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Computer-Aided Synthesis of Wastewater Treatment and Sludge Disposal Systems

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COMPUTER-AIDED SYNTHESIS OF WASTEWATER TREATMENT AND SLUDGE DISPOSAL SYSTEMS

by

Lewis A. Rossman
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work presented here describes the development and use of a computer-aided preliminary design procedure for wastewater treatment and sludge disposal systems. It enables a designer to efficiently synthesize and analyze large numbers of alternative treatment schemes and rank them with respect to several different cost, energy, and environmental criteria. Such a design tool should enhance our capability to develop more innovative and efficient waste treatment systems in these times of stricter environmental standards and increasing resource costs.

Francis T. Mayo
Director, Municipal Environmental
Research Laboratory

ABSTRACT

A computer-aided design procedure for the preliminary synthesis of wastewater treatment and sludge disposal systems is developed. It selects the components in the wastewater treatment and sludge disposal trains from a list of candidate process units with fixed design characteristics so that criteria on effluent quality, cost, energy, land utilization, and subjective undesireability are best satisfied. The computational procedure uses implicit enumeration coupled with a heuristic penalty method that accounts for the impact of return sidestreams from sludge processing. The programmed version of the design procedure, called EXEC/OP, has been interfaced with the unit process subroutines contained in a previously EPA developed system evaluation program known as EXECUTIVE. A number of case study design problems are presented to demonstrate the versatility of EXEC/OP. Included among these is a preliminary cost/energy-effectiveness analysis for a hypothetical design problem containing over 15,000 alternative system configurations. The design approach described in this report will be of interest to engineers and planners involved in the generation and evaluation of alternative wastewater treatment and sludge disposal systems.

This report covers a period from February 1978 to October 1978 and work was completed as of February 1979.

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SECTION 1

INTRODUCTION

The effective synthesis of waste treatment systems is a challenging engineering task. The term synthesis refers to the specification of both a system structure - the choice and arrangement of unit processes and operations - and the design of the individual units within that structure so that a set of design objectives is fulfilled. Although the primary goal may be the treatment of liquid wastes, decisions regarding sludge handling and disposal can have significant impacts on total system performance, in both an economic and environmental sense.

In the preliminary phases of the system design process the designer needs to efficiently evaluate the performance of a large number of potential system designs to identify a smaller number of attractive designs that will then become the subject of a more detailed and accurate evaluation. This screening process can become complicated for a number of reasons. First there is the rapid geometric growth in the number of alternative system designs possible as more unit processes and design levels are taken into consideration. Second, the evaluation of each system design should consider the effect that liquid sidestreams generated from sludge treatment have when recycled back to the wastewater treatment portion of the system. The feedback effect of these recycles complicates the numerical calculation of system performance. In many instances these two factors can combine to make a complete evaluation of all possible system designs computationally intractable. If only intuition were used to select a more manageable number of designs to examine, one could never be sure that some truly attractive alternative was not overlooked.

A third reason for the complexity of the screening process is reflected in the multi-objective nature of the design problem. For example, the least-cost waste treatment scheme need not be the most preferred. Other criteria related to such considerations as energy consumption, reliability, resource recovery, and public acceptance can have a significant role in the decision making process. The 1977 Clean Water Act (P.L. 95-217) [1] recognizes this fact by allowing trade-offs to be made among factors such as these for treatment systems eligible for federal construction grants. Thus the preliminary screening process should also be capable of generating alternative system designs that show the kinds of trade-offs that may exist between various design criteria.

This report describes a computerized system synthesis model, called EXEC/OP, that can aid the designer in the preliminary stages of the system design process. The model can be thought of as an optimization version of a previously EPA developed treatment system evaluation program known as EXECUTIVE [2]. From a specified list of unit process options with fixed design or performance characteristics the model selects the combination of units that will best meet a set of system design criteria. These criteria include cost, energy consumption, land utilization, a subjective undesireability rating and effluent discharge limits. EXEC/OP also has the capability of identifying the M system designs that are within X% of the best. It avoids having to evaluate the performance of each possible system configuration by employing an implicit enumeration search technique coupled with a heuristic penalty function method used to account for the effects of recycled sidestreams from sludge processing.

The following sections of this report discuss the various features of the model and present a number of sample design problems that illustrate its versatility. The appendices contain a mathematical development of the model and a Users' Guide and program listing of EXEC/OP.

SECTION 2

CONCLUSIONS

The EXEC/OP computer program for synthesizing waste treatment systems provides a useful tool for the preliminary screening of alternative designs. Its features include an integrated design of both the wastewater and sludge treatment sub-systems, consideration of multiple components in the waste streams, selection of both the type and design level for unit processes, and consideration of multiple design criteria. The penalty augmented implicit enumeration method employed in its optimization algorithm is an efficient means of searching for the best combinations of process options. Usually only a small fraction of the computational effort that would have been required for complete enumeration of all possible alternatives is needed.

The program gives the designer a useful means for exploring trade-offs between such criteria as cost, energy consumption, land utilization, and subjective undesireability ratings. These factors can be weighted and combined into a single criterion function or can be treated as constraints placed on the system design. Additional flexibility is provided by the M next-best design feature of EXEC/OP. This can be used to identify a group of designs that are close together with respect to one primary objective (e.g. cost) but could have varying levels of other secondary objectives.

The case studies described in this report show that the program is capable of analyzing design problems with from 15,000 to 21,000 alternative system configurations in several minutes of computer processor time. The core storage requirements of the program are modest at 25 K words. The subroutines that model the performance of the treatment processes have been employed in a modular fashion so that improvements and new types of unit processes may be easily added at a later time.

SECTION 3

ELEMENTS OF THE SYSTEM DESIGN PROCESS

As with most engineering problems, the design of wastewater treatment and sludge disposal systems involves the elements of synthesis, analysis, and evaluation [3]. The element of synthesis refers to the conception of a system structure and its operating characteristics. Analysis determines how a given system structure will behave under specific design and operating conditions. The evaluation step compares the performance of alternative system designs so that a best design may be identified.

The entire design process consists of a linking together of these three elements in an iterative fashion. Information feedback from the analysis and evaluation phases is used to suggest changes to be made in the synthesis step. Any new designs so generated are then analyzed and evaluated as the process cycles through another iteration. Also, the level of detail and accuracy maintained in the analysis will usually increase as the process proceeds. In the preliminary stages, levels just high enough to perform an efficient yet reliable screening of a very large number of alternative system designs is all that is required.

There are two types of decisions to be made when synthesizing a waste treatment system. The first type involves the system structure - a choice of the kinds of treatment processes to employ and the arrangement of these units with one another in the system. Examples of such structural choices would be whether to use activated sludge or a trickling filter for BOD removal, whether to employ a single treatment train for sludge processing or separate trains for different types of sludges, and whether to use land spreading of liquid sludge or landfill a dewatered sludge. The second type of decision relates to the design of each individual unit process and operation. It specifies the values of those parameters that describe the size, operating characteristics, and performance of each unit. Examples might be the choice of an overflow rate for a settling tank, the value of the solids retention time to use in an activated sludge unit, or the choice between 10 cu. yd. and 15 cu. yd. size trucks for hauling sludge.

The identification of a best overall system design requires a search over the space of feasible structural configurations and over the space of design options associated with the individual treatment units in each configuration. The fact that the treatment units are interconnected to one another makes the performance of any one unit in the system dependent on the design decisions made for all other units in the system. Thus, for example, the best design of an activated sludge unit cannot be assured without knowing the performance achieved in primary sedimentation and, because of the recycled sidestreams, the design choices in the sludge processing train.

The evaluation of a system design must be made with respect to a set of decision criteria. The criteria that seem most relevant to waste treatment systems can usually be grouped into the categories of economics, environmental effects, performance, and feasibility of implementation. Table 1 lists the evaluation criteria that were used in the recent LA/OMA sludge management study for Los Angeles and Orange Counties in California [4]. The U.S. Congress, in the Clean Water Act of 1977, has set forth several goals that could serve as the basis for design criteria. The act provides monetary incentives for communities to employ treatment technology that will result in (a) greater recycling and reuse of water, nutrients, and natural resources; (b) increased energy conservation, reuse, and recycling; (c) improved cost-effectiveness in meeting specific water quality goals; (d) improved toxics management [1].

Criteria such as described above may be expressed in the form of a performance objective to be minimized or maximized, as constraint relations with fixed target levels, or as fuzzy combinations of objectives and constraints (e.g., design a system that has some resource conservation in it but is not too costly). Alternative designs that do not meet the constraint target levels can be discarded as infeasible. Of the remaining designs, if one ranks better in each objective than all other designs then this is clearly the best choice. What is more likely to occur though is that one design performs better than another with respect to one objective but is inferior with regard to a second objective.

For example, the treatment system that minimizes cost would probably not be the system that also minimizes energy consumption. In such cases the objectives are said to be conflicting and a final choice cannot be made without the designer imposing a subjective value judgment on the relative worth of one objective versus another. For the cost-energy situation, the designer would be faced with the question, "how much increase in cost am I willing to accept as I move from the most cost-effective system to the most energy-effective system?". Engineering analysis can only inform the designer of what trade-offs exist among the objectives in the alternative designs available. It cannot answer questions involving value judgments and thus cannot serve as the means for automatically reaching a final design decision.

The traditional approach to waste treatment system design has been to divide the system into its various component stages (e.g., primary treatment, secondary treatment, sludge stabilization, sludge dewatering, and final sludge disposal), define performance objectives for each stage, and select the treatment units that best accomplish these objectives. The result can be an uncoordinated and wasteful overall system design. More systematic approaches have recognized the interaction between various treatment components and have used mathematical models programmed for computer implementation to evaluate the overall performance of alternative system designs. The pioneering effort in this area was made by Smith and his

TABLE 1. EVALUATION CRITERIA FOR THE LA/OMA SLUDGE MANAGEMENT STUDY

Direct Cost	
	Capital Costs
	Operation and Maintenance Costs
	Revenues
Indirect Costs	
	Employment Generation
	Induced Land Value Changes
	Alterations in Economic Productivity
Energy Impacts	
	Direct Energy Demands
	Indirect Energy Demands
Environmental Impacts	
	Public Health Hazards
	Land Form Alteration
	Soil Contamination, Conditioning, Reclamation
	Water Quality
	Air Quality
	Ecosystem Impacts
	Resource Utilization
	Social Resources
	Growth Inducement
	Safety
	Control of Hazardous Substances
	Transportation System Impact
System Effectiveness	
	Implementability
	Flexibility with Time
	Reliability
	Compatibility with Existing Land Use
	Compatibility with Related Planning Programs
	Compatibility with Legal Requirements

co-workers at the U.S. Environmental Protection Agency [5]. This work has culminated in the development of EXECUTIVE, a computer program that simulates the steady state performance and evaluates the cost of a number of wastewater and sludge treatment unit processes that can be arranged into any reasonable system configuration [2]. Additional simulation programs devoted primarily to wastewater treatment systems have been reported on by Silveston [6], Chen, et. al. [7], and Shoemaker and Barkley [8]. Similar works devoted mainly to sludge management include those of Bennet, et. al. [9], Kos, et. al. [10], Smith and Eilers [11], Burley and Bayley [12], and the San Francisco Bay Region [13].

All of the above approaches are evaluative in nature - they rely on the designer to first specify the system design in advance. For a large number of alternative designs the computational burden can become excessive if each alternative must be synthesized and analyzed separately. To overcome this limitation, a number of mathematical optimization models have been developed for waste treatment systems in recent years. With varying degrees of generality and sophistication these models will select values for the system design variables that will meet effluent discharge standards at least total cost.

Table 2 compares a number of these models with respect to several features thought to be of particular value in the preliminary phases of the system design process. These features can be summarized as follows:

(1) The design of the wastewater and sludge treatment sub-systems should be done in an integrated fashion, with consideration given to the treatment requirements of the sidestreams produced during sludge processing;

(2) The model should select both a system structure and the design of the individual process units within that structure, at least from among a finite number of discrete alternatives;

(3) The capability should exist to handle multiple pollutants or waste stream parameters and their interactions;

(4) Whenever possible, principles of mass balance and reaction kinetics should be employed in predicting process performance and resource utilization;

(5) A capability to consider other kinds of system evaluation criteria besides cost should be included;

(6) A solution method more computationally efficient than complete enumeration of all possible system designs should be used.

None of the models in Table 2 contains all six features. It is possible to discern two types of modeling approaches in these past efforts. The first, representative of the dynamic programming models, can only synthesize the wastewater treatment sub-system with respect to one or two pollutants

TABLE 2. ASSESSMENT OF WASTE TREATMENT SYSTEM OPTIMIZATION MODELS

Authors	Integrates Wastewater and Sludge Treatment	Determines System Structure	Includes Multiple Pollutants	Uses Mass Balance and Process Kinetics Models	Includes Multiple Design Criteria	Optimization Technique	Comments
Lynn, et al. (1962) [14]	No	Yes	No	No	No	Linear Programming	Pioneering application of optimization techniques
Evenson, et al. (1969) [15]	No	Yes	No	No	No	Dynamic Programming	Uses a fixed unit cost to account for sludge disposal
Shih & Krishnan (1969) [16] and Shih & DeFilippi (1970) [17]	No	Yes	No	No	No	Dynamic Programming	
Ecker & McNamara (1971) [18]	No	Yes	No	No	No	Geometric Programming	
Berthouex and Polkowski (1970) [19]	Yes	No	Yes	Yes	Yes	Nonlinear Programming	Considers variance in BOD removal as a second design criterion
Mishra, et al. (1973) [20]	No	Yes	Yes	Yes	No	Nonlinear Programming	Optimizes recycle arrangements and parallel treatment schemes
CIRIA (1973) [21] Bowden, et al. (1976) [22]	Yes	No	Yes	Yes	No	Nonlinear Programming	Considers recycle of sidestreams from sludge treatment
U. S. Army Corps of Engrs. (1976) [23]	Yes	Yes	Yes	Yes	No	Complete Enumeration	Does not consider recycle of sidestreams
Patterson (1976) [24]	No	Yes	No	No	No	Dynamic Programming	Refinement of earlier dynamic programming model
Dick & Simmons (1976) [25]	Yes	No	Yes	Yes	No	Nonlinear Programming	Employs more fundamental process models than CIRIA model

using simple process performance relations. The second is representative of the various nonlinear programming models. It requires that the system structure first be specified in advance and then proceeds to optimize the integrated design of the individual units within that structure. It is capable of dealing with a complex system structure, multiple pollutants and realistic process performance models. Although a recent paper by Adams and Panagiotokapoulos [26] addresses many of these same concerns and suggests an approach for dealing with them, detailed computational results are only presented for a relatively simple design problem previously considered by Shih and Krishnan [16].

The decision model described in this report, EXEC/OP, has been designed to include the six features listed above. In addition, it is capable of identifying the M system designs that are within X% of the best design, where M and X are specified by the designer. This feature is especially useful in sensitivity analysis. In multi-criteria studies, it can identify system designs that are close to one another with regard to one criterion (e.g., cost) but could have varying levels of other criteria (e.g., energy consumption, land utilization). The emphasis has been placed on developing a useful design tool, capable of generating attractive alternatives that could warrant more critical evaluation, rather than producing an automated procedure for arriving at an optimal design.

SECTION 4

AN OVERVIEW OF THE SYSTEM SYNTHESIS MODEL

This section provides a description of the various conventions and assumptions employed in the system synthesis model EXEC/OP. It also discusses the initial steps needed to organize any given design problem into a suitable form for EXEC/OP. Detailed instructions on the use of the program can be found in Appendix B.

EXEC/OP views a waste treatment system as consisting of three treatment trains - one for wastewater, one for secondary sludge, and one for primary or mixed primary and secondary sludge. Figure 1 shows how these trains are connected to one another. Note how the liquid sidestreams off of the sludge treatment trains are recycled back to the wastewater treatment train. The mixing of secondary sludge with primary sludge is shown with a dashed line to indicate that the exact point of mixing will depend on the choice of treatment units in the secondary sludge train.

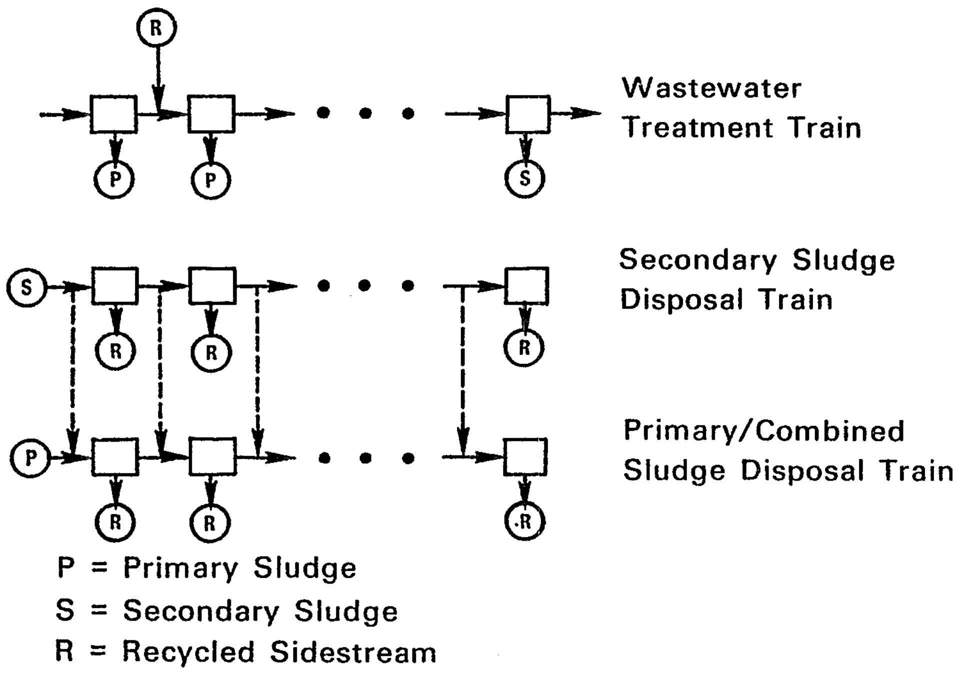

Figure 1. Conceptual flow diagram of a waste treatment system

The building blocks of each treatment train are referred to as treatment stages. For each stage the designer indicates the various unit process options that are available for selection. These units can be different types of treatment processes or operations (e.g., activated sludge versus trickling filter), or different design levels of the same process (e.g., activated sludge with mixed liquor volatile solids concentration of 2000, 2500, or 3000 mg/l). Table 3 lists the types of unit processes and operations that are currently available to EXEC/OP. Each of these has a performance model, in the form of an EXEC/OP subroutine, that will compute effluent quality, sidestream quality, equipment size, and resource utilization (cost, energy, land) as a function of the influent waste quality and a set of process design parameters. Most of these subroutines have been taken from the EPA EXECUTIVE program [2]. Appendix C lists the design parameters associated with each process, indicates which additional design information is computed by the process model, and cites references for the technical details of the models.

