level</th>
<th>Capital Debt, mil $</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J</td>
<td>K</td>
<td>Existing</td>
<td>Proposed</td>
<td>Existing</td>
</tr>
<tr>
<td>1975</td>
<td>2</td>
<td>45.00</td>
<td>184.21</td>
<td>1 2</td>
<td>3.2259</td>
</tr>
<tr>
<td>1975</td>
<td>3</td>
<td>0.00</td>
<td>196.79</td>
<td>0.0000</td>
<td>7.7467</td>
</tr>
<tr>
<td>1975</td>
<td>4</td>
<td>0.00</td>
<td>186.67</td>
<td>0.0000</td>
<td>1.5455</td>
</tr>
<tr>
<td>1975</td>
<td>5</td>
<td>0.00</td>
<td>46.34</td>
<td>0.0000</td>
<td>0.6675</td>
</tr>
<tr>
<td>1975</td>
<td>6</td>
<td>0.00</td>
<td>89.13</td>
<td>0.0000</td>
<td>1.3812</td>
</tr>
<tr>
<td>1975</td>
<td>7</td>
<td>0.00</td>
<td>59.83</td>
<td>0.0000</td>
<td>2.0628</td>
</tr>
<tr>
<td>1975</td>
<td>8</td>
<td>0.00</td>
<td>41.68</td>
<td>0.0000</td>
<td>2.0537</td>
</tr>
<tr>
<td>1975</td>
<td>9</td>
<td>0.00</td>
<td>6.57</td>
<td>0.0000</td>
<td>0.7091</td>
</tr>
<tr>
<td>1975</td>
<td>10</td>
<td>0.00</td>
<td>184.21</td>
<td>2 3.2259</td>
<td>94.2024</td>
</tr>
</tbody>
</table>

66
Table 32. Sensitivity analysis of model.a

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

aUsing alternative No. 8.
bProjected 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.

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

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

<table>
<thead>
<tr>
<th>Alternative No.</th>
<th>With Inflationb</th>
<th>Without Inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 yr Annual Costs</td>
<td>20 yr Present Worths</td>
</tr>
<tr>
<td></td>
<td>Total (mil $)</td>
<td>Average (mil $)</td>
</tr>
<tr>
<td>EFFLUENT LEVEL 2c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>141.88</td>
<td>7.09</td>
</tr>
<tr>
<td>42</td>
<td>143.51</td>
<td>7.18</td>
</tr>
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<td>43</td>
<td>158.09</td>
<td>7.90</td>
</tr>
<tr>
<td>44</td>
<td>152.09</td>
<td>7.60</td>
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<td>7.52</td>
</tr>
<tr>
<td>46</td>
<td>147.70</td>
<td>7.38</td>
</tr>
<tr>
<td>47</td>
<td>167.10</td>
<td>8.35</td>
</tr>
<tr>
<td>EFFLUENT LEVELS 2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>170.19</td>
<td>8.51</td>
</tr>
<tr>
<td>42</td>
<td>180.27</td>
<td>9.01</td>
</tr>
<tr>
<td>43</td>
<td>205.05</td>
<td>10.25</td>
</tr>
<tr>
<td>44</td>
<td>194.28</td>
<td>9.71</td>
</tr>
<tr>
<td>45</td>
<td>192.08</td>
<td>9.60</td>
</tr>
<tr>
<td>46</td>
<td>188.16</td>
<td>9.41</td>
</tr>
<tr>
<td>47</td>
<td>225.46</td>
<td>11.27</td>
</tr>
<tr>
<td>EFFLUENT LEVELS 2.3,4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>203.49</td>
<td>10.17</td>
</tr>
<tr>
<td>42</td>
<td>221.47</td>
<td>11.07</td>
</tr>
<tr>
<td>43</td>
<td>255.54</td>
<td>12.78</td>
</tr>
<tr>
<td>44</td>
<td>240.40</td>
<td>12.02</td>
</tr>
<tr>
<td>45</td>
<td>237.71</td>
<td>11.89</td>
</tr>
<tr>
<td>46</td>
<td>232.72</td>
<td>11.64</td>
</tr>
<tr>
<td>47</td>
<td>287.81</td>
<td>14.39</td>
</tr>
</tbody>
</table>

aSalt Lake County Plants, no existing plant debt.  
bAnnual increases of cost indexes, interest rate constant.  
cMinimum cost alternative.

REFERENCES


Utah State Division of Health. 1971. Summary of class "C" water quality requirements. Salt Lake City, Utah.


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.

EDIT. 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.

LIST. 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.

<table>
<thead>
<tr>
<th>Heading</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNUAL</td>
<td>Annual repayment of previous years capital debt, mil $.</td>
</tr>
<tr>
<td>BACK</td>
<td>Alternative in previous year that provided the minimum total present worth cost to provide alternative M this year.</td>
</tr>
<tr>
<td>CAPAC</td>
<td>Capacity of treatment plant or trunk sewer, mgd.</td>
</tr>
<tr>
<td>CAP LIMIT</td>
<td>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.</td>
</tr>
<tr>
<td>DEBT</td>
<td>Existing capital debt of the facility, mil $.</td>
</tr>
<tr>
<td>DEMAND</td>
<td>Annual increase in the quantity of wastewater, mgd.</td>
</tr>
<tr>
<td>DESIGN</td>
<td>Design capacity of the facility, mgd.</td>
</tr>
<tr>
<td>DESIGN INDEX</td>
<td>Indicates which cost coefficients were used to calculate construction and O &amp; M costs of treatment plants.</td>
</tr>
<tr>
<td>EXISTING</td>
<td>Existing capacity of the facility, mgd.</td>
</tr>
<tr>
<td>EXPANSION</td>
<td>Construction cost of proposed expansion, mil $.</td>
</tr>
<tr>
<td>FLOW</td>
<td>Quantity of wastewater treated by treatment plant or transported by trunk sewer in year L, mgd.</td>
</tr>
<tr>
<td>FLOWL</td>
<td>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.</td>
</tr>
<tr>
<td>J</td>
<td>Wastewater treatment plant number.</td>
</tr>
<tr>
<td>K</td>
<td>Destination of trunk sewer from plant J to plant K.</td>
</tr>
<tr>
<td>L</td>
<td>Index of year with L = 1 for the initial year of study.</td>
</tr>
<tr>
<td>LIFT STATIONS</td>
<td>Number of lift stations required by trunk sewer.</td>
</tr>
<tr>
<td>M</td>
<td>Alternative treatment system be considered.</td>
</tr>
<tr>
<td>MB</td>
<td>Alternative in previous year that provided the minimum total present worth cost to provide alternative M this year.</td>
</tr>
<tr>
<td>O &amp; M</td>
<td>Annual operation and maintenance costs, mil $.</td>
</tr>
<tr>
<td>OPTVAL</td>
<td>Cumulative total present worth going from the initial year to the present year.</td>
</tr>
<tr>
<td>TOTAL</td>
<td>Total capital debt equals existing capital debt minus annual repayment plus cost of expansion, mil $.</td>
</tr>
<tr>
<td>TSTAR</td>
<td>Design period of facility, yr.</td>
</tr>
<tr>
<td>VALUE</td>
<td>Present worth value of alternative M in year L, mil $.</td>
</tr>
</tbody>
</table>

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 $y = kX^2$. 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
**Figure 26. Edit data listing.**

**List data - run 3**

**Optimum Alternatives**

<table>
<thead>
<tr>
<th>L</th>
<th>M</th>
<th>H</th>
<th>J</th>
<th>K</th>
<th>Cap</th>
<th>Flow</th>
<th>Slope</th>
<th>Demand</th>
<th>Total</th>
<th>Cost</th>
<th>Total</th>
<th>Value</th>
<th>Initial</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2.27</td>
<td>0.306</td>
<td>0.0267</td>
<td>0.0000</td>
<td>0.0279</td>
<td>2.27</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4.59</td>
<td>0.000</td>
<td>0.0000</td>
<td>0.0539</td>
<td>0.539</td>
<td>0.000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>108.34</td>
<td>3.2259</td>
<td>0.2812</td>
<td>96.2314</td>
<td>94.1760</td>
<td>108.34</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4.55</td>
<td>0.0467</td>
<td>0.0000</td>
<td>0.5104</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>194.79</td>
<td>0.0000</td>
<td>0.0000</td>
<td>7.7467</td>
<td>7.7467</td>
<td>194.79</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>16.00</td>
<td>0.1138</td>
<td>0.0000</td>
<td>0.0109</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

**Figure 27. List data.**

Alternatives. AK and ALPHA represent k and a 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 \( H^2 \), where H is the pumping head. BK(12) is presented as k x 1000, 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 for the general operation and maintenance costs of a lift station feeding the gravity trunk sewer. The values for pumping head and slope are calculated for the general operation and maintenance costs of a lift station feeding the gravity trunk sewer.
Figure 28. Present worth values for each alternative.

```
PESENT WORTH VALUES USED TO SELECT OPTIMUM PATH - RUN

<table>
<thead>
<tr>
<th>L</th>
<th>M</th>
<th>BACK</th>
<th>VALUE</th>
<th>OPTVAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>5</td>
<td>2.6329</td>
<td>2.6329</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>1.4657</td>
<td>1.4657</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>5</td>
<td>2.9211</td>
<td>2.9211</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>5</td>
<td>3.0550</td>
<td>3.0550</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
<td>11.6497</td>
<td>14.2826</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>6</td>
<td>12.1783</td>
<td>13.6440</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>9</td>
<td>12.4591</td>
<td>15.3602</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>20</td>
<td>11.3754</td>
<td>14.9305</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
<td>10.5348</td>
<td>24.8174</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>6</td>
<td>14.7065</td>
<td>26.6570</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>9</td>
<td>11.2768</td>
<td>26.5702</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>20</td>
<td>11.2842</td>
<td>25.7147</td>
</tr>
</tbody>
</table>
```

Figure 29. Ranking of final alternatives.

```
RANKING OF FINAL ALTERNATIVES - RUN

<table>
<thead>
<tr>
<th>SEQUENCE</th>
<th>ALTERNATIVE</th>
<th>OPTVAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>96.7633</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>98.1765</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>99.3225</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>99.3637</td>
</tr>
</tbody>
</table>
```

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, L; the origin, M; and the destination, K, on the data card. If a treatment plant is treating its own wastewater, the destination, K, is set equal to the origin, M. 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

<table>
<thead>
<tr>
<th>YEAR</th>
<th>L</th>
<th>M</th>
<th>VALUE MIL $</th>
<th>OPTIMAL MIL $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>1</td>
<td>5</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>1975</td>
<td>2</td>
<td>5</td>
<td>2.6329</td>
<td>2.6329</td>
</tr>
<tr>
<td>1976</td>
<td>3</td>
<td>5</td>
<td>11.6497</td>
<td>14.8174</td>
</tr>
<tr>
<td>1977</td>
<td>4</td>
<td>5</td>
<td>10.5346</td>
<td>10.5346</td>
</tr>
<tr>
<td>1978</td>
<td>5</td>
<td>5</td>
<td>9.5343</td>
<td>34.3517</td>
</tr>
<tr>
<td>1979</td>
<td>6</td>
<td>5</td>
<td>13.4845</td>
<td>47.8001</td>
</tr>
<tr>
<td>1980</td>
<td>7</td>
<td>5</td>
<td>12.2672</td>
<td>60.0567</td>
</tr>
<tr>
<td>1981</td>
<td>8</td>
<td>5</td>
<td>11.1835</td>
<td>71.2402</td>
</tr>
<tr>
<td>1982</td>
<td>9</td>
<td>5</td>
<td>10.2419</td>
<td>81.4571</td>
</tr>
<tr>
<td>1983</td>
<td>10</td>
<td>5</td>
<td>9.4574</td>
<td>90.6031</td>
</tr>
<tr>
<td>1984</td>
<td>11</td>
<td>6</td>
<td>5.9802</td>
<td>98.7633</td>
</tr>
</tbody>
</table>

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

SUMMARY OF ANNUAL COSTS - RUN 3 - 1

<table>
<thead>
<tr>
<th>TEAM</th>
<th>ALTERNATIVE</th>
<th>CAPITAL TOTAL MIL $</th>
<th>DEBT ANNUAL MIL $</th>
<th>O &amp; M ANNUAL MIL $</th>
<th>TOTAL ANNUAL MIL $</th>
<th>P.W. TOTAL ANNUAL MIL $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>5</td>
<td>4.0726</td>
<td>0.4656</td>
<td>2.3468</td>
<td>2.8122</td>
<td>2.6509</td>
</tr>
<tr>
<td>1978</td>
<td>5</td>
<td>90.2255</td>
<td>8.6398</td>
<td>3.7044</td>
<td>12.3442</td>
<td>9.6551</td>
</tr>
<tr>
<td>1979</td>
<td>5</td>
<td>112.5923</td>
<td>11.0829</td>
<td>7.4261</td>
<td>18.5090</td>
<td>13.5551</td>
</tr>
<tr>
<td>1980</td>
<td>5</td>
<td>100.6114</td>
<td>10.2269</td>
<td>7.8050</td>
<td>18.0319</td>
<td>12.3562</td>
</tr>
<tr>
<td>1982</td>
<td>5</td>
<td>84.3172</td>
<td>8.6715</td>
<td>5.9078</td>
<td>14.5793</td>
<td>10.2981</td>
</tr>
<tr>
<td>1983</td>
<td>5</td>
<td>76.2893</td>
<td>7.9679</td>
<td>5.9936</td>
<td>13.9614</td>
<td>9.4192</td>
</tr>
<tr>
<td>1984</td>
<td>6</td>
<td>69.2354</td>
<td>7.3109</td>
<td>4.3761</td>
<td>11.6871</td>
<td>6.0321</td>
</tr>
</tbody>
</table>

Figure 31. Summary of annual costs.

QUALITY - CAPACITY EXPANSION PROJECTS - RUN 3 - 1

<table>
<thead>
<tr>
<th>TEAM</th>
<th>UNISON</th>
<th>DESTINATION</th>
<th>CAPACITY</th>
<th>EXISTING</th>
<th>PROPOSED</th>
<th>TREATMENT LEVEL</th>
<th>EXISTING</th>
<th>PROPOSED</th>
<th>EXPANSION</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>1</td>
<td>2</td>
<td>0.60</td>
<td>0.15</td>
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<td>2</td>
<td>0.0500</td>
<td>1.0750</td>
<td>1.0750</td>
<td>1.0750</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>3</td>
<td>4.00</td>
<td>10.34</td>
<td>1</td>
<td>2</td>
<td>0.2859</td>
<td>9.7314</td>
<td>9.7314</td>
<td>9.7314</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>4</td>
<td>0.00</td>
<td>18.68</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>5</td>
<td>0.00</td>
<td>18.68</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>6</td>
<td>0.00</td>
<td>18.68</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>7</td>
<td>0.00</td>
<td>18.68</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
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<td>18.34</td>
<td>2</td>
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<td>69.3133</td>
<td>73.5948</td>
<td>15.2900</td>
<td>15.2900</td>
</tr>
<tr>
<td>1976</td>
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<td>9</td>
<td>10.00</td>
<td>11.41</td>
<td>2</td>
<td>4</td>
<td>69.3133</td>
<td>73.5948</td>
<td>15.2900</td>
<td>15.2900</td>
</tr>
<tr>
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<td>1</td>
<td>10</td>
<td>0.00</td>
<td>15.76</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
<td>1976</td>
<td>1</td>
<td>11</td>
<td>0.00</td>
<td>15.76</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
<tr>
<td>1976</td>
<td>1</td>
<td>12</td>
<td>0.00</td>
<td>15.76</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0500</td>
<td>1.6553</td>
<td>1.6553</td>
<td>1.6553</td>
</tr>
</tbody>
</table>

Figure 32. Quality-capacity expansion projects.
Table 36. Listing of input card parameters.

<table>
<thead>
<tr>
<th>Card Column</th>
<th>Name</th>
<th>Definition</th>
<th>Eq</th>
<th>Ref</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>IRUN</td>
<td>Run number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>NUMPLT</td>
<td>Number of existing and proposed treatment plants (max - 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-10</td>
<td>NUMYR</td>
<td>Number of planning years (max - 50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-18</td>
<td>NUMALT</td>
<td>Number of alternative plans (max - 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-28</td>
<td>NYEAR</td>
<td>Initial year of study</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33-34</td>
<td>IFLOW</td>
<td>Flow projection: 1 - wastewater, 0 - population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-42</td>
<td>ITSTAR</td>
<td>Design period: 1 - optimal, 0 - capital recovery period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>IEDIT</td>
<td>Number of years that edit data is printed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-10</td>
<td>ILIST</td>
<td>Number of years that list data is printed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-18</td>
<td>IPW</td>
<td>Number of years that present worth data is printed for optimum alternatives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-26</td>
<td>IRANK</td>
<td>Print ranking of alternatives at end of planning period: 1 - yes, 0 - no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33-34</td>
<td>NRANK</td>
<td>Number of alternatives for which annual present worths are to be printed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-42</td>
<td>NALTPR</td>
<td>Number of alternatives to be analysed in detail in terms of annual costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49-50</td>
<td>IPROJ</td>
<td>Print list of quality-capacity expansion projects: 1 - yes, 0 - no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57-58</td>
<td>IANUAL</td>
<td>Number of years that summary of optimum operations is printed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65-66</td>
<td>NONDYN</td>
<td>Bypass dynamic programming portion and suboptimize individual alternatives: 1 - yes, 0 - no</td>
<td></td>
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<td>PER (14)</td>
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<td>yr</td>
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<td>PERL</td>
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<td>PER (14)</td>
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<td>Opd/capita of wastewater flow</td>
<td>GPDCAP (16)</td>
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<td>Peak flow factor</td>
<td>f (16)</td>
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<td>SLOPEM</td>
<td>Minimum slope of gravity sewer</td>
<td>ft/1000 ft</td>
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<td>HEAD</td>
<td>Average pumping head of lift station</td>
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<td>ENR-B cost index for construction of treatment plants and lift stations in base year of cost data</td>
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<td>ENR-B cost index for initial year of study</td>
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<td>Annual increase in ENR-B index</td>
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<td>SINDA</td>
<td>WPC-S or EPA-S cost index for trunk sewers for the base year of cost data</td>
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Table 36. Continued.

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<td>Annual increase in WPC-S or EPA-S cost index</td>
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<td>Labor rates or other O &amp; M cost index for base year of cost data</td>
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<td></td>
<td>OMINDF</td>
<td>Annual increase in labor rates or other O &amp; M index</td>
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<td>AK(i)</td>
<td>Cost coefficient of capital costs: Treatment plants, i = 1, , 10: trunk sewers, i = 11: and lift station, i = 12</td>
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<td>ALPHA(i)</td>
<td>Economy of scale of capital costs: Treatment plants, i = 1, , 10: trunk sewers, i = 11: and lift stations, i = 12</td>
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<td>BK(i)</td>
<td>Cost coefficients of O &amp; 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)</td>
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<td>BALPHA(i)</td>
<td>Economy of scale of O &amp; M costs: Treatment plants, i = 1, , 10: lift station, i = 11: and lift station power, i = 12</td>
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<tr>
<td>7</td>
<td>1-2</td>
<td>j</td>
<td>Treatment plant number</td>
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<td>CAPP(j)</td>
<td>Capacity of treatment plant</td>
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<td>mgd</td>
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<td></td>
<td>DEBTP(j)</td>
<td>Capital debt of treatment plant j</td>
<td></td>
<td></td>
<td>mil $</td>
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<td>25-32</td>
<td></td>
<td>ELEV(j)</td>
<td>Elevation of treatment plant j</td>
<td></td>
<td></td>
<td>ft</td>
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<td>LTREAT(j)</td>
<td>Level of treatment at plant j</td>
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<td>BNAME(j, i)</td>
<td>Name of treatment plant j</td>
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<tr>
<td>8</td>
<td>1-2</td>
<td>j</td>
<td>Origin of trunk sewer, plant j</td>
<td></td>
<td></td>
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<tr>
<td>9-10</td>
<td></td>
<td>k</td>
<td>Destination of trunk sewer, plant k</td>
<td></td>
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<tr>
<td>17-24</td>
<td></td>
<td>DIST(j, k)</td>
<td>Length of trunk sewer</td>
<td></td>
<td></td>
<td>ft</td>
</tr>
<tr>
<td>25-32</td>
<td></td>
<td>CAPS(j, k)</td>
<td>Capacity of trunk sewer</td>
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<td></td>
<td>mgd</td>
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<td>33-40</td>
<td></td>
<td>DEBTS(j, k)</td>
<td>Debt of trunk sewer</td>
<td></td>
<td></td>
<td>mil $</td>
</tr>
<tr>
<td>9</td>
<td>1-2</td>
<td>j</td>
<td>Number of treatment plant j</td>
<td></td>
<td></td>
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<tr>
<td>9-10</td>
<td></td>
<td>n</td>
<td>Year of population data. Use '0' for initial year of study, and '1' for next year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-28</td>
<td></td>
<td>POP(j, n)</td>
<td>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</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>1-2</td>
<td>n</td>
<td>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</td>
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Table 36. Continued.