It is important to understand that the design level or performance of each process option is fixed in advance by the analyst by assigning values to these input design parameters. Thus, for example, if EXEC/OP should choose gravity thickening over air flotation thickening at some sludge treatment stage, it does so on the basis of the solids loading rate and thickened solids concentration that was assumed for each type of thickener. Of course the designer is free to employ several gravity and/or flotation thickener options, each with different performance levels, to help refine the selection.

Within each treatment train only a serial arrangement of processing stages is possible. Parallel treatment units or recycling of waste streams among the units of the same treatment train is not allowed. Thus a group of process units that normally operates with a recycle flow, such as the aeration basin and final settler of the activated sludge process, is treated as a single unit with its own performance model and EXEC/OP subroutine. Added flexibility for creating alternative configurations of units is provided by means of the "null process" unit. This simply indicates that the choice of no processing at a given stage is also a possibility. Examples illustrating the use of the null process alternative are shown in the various sample design problems considered throughout this report.

Each treatment stage has an influent waste stream entering it, an effluent stream leaving it for the next stage, and, in most cases, a sidestream generated from the processing activity. For wastewater treatment stages these sidestreams would be sludge streams while for sludge treatment stages they may be filtrates, supernatants, etc. Each sludge stream is assigned to either the primary or secondary sludge treatment trains for processing. Of course eventual mixing of these streams is possible depending at what stage secondary sludge treatment ends. All sidestreams from sludge treatment are sent to a designated stage in the wastewater treatment train.

The contents of each wastewater and sludge stream are modeled with the parameters listed in Table 4. In addition to these, each sludge stream is

TABLE 3. UNIT PROCESSES CONTAINED IN EXEC/OP

Wastewater Treatment	Sludge Treatment
Raw Wastewater Pumping	Gravity Thickening
Preliminary Treatment	Air Flotation Thickening
Primary Sedimentation	Anaerobic Digestion
Aeration and Final Settler (Activated Sludge)	Aerobic Digestion
	Nonoxidative Heat Treatment
Primary Sedimentation, Aeration, Final Settler with waste activated sludge returned to the primary settler	Elutriation
	Sand Drying Beds
Trickling Filter	Vacuum Filtration
Rotating Biological Contactor	Centrifugation
Chlorination	Multiple Hearth Incineration
	Truck Transport/Land Spreading
	Truck Transport/Landfilling
	Sludge Holding Tanks

TABLE 4. WASTE STREAM PARAMETERS IN EXEC/OP

Q	Volumetric Flow, mgd
SOC	Suspended Organic Carbon, mg/l
SNBC	Suspended Nonbiodegradable Carbon, mg/l
SON	Suspended Organic Nitrogen, mg/l
SOP	Suspended Organic Phosphorus, mg/l
SFM	Suspended Fixed Matter, mg/l
SBOD	Suspended 5-Day BOD, mg/l
VSS	Volatile Suspended Solids, mg/l
TSS	Total Suspended Solids, mg/l
DOC	Dissolved Organic Carbon, mg/l
DNBC	Dissolved Nonbiodegradable Carbon, mg/l
DN	Dissolved Nitrogen, mg/l
DP	Dissolved Phosphorus, mg/l
DFM	Dissolved Fixed Matter, mg/l
ALK	Alkalinity, mg/l
DBOD	Dissolved 5-Day BOD, mg/l
NH3	Ammonia Nitrogen, mg/l
NO3	Nitrate Nitrogen, mg/l

characterized as to its origin (primary, secondary, or mixed primary and secondary) and the type of stabilization it receives (no stabilization, lime stabilization, digestion, digestion plus elutriation, and heat treatment). This feature allows many of the sludge treatment processes to be assigned different design parameter values depending on the type of sludge handled.

In summary, the preliminary steps needed to organize a design problem into a format acceptable to EXEC/OP are as follows:

(1) Determine the number of treatment stages to employ in the wastewater and sludge treatment trains;

(2) Decide on what process options and design parameter values to use at each treatment stage;

(3) Assign each sludge sidestream generated from wastewater treatment to either the primary or secondary sludge treatment train;

(4) Determine to which wastewater treatment stage the sidestreams from sludge treatment should be recycled.

In practice it will probably be necessary to perform steps 1 and 2 simultaneously to insure that the desired options are considered in the proper order.

Figure 2 illustrates what may be the result of applying these preparatory steps to a hypothetical design problem. Noteworthy features of this example as as follows:

(1) Several design options for the same process are included at stages 3, 4, 9, and 12;

(2) Sludge from primary sedimentation is sent to the primary sludge train while sludge from the activated sludge unit is sent to the secondary sludge train;

(3) The null process option is used in several places to increase the number of possible system configurations;

(4) The mixing point for secondary and primary sludges will depend on at what stage secondary sludge treatment ends. E.g., if the null process is chosen by EXEC/OP at stages 6 and 7, mixing occurs at stage 8. If the null process is chosen at stage 7 but not at stage 6, then stage 9 becomes the mixing point;

(5) The sidestreams generated from sludge processing are returned to stage 3.

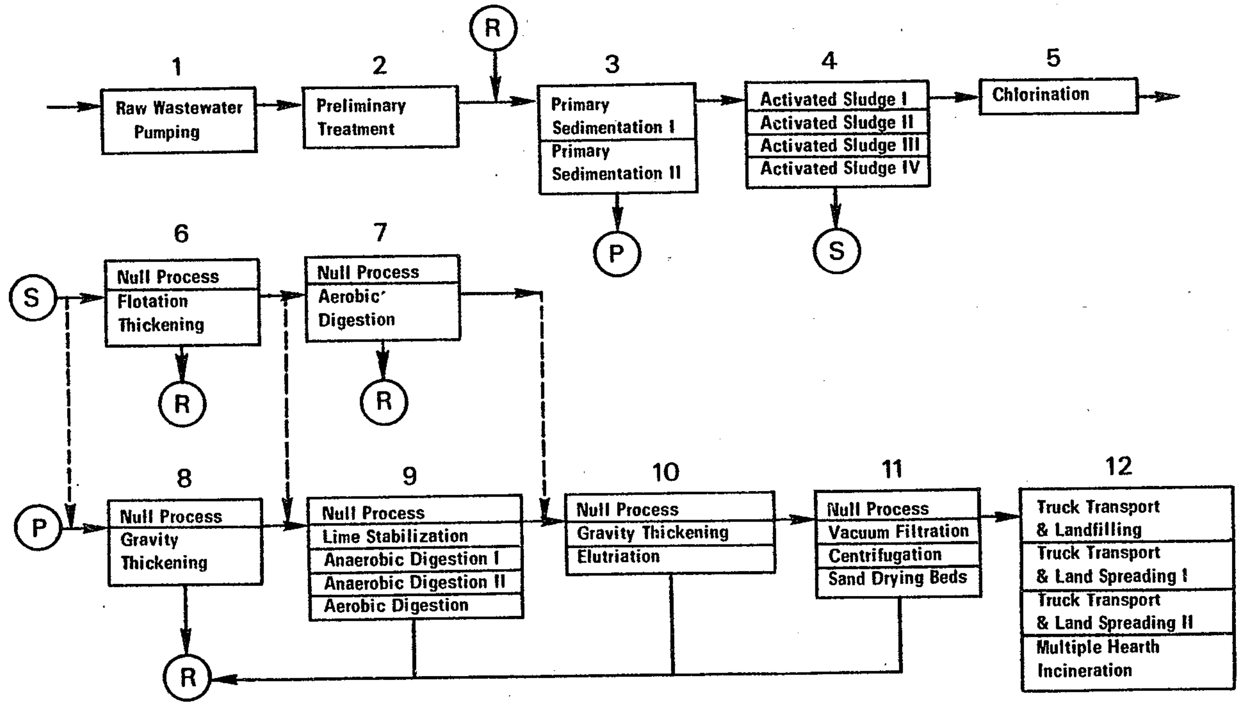

Figure 2. Multi-option flow diagram for a hypothetical design problem

Once a multi-option flow diagram such as Figure 2 has been established, EXEC/OP can be used to select the process option at each stage of the system that will best meet a particular set of design criteria. The current version of EXEC/OP contains eight criteria. They are as follows:

(1) Initial construction cost (million dollars);

(2) Annual operation and maintenance costs, including all energy costs (dollars/million gallons of flow treated);

(3) Total equivalent annual cost consisting of amortized capital costs plus annual operation and maintenance costs (dollars/million gallons of flow treated);

(4) Gross energy consumption consisting of the direct electrical energy needed to operate equipment, the kwh equivalent of all fuel consumed, and the kwh equivalent of the energy used in chemical production (kwh/million gallons of flow treated);

(5) Gross energy production as the kwh equivalent of the usable energy contained in treatment by-products such as digester gas and incinerator exhaust gas (kwh/million gallons of flow treated);

(6) Net energy consumption which is the difference between criteria 4 and 5 (kwh/million gallons of flow treated);

(7) Total land utilization, excluding those process units with small land requirements (acres);

(8) Subjective system undesireability rating.

The first seven criteria should be self-explanatory. The system undesireability rating is arrived at in the following way. Each process option is given a rating by the designer on some convenient scale, say 0 to 10. The higher this rating, the more undesireable the process from whatever standpoint the designer wishes to view it. For example, anaerobic digestion may be rated as 10 and truck transport/land application of sludge be rated at 3 on the basis of reliability. If public acceptance were the issue, these scores might be reversed. Scoring systems can also be devised that take into account several forms of undesireable effects. The total system score is simply the sum of the unit process scores for those options selected in the system design. This is an admittedly crude attempt to incorporate qualitative factors into the screening process. Obviously the designer should use this feature with considerable caution to insure that treatment options are being compared on an equitable and acceptable basis.

The heating value of all fuels is converted into an equivalent electrical energy rating by using an assumed conversion efficiency figure. This figure reflects the thermodynamic efficiency of converting heat energy into electrical energy. Typical values would be from 8,500 BTU/kwh (40 percent conversion efficient) to 11,300 BTU/kwh (30 percent conversion efficiency).

The criteria listed above can be combined into a weighted objective function whose value is to be minimized or can be assigned target limits and treated as constraint conditions by EXEC/OP. The objective function would have the form

$$v = w_1 c_1 + w_2 c_2 + w_3 c_3 + w_4 c_4 - w_5 c_5 + w_6 c_6 + w_7 c_7 + w_8 c_8$$

where the w_i, $i=1,\ldots, 8$ are weighting coefficients chosen by the designer and the c_i, $i=1,\ldots, 8$ are the individual criteria values. Note that $w_5 c_5$ is given a negative value since energy production is to be maximized. The weights should reflect the relative value that each criterion should contribute to deciding which system design is "best". For example, if reducing total cost were thought to be twice as important as reducing gross energy consumption, then the values of w_3 and w_4 should be in the ratio 2:1. For simply minimizing total cost, one would set $w_3 = 1.0$ and all other $w_i = 0$.

Another use for these weights would be to assign a cost credit to any energy produced through waste treatment. For example, if the value of such energy net of its conversion cost was \$0.011/kwh and one was trying to minimize total cost then $w_3 = 1.0$ and $w_5 = 0.011$ with all other $w_i = 0$.

Note that the cost of energy consumption is accounted for in the cost criteria 2 and 3.

When the above criteria are considered as constraints, each is assigned an upper limit (or lower limit for energy production) which cannot be exceeded by any feasible system design. An additional set of constraints consists of the required effluent quality of the wastewater discharge. EXEC/OP can consider effluent standards for 5-day BOD, total suspended solids, phosphorus, ammonia nitrogen, and nitrate nitrogen. Limits on discharges of residuals to the land and air can appear as part of the design parameter data for the individual process units. For example, the process model for land application of sludge asks the designer to supply an allowable nitrogen loading rate in lb N/acre.

EXEC/OP can operate in two different modes of calculation. In the optimization mode it selects the combination of process options that will best meet the stipulated design criteria. In this mode the program can also be asked to identify the M next-best designs that are within X% of best, where M and X are chosen by the designer. The single design evaluation mode allows the user to obtain a detailed description of the performance of a particular system design. This includes the composition of all wastewater and sludge streams and the values of all computed unit process design parameters - information that is not available from the optimization mode because it would require a prodigious amount of computer output. The same input data is used for both modes except that the last lines of data for a single design evaluation lists the process option to be selected at each stage of the system.

The computational algorithm of EXEC/OP employs two basic features. The first is the replacement of the recycle stream from the sludge treatment trains by a vector of penalty terms. These penalties approximate the change in the value of each design criterion as a unit of mass flow of each component of the sidestreams from sludge treatment is returned for treatment in the wastewater treatment train. This device converts the entire treatment system into a serial one, where the waste stream entering stage i is only affected by the decisions made at stages 1, 2,..., i-1.

The second computational feature is an implicit enumeration algorithm that is used to find the optimal unit process choices for the penalty-augmented serial system. It is able to screen out large categories of possible process combinations by employing a simple bounding property. The result is that only a small fraction of the total number of system configurations need to be explicitly evaluated.

Since the values of the recycle penalties depend on the choice of unit processes in the system, an iterative procedure is employed to update the values of these penalties. After each iteration has identified a new, potentially optimal system design by implicit enumeration, the units selected for that design are used to establish new penalty values and another iteration begins. The process stops when a previously generated system design is once again arrived at. The final design is taken as the best design arrived at over all iterations. The penalty values associated with this design are then used once again in the implicit enumeration procedure to identify the M next-best designs. A more detailed, mathematical description of the complete algorithm is presented in Appendix A.

The use of recycle penalties is a heuristic device and thus there is no guarantee that EXEC/OP will be able to identify the true mathematical optimum design. However the error involved would most certainly be small since the recycle stream from sludge processing usually represents only a fraction of the total waste loading on the system. Also, the search for the M next-best designs based on penalty values may be able to identify a design that actually performs better than the best design arrived at in the optimization portion of the algorithm. An example of this is shown in one of the case studies presented in the next section. Finally, given the nature of the preliminary screening process, the designer is less interested in obtaining a mathematical optimum than in generating a set of attractive alternatives and eliminating those that are clearly inferior. EXEC/OP was developed with this type of goal in mind.

SECTION 5

CASE STUDIES

This section demonstrates the capabilities of EXEC/OP by means of several system design case studies. It should be understood that the problems analyzed are purely hypothetical. The values used for the process design parameters were specifically chosen to make several processes competitive with one another. Therefore, no general conclusions regarding the general superiority of one type of process versus another should be drawn from these examples.

The case studies to be presented were chosen to illustrate the following types of design problems:

(1) Cost minimization of a conventional secondary treatment system with the emphasis on the choice of sludge management strategies;

(2) A cost minimization of secondary treatment featuring several non-conventional arrangements of primary sedimentation and activated sludge units;

(3) Refinement of the design for Case Study 1 with the emphasis on the choice of design parameter values for a fixed arrangement of process units;

(4) A detailed performance evaluation of the design arrived at in Case Study 3;

(5) A cost/energy-effectiveness analysis for the process options considered in Case Study 1.

All of the case studies are for a 10 mgd system whose influent wastewater characteristics are given in Table 5. Values assumed for various economic parameters are shown in Table 6. All examples must provide an effluent quality of 30 mg/l of 5-day BOD and 30 mg/l of suspended solids.

CASE STUDY 1

In this example, the least cost combination of process units will be found for the multi-option flow diagram in Figure 3. In addition, the four system designs closest to least-cost will also be sought. Note that several choices of primary sedimentation and activated sludge design levels are available. Separate thickening and/or aerobic digestion of

TABLE 5. INFLUENT WASTE CHARACTERISTICS USED FOR CASE STUDIES

Component	Value
Volume flow, mgd	10. (37,850 cu m/day)
Suspended organic carbon, mg/l	105.
Suspended nonbiodegradable carbon, mg/l	30.
Suspended organic nitrogen, mg/l	10.
Suspended organic phosphorus, mg/l	2.
Suspended fixed matter, mg/l	30.
Suspended 5-day BOD, mg/l	140.
Volatile suspended solids, mg/l	224.
Total suspended solids, mg/l	254.
Dissolved organic carbon, mg/l	43.
Dissolved nonbiodegradable carbon, mg/l	11.
Dissolved nitrogen, mg/l	19.
Dissolved phosphorus, mg/l	4.
Dissolved fixed matter, mg/l	500.
Alkalinity, mg/l	250.
Dissolved 5-day BOD, mg/l	60.
Ammonia nitrogen as N, mg/l	15.
Nitrate nitrogen as N, mg/l	0.

TABLE 6. ECONOMIC PARAMETERS USED FOR CASE STUDIES

EPA Sewage Treatment Plant Cost Index	2.88 (December 1977)
Wholesale Price Index	2.00 (December 1977)
Discount Rate	0.06375
Planning Period	20 yr.
Direct Hourly Wage	5.91 $/hr.
Fraction of Direct Hourly Wage Charged to Indirect Labor Costs	0.15
Cost of Electricity	0.033 $/kwh
Cost Escalator for Yardwork, Laboratories, Legal Fees, Engineering and Interest	1.33
Efficiency of Converting Heat Value of Fuels to Equivalent Electrical Energy	0.31

waste activated sludge is also possible. Ultimate sludge disposal can be accomplished by either land spreading at one of two alternative sites, landfilling, or incineration. The process options shown in Figure 3 can be arranged into 15,360 different system configurations.