<table>
<thead>
<tr>
<th>Card</th>
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<th>Ref</th>
<th>Units</th>
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<tr>
<td>9-10</td>
<td>LQUAL(n)</td>
<td>Treatment level required for effluent standard</td>
<td>LQUAL</td>
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<tr>
<td>11</td>
<td>$n$</td>
<td>Time period</td>
<td>$n$</td>
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<tr>
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<td>$j$</td>
<td>Treatment plant number</td>
<td>$j$</td>
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<tr>
<td>17-18</td>
<td>LQUAL(Jin, j)</td>
<td>Treatment level required for plant $j$ in period $n$</td>
<td>LQUAL</td>
<td>17</td>
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<tr>
<td>12</td>
<td>$m$</td>
<td>Alternative paths from plant $j$ to plant $k$ for alternative $m$. Set $j$ if treatment plant is being used</td>
<td>IPATH</td>
<td>18</td>
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<td>MTREAT(j,m)</td>
<td>Treatment level required by alternative $m$ for plant $j$</td>
<td>MTREAT</td>
<td>23</td>
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<td></td>
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<td>33-40</td>
<td>CAPMAX(j,m)</td>
<td>Maximum allowable flow from plant $j$. If this limit is exceeded, the CAP LIMIT index will be set equal to $m$, and a value of $10^9$ is added to the present worth in the dynamic programming portion</td>
<td>mgd</td>
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Figure 33. Summary of optimum operations.
Figure 34. Control parameters.

Table 37. Design index selection of treatment alternatives.

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<td>1</td>
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<td>4</td>
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Figure 35. Output listing of cost equation coefficients.

Figure 36. Output listing of wastewater treatment plant data.
### Trunk Sewer Input Data and Calculated Parameters - Run 3

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<th>FROM</th>
<th>TO</th>
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<th>DEBT</th>
<th>MEAD</th>
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<tr>
<td>J</td>
<td>K</td>
<td>FT</td>
<td>MGD</td>
<td>FT/1000 FT</td>
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Figure 37. Output listing of trunk sewer data.

### Annual Cost Factors - Run 3

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<th>INTEREST RATE</th>
<th>CHF STP</th>
<th>CHF SEWER</th>
<th>CHF LIFT STATION</th>
<th>BUILDING COST FACTOR</th>
<th>SENAER COST FACTOR</th>
<th>N &amp; M COST FACTOR</th>
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<td>0.0866</td>
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</table>

Figure 38. Output listing of annual cost factors.
Figure 39. Output listing of population data.

Figure 40. Wastewater quantities and time-phased treatment levels.
### Figure 41. Individual plant time-phased treatment levels.

#### INHA ALTERNATIVE PATH TABLE - RUN 3

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<tr>
<th>ALT PLANT TREATMENT</th>
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<td>6</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>0.00</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Figure 42. Alternative trunk sewer path table.
Figure 43. Pictorial layout of input cards.
Appendix B

Generalized Model Flow Chart

Start

Enter Model Control Parameters

Enter Cost Equation Parameters

Enter Parameters for Treatment Plants

Enter Parameters for Trunk Sewers

Calculate Slope of Trunk Sewers

Calculate Annual Cost Factors

Enter Population or Wastewater Data

Enter Time Phased Treatment Levels

Calculate Quantity of Wastewater Flow

Output Base Flows to Treatment Plants

Enter Connecting Trunk Sewer Links for Each Alternative

Build and Load Path Tables for Each Alternative

Output Path Tables for Each Alternative

Bypass Dynamic Programming Section?

Initialize System Parameters

Optimize All Plants and Sewers for Each Year L

Analyze Each Alternative M

Calculate Wastewater Loads at L, L + LAG, and L + 20

Output Flows Collected

Select Best Back Path

Analyze Each Plant J

Calculate Quantity of Wastewater Treated by Plants

Calculate Annual Increase in Demand Over 20 Years

Initialize Plant Parameters

Is Quantity Treated Less Than Minimum?

Yes

Set Check

No

Determine Design Index

A

B

93
Determine Temporary Capacity for Trunk Sewers and Lift Stations

Yes

Does Capacity Meet Demand?

No

Calculate Cost for Gravity Trunk Sewer

Yes

Calculate Cost for Gravity Trunk Sewer and Lift Station

No

Calculate O & M Costs for Lift Stations

Yes

Calculate Annual Debt Repayment

No

Last Treatment Plant?

Yes

Select Optimum Back Route

K

No

Output Edit Data

C

Yes

Does Capacity Meet Demand?

No

Determine Optimum Design Period for Trunk Sewers

Determine Optimum Design Period for Lift Stations

C

Yes

Does Present Capacity & Treatment Level Meet Demand?

No

Calculate Optimum Design Period

Calculate Plant Design Capacity

Yes

Does Design Capacity Exceed Maximum?

No

Is There An Alternative Flow Path?

Yes

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

D

Determine Loads on The Trunk Sewers
Calculate all financials for each year.

Rede calculation and data for.

Output summary of present capacity.

Check for bank optimized value.

No: Yes.

Output list.

Yes: No.

Yes: No.

Yes: No.

Optimal data.

Yes: No.

Back path.

Yes: No.

Last path.

Optimize data.

Yes: No.

Calculate annual decrease in drawing over 20 years.

Calculate quantity at each face.

Analyze each path.

Calculate flows.

Yes: No.

Calculate annual decrease in waste output over 20 years.

Calculate quantity at each face.
Determine Temporary Capacity For Trunk Sewers and Lift Stations

Set Capacity Equal to Maximum
Set Check
Calculate Cost To Increase Capacity
Calculate Cost To Upgrade Plant
Calculate Annual Debt Repayment
Calculate O & M Cost of Plant
Calculate Present Worth of Annual Payments
Determine Loads on the Trunk Sewers

Yes
Does Capacity Meet Demand?
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?
Yes
Calculate Cost for Gravity Trunk Sewers
Calculate Cost for Gravity Trunk Sewer and Lift Station

No

Calculate O & M Costs for Lift Stations
Calculate Annual Debt Repayment
Calculate Present Worths Of Annual Payments
Retire Debt
Output List Data

No
Last Treatment Plant?
Yes

No
Last Year?
Yes
Output Summary Of Annual Costs
Output List of Quality - Capacity Expansion Projects

No
Last Optimum Path To Be Analyzed?
Yes
End

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Appendix C
Program Listing

******************************************************
WASTEWATER TREATMENT OPTIMIZATION MODEL - WTM
BURKHARDS 6/00 - FORTHAN IV
UTAH STATE UNIVERSITY

******************************************************
FILE S=WASTEIN
FILE G=WASTEOUT

DIMENSION AK(12), ALPHA(12), BK(12), HALPHA(12)
DIMENSION IMLT(99), JMLT(11)
DIMENSION CAPP(10), DEBT(10), ELEV(10), LTREAT(10)
DIMENSION ANAME(10,9), BNAME(9)
DIMENSION D1IST(10,11), CAPS(10,11), DEBT(10,11), SHEAV(10,11),
1 SLUPE(10,11)
DIMENSION KRETURN(51), CRFP(51), CHFS(51), CHFL(51)
DIMENSION FACCAP(51), FACSEM(51), FACDM(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(10,10,11)
DIMENSION TCPP(10,2,10), TUEBTP(10,2,10)
DIMENSION TCPP(10,11,2,10), TOEBTP(10,11,2,10)
DIMENSION ACPP(10), ADRT(10), ADEBT(10), FDEBT(10), LTTRT(10)
DIMENSION CUEBTP(10), AOMP(10), MBACK(51,10)
DIMENSION AOMS(11)
DIMENSION ACAPS(10,11), ADEBT(10,11), FDEBT(10,11)
DIMENSION NUMLS(10,11)
DIMENSION BOMS(11), COEBTP(10), BDEBT(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 TKRT(100), NUMLS(100)
DIMENSION TOTCAP(51), TAN(51), TOM(51)
DIMENSION ANP(10), OMP(10), OMS(10,11), ANS(10,11)
DIMENSION DUEBT(10,10), DEBT(10,10)
DIMENSION LQUAL(10,71), LCHECK(10,10,10)
DIMENSION CAPMIN(10,10), CAPMAK(10,10)
DIMENSION COLECT(10), COLLAG(10), FUTURE(10)
DIMENSION IALT(10,10)
DIMENSION LCHECK(10)
DIMENSION TUP(71), ECAPS(11), KTREAT(10,2,10)
EQUIVALENCE (IPATH,IOUT)
EQUIVALENCE (POP,QUANT)
DATA ASPACE/' /
1 FFORMAT (12)
2 FFORMAT ('ICONTROL PARAMETERS - RUN', 14// 64X, 'CARD', 4X, 'COL'//)
3 FFORMAT (3(12, 6X), 14, 4X, 2(12, 6X))
2')   172 FORMAT (' ', ---,---',---', ---',---', ---', ---',---', ---', ---', ---',---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---', ---'
Determine Annual Factors

```fortran
C DETERMINE ANNUAL FACTORS

C WRITE (6,35) IRUN
C WRITE (6,36)
C WRITE (6,37)
RETURN(1) = RATE
Dx 210 L = 1, NUMYK + 1
IF(L.EQ.1) GO TO 209
RETURN(L) = RETURN(1) + ANRATE = (L*1)
C CONTINUE
209 RETURN(L) = RETURN(1) + ANRATE = (L*1)
C CONTINUE
C CRPFL(L) = (RETURN(L) * ( 1.0 + RETURN(L)) ** PERP) / 
1.0 + RETURN(L) ** PERP = 1.0
C CRFS(L) = (RETURN(L) * (1.0 + RETURN(L)) ** PERS) / 
1.0 + RETURN(L) ** PERS = 1.0
C CRFL(L) = (RETURN(L) * ( 1.0 + RETURN(L)) ** PERL) / 
1.0 + RETURN(L) ** PERL = 1.0
C CRCS(L) = (PINUB * PINUF * (L-1) ) / PINDA
C FACSEW(L) = (SINUB + SINUF * (L-1) ) / SINDA
C FACUM(L) = (DMINUB + DMINUF * (L-1) ) / OMINDA
CYEAR = L + NYEAR - 1
C WRITE (6,38) IYEAR, RETURN(L), CRPFL(L), CRFS(L), CRFL(L), 
1 FACCAP(L), FACSEW(L), FACUM(L)
C 210 CONTINUE
C ENTER POPULATION DATA
C ENTER WASTEWATER QUANTITIES INSTEAD IF IP = 1
C
Du 219 K = 1,999
KLAU (5,45) J, N, POPUL
IF(J.EQ.99) GO TO 220
IF(N.GT.50) GO TO 215
IF(J.NE.LL) GO TO 215
L = N + 1
I = IPLT(J)
IF(I.EQ.0) GO TO 215
IF(I.GT.NUMPLT) GO TO 215
PUP(I*L) = POPUL
LASTYK = N
Dx TO 219
```

102
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
   DU 225 J = 1 NUMPLT
   IF(POP(J,N),EQ.0,0) GO TO 225
   DU 224 L = 1 ISPACE
   DU 223 N = N+1, 71
   IF(POP(J,N),EQ.0,0) GO TO 223
   ITIM = N+L
   PUPQNT = (POP(J,N) - POP(J,L))/ITIM
   DU 222 NUM = 1 ITIM = 1
   PUP(J,L+1) = POP(J,L) + PUPQNT
   L = L + 1
222 CONTINUE
   DU IU 224
223 CONTINUE
224 CONTINUE
225 CONTINUE
   IF(LASTYR,LE,0) LASTYR = NUMYR
   DU 228 J = 1 NUMPLT
   IF(PUP(J,LASTYR+1),EQ.0,0) GO TO 228
   PUPQNR = PUP(J,LASTYR+1) - PUP(J,LASTYR)
   DU 227 L = LASTYR+2 LASTYR+21
   PUP(J,L) = POP(J,L-1) + PUPQNT
227 CONTINUE
228 CONTINUE

C LIST POPULATION INPUT DATA
C DU NOT LIST IF WASTEWATER QUANTITIES ARE ENTERED INSTEAD OF POPULATIONS
C
230 CONTINUE
   DU (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)
   DU 230 L = 1 NUMYR + 21
   IFER = L - 1
   IYEAR = NUMYR + L - 1
   WRITE(6,48) IFER, IYEAR, NUMPLT, (POP(J,L), J = 1,NUMPLT)
230 CONTINUE
C TIME PHASED TREATMENT LEVELS
C
234 CONTINUE
   DU 235 L = 100
   RLAD (5,55) N, LQ
   IF(N,EQ.99) GO TO 236
   IF(N,EQ.50) GO TO 234
   IF(LQ,EQ.0) GO TO 234
   IF(LQ,EQ.0) GO TO 234
   L = N + 1
   LQUAL(L) = LQ
   GO TO 235
234 WRITE (6,56) N, LQ
235 CONTINUE
236 CONTINUE
   DU 240 L = 2 NUMYR + 21
   LQUAL(L),EQ.0) LQUAL(L) = LQUAL(L-1)
240 CONTINUE
C CALCULATE FLOWS FROM POPULATION DATA
C IF(IPOP.GE.1) GO TO 246
DU 246 J = 1,NUMPLT
DU 246 L = 1,NUMYR + 21
QUANT(J,L) = POP(J,L) * GPOCAP * PEAK / 1000000.0
244 CONTINUE
246 CONTINUE
244 GO TO 249
C CALCULATE FLOWS FROM WASTEWATER QUANTITIES
C DU 248 J = 1,NUMPLT
DU 248 L = 1,NUMYR + 21
QUANT(J,L) = POP(J,L) * PEAK
247 CONTINUE
248 CONTINUE
249 CONTINUE
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)
DU 250 L = 1,NUMYR + 21
IPEK = L + 1
IYEAR = NYEAR + L - 1
WRITE (6,63) IPER, IYEAR, LQUAL(L), NUMPLT, (QUANT(J,L), J = 1,1,NUMPLT)
IF(LQE,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 ENTER TIME PHASED TREATMENT LEVELS FOR EACH PLANT AS NEEDED
C DU 252 J = 1,NUMPLT
DU 251 L = 1,NUMYR + 21
LQUAL(J,L) = 1
251 CONTINUE
252 CONTINUE
DU 254 K = 1,999
READ (5,64) N, J, LQ
IF(N.EQ.999) 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
IF(LQ.GT.4) GO TO 253
L = N + 1
I = JPLT(J)
IF(I.LT.0) GO TO 253
IF(I.GT.NUMPLT) GO TO 253
LQUAL(I,L) = LQ
GO TO 254
253 WRITE (6,65) N,J,LQ
254 CONTINUE
255 CONTINUE
UU 257 I = 1, NUMPLT
DU 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
WHITE (6,66) IRUN
ISPACE = 4 * NUMPLT = 4
WHITE (6,67) ISPACE (ASPACE* I = 1* ISPACE)
WHITE (6,68) NUMPLT, (JPLT(I), I = 1*NUMPLT)
UU 258 L = 1, NUMYR + 21
IPER = L = 1
ITEAR = NYEAR + L = 1
WHITE (6,69) IPER, ITEAR* NUMPLT* (LQUALJ(I,L) * = 1*NUMPLT)
258 CONTINUE
C
C ENTER ALTERNATIVE CONNECTING TRUNK SEWER LINKS
C
DU 263 M = 1, NUMALT
259 RLAU (5,70) MA, J, K, LT, AMIN, AMAX
IF (AMAX LE 0.0) AMAX = 999.99
IF (MA EQ 0) 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
I = IPLT(J)
IF (J,EQ 0) GO TO 261
IF (J,GT NUMPLT) GO TO 261
I = IPLT(K)
IF (J, EQ 0) IK = NUMPLT + 1
IF (IK, EQ 0) GO TO 261
IF (IK, GT NUMPLT + 1) GO TO 261
NALT(M) = MA
IF (IPATH(I,J,NUMPLT+1,M) EQ 1) GO TO 260
HTREAT(I,J,M) = LT
CAPMIN(I,J,M) = AMIN
CAPMAX(I,J,M) = AMAX
260 CONTINUE
IF (IPATH(I,J,IK,M) = 1
GO TO 262
261 WHITE (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
IUUT(J,K,M) = OUTPUT TABLE (COMMON WITH IPATH(J,K,M)
C
DU 264 M = 1, NUMALT
265 J = 1, NUMPLT
266 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
LUAA INPUT TABLE WITH ALTERNATIVE DEMANDS

GU 280 M = 1*NUMALT
GU 279 L = 1*5
GU 278 J = 1*NUMPLT
IN(CAPMAX(J,M),LE,0,0) CAPMAX(J,M) = 999.99
GU 272 K = 1*NUMPLT

FOR PLANT J FIND OUTPUT ROUTE, K NOT EQUAL J

IF(K.LE.J) GO TO 272
IF(INOUT(J,K,M) ,EQ. 1) GU TO 274

272 CONTINUE

NU CHANGE FOR THIS J

GU TO 278

N = DESTINATION OF WASTE LOADS

274 N = K
IF(INOUT(J,NUMPLT+1,M),NE.1) GO TO 275
IAIT(J,M) = N
LUUT(J,K,M) = 0
IN(J,K,M) = 0
GU TO 276

275 CONTINUE

SEARCH NODE J FOR NUMBER = 1 AND TRANSFER TO NODE N OF INPUT TABLE

GU 276 I = 1*NUMPLT
IF(I.EQ.K) GO TO 276
IF(IN(I,J,K,M),EQ.1) IN(I,N,M) = 1

276 CONTINUE

278 CONTINUE

279 CONTINUE

280 CONTINUE

OUTPUT TABLES

ISPACE = NUMPLT + 2 = 4
LSPACE = NUMPLT + 4 = 2
WHITE (6.75) IHUN
WHITE (6.76) ISPACE, (ASPACE, I = 1,ISPACE), LSPACE
1 (ASPACE, I = 1, LSPACE)
NUMOUT = NUMPLT + 1
JPLT(NUMOUT) = NUMPLT + 1
WHITE (6.77) NUMPLT, (JPLT(I), I=1,NUMPLT), NUMOUT, (JPLT(I),
1 I = 1,NUMOUT)
GU 290 M = 1*NUMALT
GU 286 IJ = 1, NUMPLT
IN = IALT(I,J,M)
IF(IK.LE.0) GO TO 284
IF(IK.GT,NUMPLT) GU TO 284
WHITE (6.80) NALT(M), JPLT(IJ), MTREAT(IJ,M), CAPMIN(IJ,M),
1 CAPMAX(IJ,M), JPLT(K), NUMPLT, (IN(I,J,M), I = 1, NUMPLT),
2 NUMOUT, (IOUT(I,J,K,M) K = 1, NUMOUT)
GU TO 286