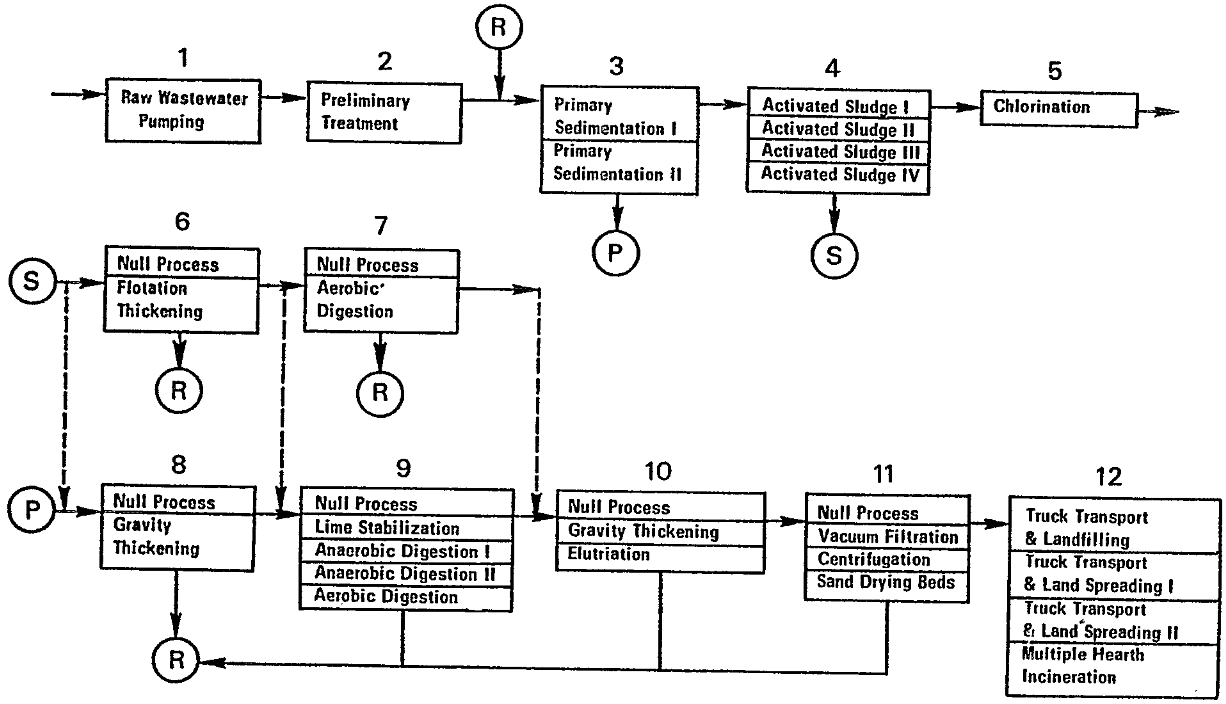

Figure 3. Multi-option flow diagram for case study 1

Table 7 provides information on the input design parameters for the unit process options. Additional data for the vacuum filtration and centrifugation options are given in Table 8. Since this example seeks to minimize total cost, the only non-zero selection criterion weight is for criterion 3, total cost. All constraint limits on the various criteria have been set to arbitrarily high numbers (or to 0 for energy production).

The results of running this problem with EXEC/OP are shown in Table 9. The first portion of the table lists the designs arrived at for each iteration of the optimization phase of EXEC/OP. These are then followed by a listing of the 5 least-cost designs identified in the sensitivity phase of the program. These results show that three iterations were needed on the penalty terms to obtain the least-cost design. It consists of using 60 percent solids removal in primary sedimentation, activated sludge at 3000 mg/l mixed liquor volatile solids and 30 percent recycle, anaerobic digestion of mixed primary and secondary sludge for 15 days, thickening to 5 percent solids, sludge drying on sand beds, and incineration of dried sludge. The total cost is 27.6 ¢/1000 gal. The somewhat surprising result of choosing sludge incineration over land disposal may be due to the high cost of land,

TABLE 7. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 1

PRI = primary sludge Process	WAS = waste activated sludge Design Parameter	MIX = PRI + WAS Value
Pumping	Pumping Head, Ft.	30.0
Preliminary Treatment	Grit Removal Flow Measurement Screening	Yes Yes Yes
Primary Sedimentation I	TSS removal, %	40.0
Primary Sedimentation II	TSS removal, %	60.0
Activated Sludge I[a]	MLVSS, mg/l Recycle ratio	2000.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2000.0 0.5
Activated Sludge III	MLVSS, mg/l Recycle ratio	3000.0 0.3
Activated Sludge IV	MLVSS, mg/l Recycle ratio	3000.0 0.5
Chlorination	Chlorine dosage, mg/l Contact time, min.	8.0 30.0
Air Flotation Thickening	Solids recovery ratio Underflow TSS, % Loading, lb/day/sq ft	0.95 4.0 48.0
Gravity Thickening	Solids recovery ratio Underflow TSS, Loading, lb/day/sq ft	0.9 8.0 (PRI) 5.0 (MIX) 16.0 (PRI) 8.0 (MIX)

[a]All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS.

(continued)

TABLE 7 (continued)

Process	Design Parameter	Value
Anaerobic Digestion I	Detention time, days	15.0
Anaerobic Digestion II	Detention time, days	20.0
Aerobic Digestion	Detention time, days	10.0 (WAS) 20.0 (PRI & MIX)
Lime Stabilization	Dosage, lb/ton dry solids	200.0
Elutriation	Solids recovery ratio	0.76
	Underflow TSS, %	4.0
	Loading, lb/day/sq ft	8.0
	Washwater ratio	3.0
Vacuum Filtration	Loading, gph/sq ft	10.0
	Chemical dosage, %	See Table 8
Centrifugation	Solids recovery ratio	See Table 8
	Cake solids, %	
	Feed rate, gpm	
Sand Drying Beds	Cake solids %	30.0
	Storage detention time, days	15.0
Incineration	Mass loading, lb/hr/sq ft	2.0
	Heat value of volatiles, BTU/lb	10000.0
	Type of fuel	oil
Land Spreading I	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0
	N application rate, lb/acre/yr	400.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Land Spreading II	One way haul distance, miles	30.0
	Cost of land, $/acre	2000.0
	N application rate, lb/acre/yr	600.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Landfilling	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0

TABLE 8. INPUT DESIGN PARAMETERS FOR VACUUM FILTRATION AND CENTRIFUGATION

Vacuum Filtration Chemical Requirements

Ferric Chloride, % / Lime, %

	Stabilization Process Used			
Sludge Type	Raw	Limed	Digested	Digested/Elutriated
Primary	2.1/8/8	2.1/0	3.8/12.	3.4/0
Primary + Waste Activated	2.6/10.	2./0	5.5/18.5	6.25/0

Centrifugation Design Variables

Solids recovery ratio / Cake solids, % / Polymer dose, lb/ton / Feed rate, gpm

	Stabilization Process Used			
Sludge Type	Raw	Limed	Digested	Digested/Elutriated
Primary	.9/32/3/90	.9/30/3/160	.9/25/2/100	.9/25/2/100
Primary & Waste Activated	.9/19/6/80	.9/30/4/160	.85/22/4/80	.95/22/4/80

TABLE 9. LEAST-COST DESIGNS FOR CASE STUDY 1

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption kwh/mil gal.	Energy Production kwh/mil gal.
Optimization Phase					
1	Primary Sedimentation II Activated Sludge III	Gravity Thickening Anaerobic Digestion I Elutriation Land Spreading I	29.1	1234	411
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Incineration	27.6	1307	419
3	Same as Design 2				
Sensitivity Phase					
1	Same as Design 2 of Optimization Phase		27.6	1307	419
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Land Spreading I	27.8	1265	418

(continued)

TABLE 9 (continued)

Design	Wastewater Process Selections	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil gal.	Energy Production, kwh/mil gal.
3	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Landfilling	27.8	1225	419
4	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion II Gravity Thickening Sand Drying Beds Incineration	28.0	1353	426
5	Primary Sedimentation I Activated Sludge III	Anaerobic Digestion II Gravity Thickening Sand Drying Beds Landfilling	28.1	1271	426

[a]All designs utilize Pumping, Preliminary Treatment, and Chorination in the wastewater treatment train.

the low cost of dewatering on sand beds, the rather severe nitrogen limitation on the nearby sludge spreading site, and the absence of any air pollution controls on the incinerator. Note that designs 2 and 3 of the sensitivity phase are only 0.7 percent (0.2 ¢/1000 gal) more expensive. Design 3 uses landfilling instead of incineration and design 2 employs land spreading of liquid sludge.

It is interesting to observe the effect of the recycles from sludge treatment on the design choices in this problem. Had no account been taken of these recycles, design 1 of the optimization phase would have been designated as least-cost. Note that its true cost is 29.1 ¢/1000 gal. which is 5.4 percent more expensive than design 2.

The total computational effort for arriving at the results in Table 9 was estimated as being only 5.5 percent of that needed to evaluate all 15,360 alternatives one at a time. The solution time for this problem was approximately 360 seconds on a DEC PDP-11/70 computer.

CASE STUDY 2

The multi-option flow diagram for this example is shown in Figure 4. It represents an activated sludge system that features the options of returning the waste activated sludge to the primary clarifier or not using

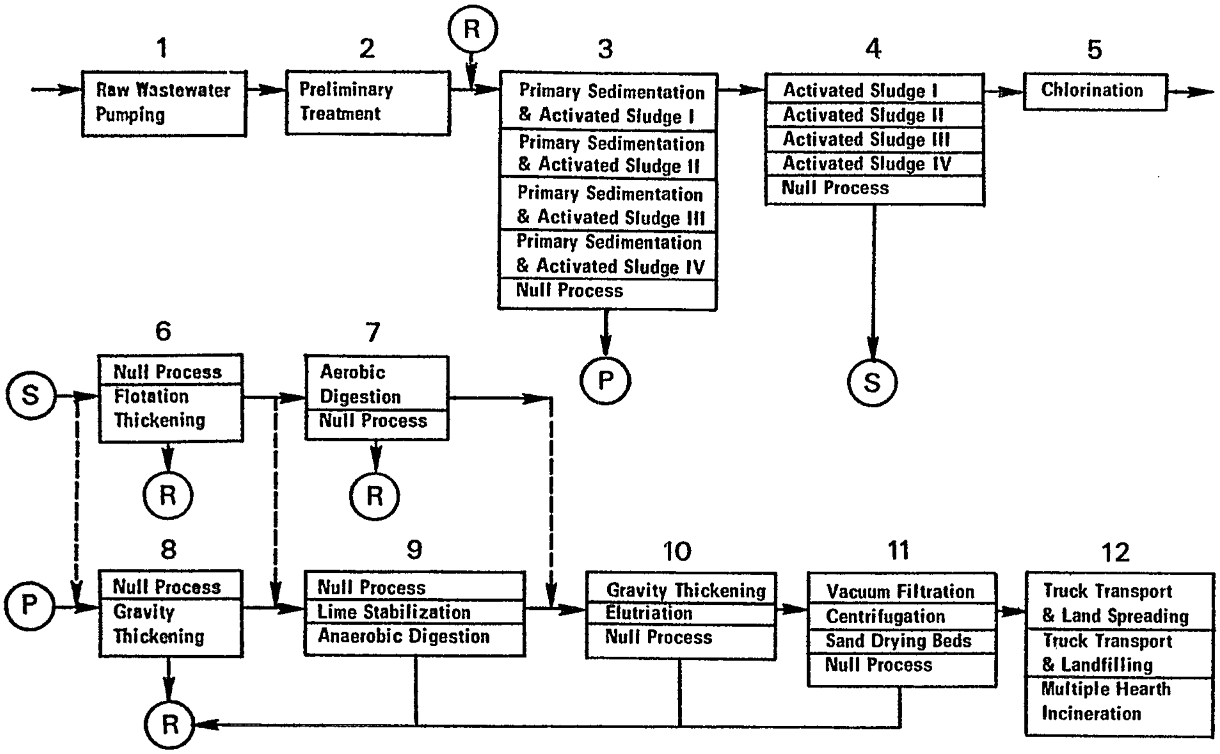

Figure 4. Multi-option flow diagram for case study 2

any primary sedimentation. Several different design levels for the activated sludge units have been considered. Note how the "null process" is used at stages 3 and 4 to allow a choice of one or the other of the two types of activated sludge options. The values of the input design parameters for the unit process options are given in Table 10. The options shown in Figure 4 can be arranged into 21,600 different systems. Once again EXEC/OP will be used to estimate the top five least-cost designs.

The results for this study are displayed in Table 11. Note that one of the "next best" designs (number 1) is actually lower in cost (by only 0.5 percent) than the best design found in the optimization phase (number 2). This is a result of the heuristic nature of the optimization algorithm of EXEC/OP and it demonstrates another advantage to using the next-best design feature of the program.

The least-cost design employs activated sludge at a mixed liquor volatile solids concentration of 3000 mg/l and a recycle ratio of 0.3 with the waste activated sludge returned to the primary sedimentation tank. Sludge processing consists of anaerobic digestion, gravity thickening, sand drying, and incineration. Total cost is 27.8 ¢/1000 gal. As mentioned above, substitution of landfilling for incineration increases costs by only 0.5 percent to 27.9 ¢/1000 gal. In comparison, the same design obtained in Case Study 1, where no recycling of waste activated sludge to primary sedimentation was considered, had a total cost of 27.6 ¢/1000 gal. Its energy production from anaerobic digestion was 419 kwh/mil. gal. as opposed to 354 kwh/mil. gal. for this case study. Thus for the design data used in these examples, there does not appear to be any advantage to returning waste activated sludge to the primary clarifier rather than mixing it with primary sludge prior to digestion.

The computations required to arrive at the results in Table 11 represented only 2.2 percent of the effort needed to evaluate all 21,600 possible designs individually. The solution time for this problem was 282 seconds on the DEC PDP 11/70 computer.

CASE STUDY 3

This example demonstrates how EXEC/OP can be used to "fine tune" the design levels of the process units in a system design. The process units chosen as the least-cost alternative for Case Study 1 will be used for this purpose. Figure 5 shows the multi-option flow diagram for this problem. The design levels for the primary sedimentation, activated sludge, anaerobic digestion, and gravity thickening units are to be refined so that total system cost is minimized. The design option denoted as number I for each of these units corresponds to the design level associated with the least-cost system of Case Study 1. Recall that the total cost of this system was 27.6 ¢/1000 gal. The treatment stages in this flow diagram have been set up to be compatible with those of Case Study 1. Because of this the "null process" units at stages 7 and 8 are redundant and could be eliminated if so desired (leaving a system with 10 stages instead of 12).

TABLE 10. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 2

PRI = primary sludge WAS = waste activated sludge MIX = PRI + WAS

Process	Design Parameter	Value
Pumping	See Table 7	
Preliminary Treatment	See Table 7	
Primary Sedimentation	TSS removal, %	50.0
Activated Sludge I[a]	MLVSS, mg/l Recycle ratio	2000.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2000.0 0.5
Activated Sludge III	MLVSS, mg/l Recycle ratio	3000.0 0.3
Activated Sludge IV	MLVSS, mg/l Recycle ratio	3000.0 0.5
Chlorination	See Table 7	
Air Flotation Thickening	See Table 7	
Aerobic Digestion	Detention time, days	10.0
Gravity Thickening	Solids recovery ratio Underflow TSS, % Loading, lb/day/sq. ft.	0.9 2.0 (WAS) 5.0 (MIX) 6.0 (WAS) 8.0 (MIX)
Anaerobic Digestion	Detention time, days	15.0
Lime Stabilization	See Table 7	

[a]All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

(continued)

TABLE 10 (continued)

Process	Design Parameter	Value
Elutriation	Solids recovery ratio	0.76
	Underflow TSS, %	2.0 (WAS)
		4.0 (MIX)
	Loading, lb/day/sq. ft.	6.0 (WAS)
		8.0 (MIX)
	Washwater ratio	3.0
Vacuum Filtration	Loading, gph/sq. ft.	10.0
	Chemical dosage, %	See Table 8
Centrifugation	Solids recovery ratio	See Table 8
	Cake solids, %	"
	Feed rate, gpm	"
Sand Drying Beds	See Table 7	
Land Spreading	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0
	N application rate, lb/acre/yr	400.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Landfilling	See Table 7	
Incineration	See Table 7	

TABLE 11. LEAST-COST DESIGNS FOR CASE STUDY 2

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil. gal.	Energy Production, kwh/mil. gal.
Optimization Phase					
1	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Elutriation Land Spreading	28.9	1278	356
2	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Sand Drying Beds Landfilling	27.9	1217	354
3	Same as Design 2				
Sensitivity Phase					
1	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Sand Drying Beds Incineration	27.8	1299	354
2	Same as Design 2 of Optimization Phase		27.9	1217	354

[a]All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

(continued)

TABLE 11 (continued)

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil. gal.	Energy Production, kwh/mil. gal
3	Primary Sedimentation + Activated Sludge IV	Anaerobic Digestion Gravity Thickening Sand Drying Beds Incineration	28.1	1331	354
4	Primary Sedimentation + Activated Sludge IV	Anaerobic Digestion Gravity Thickening Sand Drying Beds Landfilling	28.2	1249	354
5	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Land Spreading	28.3	1261	354