284 WHITE (6.82) NALT(M), JPLT(IJ), MTREAT(IJ,M), CAPMIN(IJ,M),
1 CAPMAX(IJ,M),
NUMPLT, (IN(I,J,M), I = 1, NUMPLT),
2 NUMOUT, (IUUT(IJ, K, M), K = 1, NUMOUT)
286 CONTINUE
\*I $= 90$
290 CONTINUE
C
PASSED DYNAMIC PROGRAMMING SECTION OF MODEL
C
IF (NUMDYNE.1) GO TO 500
C
INITIALIZE SYSTEM PARAMETERS
C
DU 306 M = 1,NUMALT
MDACK(2,M) = 1
VALUE(I,M) = 0.0
OPTVAL(I,M) = 0.0
DU 304 J = 1,NUMPLT
ICAPP(J,1,M) = CAPP(J)
TWETP(J,1,M) = DEBTP(J)
KTHEAT(J,1,M) = LiTHEAT(J)
DU 302 K = 1,NUMPLT + 1
TWAPS(J,K,1,M) = CAPS(J,K)
TWETS(J,K,1,M) = DEHTS(J,K)
302 CONTINUE
304 CONTINUE
306 CONTINUE
C
OPTIMIZE ALL PLANTS AND INTERCEPTORS FOR EACH YEAR L
C
AUVAL = 1000.0
DU 440 L = 2,NUMYR + 1
DU 400 M = 1,NUMALT
TEMPA = 999999999999.
C
DETERMINE LOAD ON PLANTS AT L, L + LAG, AND L + 20
C
DU 307 J = 1,NUMPLT
CULECT(J) = 0.0
CLLAG(J) = 0.0
FUTURE(J) = 0.0
307 CONTINUE
DU 309 J = 1,NUMPLT
DU 308 I = 1,NUMPLT
CULECT(J) = CULECT(J) + QUANT(I,J,M) * IN(I,J,M)
CLLAG(J) = CLLAG(J) + QUANT(I,J+LAG) * IN(I,J,M)
FUTURE(J) = FUTURE(J) + QUANT(I,J+20) * IN(I,J,M)
308 CONTINUE
309 CONTINUE
C
ADD EXCESS FLOWS FROM PLANTS WITH MAXIMUMS CAPACITIES
C
DU 310 J = 1,NUMPLT
IF (IOUT(IJ,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
W = COLECT(J) = CAPMAX(J,M)
IF (W.LE.0.0) Q = 0.0
QW = CLLAG(J) = CAPMAX(J,M)
IF (QW.LE.0.0) QL = 0.0
QF = FUTURE(J) = CAPMAX(J,M)
IF (QF.LE.0.0) Q = 0.0
CULECT(K) = CULECT(K) + Q
COLLAG(K) = COLLAG(K) + QL
FUTURE(K) = FUTURE(K) + WF

310 CONTINUE

OUTPUT FLOWS COLLECTED AT TREATMENT PLANTS

IF(EDIT.LE.0) GO TO 312
WHITE (6,92) IRUN
ISPACE = 4 * NUMPLT = 4
WHITE (6,93) ISPACE, (ASPACE, I = 1, ISPACE)
WHITE (6,94) NUMPLT, (JPLT(I), I = 1,NUMPLT)
IPER = L = 1
IYEAR = NYEAR + L - 1
WHITE (6,95) IPER, IYEAR, NALT(M),NUMPLT,(CULECT(J),J=1,NUMPLT)
IP = IPER + LAG
IT = IYEAR + LAG
WHITE (6,95) IP, IT, NALT(M), NUMPLT, (COLLAG(J), J = 1, NUMPLT)
IP = IPER + 20
IT = IYEAR + 20
WHITE (6,95) IP, IT, NALT(M), NUMPLT, (FUTURE(J), J = 1,NUMPLT)

312 CONTINUE

IF(EDIT.LE.0) GO TO 313
WHITE (6,101) IRUN
WHITE (6,102)
WHITE (6,103)

313 CONTINUE

SELECT BEST BACK PATH

MBACK(L,M) = 1
DU 390 MB = 1,NUMALT
TVVALUE = 0.0

FIND COSTS AND CAPACITY FOR EACH TREATMENT PLANT

DU 380 J = 1,NUMPLT
TREAT = CULECT(J) + IDOUT(J,NUMPLT + 1,M)
TREATL = COLLAG(J) + IDOUT(J,NUMPLT + 1,M)
ICHECK(J,M,MH) = 0

DETERMINE ANNUAL DEMAND OVER 20 YEARS

DEMAND = (FUTURE(J) - CULECT(J)) / 20.0
ULMP = DEMAND * IDOUT(J,NUMPLT + 1,M)

INITIALIZE PARAMETERS

ALAPP(J) = TCAPP(J,1,MB)
AUEBTP(J) = TDEBTP(J,1,MB)
FUEBTP(J) = 0.0
LITMET(J) = KTREAT(J,1,MB)
INDEX = 0
ITREAT = MTREAT(J,MB)
IF(LQUAL(L+LAG,GT*MTREAT(J,MB)) ITREAT = LQUAL(L+LAG)
IF(LQUAL(J,L+LAG,GT*ITREAT) ITREAT = LQUAL(J,L+LAG)
TSTAR = 0.0
CUSTA = 0.0
CUSTB = 0.0

CHECK TREATMENT PLANTS FOR MINIMUM FLOWS
C
IF(TREATL.GE.CAPMIN(J,M)) GO TO 316
IF(ICHECK(J,M,MB).LE.1) GO TO 315
ICHECK(J,M,MB) = 1
TVALUE = TVALUE + AUVVAL
315 CONTINUE
GO TO 317
316 CONTINUE
IF(ICHECK(J,M,MB).NE.1) GO TO 317
ICHECK(J,M,MB) = 0
TVALUE = TVALUE + AUVVAL
317 CONTINUE
C
DETERMINE DESIGN INDEX
GO TO 316
IF(TREATL.LE.LTRET(J)) GO TO 323
GO TO (319, 320, 321) LTRET(J)
316 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
DUES PRESENT CAPACITY AND TREATMENT LEVEL OF PLANT MEET DEMAND?
IF(TREATL.LE.0.0) GO TO 336
IF(TREATL.LE.ACAPP(J), AND, ITREAT.LT.LTRET(J)) GO TO 336
C
DETERMINE OPTIMUM DESIGN PERIOD FOR TREATMENT PLANTS
TSTAR = PERP
IF(TSTAR.LE.0.0) GO TO 328
IF(INDEX.LE.0.0) GO TO 328
ITIME = 1.25
TSTAH = (ALUG(TSTAR * RETURN(L) / ALPHA(INDEX)) + 1.0)/RETURN(L)
327 CONTINUE
328 CONTINUE
IF(TREATL.LT.ACAPP(J)) GO TO 332
ACAPP(J) = TREATL + DEHP + TSTAR
C
CHECK TREATMENT PLANTS AGAINST MAXIMUM FLOWS
IF(ACAPP(J).LE.CAPMAX(J,M)) GO TO 330
ACAPP(J) = CAPMAX(J,M)
IF(CIALT(J,M).GE.1.0) GO TO 330
IF(ICHECK(J,M,MB).EQ.2) GO TO 329
ICHECK(J,M,MB) = 2
TVALUE = TVALUE + AUVVAL
329 CONTINUE
GO TO 331
330 CONTINUE
IF(ICHECK(J,M,MB).NE.2) GO TO 331
ICHECK(J,M,MB) = 0
TVALUE = TVALUE + AUVVAL
331 CONTINUE
C
C
109
C DETERMINE THE COST TO INCREASE CAPACITY OF PLANT
C
C CUSTA = 0.0
C IF(ACAPP(J),LE,TCAPP(J,1,MB)) GO TO 332
C IF(LTRET(J).LE,0.0) GO TO 332
C CUSTA *(AK(LTRET(J))* (ACAPP(J) - TCAPP(J,1,MB)) **
C 1 ALPHA(LTRET(J))* FACCAP(L)
C 332 CONTINUE
C C DETERMINE COST OF UPGRADE TREATMENT PLANT
C IF(LTRET(J).LE,LTRET(J)) GO TO 336
C IF(INDEX.EQ,0) GO TO 336
C CUSTA = (AK(INDEX) * (ACAPP(J)) ** ALPHA(INDEX))* FACCAP(L)
C LTRET(J) = LTRET(J)
C 336 CONTINUE
C C DETERMINE TEMPORARY FUTURE COST OF EXPANSION
C FUBTP(J) = COSTA + COSTS
C C DETERMINE AMOUNT OF ANNUAL CAPITAL PAYMENT ON LAST YEARS DEBT
C CUEBT(J) = ADEBTP(J) * CRFP(L-1)
C C CALCULATE O & M COSTS FOR TREATMENT PLANT
C AUMP(J) = 0.0
C IF(KTREAT(J,1,MB),LE,0) GO TO 338
C AUMP(J) = BK(KTREAT(J,1,MB)) * (TREAT ** BALPHA(KTREAT(J,1,MB)))
C 1 FACOM(L)
C 338 CONTINUE
C C DETERMINE THE TEMPORARY DISCOUNTED COSTS FOR DEBT AND O & M OF PLANT
C AVGRET = (RETURN(1) * RETURN(L)) / 2.0
C BUMP = COEBTP(J) / ((1.0 + AVGRET) ** (L-1))
C BUMP = AUMP(J) / ((1.0 + AVGRET) ** (L-1))
C TVALUE = TVALUE + BODEBTP + BOMP
C TOMP = (FDEBTP(J) * CRFP(L)) / ((1.0 + AVGRET) ** (L))
C TVALUE = TVALUE + TOMP
C C DETERMINE THE LOADS ON THE INTERCEPTORS
C IF(IALT(J,M),LE,0) GO TO 339
C KOUT = IALT(J,M)
C FLOW = COLECT(J) = CAPMAX(J,M)
C IF(FLOW.LE,0.0) FLOW = 0.0
C FLOWL = COLLAG(J) = CAPMAX(J,M)
C IF(FLOWL.LE,0.0) FLOWL = 0.0
C GO TO 341
C 339 CONTINUE
C KOUT = NUMPLT + 1
C GO 340 K = 1 + NUMPLT
C IF(K.EQ.J) GO TO 340
C IF(IOUT(J,K,M),LE,0) KOUT = K
C 340 CONTINUE
C FLOW = COLECT(J)
C FLOWL = COLLAG(J)
C 341 CONTINUE
C
C SINCE THE TREATMENT PLANTS HAVE ONLY ONE DISCHARGE ROUTE
OR A MAXIMUM CAPACITY, THE TRUNK SEWER HAS THE SAME VALUE
FOR DEMAND

C

C COSTS = 0.0
ISTARS = 0.0

C DUES CAPACITY OF TRUNK SEWER MEET DEMAND?