[a]All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

TABLE 12. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 3

Process	Design Parameter	Value
Pumping	See Table 7	
Preliminary Treatment	See Table 7	
Primary Sedimentation I	TSS removal, %	60.0
Primary Sedimentation II	TSS removal, %	50.0
Primary Sedimentation III	TSS removal, %	55.0
Activated Sludge I[a]	MLVSS, mg/l Recycle ratio	3000.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2500.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2500.0 0.3
Activated Sludge III	MLVSS, mg/l Recycle ratio	3500.0 0.3
Activated Sludge IV	MLVSS, mg/l Recycle ratio	2500.0 0.35
Activated Sludge V	MLVSS, mg/l Recycle ratio	3000.0 0.35
Activated Sludge VI	MLVSS, mg/l Recycle ratio	3500.0 0.35
Activated Sludge VII	MLVSS, mg/l Recycle ratio	2500.0 0.25
Activated Sludge VIII	MLVSS, mg/l Recycle ratio	3000.0 0.25

[a]All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

(continued)

TABLE 12 (continued)

Process	Design Parameter	Value
Activated Sludge IX	MLVSS, mg/l Recycle ratio	3500.0 0.25
Chlorination	See Table 7	
Anaerobic Digestion I	Detention time, days	15.0
Anaerobic Digestion II	Detention time, days	12.0
Anaerobic Digestion III	Detention time, days	17.0
Gravity Thickening I	Solids recovery ratio Underflow TSS, % Loading, lb/day/sq. ft.	0.9 5.0 8.0
Gravity Thickening II	Solids recovery ratio Underflow TSS, % Loading, lb/day/sq. ft.	0.9 4.0 12.0
Gravity Thickening III	Solids recovery ratio Underflow TSS, % Loading, lb/day/sq. ft.	0.9 7.0 5.0
Sand Drying Beds	See Table 7	
Incineration	See Table 7	

[a]All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

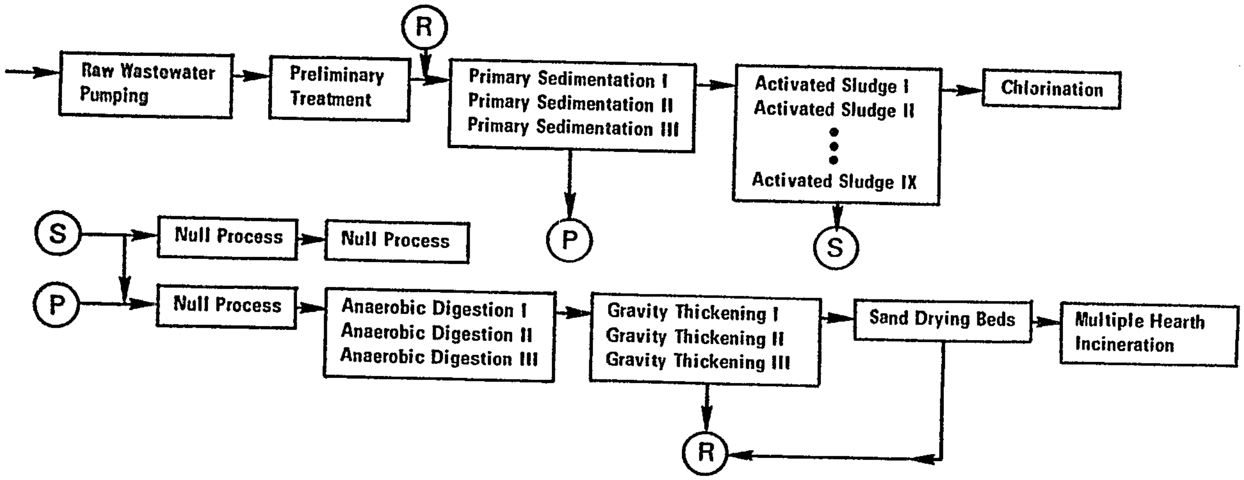

Figure 5. Multi-option flow diagram for case study 3

The significant input design parameter values associated with the unit process options are given in Table 12. The resulting least-cost selection arrived at by EXEC/OP is shown in Table 13. Since only the single least-cost design is desired there is no sensitivity phase listing for this example. Only two iterations on the recycle penalty values were needed to reach a design whose total cost is 26.95 ¢/1000 gal. This gives only a 2.4 percent savings over the initial design. The improved design indicates that one should try to remove as much solids as possible in primary sedimentation, use the highest solids concentration and lowest recycle ratio in activated sludge, use the minimum amount of digestion time and thicken to the greatest extent possible. The CPU time required for this problem was 26.63 seconds on the DEC PDP 11/70.

TABLE 13. LEAST-COST DESIGN FOR CASE STUDY 3

Design	Wastewater Process Selections	Sludge Process Selections	Total Cost ¢/1000 gal.	Gross Energy Consumption, kwh/mil gal.	Energy Production, kwh/mil gal.
1	Pumping Preliminary Treatment Primary Sedimentation I Activated Sludge IV Chlorination	Anaerobic Digestion II Gravity Thickening III Sand Drying Beds Incineration	26.95	1240	414
2	Same as Design 1				

The results of this case study leads one to speculate on the relative importance of system structural choices versus individual unit design choices. It may be that in general the former are more critical. This would follow as a result of the fact that the acceptable ranges of the design parameters for most processes are usually fairly small and, as borne out in this example, the total system resource utilization will be relatively insensitive to adjustments in the design of a single process unit.

CASE STUDY 4

This example demonstrates the single design evaluation feature of EXEC/OP. Detailed performance is to be obtained for the least-cost design arrived at in Case Study 3. This simply requires that the EXEC/OP input data for Case Study 3 be re-run with the addition of two lines of data that specify the choice of process options at each stage of the system to be analyzed.

The results of running EXEC/OP on this problem are shown in the printout reproduced in Figure 6. Summaries of the process options, the selection criteria, and the economic parameters are first presented. Note that each process option is identified by a user assigned option number, a standard process code number, and the number of the stage at which the process appears. Next there appears a listing of the criterion values associated with the process option chosen at each stage of the system. This is followed by a detailed listing of the input and computed output design parameter values and the composition of the influent, effluent, and sidestream waste streams for each process. For reasons of programming economy, the process design data are listed in the order in which they are specified for each process description given in Appendix C without any additional explanatory headings. The headings on the waste stream constituents correspond to the abbreviations used in Table 4.

CASE STUDY 5

The examples presented up until now have all been single objective design problems, i.e., minimize total cost. In this case study the conflicting objectives of minimizing cost and minimizing energy consumption will be considered. It is shown how EXEC/OP can be used to efficiently identify those system designs that offer meaningful trade-offs between these two objectives. The implication behind a cost/energy-effectiveness analysis is that the market price of energy or fuel does not represent its true social value as a scarce resource and that the least-cost design will not also be the least-energy design.

The set of design options to be used in this example is the same as used in Case Study 1 (see Figure 3). The analysis is performed by making a series of runs with EXEC/OP in which total cost is minimized while energy consumption is constrained not to exceed a specified target level. As the target level is varied, systems with different cost-energy combinations will be generated. None of these designs will be inferior in the sense that there will exist some other design that has both lower values of cost and

EXECUTIVE PROGRAM
(OPTIMIZATION VERSION)
FOR
PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
SYSTEMS AND ECONOMIC ANALYSIS SECTION
CINCINNATI, OHIO 45268

CASE STUDY 4

PROCESS ALTERNATIVES

OPTION NO.	PROCESS NO.	STAGE NO.	SIDESTREAM DESTINATION	REMARKS
1	15	1	8	RAW WASTEWATER PUMPING
2	1	2	8	PRELIMINARY TREATMENT
3	2	3	8	PRIMARY SEDIMENTATION (50% SOLIDS REMOVAL)
4	2	3	8	(55% SOLIDS REMOVAL)
5	2	3	8	(60% SOLIDS REMOVAL)
6	3	4	6	ACTIVATED SLUDGE (MLVSS=2500, R=.3)
9	3	4	6	(MLVSS=3000, R=.3)
10	3	4	6	(MLVSS=3500, R=.3)
11	3	4	6	(MLVSS=2500, R=.35)
12	3	4	6	(MLVSS=3000, R=.35)
13	3	4	6	(MLVSS=3500, R=.35)
14	3	4	6	(MLVSS=2500, R=.25)
15	3	4	6	(MLVSS=3000, R=.25)
16	3	4	6	(MLVSS=3500, R=.25)
17	12	5	6	CHLORINATION (8 MG/L DOSAGE)
30	0	6	3	NULL PROCESS
30	0	7	3	NULL PROCESS
30	0	8	3	NULL PROCESS
18	6	9	3	ANAEROBIC DIGESTION (15 DAYS)
19	6	9	3	(12 DAYS)
20	6	9	3	(17 DAYS)
21	8	10	3	GRAVITY THICKENING (TO 5% SOLIDS)
22	8	10	3	(TO 4% SOLIDS)
23	8	10	3	(TO 7% SOLIDS)
24	10	11	3	SAND DRYING BEDS (30% CAKE SOLIDS)
25	14	12	3	INCINERATION (2 LB/HR/SQ FT)

Figure 6. EXEC/OP output for case study 4

SELECTION CRITERIA

	CRITERION	WEIGHT	LIMIT
1.	INITIAL CONSTR. COST, M$	0.00	10000.00
2.	ANNUAL O & M COST, $/MG	0.00	10000.00
3.	TOTAL ANNUAL COST, $/MG	1.00	10000.00
4.	ENERGY CONSUMED, KWH/MG	0.00	10000.00
5.	ENERGY PRODUCED, KWH/MG	0.00	0.00
6.	NET ENERGY CONSUMED, KWH/MG	0.00	10000.00
7.	LAND REQUIRED, ACRES	0.00	10000.00
8.	UNDESIREABILITY INDEX	0.00	10000.00

ECONOMIC DATA

CONSTRUCTION COST INDEX	2.8800
WHOLESALE PRICE INDEX	2.0000
DIRECT HOURLY WAGE, $/HR	5.9100
FRACTION CHARGED TO SUPERVISION	0.1500
COST ESCALATOR FOR MISC. FEES	1.3300
COST OF ELECTRICITY, $/KWH	0.0330
FUEL CONVERSION EFFICIENCY	0.3100
DISCOUNT RATE	0.0637
CAPITAL RECOVERY FACTOR	0.0899

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0.00	0.91	10.09	32.39	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.28	9.36	16.15	5.22	0.00	5.22	0.00	0.00
3	5	6.68	0.59	12.37	26.88	8.71	0.00	8.71	0.00	0.00
4	16	1.69	1.48	47.26	83.59	625.09	0.00	625.09	0.00	0.00
5	17	0.00	0.29	17.52	24.65	120.53	0.00	120.53	0.00	0.00
9*	19	8.37	0.52	5.44	18.33	236.55	413.99	-177.44	0.00	0.00
10	23	4.39	0.14	1.88	5.21	1.53	0.00	1.53	0.00	0.00
11	24	3.95	0.32	19.60	27.54	0.90	0.00	0.90	0.89	0.00
12	25	3.95	0.88	13.05	34.78	99.66	0.00	99.66	0.00	0.00
SYSTEM VALUES		8.37	5.40	136.57	269.51	1239.56	413.99	825.57	0.89	0.00

Figure 6. (continued)

PROCESS PERFORMANCE CHARACTERISTICS

VOLUME FLOW, MGD
CONCENTRATION, MG/L
CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT AND OUTPUT DESIGN DATA.

STAGE 1 PROCESS OPTION 1

INPUT DESIGN DATA:

30.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.004	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

14.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

STAGE 2 PROCESS OPTION 2

INPUT DESIGN DATA:

1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
10.049	108.567	33.639	10.425	2.073	33.330	139.866	237.592	265.946
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
43.625	11.000	22.409	4.915	500.000	262.173	61.167	15.013	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6. (continued)

STAGE 3 PROCESS OPTION 5

INPUT DESIGN DATA:

0.600	200.000	14.000	0.000	0.000	0.000	0.000	0.000	
0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	

OUTPUT DESIGN DATA:

868.395	11.572	251.229	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.049	108.567	33.639	10.425	2.073	33.330	139.866	237.592	265.946
10.019	43.557	13.496	4.182	0.832	13.372	56.115	95.323	106.698
0.030	21713.410	6727.855	2084.939	414.547	6665.948	27973.236	47518.363	53189.203
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.625	11.000	22.409	4.915	500.000	262.173	61.167	15.013	0.000
43.625	11.000	22.409	4.915	500.000	262.173	61.167	15.013	0.000
43.625	11.000	22.409	4.915	500.000	262.173	61.167	15.013	0.000

STAGE 4 PROCESS OPTION 16

INPUT DESIGN DATA:

30.000	30.000	3500.000	0.250	200.000	0.500	10.000	0.480	
7.000	0.050	800.000	30.000	1.000	1.000	1.000	1.000	

OUTPUT DESIGN DATA:

117.282	4.154	0.007	13.573	10.000	0.266	0.678	0.678	1381.824
0.000	2118.176	305.168	820.827	94.737	0.250	7.000	9888385.000	6866.934
0.987	2.505							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.019	43.557	13.496	4.182	0.832	13.372	56.115	95.323	106.698
10.000	10.513	7.393	2.034	0.240	5.699	7.445	24.301	30.000
0.019	7472.423	5254.837	1445.460	170.477	4050.645	5291.604	17271.926	21322.572
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.625	11.000	22.409	4.915	500.000	262.173	61.167	15.013	0.000
17.271	11.000	21.819	5.183	500.000	262.173	22.545	21.819	0.000
17.271	11.000	21.819	5.183	500.000	262.173	22.545	21.819	0.000

Figure 6. (continued)

STAGE 5 PROCESS OPTION 17

INPUT DESIGN DATA:

8.000	30.000	220.000	2.500	180.000	0.000	0.000	0.000	
0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	

OUTPUT DESIGN DATA:

27852.041	121.618	38.006	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	10.513	7.393	2.034	0.240	5.699	7.445	24.301	30.000
10.000	10.513	7.393	2.034	0.240	5.699	7.445	24.301	30.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
17.271	11.000	21.819	5.183	500.000	262.173	22.545	21.819	0.000
17.271	11.000	21.819	5.183	500.000	262.173	22.545	21.819	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

STAGE 9 PROCESS OPTION 19

INPUT DESIGN DATA:

12.000	30.000	0.500	0.310	0.000	0.000	0.000	0.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	

OUTPUT DESIGN DATA:

0.234	1154.105	78.854	75964.641	39894.750	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.049	16207.044	6158.303	1837.681	320.176	5654.725	19203.240	35823.391	40867.770
0.049	6637.448	6158.303	770.373	134.221	5654.725	896.000	15797.126	21451.852
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
33.435	11.000	22.181	5.018	500.000	262.173	46.234	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6. (continued)

STAGE 12 PROCESS OPTION 25

INPUT DESIGN DATA:

2.000	2.000	35.000	5.000	0.000	10000.000	1.000	0.300
1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

411.000	198371.703	7904.947	3073.583	7955.021	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.003	90171.328	83662.039	10465.706	1823.422	76820.797	12172.380	214607.750	300000.000
0.049	834.422	774.187	96.847	16.873	710.880	112.640	1985.925	2696.804
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.861	298.667	17.645	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6. (continued)

STAGE 10 PROCESS OPTION 23

INPUT DESIGN DATA:

0.900	70000.000	700.000	5.000	70000.000	70000.000	70000.000	5.000	
5.000	5.000	0.000	0.000	0.000	0.000	0.000	1.000	

OUTPUT DESIGN DATA:

1756.655	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.049	6637.448	6158.303	770.373	134.221	5654.725	896.000	15797.126	21451.852
0.014	21658.799	20095.293	2513.822	437.979	18452.055	2923.758	51547.941	70000.000
0.036	916.534	850.371	106.377	18.534	780.834	123.724	2181.350	2962.184
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000

STAGE 11 PROCESS OPTION 24

INPUT DESIGN DATA:

0.300	2000.000	0.300	0.300	0.300	15.000	1.000	3000.000	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	

OUTPUT DESIGN DATA:

40519.719	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.014	21658.799	20095.293	2513.822	437.979	18452.055	2923.758	51547.941	70000.000
0.003	90171.328	83662.039	10465.706	1823.422	76820.797	12172.380	214607.750	300000.000
0.014	618.823	574.151	71.823	12.514	527.202	83.536	1472.798	2000.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000
170.715	11.000	715.931	190.974	500.000	2738.860	298.667	17.645	0.000

Figure 6. (continued)

energy. It is only from this reduced, non-inferior set of alternatives that trade-offs between cost and energy need to be made to arrive at a final design decision [27].

The concept of the non-inferior or efficient set of alternatives in a multi-objective design problem is graphically illustrated in Figure 7. This figure considers a case where there are only ten feasible system designs and plots the position of each alternative on a set of cost-energy axes. Consider a comparison between alternative A and alternative B. No meaningful trade-off exists since B dominates A in both cost and energy. A is said to be inferior to B and can be discarded from the decision making process, providing that cost-and energy-effectiveness are the only decision criteria. The non-inferior or efficient set of designs are those that are not inferior to any other design. By inspection we see that alternatives B, D, F, and H form the non-inferior set for Figure 7. All other alternatives could be ignored.

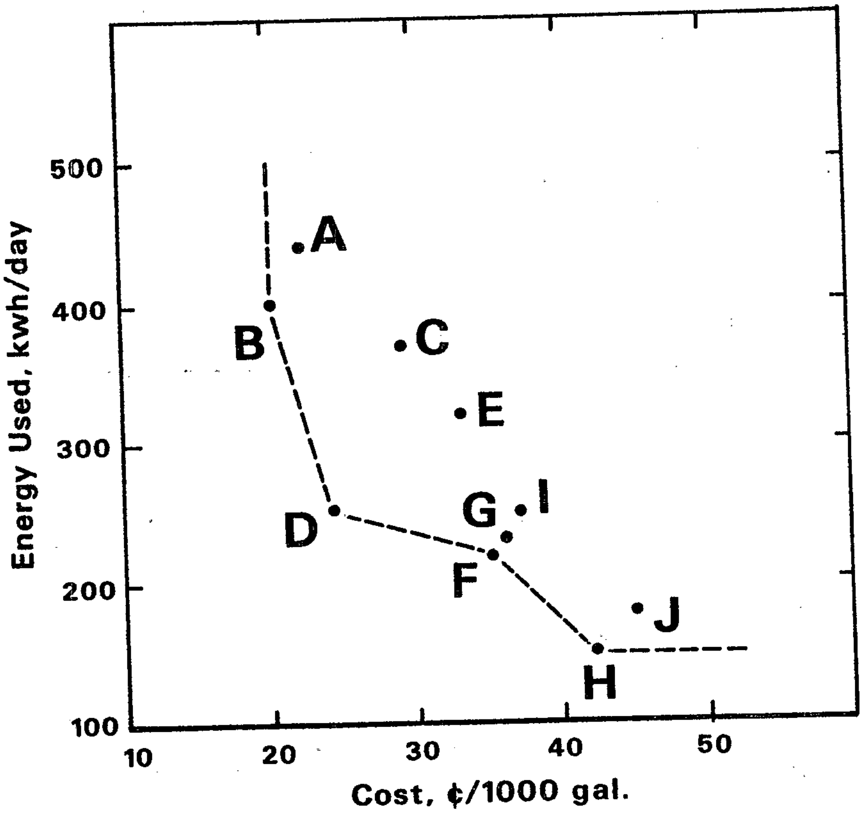

Figure 7. Illustration of the non-inferior set

For the ten designs considered in Figure 7 it was possible to identify the non-inferior set by inspection. Had there been a larger number of alternatives and objectives a more systematic procedure would be needed. The constraint method, as described above, wherein cost is minimized while energy is constrained not to exceed various target levels, is one such procedure. Thus in Figure 7, if we minimize cost and constrain energy to not exceed 150 kwh/day we obtain alternative H; for energy constrained anywhere between 150 and 220 kwh/day alternative F is identified; and so on. Of course a final choice between systems B, D, F, and H would depend on the designer's subjective preferences regarding the relative value of the cost and energy figures for these designs. Although the concept of non-inferiority was demonstrated here for only two objectives it also applies to higher dimensional problems as well.

Referring back to the process options of Figure 3, EXEC/OP was used to perform a cost/energy-effectiveness analysis for two different conditions: a) no energy recovery was practiced and b) digester gas was converted into electricity with 31 percent efficiency at a net credit of 0.011 \$/kwh (the commercial price of electricity minus an assumed conversion cost of 0.022 \$/kwh). In both cases the same EXEC/OP input data as in Case Study 1 (Tables 7 and 8) was used with the following exceptions. With no energy recovery, the value of the constraint limit on gross energy consumption was reduced from one run to the next to obtain a series of least-cost designs under progressively tighter energy constraints. A similar procedure was followed for the case of digester gas recovery except that the weighting coefficient for energy production was set equal to the cost credit of 0.011 \$/kwh and the net energy consumption constraint limit was reduced at each successive run of EXEC/OP.

As an example of the type of results obtained from this procedure, Table 14 summarizes the EXEC/OP output for the case where net energy consumption (with digester gas recovery) was constrained to be at or below 850 kwh/mil. gal. Note that the first design arrived at in the optimization phase is infeasible because its net energy consumption is 911 kwh/mil. gal. The best design is found to be number 2. In comparison with the least-cost, energy unconstrained design it substitutes landfilling for incineration of sludge, thus reducing net energy consumption from 888 kwh/mil. gal. to 806 kwh/mil. gal. Note that the objective function values for this design equals the total cost of the system, 27.76 ¢/1000 gal. minus the energy credit of 0.011 \$/kwh times 418.9 kwh/mil. gal. (the energy content of the digester gas), or 0.46 ¢/1000 gal. giving a total of 27.3 ¢/1000 gal.

The results of the cost/energy-effectiveness analysis are summarized in Table 15. All of these non-inferior designs utilize the same wastewater treatment - 60 percent solids removal in primary sedimentation and activated sludge with 3000 mg/l MLVSS and 30 percent recycle. As an example of the kinds of trade-offs that these alternative systems present, consider those with no energy recovery. Table 15 shows that a maximum energy reduction of 23 percent can be realized at a 16 percent increase in system cost by going from system 1a to system 5a. A more attractive trade-off may be with system 2a which offers a 6.3 percent energy reduction for less than a one

TABLE 14. LEAST-COST ENERGY CONSTRAINED DESIGN FOR CASE STUDY 5

Design	Wastewater Process Selections	Sludge Process Selections	Objective Value	Total Cost ¢/1000 gal.	Net Energy Consumption kwh/mil gal.	Energy Production kwh/mil gal.
Optimization Phase						
1	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Elutriation Sand Drying Beds Incineration	27.68	28.1	911.3	421.4
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Landfilling	27.30	27.76	806.0	418.9
3	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Land Spreading I	27.31	27.77	846.9	418.1
4	Same as Design 3					

[a]All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

TABLE 15. NON-INFERIOR COST/ENERGY SYSTEMS FOR CASE STUDY 5

System	Air Flotation Thickening	Anaerobic Digestion. I (15 days)	Lime Stabilization	Gravity Thickening	Centrifugation	Sand Drying Beds	Incineration	Landfilling	System Cost, ¢/1000 gal.	System Net Energy, kwh/mil. gal.
No Energy Recovery										
1a		MIX		MIX		MIX	MIX		27.6	1307
2a		MIX		MIX		MIX		MIX	27.8	1225
3a			MIX		MIX			MIX	30.7	1090
4a					MIX			MIX	31.5	1033
5a			MIX			MIX		MIX	31.9	1009
Recovery of Methane										
1b		MIX		MIX		MIX	MIX		27.2	888
2b		MIX		MIX		MIX		MIX	27.3	806
3b	WAS	MIX		MIX		MIX		MIX	27.6	734

PRI = primary sludge WAS = waste activated sludge MIX = PRI + WAS

Note: All systems utilize the same wastewater treatment train - Pumping, Preliminary Treatment, Primary Sedimentation II (60% solids removal), Activated Sludge III (3000 mg/l MLVSS and 30% recycle), and Chlorination.

percent increase in cost. Of course the final choice will depend on the designer's feelings regarding the relative importance of these objectives as well as any other criteria that are relevant to the design process.

The computer runs made for this case study averaged about 2.5 minutes of CPU time each on a DEC PDP-11/70 computer. From three to four iterations on the penalty terms for sludge treatment recycle streams per run were needed. In addition, each run was asked to identify the five most least-costly solutions. It is estimated that on the average, the computational effort required of each run was only 2.5 percent of that needed to evaluate all 15,360 possible system arrangements individually.

Hopefully these case studies have shown how EXEC/OP can be used as a practical tool for the preliminary synthesis of waste treatment systems. Perhaps its most productive use would be to generate alternative system designs that emphasize different objectives in various degrees. It can also be used to explore the sensitivity of these designs to uncertainty in various process performance parameters. The information derived from such analyses would ultimately enter into the value trade-off process that culminates in a final design decision.

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APPENDIX A

MATHEMATICAL DEVELOPMENT OF THE SYSTEM SYNTHESIS MODEL

To simplify the notation we consider a system consisting of one wastewater treatment train and one sludge treatment train with the sidestreams from sludge treatment returned to the head of the plant. The total number of treatment stages in the system is N where the first L of these belong to the wastewater treatment train.

Each waste stream is characterized by its volumetric flow rate and the mass flow rates of a number of pollutants of interest (e.g., suspended BOD, dissolved BOD, total suspended solids, volatile suspended solids, various forms of nitrogen, etc.). In general, these streams could also be described by such physical characteristics as temperature, viscosity, specific resistance, etc. Let each stream contain M components with x_{im} the flow rate of component m influent to stage i and s_{im} the flow rate of component m in the sidestream generated at stage i. Denote the vector representations of these waste flows at stage i as X_i and S_i, respectively.

To once again simplify the notation, assume that each stage has J alternative process units available for selection. Let z_{ij} be a decision variable whose value is 1 if unit j is chosen at stage i and is 0 otherwise. Also let f_{ij} and g_{ij} be vector valued functions that describe how the influent waste stream to stage i (X_i) is transformed into an effluent stream (X_{i+1}) and a sidestream (S_i), respectively, when unit j is chosen. These functions will take into account the type of unit employed, its design specifications, and the nature of the influent waste stream. No restriction is placed on their level of complexity.

To complete the mathematical specification of the problem, assume that K different design criteria must be satisfied. In order to formulate a meaningful optimization model, assume that one of these is stated as an objective to be minimized (e.g., total cost) and all others have target values b_k that must not be exceeded. Alternatively, two or more of the criteria could be combined into a single objective function by forming a weighted sum. Let c_{ijk} be the contribution to criterion k by choosing process unit j at stage i. The same remarks made for the functions f_{ij} and g_{ij} apply to c_{ijk}. In addition, it is assumed that the c_{ijk} are positive and non-decreasing with respect to the waste stream components x_{im}.

The system design problem can now be written in the following form:

$$\text{Minimize } v_1 = \sum_{i=1}^{N} \sum_{j=1}^{J} z_{ij} c_{ij1} (X_i) \qquad (1)$$

$$\text{subject to } v_k = \sum_{i=1}^{N} \sum_{j=1}^{J} z_{ij} c_{ijk} (X_i) \leq b_k \quad k = 2,\ldots,K \qquad (2)$$

$$X_{i+1} = \sum_{j=1}^{J} z_{ij} f_{ij} (X_i) \qquad i = 1,\ldots,N \qquad (3)$$

$$S_i = \sum_{j=1}^{J} z_{ij} g_{ij} (X_i) \qquad i = 1,\ldots N \qquad (4)$$

$$\sum_{j=1}^{J} z_{ij} = 1 \qquad i = 1,\ldots,N \qquad (5)$$

$$z_{ij} = 0 \text{ or } 1 \qquad i = 1,\ldots,N \quad j = 1,\ldots,J \qquad (6)$$

$$X_{L+1} = \sum_{i=1}^{L} S_i \qquad (7)$$

$$X_1 = X_o + \sum_{i=L+1}^{N} S_i \qquad (8)$$

where v_k is the value of criterion k and X_o is the plant influent waste stream vector.

Equations (1) and (2) represent the design criteria, (3) and (4) express the stagewise transformation of influent waste flows and the generation of sidestreams, while (5) and (6) insure that only one process unit is chosen at each stage. Equation (7) expresses the influent to the sludge treatment train as the sum of the sludge sidestreams generated in the wastewater treatment train. Finally, equation (8) closes the loop by adding the sludge treatment sidestreams to the plant influent.

Explicit constraints on effluent discharges from the system need not appear in the formulation since they can be satisfied by careful specification of the unit process alternatives. For example, the process waste stream transformation functions f_{ij} can be chosen so that effluent concentration is the fixed design parameter rather than such quantities as percent removal or size of the unit.

The above model is a nonlinear integer programming problem with decision variables z_{ij} and state variables x_{im} and s_{im}. Considerable difficulty is caused by the presence of the recycle equation (8). Removal of this relation would make the waste stream vector entering stage i dependent only on the process units chosen at stages 1 through i-1 and results in a much simpler problem. Suppose that equation (8) is ignored and instead a penalty is attached to each component of the sidestreams generated by sludge treatment. Let the penalty p_{km} be the increase in criterion k per unit increase in component m of the recycle stream. A method for computing these penalties is given below. Now replace the original optimization problem with a penalty-augmented one wherein equation (8) is dropped and penalty terms are added to equations (1) and (2) to give the following revised system criterion values:

$$v_k' = v_k + \sum_{i=L+1}^{N} \sum_{m=1}^{M} p_{km} \, s_{im} \tag{9}$$

An efficient implicit enumeration technique is available to solve this new penalty-augmented problem [A1]. It makes use of the following bounding property. Suppose that a feasible system design $\bar{z}_{ij}$ with criterion values $\bar{v}_k'$ has been found. If at stage q a different process r is proposed and

$$\sum_{i=1}^{q-1} \sum_{j=1}^{J} \bar{z}_{ij} \, c_{ijk} + c_{qrk} > \begin{cases} \bar{v}_1' & \text{for } k=1 \quad (10a) \\ & \text{or} \\ b_k & \text{for any } k \neq 1 \quad (10b) \end{cases}$$

then process r and all combination of process units beyond stage q can be excluded from consideration. (Note that penalty terms should be added to expression (10) if q > L.). This type of result can considerably reduce the number of unit process combinations that need to be evaluated. A systematic procedure for using this property to identify the optimal values of the z_{ij} is given in Figure A1.

The problem remains of establishing representative values for the penalties for sludge treatment recycle streams. Since these values will depend on the choice of process units, which are unknowns, a heuristic,

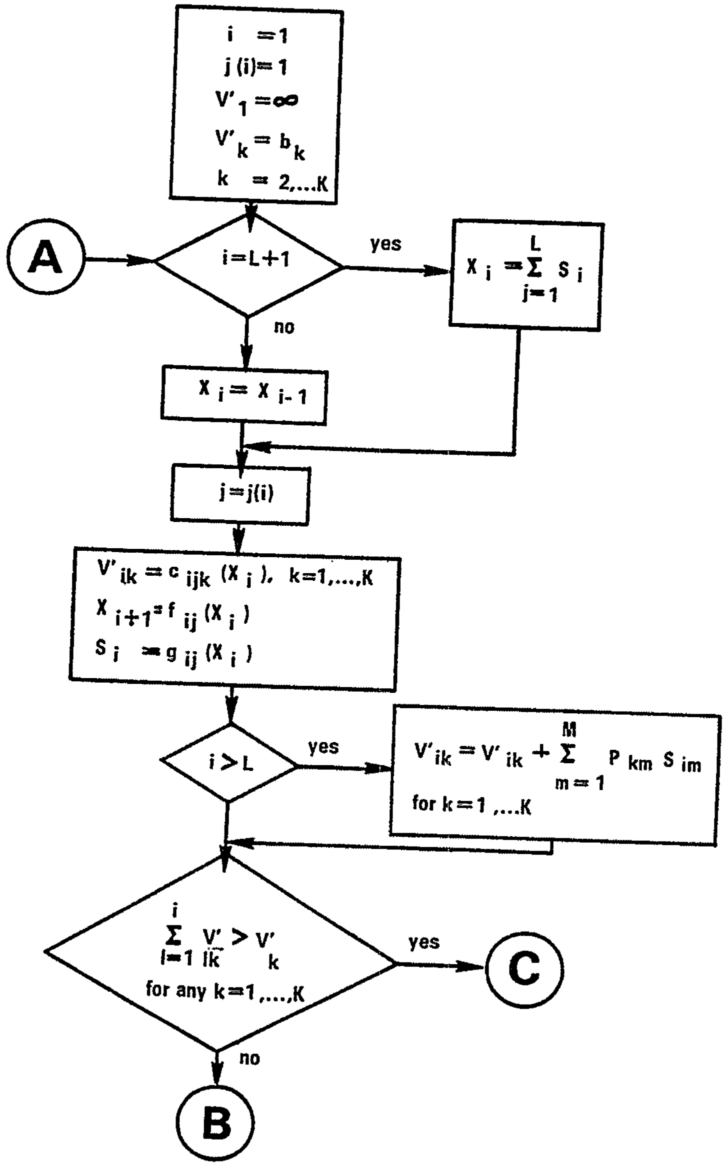

Figure A1. Flow chart of the implicit enumeration procedure (continued)

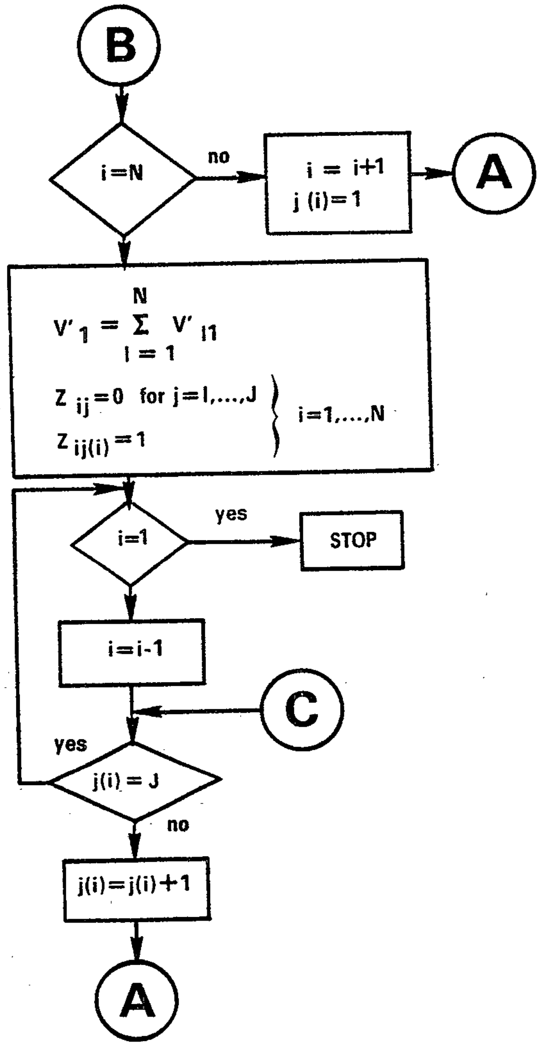

Figure A1. (continued)

iterative approach that successively generates new system designs and corresponding penalty values is employed. It is described in the flowchart of Figure A2.

After each iteration has identified a new candidate design, the criterion values with and without the sludge treatment recycle stream ($v_k(X_1)$ and $v_k(X_o)$, respectively) for this design are computed. Then new penalty values can be found from

$$p_{km} = \left[\frac{(\Delta v_k)_m}{(\Delta X_o)_m}\right] \left[\frac{v_k(X_1) - v_k(X_o)}{\sum_{\ell=1}^{M} (\Delta v_k)_\ell}\right] , \quad (11)$$

where $(\Delta v_k)_m$ is the change in $v_k(X_o)$ when a quantity $(\Delta X_o)_m$ is added to the m-th component of the plant influent. The $(\Delta v_k)_m$ are evaluated numerically by solution of equations (1)-(4) and (7) as X_o is pertubed by an amount $(\Delta X_o)_m$ under the current candidate system design. The first term in brackets is a numerical approximation to the partial derivative of criterion k with respect to system recycle component m. The second term is an adjustment factor that allows $v_k(X_1)$ to satisfy a first order Taylor series expansion about $v_k(X_o)$.