UU 344 K = 1, NUMPLT
ACAPS(J,K) = TCAPS(J,K,1,M8)
AUEBTS(J,K) = TDEBTS(J,K,1,M8)
FUEBTS(J,K) = 0.0
GUEBTS(K) = 0.0
WNUMS(K) = 0.0

344 CONTINUE
IF(KOUT.EQ.NUMPLT+1) GO TO 358
IF(LOWL.LE.ACAPS(J,KOUT)) GO TO 351

C DETERMINE OPTIMUM DESIGN PERIOD FOR TRUNK SEWERS

C ISTAR = PEHS
IF(TITSTAR.LE.0) GO TO 346
UU 346 ITIME = 1/25
ISTARS = (ALOG((TITARS*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)

346 CONTINUE

C DETERMINE OPTIMUM DESIGN PERIOD FOR LIFT STATIONS

C TITARL = PEHL
IF(TITARL.LE.0) GO TO 348
UU 348 ITIME = 1/25
TITARL = (ALOG((TITARL*RETURN(L))/ALPHA(11) + 1.0))/RETURN(L)

348 CONTINUE

C DETERMINE TEMPORARY CAPACITY OF INTERCEPTOR SEWER

ACAPS(J,KOUT) = FLOWL + UDEMAND * TITARS

C DETERMINE COST OF EXPANDING CAPACITY OF TRUNK SEWER
(INCLUDING DISTANCE AND ELEVATION DIFFERENCE)

C COSTS = 0.0
IF(UDEMAND.EQ.0.0) GU TO 358
IF(SLOPE(J,KOUT).GT.SLOPEM) GU TO 350

C GRAVITY FLOW

C COSTS = (AK(11) * (ACAPS(J,KOUT) - TCAPS(J,KOUT,1,M8)) * ALPHA(11)
1 * FACSEM(L)) * (DIST(J,KOUT) / 5280.0)
GU TO 356

C GRAVITY FLOW PLUS LIFT STATIONS

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,KOUT)).LE.1) NUMLS(J,KOUT) = 1
CUS11 = FACSEM(L) * ((AK(11) * (ACAPS(J,KOUT) - TCAPS(J,KOUT,1,M8))
1 * ALPHA(11)) * (DIST(J,KOUT) / 5280.0))
CUST2 = FACCAP(L) * ((AK(12) * (ACAPS(J,KOUT) + TCAPS(J,KOUT,1,MB)) + 1 ** ALPHA(12)) * NUMS(J,KOUT))
CUSTS = COST1 + COST2

C CALCULATE THE U & M COSTS OF THE TRUNK SEWER AND LIFT STATIONS
C
351 AHEAD = 0.0
IF(NUMLS(J,KOUT) <= 0) GO TO 352
AHEAD = PHEAD / NUMS(J,KOUT)
352 CONTINUE
ALOMS(KOUT) = FACUM(L) * ((BK(11) * FLOW ** BALPHA(11) + 1 * BK(12) / 1000.0) * FLOW ** BALPHA(12) * AHEAD) * NUMS(J,KOUT)

C DETERMINE TEMPORARY FUTURE COST OF TRUNK SEWER EXPANSION
C
356 CONTINUE
FDEBTS(J,KOUT) = COSTS
C CALCULATE AMOUNT OF ANNUAL REPAYMENT OF CAPITAL FOR LAST YEARS DEBT
C
358 CONTINUE
UJ 360 K = 1,NUMPLT
FDEBTS(K) = ADEBS(J,K) * CRFS(L=1)
360 CONTINUE
C DETERMINE THE TEMPORARY DISCOUNTED COSTS FOR DEBT AND O & M
C
AVGRET = (RETURN(1) + RETURN(L)) / 2.0
UJ 362 K = 1,NUMPLT
BDEBTS(K) = FCEBTS(K) / ((1.0 + AVGRET) ** (L=1))
362 CONTINUE
I(KUUT,EQ,NUMPLT + 1) = 0 TO 364
BOMS(KOUT) = ABOMS(KOUT) / ((1.0 + AVGRET) ** (L=1))
TVALS = TVALE + BOMS(KUUT)
TPWLS = (FDEBTS(J,KUUT) + CMFS(L)) / ((1.0 + AVGRET) ** (L))
TVALE = TVALE + TPWLS
364 CONTINUE
C OUTPUT EDIT DATA
C
370 TOTAL = 0.0
UU 374 K = 1,NUMPLT
TOTAL = BDEBTS(K) + BOMS(K)
I(TOTAL <= 0.0,AND FDEBTS(J,K) <= 0.0) = 0 TO 370
WRITE(6,105) L,NALT(M),NALT(MB),JPLT(J),ICHECK(J,M,MB),TREAT,1,TSTARS,DEMP,TSSTAR,INDEX,TCAPS(J,1,MB),ACAPS(J),ADEBTS(J),2,FDEBTS(J),BDEBTS,JDEBTS,BOMP,TOTAL
370 TOTAL = 0.0
374 CONTINUE
380 CONTINUE
IF(EDIT <= 0) TO 382
WRITE(6,107) TVALE
382 CONTINUE
SELECT OPTIMUM BACK ROUTE

\[
\text{TEMPB} = \text{UPTVAL}(L-1,M) + \text{VALUE}
\]
\[
\text{IF}(\text{TEMPB} \geq \text{TEMPA}) \text{ GO TO 390}
\]
\[
\text{TEMPA} = \text{TEMPB}
\]
\[
\text{MBACK}(L,M) = MB
\]
\[
\text{VALUE}(L,M) = \text{VALUE}
\]

SIUME OPTIMUM DATA

DU 386 J = 1, NUMPLT
\[
\text{TCAPP}(J,2,M) = \text{ACAPP}(J)
\]
\[
\text{TUEBTP}(J,2,M) = \text{ADEBTP}(J)
\]
\[
\text{ULBTPF}(J,M) = \text{AEDEBTP}(J)
\]
\[
\text{KITREAT}(J,2,M) = \text{LTRETS}(J)
\]
DU 384 K = 1, NUMPLT + 1
\[
\text{LCAPS}(J,K,2*M) = \text{ACAPS}(J,K)
\]
\[
\text{TUEBTS}(J,K,2*H) = \text{ADEBTS}(J,K)
\]
\[
\text{ULBTSF}(J,K,M) = \text{FDEBTS}(J,K)
\]

384 CUNTINUE

386 CUNTINUE

390 CUNTINUE
\[
\text{TEMPH} = 0.0
\]
DU 396 J = 1, NUMPLT
\[
\text{TMFR} = \text{TEMPH} + \text{DEBTPF}(J,H) \cdot \text{CRF}(L)/(1.0 \cdot \text{AVGRET})\cdot L
\]
DU 394 K = 1, NUMPLT
\[
\text{LMPK} = \text{TEMPH} + \text{DEBTSF}(J,K,H) \cdot \text{CRFS}(L)/(1.0 \cdot \text{AVGRET})\cdot L
\]

394 CUNTINUE

396 CUNTINUE
\[
\text{VALUE}(L,M) = \text{VALUE}(L,M) \cdot \text{TMFR}
\]
\[
\text{TEMPA} = \text{TEMPA} \cdot \text{TEMPH}
\]
\[
\text{UPTVAL}(L,M) = \text{TEMPA}
\]

400 CUNTINUE

TEAKLY UPDATE OF OPTIMUM DATA FILES

RLTIRE DEBT

OUTPUT DATA FOR THIS YEAR

LIST DATA

IF(\text{LIST} \leq 0) \text{GO TO 421}
\[
\text{WRITE}(6,109) \text{IRUN}
\]
\[
\text{WRITE}(6,110)
\]
\[
\text{WRITE}(6,111)
\]
\[
\text{WRITE}(6,112)
\]
\[
\text{IPEN} = L - 1
\]

421 CUNTINUE
DU 428 M = 1, NUMALT
DU 426 J = 1, NUMPLT
\[
\text{TCAPP}(J,1,M) = \text{TCAPP}(J,2,M)
\]
\[
\text{KITREAT}(J,1,M) = \text{KTREAT}(J,2*H)
\]
\[
\text{ANNP} = \text{TOEBTP}(J,2*,M) \cdot \text{CRF}(L=1)
\]
\[
\text{TUEBTP}(J,1,M) = \text{TOEBTP}(J,2*,M) \cdot \text{ANNP} + \text{DEBTPF}(J,M)
\]
\[
\text{IF}(\text{LIST} \leq 0) \text{GO TO 422}
\]
\[
\text{IF}(\text{TOEBTP}(J,1,M) \leq 0.0) \text{GO TO 422}
\]
\[
\text{WRITE}(6,114) \text{NLALT}(M), \text{NLALT}(L,MBACK(L,M)), \text{JPLT}(J), \text{TCAPP}(J,1,M),
\]
\[
\text{JUEBTPT}(J,2*,M) \cdot \text{ANNP} + \text{DEBTPF}(J,M), \text{TOEBTP}(J,1,M)
\]

422 DU 424 K = 1, NUMPLT
\[
\text{LCAPS}(J,K,1*M) = \text{TCAPS}(J,K,2*M)
\]
\[
\text{ANNS} = \text{TOEBS}(J,K,2*M) \cdot \text{CRFS}(L=1)
\]
\[
\text{TUEBTS}(J,K,1*M) = \text{TOEBS}(J,K,2*M) \cdot \text{ANNS} + \text{DEBTSF}(J,K,M)
\]
\[
\text{IF}(\text{LIST} \leq 0) \text{GO TO 424}
\]
IF (TDEBS(J,K,1,M), EQ, 0) GO TO 424
WRITE(6,116) L, NALT(M), NALT(MBACK(L,M)), JPLT(J), JPLT(K), TCAPS(J, 1K+1,M), TDEBS(J,K,2,M), ANNS, DEBTSF(J,K+1,M), TDEBS(J,K+1,M)
424 CONTINUE
420 CONTINUE
IF (ILIST LE 0) GO TO 428
WRITE(6,117) VALUE(L,M), OPTVAL(L,M)
428 CONTINUE
420 CONTINUE
ILEDIT = ILEDIT + 1
ILIST = ILIST - 1
440 CONTINUE
C
C OUTPUT SUMMARY
C
IF (IPW LE 0) GO TO 452
WRITE(6,119) INRUN
WRITE(6,120)
LUX 450 L = 2, NUMYR + 1
LUX 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
LUX 456 I = 1, NUMALT
NUMINS(I) = I
456 CONTINUE
IF (NUMALT LE 1) GO TO 463
LUX 462 NI = 1, NUMALT = 1
I = NUMINS(NI)
LUX 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 (INRUN LE 0) GO TO 470
WRITE(6,124) IRUN
WRITE(6,125)
LUX 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 (INRANK LE 0) GO TO 490
LUX 490 IOPT = 1, NRMANK
MALT(NUMYR + 1) = NUMINS(IOPT)
M = MALT(NUMYR + 1)
LUX 480 N = 1, NUMYR
L = NUMYR = N + 2
M = MBACK(L,M)
MALT(L-1) = M