Very often a designer would be interested in identifying the system designs that are within α percent of least-cost (or least-energy, etc.). The solution procedure previously described can easily be extended to provide such information. After the best candidate design is identified, its corresponding penalty values are used once again in solving the penalty-augmented problem. Only this time the right hand side of the bounding relation (10a) is multiplied by $(1+\alpha/100)$. Each complete system design generated during the course of the implicit enumeration algorithm that is within α percent of the best design is saved. Its true performance is later evaluated by solving equations (1)-(4), (7) and (8).

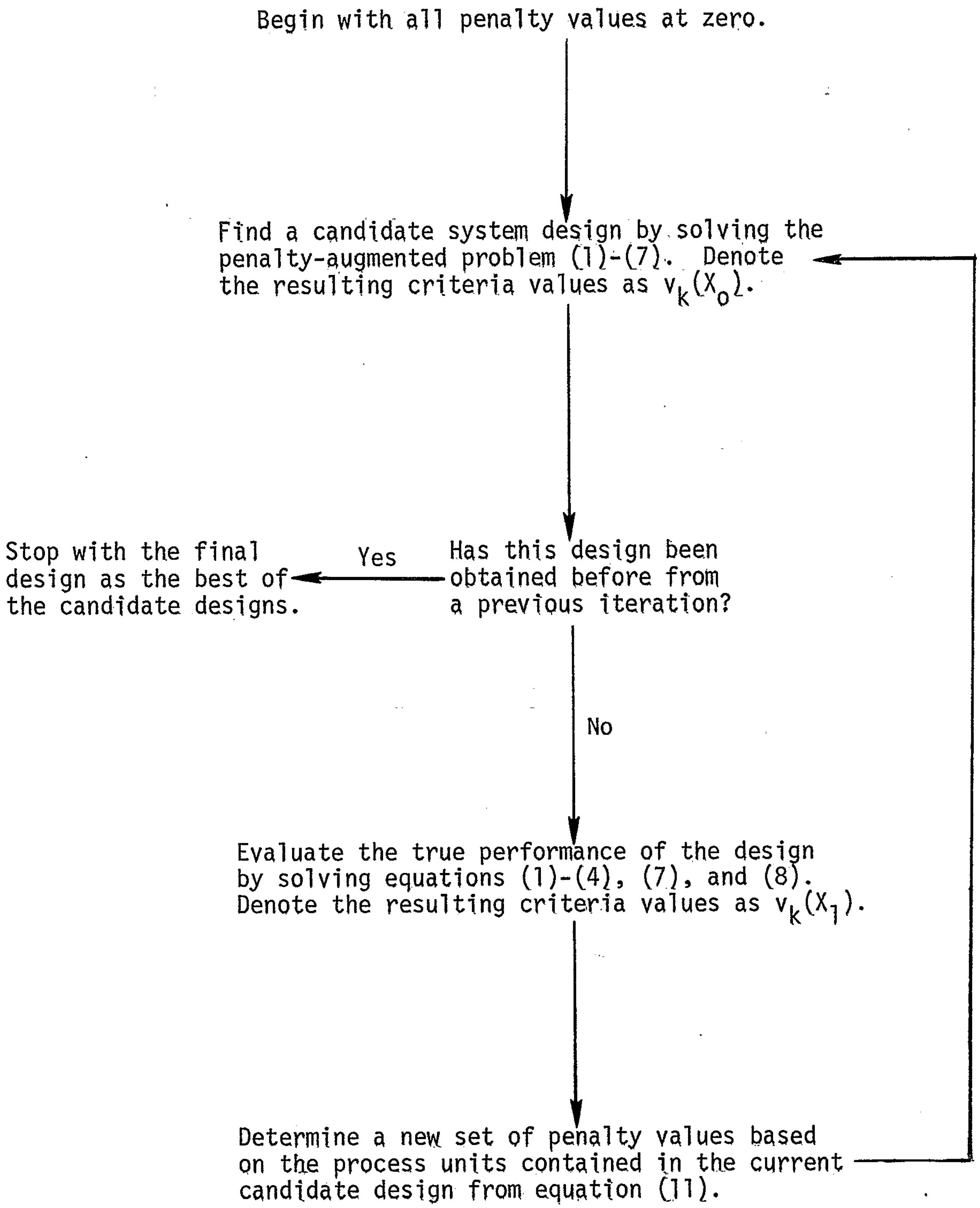

Figure A2. Overall system design algorithm

REFERENCES

A1. Rodrigo, B., F. R. and Seader, J. D., "Synthesis of Separation Sequences by Ordered Branch Search", AIChE Jour., 21, 885 (1975).

APPENDIX B

EXEC/OP USERS' GUIDE

As a preliminary step to using the EXEC/OP computer program it is suggested that the user first prepare a multi-option flow diagram of the waste treatment system. An example of such a diagram for a hypothetical design problem is shown in Figure B1. The following simple rules must be followed in preparing these diagrams:

(1) Treatment stages are numbered in order, starting with those in the wastewater treatment train, followed by those in the secondary sludge train, and then by those in the primary/mixed sludge treatment train.

(2) There must be at least one stage in each of the three treatment trains. If the possibility of separate treatment of primary and secondary sludges is not to be considered then the user can simply use a single stage with the "null process" as its only option in the secondary sludge train.

(3) The unit process options selected for consideration at each stage must be from those listed in Table B1. The same type of process can be used at several different design levels and at several different stages in the system.

(4) The sidestreams from sludge processing can be assigned to any wastewater treatment stage except the first stage.

Once a multi-option flow diagram has been prepared, EXEC/OP can be used to select the process option at each stage of the system that will best meet a set of design criteria. These criteria are listed in Table B2. They can be combined together in a weighted objective function whose value is to be minimized and they can have constraint levels associated with them whose values are not be be violated by any feasible design.

Figure B2 shows the general organization of the input data to EXEC/OP. A brief description of each category of input along with its FORTRAN format now follows:

Title Card - contains a descriptive title for the problem (40A2).

Influent Waste Cards - gives the values of the influent waste parameters listed in Table B3 (8F10.0).

Effluent Standards Card - gives the required effluent standards for 5-day BOD, suspended solids, ammonia nitrogen, nitrate nitrogen and phosphorus in mg/l, (5F10.0).

Economic Parameter Cards - gives values for the economic parameters listed in Table B4 (8F10.0).

System Structure Card - lists the number of stages in the wastewater treatment, secondary sludge, and primary sludge trains, respectively, the total number of process options considered, and the stage where sidestreams from sludge processing are returned for treatment (5I10).

Sludge Assignment Card - gives the stage where the sludge from each wastewater treatment stage is sent (must be the first stage of either the primary or secondary sludge trains) (8I10).

Process Design Data Cards - at least four cards for every process option (except the "null process"):

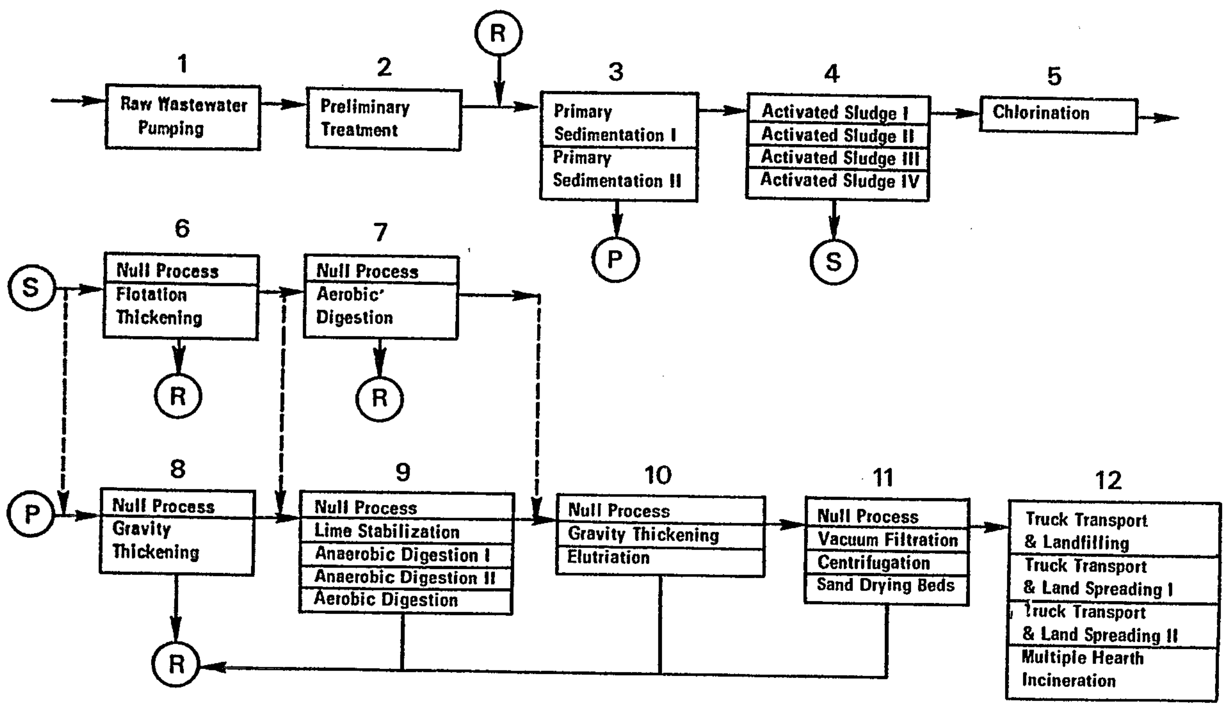

Figure B1. Multi-option flow diagram for a hypothetical design problem

TABLE B1. EXEC/OP UNIT PROCESSES

Process	Subroutine ID Number
Null Process	0
Preliminary Treatment	1
Primary Sedimentation	2
Activated Sludge (Aeration Basin and Final Settler)	3
Anaerobic Digestion	6
Vacuum Filtration	7
Gravity Thickening	8
Elutriation	9
Sand Drying Beds	10
Trickling Filter - Final Settler	11
Chlorination - Dechlorination	12
Flotation Thickening	13
Multiple Hearth Incineration	14
Raw Wastewater Pumping	15
Sludge Holding Tanks	16
Centrifugation	17
Aerobic Digestion	18
Truck Transport/Land Disposal of Sludge (Land Spreading or Landfilling)	22
Lime Stabilization	23
Rotating Biological Contactor - Final Settler	24
Primary Sedimentation - Activated Sludge - Waste Activated Sludge Returned to Primary Clarifie	25
Nonoxidative Heat Treatment	26

TABLE B2. EXEC/OP DESIGN CRITERIA

1. Initial Construction Cost, million $
2. Annual Operation and Maintenance Cost, $/mil. gal.
3. Total Equivalent Annual Cost, $/mil. gal.
4. Gross Energy Consumption, kwh/mil. gal.
5. Gross Energy Production, kwh/mil. gal.
6. Net Energy Consumption, kwh/mil. gal.
7. Land Utilization, acres.
8. Undesireability Index.

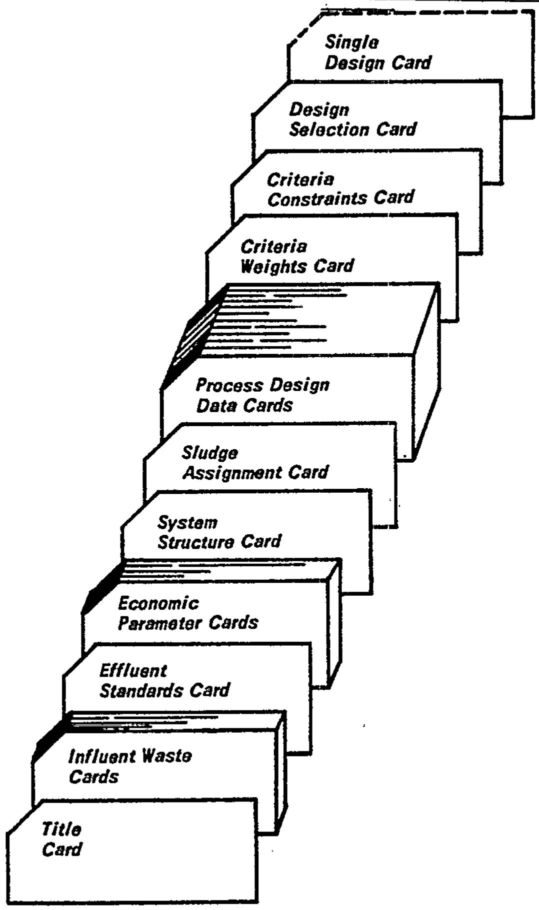

Figure B2. Organization of input data for EXEC/OP

TABLE B3. EXEC/OP WASTE STREAM PARAMETERS

Q	Volumetric Flow, mgd
SOC	Suspended Organic Carbon, mg/l
SNBC	Suspended Nonbiodegradable Carbon, mg/l
SON	Suspended Organic Nitrogen, mg/l
SOP	Suspended Organic Phosphorus, mg/l
SFM	Suspended Fixed Matter, mg/l
SBOD	Suspended 5-Day BOD, mg/l
VSS	Volatile Suspended Solids, mg/l
TSS	Total Suspended Solids, mg/l
DOC	Dissolved Organic Carbon, mg/l
DNBC	Dissolved Nonbiodegradable Carbon, mg/l
DN	Dissolved Nitrogen, mg/l
DP	Dissolved Phosphorus, mg/l
DFM	Dissolved Fixed Matter, mg/l
ALK	Alkalinity, mg/l
DBOD	Dissolved 5-Day BOD, mg/l
NH3	Ammonia Nitrogen, mg/l
NO3	Nitrate Nitrogen, mg/l

TABLE B4. EXEC/OP ECONOMIC PARAMETERS

EPA Sewage Treatment Plant Cost Index (1957-59=1.0)
Wholesale Price Index (1957-59=1.0)
Discount Rate
Length of Planning Period, yrs.
Direct Hourly Wage, $/hr.
Fraction of Direct Hourly Wage Charged to Indirect Labor
Cost of Electricity, $/kwh
Cost Escalator for Yarkwork, Laboratories, Legal Fees, Engineering and Interest
Efficiency of Converting Heating Value of Fuels into Equivalent Electrical Energy

1-st card - tells at which stage the option appears, the identification number assigned to the process, the identification number of the process subroutine (see Table B1), the maximum energy production possible from the process (in equivalent kwh/mil. gal. of plant influent), and the undesireability rating for the process (3I10, 2F10.0).

2-nd Card - contains a descriptive title for the process (40A2).

3-rd and 4-th cards - lists the values of the 16 input design parameters for the process (see Appendix C). (8F10.0).

Additional Cards - contains any supplementary input data (see Appendix C). (8F10.0).

Criteria Weight Card - lists the weights attached to each selection criterion of Table B2 (8F10.0).

Criteria Constraint Card - gives the upper allowable limit (lower limit for energy production) for each selection criterion of Table B2 (8F10.0).

Design Selection Card - gives the values of M and X where the user desires to identify the M best designs that are within 100X% of one another (with respect to the weighted objective function). (I10, F10.0).

Single Design Card - lists the identification number of the process option to be selected at each stage of the system (used only when no optimization is to be performed and the user desires detailed performance data for a particular system design) (8I10).

Appendix C provides a description of the input parameters needed for each type of unit process. A sample input deck for the flow diagram of Figure B1 is shown in Figure B3. The DEC PDP-11/70 computer on which this problem was run allows a data field to be terminated by a comma and two successive commas indicates a value of 0. Thus the input data appearing in Figure B3 does not line up in field widths of 10 spaces each. The last three lines of this data indicate that the design problem involves total cost minimization, that no constraints are placed on the design criteria (values of the constraint limits are set to very high numbers or zero for energy production), and that the five best designs whose costs are within 5 percent of one another is desired.

The resulting EXEC/OP output for this example is shown in Figure B4. The first three tables present summaries of the input data. The section titled "Optimization Phase" lists the designs arrived at while searching for the first-best solution. The "Sensitivity Phase" section gives the five top designs with respect to total cost. Each design listing in these sections indicates the process option used at each stage of the system (stages using the "null process" are skipped), the amount of sludge either generated or handled, and the values of the eight system selection criteria. The stage where mixing of primary and secondary sludges occurs is shown with an asterisk. At the end of the output is shown how efficient the search method of EXEC/OP was in comparison to a complete enumeration of all possible system configurations. (Note: the total number of possible system configurations equals the product of the number of process options considered at each stage. This number is 15,360 for the system in this sample problem).

The user is advised that because of the heuristic nature of the optimization method used in EXEC/OP, the "best" design arrived at in the "Optimization Phase" may be close to but not equal to the true optimum. In such cases one of the M next-best designs listed in the "Sensitivity Phase" results may have a better objective function value. Thus the use of the M next-best design feature provides added insurance that the true mathematical optimum. is not missed in addition to its other useful informational properties.

Should the user desire a detailed performance evaluation of any particular design configuration of the multi-option flow diagram, the single design evaluation feature of EXEC/OP can be used. For example, assume that this kind of information is requested for the least-cost design in our sample

```
                                          CASE STUDY 1
10., 105., 30., 10., 2., 30., 140., 229.
254., 43., 11., 19., 4., 500., 250., 60.
15., 0.
30., 30., 10000., 10000., 10000.
2.88, 2., .06375, 20., 5.91, .15, .033, 1.33
.31
5, 2, 5, 31, 3
8, 8, 8, 6, 6
1,1,15, 0., 0.
RAW WASTEWATER PUMPING
30., , , , , , , ,
, , , , , , , 1.
2,2,1, 0., 0.
PRELIMINARY TREATMENT
1., , , , , , , ,
, , , , , , , 1.
3,3,2, 0., 0.
PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
.4, 200., 14., , , , , ,
, , , , , , 1., 1.
3,4,2, 0., 0.
                              (60% SOLIDS REMOVAL)
.6, 200., 14., , , , , ,
, , , , , , 1., 1.
4,5,3, 0., 0.
ACTIVATED SLUDGE (MLVSS=2000, R=.3)
30., 30., 2000., .3, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,6,3, 0., 0.
                 (MLVSS=2000, R=.5)
30., 30., 2000., .5, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,7,3, 0., 0.
                 (MLVSS=3000, R=.3)
30., 30., 3000., .3, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,8,3, 0., 0.
                 (MLVSS=3000, R=.5)
30., 30., 3000., .5, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
5,9,12, 0., 0.
CHLORINATION (8 MG/L DOSAGE)
8., 30., 220., 2.5, 180., , , ,
, , , , , 1., 1., 1.
6,30,0, 0., 0.
NULL PROCESS
6,10,13, 0., 0.
```

Figure B3. Input data for hypotetical design problem

```
AIR FLOTATION THICKENING (TO 4% SOLIDS)
.95, 40000., 1150., 48., 96., 10., .45, 0.
, , , , , , , 1.
7,30,0, 0., 0.
NULL PROCESS
7,11,18, 0., 0.
AEROBIC DIGESTION (10 DAYS)
0., 0., 0., 20., 10., .48, .5, 0.
0., 7., .05, 0., 0., 0., 1., 1.
8,30,0, 0., 0.
NULL PROCESS
8,12,8, 0., 0.
GRAVITY THICKENING (TO 8% FOR PRI, 5% FOR MIXED SLUDGE)
.9, 0., 700., 0., 80000., 20000., 50000., 16.
6., 8., , , , , , 1.
9,30,0, 0., 0.
NULL PROCESS
9,13,23, 0., 0.
LIME STABILIZATION (200 LBS/TON)
200., 25., , , , , , ,
, , , , , , , 1.
9,14,6, 2000., 0.
ANAEROBIC DIGESTION (15 DAYS)
15., 30., .5, .31, , , , ,
, , , , , , , 1.
9,15,6, 2000., 0.
                          (20 DAYS)
20., 30., .5, .31, , , , ,
, , , , , , , 1.
9,16,18, 0., 0.
AEROBIC DIGESTION (20 DAYS)
0., 0., 0., 20., 20., .48, .5, 0.
0., 7., .05, 0., 0., 0., 1., 1.
10,17,8, 0., 0.
GRAVITY THICKENING (TO 5% SOLIDS)
.9, 0., 700., 0., 80000., 20000., 50000., 16.
6., 8., , , , , , 1.
10,18,9, 0., 0.
ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
.76, 0., 3., 800., 0., 60000., 20000., 40000.
16., 6., 8., , , , , 1.
10,30,0, 0., 0.
NULL PROCESS
11,19,7, 0., 0.
```

Figure B3. (continued)

```
VACUUM FILTRATION (10 GPH/SQ FT)
0., 35., 2000., 0., 0., 0., .064, .0125
0., .33, 1., , , , , 1.
10., 10., 10., 10., 10., 10., 10., 10.
10., 10., 10., 10., 10., 10., 10.
42., 0., 52., 42., 0., 40., 76., 0.
110., 68., 0., 125., 0., 0., 0.
176., 0., 200., 0., 0., 0., 240., 0.
370., , , , , , ,
, , , , , , , ,
, , , , , , ,
11,20,17, 0., 0.
CENTRIFUGATION
0., 0., 35., 0., 0., 2., 0., 2.
1., , , , , , , 1.
.9, .85, .9, .9, .85, .9, .9, .85
.85, .9, .85, .85, 0., 0., 0.
32., 10., 19., 30., 18., 30., 25., 15.
22., 25., 15., 22., 0., 0., 0.
3., 6., 6., 3., 4., 4., 2., 4.
4., 2., 4., 4., 0., 0., 0.
90., 80., 80., 160., 160., 160., 100., 80.
80., 100., 80., 80., 100., 80., 80.
11,21,10, 0., 0.
SAND DRYING BEDS (30% CAKE SOLIDS)
0., 2000., .3, .3, .3, 15., 1., 3000.
, , , , , , , 1.
11,30,0, 0., 0.
NULL PROCESS
12,22,22, 0., 0.
LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
2160., 10., 6., .5, 3000., 0., .25, 400.
500., 10., 0., 0., 0., 0., 1., 1.
12,23,22, 0., 0.
                        (30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
2160., 30., 6., .5, 2000., 0., .25, 600.
500., 10., 0., 0., 0., 0., 1., 1.
12,24,22, 0., 0.
LANDFILLING (10 MILE HAUL, 3000 $/AC)
2160., 10., 6., .5, 3000., 1., 0., 0.
, , , , , , 1., 1.
12,25,14, 0., 0.
INCINERATION (2 LB/HR/SQ FT)
2., 2., 35., 5., 0., 10000., 1., .3
1., , , , , , , 1.
0., 0., 1., 0., 0., 0., 0., 0.
10000., 10000., 10000., 10000., 0., 10000., 10000., 10000.
5, .05
```

Figure B3. (continued)

EXECUTIVE PROGRAM
(OPTIMIZATION VERSION)
FOR
PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
SYSTEMS AND ECONOMIC ANALYSIS SECTION
CINCINNATI, OHIO 45268

CASE STUDY 1

PROCESS ALTERNATIVES

OPTION NO.	PROCESS NO.	STAGE NO.	SIDESTREAM DESTINATION	REMARKS
1	15	1	8	RAW WASTEWATER PUMPING
2	1	2	8	PRELIMINARY TREATMENT
3	2	3	8	PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
4	2	3	8	(60% SOLIDS REMOVAL)
5	3	4	6	ACTIVATED SLUDGE (MLVSS=2000, R=.3)
6	3	4	6	(MLVSS=2000, R=.5)
7	3	4	6	(MLVSS=3000, R=.3)
8	3	4	6	(MLVSS=3000, R=.5)
9	12	5	6	CHLORINATION (8 MG/L DOSAGE)
30	0	6	3	NULL PROCESS
10	13	6	3	AIR FLOTATION THICKENING (TO 4% SOLIDS)
30	0	7	3	NULL PROCESS
11	18	7	3	AEROBIC DIGESTION (10 DAYS)
30	0	8	3	NULL PROCESS
12	8	8	3	GRAVITY THICKENING (TO 8% FOR PRI, 5% FOR MIXED SLUDGE)
30	0	9	3	NULL PROCESS
13	23	9	3	LIME STABILIZATION (200 LBS/TON)
14	6	9	3	ANAEROBIC DIGESTION (15 DAYS)
15	6	9	3	(20 DAYS)
16	18	9	3	AEROBIC DIGESTION (20 DAYS)
17	8	10	3	GRAVITY THICKENING (TO 5% SOLIDS)
18	9	10	3	ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
30	0	10	3	NULL PROCESS
19	7	11	3	VACUUM FILTRATION (10 GPH/SQ FT)
20	17	11	3	CENTRIFUGATION
21	10	11	3	SAND DRYING BEDS (30% CAKE SOLIDS)
30	0	11	3	NULL PROCESS
22	22	12	3	LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
23	22	12	3	(30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
24	22	12	3	LANDFILLING (10 MILE HAUL, 3000 $/AC)
25	14	12	3	INCINERATION (2 LB/HR/SQ FT)

Figure B4. EXEC/OP output for hypothetical design problem

SELECTION CRITERIA

	CRITERION	WEIGHT	LIMIT
1.	INITIAL CONSTR. COST, M$	0.00	10000.00
2.	ANNUAL O & M COST, $/MG	0.00	10000.00
3.	TOTAL ANNUAL COST, $/MG	1.00	10000.00
4.	ENERGY CONSUMED, KWH/MG	0.00	10000.00
5.	ENERGY PRODUCED, KWH/MG	0.00	0.00
6.	NET ENERGY CONSUMED, KWH/MG	0.00	10000.00
7.	LAND REQUIRED, ACRES	0.00	10000.00
8.	UNDESIREABILITY INDEX	0.00	10000.00

ECONOMIC DATA

CONSTRUCTION COST INDEX	2.8800
WHOLESALE PRICE INDEX	2.0000
DIRECT HOURLY WAGE, $/HR	5.9100
FRACTION CHARGED TO SUPERVISION	0.1500
COST ESCALATOR FOR MISC. FEES	1.3300
COST OF ELECTRICITY, $/KWH	0.0330
FUEL CONVERSION EFFICIENCY	0.3100
DISCOUNT RATE	0.0637
CAPITAL RECOVERY FACTOR	0.0899

Figure B4. (continued)

OPTIMIZATION PHASE

DESIGN 1

EXACT SYSTEM VALUE	291,128
APPROX. SYSTEM VALUE	259,484
PENALTY FROM RECYCLES	0,000

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0,00	0,91	10,09	32,39	141,37	0,00	141,37	0,00	0,00
2	2	0,00	0,28	9,36	16,15	5,22	0,00	5,22	0,00	0,00
3	4	7,65	0,59	12,45	27,07	8,78	0,00	8,78	0,00	0,00
4	7	2,16	1,54	48,22	86,06	648,00	0,00	648,00	0,00	0,00
5	9	0,00	0,29	17,68	24,85	121,80	0,00	121,80	0,00	0,00
8*	12	9,81	0,16	2,19	6,13	1,85	0,00	1,85	0,00	0,00
9	14	8,83	0,55	5,64	19,06	226,99	411,16	-184,16	0,00	0,00
10	18	4,90	0,11	1,64	4,47	1,28	0,00	1,28	0,00	0,00
12	22	3,72	0,91	42,43	74,95	78,75	0,00	78,75	284,35	0,00
SYSTEM VALUES		9,81	5,33	149,70	291,13	1234,04	411,16	822,89	284,35	0,00

DESIGN 2

EXACT SYSTEM VALUE	276,155
APPROX. SYSTEM VALUE	280,542
PENALTY FROM RECYCLES	12,321

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0,00	0,91	10,09	32,39	141,37	0,00	141,37	0,00	0,00
2	2	0,00	0,28	9,36	16,15	5,22	0,00	5,22	0,00	0,00
3	4	6,71	0,59	12,37	26,89	8,71	0,00	8,71	0,00	0,00
4	7	1,70	1,49	47,22	84,02	630,17	0,00	630,17	0,00	0,00
5	9	0,00	0,29	17,52	24,65	120,53	0,00	120,53	0,00	0,00
9*	14	8,41	0,64	6,52	22,35	299,38	418,92	-119,54	0,00	0,00
10	17	4,39	0,11	1,57	4,27	1,21	0,00	1,21	0,00	0,00
11	21	3,95	0,42	20,32	30,70	0,86	0,00	0,86	1,35	0,00
12	25	3,95	0,88	12,99	34,73	99,67	0,00	99,67	0,00	0,00
SYSTEM VALUES		8,41	5,61	137,98	276,15	1307,13	418,92	888,21	1,35	0,00

Figure B4. (continued)

DESIGN 3

EXACT SYSTEM VALUE	276,155
APPROX. SYSTEM VALUE	276,155
PENALTY FROM RECYCLES	7,934

SAME SYSTEM AS DESIGN 2

SENSITIVITY PHASE

DESIGN 1

EXACT SYSTEM VALUE 276,155

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0.00	0,91	10,09	32,39	141,37	0.00	141,37	0,00	0,00
2	2	0.00	0,28	9,36	16,15	5,22	0.00	5,22	0,00	0,00
3	4	6,71	0,59	12,37	26,89	8,71	0.00	8,71	0,00	0,00
4	7	1,70	1,49	47,22	84,02	630,17	0.00	630,17	0,00	0,00
5	9	0,00	0,29	17,52	24,65	120,53	0.00	120,53	0,00	0,00
9*	14	8,41	0,64	6,52	22,35	299,38	418,92	-119,54	0,00	0,00
10	17	4,39	0,11	1,57	4,27	1,21	0.00	1,21	0,00	0,00
11	21	3,95	0,42	20,32	30,70	0,86	0.00	0,86	1,35	0,00
12	25	3,95	0,88	12,99	34,73	99,67	0.00	99,67	0,00	0,00
SYSTEM VALUES		8,41	5,61	137,98	276,15	1307,13	418,92	888,21	1,35	0,00

Figure B4. (continued)

DESIGN 2

EXACT SYSTEM VALUE 279.791

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0.00	0.91	10.09	32.39	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.28	9.36	16.15	5.22	0.00	5.22	0.00	0.00
3	4	6.70	0.59	12.37	26.89	8.71	0.00	8.71	0.00	0.00
4	7	1.70	1.49	47.06	83.79	627.27	0.00	627.27	0.00	0.00
5	9	0.00	0.29	17.52	24.65	120.53	0.00	120.53	0.00	0.00
9*	15	8.40	0.78	7.72	26.91	348.83	425.58	-76.75	0.00	0.00
10	17	4.33	0.11	1.57	4.25	1.20	0.00	1.20	0.00	0.00
11	21	3.90	0.42	20.06	30.32	0.85	0.00	0.85	1.33	0.00
12	25	3.90	0.88	12.89	34.45	99.30	0.00	99.30	0.00	0.00
SYSTEM VALUES		8.40	5.73	138.64	279.79	1353.28	425.58	927.70	1.33	0.00

DESIGN 3

EXACT SYSTEM VALUE 277.631

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0.00	0.91	10.09	32.39	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.28	9.36	16.15	5.22	0.00	5.22	0.00	0.00
3	4	6.71	0.59	12.37	26.89	8.71	0.00	8.71	0.00	0.00
4	7	1.70	1.49	47.22	84.02	630.17	0.00	630.17	0.00	0.00
5	9	0.00	0.29	17.52	24.65	120.53	0.00	120.53	0.00	0.00
9*	14	8.41	0.64	6.52	22.35	299.38	418.92	-119.54	0.00	0.00
10	17	4.39	0.11	1.57	4.27	1.21	0.00	1.21	0.00	0.00
11	21	3.95	0.42	20.32	30.70	0.86	0.00	0.86	1.35	0.00
12	24	3.95	0.51	19.13	36.21	17.44	0.00	17.44	18.04	0.00
SYSTEM VALUES		8.41	5.24	144.12	277.63	1224.90	418.92	805.98	19.40	0.00

Figure B4. (continued)

DESIGN 4

EXACT SYSTEM VALUE 277,743

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0,00	0,91	10,09	32,39	141,37	0,00	141,37	0,00	0,00
2	2	0,00	0,28	9,36	16,15	5,22	0,00	5,22	0,00	0,00
3	4	6,60	0,59	12,36	26,86	8,70	0,00	8,70	0,00	0,00
4	7	1,64	1,49	47,13	83,81	628,67	0,00	628,67	0,00	0,00
5	9	0,00	0,29	17,49	24,62	120,31	0,00	120,31	0,00	0,00
9*	14	8,24	0,64	6,45	22,10	293,88	418,12	-124,23	0,00	0,00
10	17	4,23	0,11	1,56	4,21	1,19	0,00	1,19	0,00	0,00
12	22	3,81	0,77	43,68	67,62	65,72	0,00	65,72	336,50	0,00
SYSTEM VALUES		8,24	5,06	148,13	277,74	1265,06	418,12	846,94	336,50	0,00

DESIGN 5

EXACT SYSTEM VALUE 281,315

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0,00	0,91	10,09	32,39	141,37	0,00	141,37	0,00	0,00
2	2	0,00	0,28	9,36	16,15	5,22	0,00	5,22	0,00	0,00
3	4	6,70	0,59	12,37	26,89	8,71	0,00	8,71	0,00	0,00
4	7	1,70	1,49	47,06	83,79	627,27	0,00	627,27	0,00	0,00
5	9	0,00	0,29	17,52	24,65	120,53	0,00	120,53	0,00	0,00
9*	15	8,40	0,78	7,72	26,91	348,83	425,58	-76,75	0,00	0,00
10	17	4,33	0,11	1,57	4,25	1,20	0,00	1,20	0,00	0,00
11	21	3,90	0,42	20,06	30,32	0,85	0,00	0,85	1,33	0,00
12	24	3,90	0,50	18,97	35,97	17,28	0,00	17,28	17,78	0,00
SYSTEM VALUES		8,40	5,36	144,72	281,32	1271,26	425,58	845,68	19,11	0,00

BEST DESIGN IS NUMBER 1

SEARCH EFFORT WAS 5,3258% OF TOTAL ENUMERATION

* SLUDGE MIXING POINT

Figure B4. (continued)

design problem (i.e., design 1 in the "Sensitivity Phase" results of Figure B4). The same input data deck is used with the addition of the single design cards to the end of the deck. These cards give the number of the process unit selected at each stage of the particular system configuration under study. In this example they would be:

1, 2, 4, 7, 9, 30, 30, 30

14, 17, 21, 25

The output produced by EXEC/OP is shown in Figure B5. Each stage of the system (except those employing the null process) has its influent, effluent and sidestream waste streams described along with values of the input and computed design parameters for the process used at the stage. The abbreviations used for the components in the waste streams are explained in Table B3. The meaning of the input and output design parameter values can be found by looking up the process description in the listing of Appendix C.

The programmed version of EXEC/OP, listed in Appendix D, is dimensioned to accommodate up to 19 processing stages and 50 different types of process options. For those unit processes that require supplementary input data tables (vacuum filtration and centrifugation) a maximum of 5 different design levels may be used. The program is capable of generating up to 40 next-best designs.