114
C END CONTINUE
C WRITE (6,130) IPOPT, IRUN
C WRITE (6,131)
C WRITE (6,132)
DU 486 L = 1*NYMYR + 1
IPEH = L
IYEAR = L + NYEAR - 1
M = MALT(L)
C WRITE (6,135) IYEAR, IPER, MALT(M), VALUE(L, M), OPTVAL(L, M)
486 CONTINUE
C C C
C CONTINUE
C C C
C WRITE ALL DATA FOR OPTIMUM PATH
C 500 IF(NALTPT .LE. 0) GO TO 670
DU 670 MSUM = 1*NALTPT
C C C
C RECALCULATE THE OPTIMUM PATH
C 670 IF(NNODYN .GE. 1) GO TO 511
MALT(NMYR) + 1 = NUMINS(MSUM)
M = MALT(NMYR + 1)
DU 510 N = 1*NYMYR
L = NMYR - N + 2
M = MBACK(L, M)
MALT(L-1) = M
MALTPT = 1*NYMYR + 1
MALT(LN) = MSUM
510 CONTINUE
GO TO 513
511 DU 512 LN = 1*NYMYR + 1
MALT(LN) = MSUM
512 CONTINUE
513 CONTINUE
C C C
C INITIALIZE SYSTEM PARAMETERS
C 514 CONTINUE
C 516 CONTINUE
DU 516 J = 1*NUPMLT
ACAP(j) = CAPP(J)
AUEBSP(J) = DEBTP(J)
FUEBTP(J) = 0.0
LTHET(J) = LTHT(J)
CULECT(J) = 0.0
CULLAG(J) = 0.0
FUTURE(J) = 0.0
LWHEC(J) = 0.0
DU 514 K = 1*NUPMLT + 1
ACAPS(J, K) = CAPS(J, K)
AUEBTS(J, K) = DEBTS(J, K)
FUEBTS(J, K) = 0.0
NUMLS(J, K) = 0
514 CONTINUE
516 CONTINUE
DU 520 N = 1, 100
KYEAR(N) = 0
KHIGH(N) = 0
KEST(N) = 0
CAP1(N) = 0.0
CAP2(N) = 0.0
KINET1(N) = 0
KINET2(N) = 0
EXDEBT(N) = 0.0
DEBTEX(N) = 0.0
IUEST(N) = 0.0
NUMLSP(N) = 0

520 CONTINUE
UU 526 L = 1,NUMYR + 1
TUTCAP(L) = 0.0
TAN(L) = 0.0
TUM(L) = 0.0
TUTPH(L) = 0.0

526 CONTINUE
N = 1

C OPTIMIZE ALL PLANTS AND INTERCEPTORS FOR EACH YEAR L

C UU 650 L = 2,NUMYR + 1
INLEK = L - 1
INEAR = L + NYEAR - 1
M = MALT(L)
TVALUE = 0.0
TANUAL = 0.0

C DETERMINE LOAD ON PLANT AT L, L + LAG, AND L + 20

C UU 530 J = 1,NUMPLT
COLECT(J) = 0.0
CULLAG(J) = 0.0
FUTURE(J) = 0.0

530 CONTINUE
UU 532 J = 1, NUMPLT
UU 531 I = 1, NUMPLT
COLECT(J) = COLECT(J) + QUANT(I,L) * IN(I,J,M)
CULLAG(J) = CULLAG(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 AVOID EXCESS FLOWS FROM PLANTS WITH MAXIMUM CAPACITIES

C UU 533 J = 1, NUMPLT
INOUT(J,NUMPLT+1,M) .NE. 1) GO TO 533
K = IALT(J,M)
IN(K.EQ.0) GO TO 533
IN(K.GT.NUMPLT) GO TO 533
Q = COLECT(J) - CAPMAX(J,M)
IN(WL.LE.0.0) Q = 0.0
Q = CULLAG(J) - CAPMAX(J,M)
IN(WL.LE.0.0) QL = 0.0
Q = FUTURE(J) - CAPMAX(J,M)
IN(WL.LE.0.0) QF = 0.0
COLECT(K) = COLECT(K) + Q
CULLAG(K) = CULLAG(K) + WL
FUTURE(K) = FUTURE(K) + QF

533 CONTINUE

C OUTPUT FLOWS COLLECTED AT TREATMENT PLANTS

IP(INANUAL.LE.0) GO TO 534
WHITE (6,92) IRUN
ISPACE = 4 + NUMPLT - 4
WHITE (6,93) ISPACE* (ASPACE, I = 1, ISPACE)
WHITE (6,94) NUMPLT* (JPLT(I), I = 1, NUMPLT)
WHITE (6,95) IPER, IYEAR, MALT(M),NUMPLT*(COLECT(J),J=1,NUMPLT)
IP = IPER + LAG
IT = IYEAR + LAG
WHITE (6,95) IP, IT, NALT(M), NUMPLT, (COLLAG(J), J = 1, NUMPLT)
J' = IPER + 20
IT = IYEAR + 20
WHITE (6,95) IP, IT, NALT(M), NUMPLT, (FUTURE(J), J = 1, NUMPLT)
534 CONTINUE
IF (ANUAL.LE.0) GO TO 535
WHITE (6,140) IRUN, MSUM
WHITE (6,141)
WHITE (6,142)
535 CONTINUE

FINU COSTS AND CAPACITY FOR EACH TREATMENT PLANT

UU 642 J = 1,NUMPLT
TREAT = COLLECT(J) + IOUT(J,NUMPLT+1,M)
TREAT = COLLAG(J) + IOUT(J,NUMPLT+1,M)
PMLS = LTRET(J)
TVALE = 0.0
CUSTA = 0.0
CUSTB = 0.0
FRENTP(J) = 0.0

DETERMINE ANNUAL DEMAND OVER 20 YEARS

UAMANU = (FUTURE(J) - COLLECT(J)) / 20.0
UDEMP = DEMANU * IOUT(J,NUMPLT + 1, M)

CHECK TREATMENT PLANT FOR MINIMUM FLOWS

IF (TREAT.FR.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

DETERMINE DESIGN INDEX

INDEX = 0
ITREAT = MTREAT(J,M)
IF (QUAL(L+LAG).GT.ITREAT) ITREAT = QUAL(L+LAG)
IF (QUAL(J,L+LAG).GT.ITREAT) ITREAT = QUAL(J,L+LAG)
INDEX = ITREAT
GO TO (542, 544, 546) LTRET(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

DOES PRESENT CAPACITY AND TREATMENT LEVEL OF PLANT MEET DEMAND?
C

C APPE • ACAPP(J)
ITSTAR = 0,0
IF(TREATL.LE.0.0) GO TO 572
IF(TREATL.LE.ACAPP(J).AND.ILTREATL.LE.LTRET(J)) GO TO 572

C DETERMINE OPTIMUM DESIGN PERIOD FOR TREATMENT PLANTS

C ITSTAR = PERP
IF(ITSTAR.LE.0.0) GO TO 555
IF(INDEX.LE.0.0) GO TO 555
UU 554 ITIME = 1.25
ITSTAR = (ALOG((ITSTAR + RETURN(L))/ ALPHA(INDEX) + 1.0))/RETURN(L)
554 CONTINUE
555 CONTINUE

C DETERMINE CAPACITY OF THE PLANT

C K1EAR(N) = 1 YEAR
K1URIGN(N) = J
CAP1(N) = ACAPP(J)
CAP2(N) = ACAPP(J)
K1RETI(N) = LTRET(J)
K1RET2(N) = LTRET(J)
EXQBET(N) = ADETP(J)
UBETEX(N) = 0.0
TUEBET(N) = ADETP(J)
CUSTA = 0.0
IF(TREATL.LE.ACAPP(J)) GO TO 556
ACAPP(J) = TREATL + OEMP * ITSTAR
CAP2(N) = ACAPP(J)
556 CONTINUE

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(LLALT(J,M).GE.1) GO TO 558
IF(LLCHECK(J).EQ.2) GO TO 557
LLCHECK(J) = 2
557 CONTINUE
GU TO 559
558 CONTINUE
IF(LLCHECK(J).NE.2) GO TO 559
LLCHECK(J) = 0
559 CONTINUE

C DETERMINE THE COST TO INCREASE CAPACITY OF PLANT

C IF(ACAPP(J).LE.ECAPP) GO TO 564
IF(LTRET(J).EQ.0.0) GO TO 564
CUSTA = AK(LTRET(J)) * (ACAPP(J) - CAPI(N)) ** 1 ALPHA(LTRET(J)) * FACCAP(L)
564 CONTINUE
566 CONTINUE

C DETERMINE COST OF UPGRADING TREATMENT PLANT

C IF(TREATL.LE.LTRET(J)) GO TO 570
IF(INDEX.EQ.0.0) GO TO 570
CUSTB = (AK(INDEX)) * (ACAPP(J)) ** ALPHA(INDEX)) * FACCAP(L)
DETERMINE TEMPORARY FUTURE COST OF EXPANSION

ULIBEX(N) = COSTA + COSTB
UEBT(N) = ADEBP(J) + COSTA + COSTB
FUEBP(J) = COSTA + COSTB
N = N + 1

DETERMINE AMOUNT OF ANNUAL CAPITAL PAYMENT ON LAST YEARS DEBT

572 CONTINUE
ANP(J) = ADEBP(J) * CRFP(L=1)
TAN(L) = TAN(L) + ANP(J)

CALCULATE U & M COSTS FOR TREATMENT PLANT

UMP(J) = 0.0
IF (LPRES.EQ.0) GO TO 575
UMP(J) = RK(LPRES) * (TREAT ** BAPHA(LPRES)) * FACOM(L)
TUM(L) = TUM(L) + UMP(J)
TANUAL = TANUAL + ANP(J) + UMP(J)

575 CONTINUE

DETERMINE DISCOUNTED COSTS FOR DEBT AND U & M OF PLANT

AVGRET = (RETURN(1) + RETURN(L)) / 2.0
BDEBTP = ANP(J) / ((1.0 + AVGRET) ** (L=1))
BUMP = UMP(J) / ((1.0 + AVGRET) ** (L=1))
IVALUE = BDEBTP + BUMP

DETERMINE THE LOADS ON THE INTERCEPTORS

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
UU 578 K = K
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

SINCE THE TREATMENT PLANTS HAVE ONLY ONE DISCHARGE ROUTE
UM A MAXIMUM CAPACITY, THE TRUNK SEWER HAS THE SAME VALUE
FOR DEMAND

ISTAMS = 0.0
KALH(J) = KUUT
KWEST(N) = 0

DUES CAPACITY OF TRUNK SEWER MEET DEMAND?
C UU 580 K = 1, NUMPLT
FUEBT(j,K) = 0.0
BUEDT(K) = 0.0
NUMS(K) = 0.0
EXAPS(K) = ACAPS(j,K)
UMS(j,K) = U.0
ANS(j,K) = U.0
580 CONTINUE
CUSTS = 0.0
IF(KOUT.EQ.NUMPLT+1) GO TO 596
IF(FLOWLE.EQ.ACAPS(j,KOUT)) GO TO 589
C DETERMINE OPTIMUM DESIGN PERIOD FOR TRUNK SEWERS
C
ITSTAS = PERS
IF(ITSTAS.LE.0.0) GO TO 584
UU 584 TIME = 1.25
ITSTAS = (ALOG(ITSTAS*RETURN(L))/ALPHA(11) + 1.0)/RETURN(L)
584 CONTINUE
C DETERMINE OPTIMUM DESIGN PERIOD FOR LIFT STATIONS
C
ITSTAL = PERS
IF(ITSTAL.LE.0.0) GO TO 587
UU 587 TIME = 1.25
ITSTAL = (ALOG(ITSTAL*RETURN(L))/ALPHA(11) + 1.0)/RETURN(L)
587 CONTINUE
C DETERMINE TEMPORARY CAPACITY OF TRUNK SEWERS
C
KYEAR(N) = IYEAR
KURIGN(N) = J
KUIUGN(N) = KOUT
CAPI(N) = ACAPS(j,KOUT)
NUMLSP(N) = 0
EADEBT(N) = ADEBTs(j,KOUT)
DBTEX(N) = 0.0
UEBT(N) = ADEBTs(j,KOUT)
ACAPS(j,KOUT) = FLOWL + DEMAND * TSTARS
CAPS(N) = ACAPS(j,KOUT)
C DETERMINE CUST OF EXPANDING CAPACITY IF TRUNK SEWER
C (INCLUDING DISTANCE AND ELEVATION DIFFERENCE)
C
CUSTS = 0.0
IF(UDEMAND.EQ.0.0) GO TO 592
IF(SLOPE(j,KOUT).GT.SLOPEM) GO TO 588
C GRAVITY FLOW
C
CUSTS = (AK(11) * ((ACAPS(j,KOUT)-ECAPS(KOUT))** ALPHA(11))
1 * FALSEM(L)) * (DIST(j,KOUT) / 5280.0)
GO TO 592
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
CUST1 = FACSEW(L) * ((AK(11) * (ACAPS(J,KOUT) + ECAPS(KOUT)))
           * ALPHA(11) * (DIST(J,KOUT) / 5280.0) )
CUST2 = FACCAP(L) * ((AK(12) * (ACAPS(J,KOUT) + ECAPS(KOUT)))
           * ALPHA(12) * NUMLS(J,KOUT) )
CUSTS = CUST1 + CUST2

DETERMINE FUTURE COST OF TRUNK SEWER EXPANSION

592 CONTINUE
FUCTS(J,KOUT) = CUSTS
WHTEXT(N) = COSTS
WHT(N) = ADBTS(J,KOUT) + COSTS
N = N + 1

CALCULATE THE O & M COSTS OF THE TRUNK SEWER AND LIFT STATIONS

599 AHEAD = 0.0
IF (NUMLS(J,KOUT) LE 0) GO TO 590
AHEAD = PHEAD / NUMLS(J,KOUT)
590 CONTINUE
UMS(J,KOUT) = FACUM(L) * (BK(11) * FLOW ** ALPHA(11) +
                          1 * (BK(12) / 1000.0) * FLOW ** ALPHA(12) * AHEAD ) * NUMLS(J,KOUT))
TANUAL = TANUAL + UMS(J,KOUT)

CALCULATE AMOUNT OF ANNUAL REPAYMENT OF CAPITAL FOR LAST YEARS DEBT

596 CONTINUE
UU 597 K = 1 * NUMPLT
ANS(J,K) = ADBTS(J,K) * CRFS(L-1)
597 CONTINUE
600 CONTINUE

TOTAL ANNUAL DEBT FOR CAPITAL

UU 606 K = 1 * NUMPLT
TAN(L) = TAN(L) + ANS(J,K)
TANUAL = TANUAL + ANS(J,K)
606 CONTINUE

DETERMINE THE DISCOUNTED COSTS FOR DEBT AND O & M

AVGRET = (RETURN(1) + RETURN(L)) / 2.0
UU 610 K = 1 * NUMPLT
BDEBS(K) = ANS(J,K) / ((1.0 + AVGRET) ** (L-1))
TVALUE = TVVALUE + BDEBS(K)
610 CONTINUE
IF (KOUT EQ NUMPLT) GO TO 612
BUMS(KOUT) = UMS(J,KOUT) / ((1.0 + AVGRET) ** (L-1))
TVALUE = TVVALUE + BUMS(KOUT)
612 CONTINUE

RETIRE DEBT

TUTCAP(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
UU 622 K = 1 * NUMPLT
TUTCAP(L) = TOTCAP(L) + ADBTS(J,K) - ANS(J,K)
AUETS(J,K) = ADETS(J,K) - ANS(J,K) + FDETS(J,K)
IF(AUETS(J,K) LE 0.0) ADETS(J,K) = 0.0

022 CONTINUE

C LIST DATA

IF(IANUAL, LE.0) GO TO 640
TOTAL = ANP(J) + UNP(J)
IF(FDEBTP(J), GT.0.0) GO TO 624
IF(TOTAL, LE.0.0) GO TO 626

024 CONTINUE

WHITE(6,146) IYEAR, NALT(MALT(L)), JPLT(J), LCHECK(J), TREAT, TREATL,
1 UEMP, TSTAB, INDEX, ECAPP, ACAPP(J), ADEBTP(J), FDEBTP(J),
2 ANP(J), UNP(J), TOTAL, TVALE

026 TOTAL = 0.0
DU 636 K = 1, NUMPLT
TOTAL = ANS(J,K) + DMS(J,K)
IF(FDEBTS(J,K), GT.0.0) GO TO 630
IF(TOTAL, LE.0.0) GO TO 634

030 CONTINUE

IF(K, EQ. KOUT) GO TO 632
WHITE(6,147) IYEAR, NALT(MALT(L)), JPLT(J), JPLT(K), NUMLS(J,K),
1 ECAPS(K), ADEBTS(J,K), ANS(J,K), TOTAL
QU TO 634

032 WHITE(6,148) IYEAR, NALT(MALT(L)), JPLT(J), JPLT(K), FLOW,
1 PLULM, DEMAND, TSTARS, NUMLS(J,KOUT), ECAPS(KOUT),
2 ACAPS(J,KOUT), ADEBTS(J,KOUT), FDEBTS(J,KOUT), ANS(J,KOUT),
3 UMS(J,KOUT), TOTAL

034 TOTAL = 0.0
036 CONTINUE

040 CONTINUE

TUTPW(L) = TOTPw(L) + TVALE

042 CONTINUE

IF(IANUAL, LE.0) GO TO 640
WHITE(6,150) IANUAL, TOTPw(L)

046 CONTINUE

IANUAL = IANUAL + 1

050 CONTINUE

C SUMMARY OF ANNUAL COSTS

TA = 0.0
TP = 0.0
WHITE(6,156) IRUN, MSUM
WHITE(6,158)
WHITE(6,160)
WHITE(6,161)
WHITE(6,162)
TOTAL = 0.0
DU 660 L = 2, NUMYR + 1
IYEAR = NYEAR + 1 + L
TOTAL = TAN(L) + TUT(L)
TA = TA + TOTAL
TP = TP + TUTPW(L)
WHITE(6,165) IYEAR, NALT(MALT(L)), TOTCAP(L), TAN(L), TOT(L),
1 TOTAL, TUTPW(L)

060 CONTINUE

WHITE(6,166) TA, TP

C QUALITY = CAPACITY EXPANSION PROJECTS

122
```
I*IPROJ. NE.1) GO TU 670
WRITE (6*160) IRUN, MSUM
WRITE (6*170)
WRITE (6*171)
WRITE (6*172)
NUMPRU = N
UU 670 N = 1, NUMPRU = 1
I*KULST(N). NE.0.0) GO TU 664
WRITE (6*170) KYEAR(N), JPLT(KOHIGN(N)), CAP1(N), CAP2(N),
1 KRETI(N), KRRET2(N), EXDEBT(N), DEBTX(N), TDEBT(N)
UU TU 670
664 WRITE (6*170) KYEAR(N), JPLT(KOHIGN(N)), JPLT(KUEST(N)), CAP1(N),
1 CAP2(N), EXDEBT(N), DEBTX(N), TDEBT(N)
670 CONTINUE
STOP
END

******************************************************************************
DATA WASTEIN
******************************************************************************
01 10 10 04 1974 00 00
01 01 01 01 01 01 01 01 00
20 x0 50.0 10.0 02 0.060 0.01675 100.0 2.25 -0.100 25.0
340.66 340.66 340.66 70.17 211.66 211.66 211.66 15.184 4.36 4.36 0.21
1.201 0.773 0.0537 0.775
1.532 0.800 0.0599 0.605
1.712 0.789 0.1070 0.746
2.362 0.758 0.1650 0.730
0.958 0.867 0.0133 0.942
0.830 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
0.870 0.646 0.030 0.722
0.127 0.390 0.0018 0.664
0.128 0.615 0.0288 0.897
01 2427 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 5xS.0. #1
05 7.3 0.3715 4253. 01 GHANGER-HUNTER
06 8.0 0.3514 4286. 01 SALT LAKE COUNTY COTTONWOOD
07 4.0 0.4263. 01 MURRAY
08 3.6 0.0990 4277. 01 TRI-COMMUNITY
09 1.5 0.3111 4300. 01 SANDY
10 0.0 0.4236. 00 NEW REGIONAL WWTP
01 02 1250. 0.0 0.0
02 01 1250. 0.0 0.0
02 03 38300. 0.0 0.0
03 01 41700. 0.0 0.0
02 10 40300. 0.0 0.0
03 02 38300. 0.0 0.0
03 04 7500. 0.0 0.0
03 10 9400. 0.0 0.0
03 04 41700. 0.0 0.0
04 02 38300. 0.0 0.0
04 03 7500. 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
123
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