EXECUTIVE PROGRAM
(OPTIMIZATION VERSION)
FOR
PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
SYSTEMS AND ECONOMIC ANALYSIS SECTION
CINCINNATI, OHIO 45268

CASE STUDY 1

PROCESS ALTERNATIVES

OPTION NO.	PROCESS NO.	STAGE NO.	SIDESTREAM DESTINATION	REMARKS
1	15	1	8	RAW WASTEWATER PUMPING
2	1	2	8	PRELIMINARY TREATMENT
3	2	3	8	PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
4	2	3	8	(60% SOLIDS REMOVAL)
5	3	4	6	ACTIVATED SLUDGE (MLVSS=2000, R=.3)
6	3	4	6	(MLVSS=2000, R=.5)
7	3	4	6	(MLVSS=3000, R=.3)
8	3	4	6	(MLVSS=3000, R=.5)
9	12	5	6	CHLORINATION (8 MG/L DOSAGE)
30	0	6	3	NULL PROCESS
10	13	6	3	AIR FLOTATION THICKENING (TO 4% SOLIDS)
30	0	7	3	NULL PROCESS
11	18	7	3	AEROBIC DIGESTION (10 DAYS)
30	0	8	3	NULL PROCESS
12	8	8	3	GRAVITY THICKENING (TO 8% FOR PRI, 5% FOR MIXED SLUDGE)
30	0	9	3	NULL PROCESS
13	23	9	3	LIME STABILIZATION (200 LBS/TON)
14	6	9	3	ANAEROBIC DIGESTION (15 DAYS)
15	6	9	3	(20 DAYS)
16	18	9	3	AEROBIC DIGESTION (20 DAYS)
17	8	10	3	GRAVITY THICKENING (TO 5% SOLIDS)
18	9	10	3	ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
30	0	10	3	NULL PROCESS
19	7	11	3	VACUUM FILTRATION (10 GPH/SQ FT)
20	17	11	3	CENTRIFUGATION
21	10	11	3	SAND DRYING BEDS (30% CAKE SOLIDS)
30	0	11	3	NULL PROCESS
22	22	12	3	LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
23	22	12	3	(30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
24	22	12	3	LANDFILLING (10 MILE HAUL, 3000 $/AC)
25	14	12	3	INCINERATION (2 LB/HR/SQ FT)

Figure B5. EXEC/OP output for single design evaluation

SELECTION CRITERIA

	CRITERION	WEIGHT	LIMIT
1.	INITIAL CONSTR. COST, M$	0.00	10000.00
2.	ANNUAL O & M COST, $/MG	0.00	10000.00
3.	TOTAL ANNUAL COST, $/MG	1.00	10000.00
4.	ENERGY CONSUMED, KWH/MG	0.00	10000.00
5.	ENERGY PRODUCED, KWH/MG	0.00	0.00
6.	NET ENERGY CONSUMED, KWH/MG	0.00	10000.00
7.	LAND REQUIRED, ACRES	0.00	10000.00
8.	UNDESIREABILITY INDEX	0.00	10000.00

ECONOMIC DATA

CONSTRUCTION COST INDEX	2.8800
WHOLESALE PRICE INDEX	2.0000
DIRECT HOURLY WAGE, $/HR	5.9100
FRACTION CHARGED TO SUPERVISION	0.1500
COST ESCALATOR FOR MISC. FEES	1.3300
COST OF ELECTRICITY, $/KWH	0.0330
FUEL CONVERSION EFFICIENCY	0.3100
DISCOUNT RATE	0.0637
CAPITAL RECOVERY FACTOR	0.0899

Figure B5 (continued)

STAGE NO.	PROCESS OPTION	SLUDGE, TONS/DAY	SELECTION CRITERIA 1	2	3	4	5	6	7	8
1	1	0,00	0,91	10,09	32,39	141,37	0,00	141,37	0,00	0,00
2	2	0,00	0,28	9,36	16,15	5,22	0,00	5,22	0,00	0,00
3	4	6,71	0,59	12,37	26,89	8,71	0,00	8,71	0,00	0,00
4	7	1,70	1,49	47,22	84,02	630,17	0,00	630,17	0,00	0,00
5	9	0,00	0,29	17,52	24,65	120,53	0,00	120,53	0,00	0,00
9*	14	8,41	0,64	6,52	22,35	299,38	418,92	-119,54	0,00	0,00
10	17	4,39	0,11	1,57	4,27	1,21	0,00	1,21	0,00	0,00
11	21	3,95	0,42	20,32	30,70	0,86	0,00	0,86	1,35	0,00
12	25	3,95	0,88	12,99	34,73	99,67	0,00	99,67	0,00	0,00
SYSTEM VALUES		8,41	5,61	137,98	276,15	1307,13	418,92	888,21	1,35	0,00

PROCESS PERFORMANCE CHAPACTEPISTICS

VOLUME FLOW, MGD
CONCENTPATION, MG/L
.CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT AND OUTPUT DESIGN DATA.

STAGE 1 PROCESS OPTION 1

INPUT DESIGN DATA:

30.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

14.805	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

Figure B5 (continued)

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

STAGE 2 PROCESS OPTION 2

INPUT DESIGN DATA:

1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	105.000	30.000	10.000	2.000	30.000	140.000	229.000	254.000
10.056	108.813	33.970	10.453	2.077	33.632	139.709	238.192	266.851
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.000	11.000	19.000	4.000	500.000	250.000	60.000	15.000	0.000
43.462	11.000	22.449	4.924	500.000	262.320	60.864	15.018	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure B5 (continued)

STAGE 3 PROCESS OPTION 4

INPUT DESIGN DATA:

6.600	200.000	14.000	0.000	0.000	0.000	0.000	0.000	
0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	

OUTPUT DESIGN DATA:

868.395	11.580	251.400	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.056	108.813	33.970	10.453	2.077	33.632	139.709	238.192	266.851
10.026	43.656	13.629	4.194	0.833	13.493	56.052	95.563	107.062
0.030	21762.654	6793.905	2090.564	415.464	6726.337	27941.836	47638.387	53370.289
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.462	11.000	22.449	4.924	500.000	262.320	60.864	15.018	0.000
43.462	11.000	22.449	4.924	500.000	262.320	60.864	15.018	0.000
43.462	11.000	22.449	4.924	500.000	262.320	60.864	15.018	0.000

STAGE 4 PROCESS OPTION 7

INPUT DESIGN DATA:

30.000	30.000	3000.000	0.300	200.000	0.500	10.000	0.480	
7.000	0.050	800.000	30.000	1.000	1.000	1.000	1.000	

OUTPUT DESIGN DATA:

116.915	4.140	0.008	12.500	10.000	0.266	0.792	0.792	1176.348
0.000	1823.652	259.276	707.547	94.311	0.300	7.000	9848124.000	6838.975
0.982	3.008							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.026	43.656	13.629	4.194	0.833	13.493	56.052	95.563	107.062
10.000	10.505	7.409	2.028	0.238	5.725	7.386	24.275	30.000
0.026	5543.186	3909.778	1069.922	125.568	3021.059	3897.638	12809.297	15830.355
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
43.462	11.000	22.449	4.924	500.000	262.320	60.864	15.018	0.000
17.276	11.000	21.864	5.197	500.000	262.320	22.604	21.864	0.000
17.276	11.000	21.864	5.197	500.000	262.320	22.604	21.864	0.000

Figure B5 (continued)

STAGE 5 PROCESS OPTION 9

INPUT DESIGN DATA:

8.000	30.000	220.000	2.500	180.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000

OUTPUT DESIGN DATA:

27852.027	121.618	38.006	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
10.000	10.505	7.409	2.028	0.238	5.725	7.386	24.275	30.000
10.000	10.505	7.409	2.028	0.238	5.725	7.386	24.275	30.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
17.276	11.000	21.864	5.197	500.000	262.320	22.604	21.864	0.000
17.276	11.000	21.864	5.197	500.000	262.320	22.604	21.864	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

STAGE 9 PROCESS OPTION 14

INPUT DESIGN DATA:

15.000	30.000	0.500	0.310	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

0.234	1154.105	112.291	76868.531	40369.461	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.056	14281.460	5463.608	1619.795	281.750	5017.286	16851.502	31573.547	36055.078
0.056	5808.716	5463.608	671.640	116.826	5017.286	645.353	13824.745	18842.031
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
31.384	11.000	22.180	5.050	500.000	262.320	43.216	18.176	0.000
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure B5 (continued)

STAGE 10 PROCESS OPTION 17

INPUT DESIGN DATA:

0.900	50000.000	700.000	8.000	80000.000	20000.000	50000.000	16.000
6.000	8.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

1098.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.056	5808.716	5463.608	671.640	116.826	5017.286	645.353	13824.745	18842.031
0.019	15414.252	14498.458	1782.293	310.015	13314.078	1712.535	36685.922	50000.000
0.037	878.985	826.763	101.634	17.678	759.224	97.656	2091.984	2851.209
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000

STAGE 11 PROCESS OPTION 21

INPUT DESIGN DATA:

0.300	2000.000	0.300	0.300	0.300	15.000	1.000	3000.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

OUTPUT DESIGN DATA:

61423.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.019	15414.252	14498.458	1782.293	310.015	13314.078	1712.535	36685.922	50000.000
0.003	88786.094	83511.117	10266.005	1785.687	76689.086	9864.201	211310.906	300000.000
0.019	616.570	579.938	71.292	12.401	532.563	68.501	1467.437	2000.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000

Figure B5 (continued)

STAGE 12 PROCESS OPTION 25

INPUT DESIGN DATA:

2.000	2.000	35.000	5.000	0.000	10000.000	1.000	0.300	
1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	

OUTPUT DESIGN DATA:

411.000	198371.703	7909.922	3075.518	7955.021	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000							

INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:

Q	SOC	SNBC	SON	SOP	SFM	SBOD	VSS	TSS
0.003	88786.094	83511.117	10266.005	1785.687	76689.086	9864.201	211310.906	300000.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DOC	DNBC	DN	DP	DFM	ALK	DBOD	NH3	NO3
126.036	11.000	638.480	169.974	500.000	2462.513	215.118	18.176	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure B5 (continued)

APPENDIX C

LISTING OF UNIT PROCESS DESCRIPTIONS

The following pages provide a listing of the design parameters used in the individual unit process model subroutines of EXEC/OP. The processes are listed in order of their subroutine identification number. Input parameters are those which must be supplied as input data to the program. Normally there are 16 parameters for each process. Of these 16, those that are not described in these pages are assigned the value of 0. Output parameters are those which are calculated during the execution of EXEC/OP.

The nominal sizes of all equipment are based on providing enough capacity for normal system operation. Actual sizes are computed by multiplying the nominal values by an excess capacity factor. These factors account for any reserve capacity needed to handle peak flows or for periodic cleaning and maintenance. They are specified as part of the input parameter list for each unit process.

Process: Preliminary Treatment

Subroutine ID Number: 1

Input Design Parameters:

1 - program control number: 0 = grit removal and flow measurement;
1 = grit removal, flow measurement, and screening

16 - excess capacity factor

Output Design Parameters: None

Notes:

1. Cost functions are from Ref. C1.

2. Energy consumption is from Refs. C2 and C3.

Process: Primary Sedimentation

Subroutine ID Number: 2

Input Design Parameters:

1 - fractional removal of influent suspended solids (.4-.6)

2 - ratio of solids concentration in settler underflow to solids concentration in settler influent (150 - 250)
3 - hours per week that sludge pumps are operated
15 - excess capacity factor for sludge pumps
16 - excess capacity factor for settler basin

Output Design Parameters:

1 - overflow rate for settler, gpd/sq. ft.
2 - surface area of settler, sq. ft./1000
3 - pumping capacity of sludge pumps, gpm

Notes:

1. Relation between fractional solids removal and overflow rate is from Ref. C4.

2. Cost functions are from Ref. C1.

3. Energy consumption is from Refs. C2 and C3.

Process: Activated Sludge (Aeration Basin and Final Settler)

Subroutine ID Number: 3

Input Design Parameters:

1 - effluent BOD, mg/l
2 - effluent suspended solids, mg/l
3 - mixed liquor volatile suspended solids, mg/l (2000 - 4000)
4 - sludge recycle ratio (.2-.8)
5 - half-velocity constant, mg/l (20-1000)
6 - true yield coefficient (.5-.7)
7 - maximum substrate removal rate coefficient, 1/day (3-20)
8 - biomass decay coefficient at a 1 day sludge age, 1/day (.1-.5)
9 - maximum removal rate coefficient for nitrification, 1/day (7)
10 - oxygen transfer efficiency of aeration equipment (.05-.08)
11 - overflow rate of final settler, gpd/sq. ft. (600-800)
12 - return sludge pumping head, ft. (10-20)
13 - excess capacity factor for final settler
14 - excess capacity factor for return sludge pumping
15 - excess capacity factor for air blowers
16 - excess capacity factor for aeration basin

Output Design Parameters:

1 - influent 5-day BOD, mg/l
2 - sludge age (solids retention time), days
3 - ratio of settler effluent to settler influent solids concentration
4 - surface area of final settler, sq. ft./1000
5 - maximum substrate removal rate coefficient, 1/day

6 - biomass decay coefficient, 1/day
7 - aeration basin volume, million gallons
9 - concentration of active biomass in aeration, mg/l
11 - concentration of refractory organic solids in aeration, mg/l
12 - concentration of nondegradable solids in aerator due to cell destruction, mg/l
13 - concentration of inert inorganic solids in aerator, mg/l
14 - concentration of BOD removed in aerator, mg/l
15 - sludge return ratio
16 - maximum removal rate coefficient for nitrification, 1/day
17 - diffused air requirement for the aerator, scf/day
18 - size of air blower required, cfm
19 - diffused air requirement per gallon of entering wastewater, scf/gal.
20 - volume of return sludge stream, mgd.

Notes:

1. BOD removal kinetics, sludge production, and air requirements are based on the models of Refs. C5, C6, and C7. The input kinetic parameters (items 5-9) are also based on these models.

2. Nitrification is normally assumed to begin after a sludge age of 5 days. If nitrification is not allowed then input design parameter 16 should equal 0.

3. Cost functions are from Ref. C1.

4. Energy consumption is from Refs. C3 and C8.

Process: Anaerobic Digestion

Subroutine ID Number: 6

Input Design Parameters:

1 - detention time, days (15-30)
2 - sludge temperature in digestor, degrees C (30-40)
3 - climate correction factor (1.0 for northern U.S., 0.5 for middle U.S., 0.3 for southern U.S.)
4 - efficiency in converting BTU content of digestor gas into equivalent kwh
16 - excess capacity factor

Output Design Parameters:

1 - rate constant for digestor, 1/day
2 - rate constant for biodegradable carbon, 1/day
3 - digestor volume, cu. ft./1000
4 - methane production, scf/day
5 - carbon dioxide production, scf/day

Notes:

1. Kinetics of biodegradable carbon destruction is described in Ref. C4.
2. Cost functions are from Ref. C1.
3. Energy consumption is from Refs. C2 and C3.

Process: Vacuum Filtration

Subroutine ID Number: 7

Input Design Parameters:

2 - hours per week of operation
3 - suspended solids concentration in filtrate, mg/l (1500-2500)
7 - cost of ferric chloride, $/lb
8 - cost of Lime, $/lb
10 - cost of polymer, $/lb
11 - identification number of supplementary input tables
16 - excess capacity factor

Supplementary Input Design Parameter Tables:

1 - filter dewatering rate, gph/sq. ft. (8-18)
2 - ferric chloride dosage, lb/ton (0-200)
3 - lime dosage, lb/ton (0-400)
4 - polymer dosage, lb/ton (0-40)

Output Design Parameters:

1 - percent moisture of filtered sludge
2 - filter surface area, sq. ft.
3 - filter cake dry solids production rate, lb/day

Notes:

1. Supplementary input data tables consist of parameter values for the 15 categories of sludge types shown below and are entered into the program input by column

	Raw	Limed	Digested	Digested + Elutriated	Heat Treated
Primary					
Secondary					
Primary + Secondary					

2. Prediction of cake moisture and required surface area is from Ref. C9.

3. Cost functions are from Ref. C1.

4. Energy consumption is from Refs. C2 and C3.

Process: Gravity Thickening

Subroutine ID Number: 8

Input Design Parameters:

1 - solids recovery ratio (.9-.98)
3 - overflow rate, gpd/sq. ft. (400-800)
5 - underflow thickened solids concentration for primary sludge, mg/l
6 - underflow thickened solids concentration for secondary sludge, mg/l
7 - underflow thickened solids concentration for mixed primary and secondary sludge, mg/l
8 - solids loading rate for primary sludge, lb/day/sq. ft. (20-30)
9 - solids loading rate for secondary sludge, lb/day/sq. ft. (4-18)
10 - solids loading rate for mixed primary and secondary sludge, lb/day/sq. ft. (8-20)
16 - excess capacity factor

Output Design Parameters:

1 - surface area of thickener, sq. ft.

Notes:

1. Cost functions are from Ref. C1.
2. Energy consumption is from Refs. C2 and C3.

Process: Elutriation

Subroutine ID Number: 9

Input Design Parameters:

1 - solids recovery ratio (.7-.9)
3 - ratio of wash water volume to influent volume (3)
4 - overflow rate, gpd/sq. ft. (400-600)
6 - underflow solids concentration for primary sludge, mg/l
7 - underflow solids concentration for secondary sludge, mg/l
8 - underflow solids concentration for mixed primary and secondary sludge, mg/l
9 - solids loading rate for primary sludge, lb/day/sq. ft. (20-30)
10 - solids loading rate for secondary sludge, lb/day/sq. ft. (4-18)
11 - solids loading rate for mixed primary and secondary sludge, lb/day/sq. ft. (8-20)
16 - excess capacity factor

Output Design Parameters:

1 - surface area of elutriation tank, sq. ft.

Notes:

1. Wastewater effluent is used as wash water stream
2. Cost functions are from Ref. C1.
3. Energy consumption is from Refs. C2 and C3.

Process: Sand Drying Beds

Subroutine ID Number: 10

Input Design Parameters:

2 - suspended solids concentration in filtrate, mg/l (200-3000)
3 - solid fraction of sludge cake for primary sludge (.2-.4)
4 - solid fraction of sludge cake for secondary sludge (.15-.3)
5 - solid fraction of sludge cake for mixed primary and secondary sludge
6 - detention time required for sludge holding tanks, days (5-20)
7 - excess capacity factor for sludge holding tanks
8 - cost of land for drying beds, $/acre
16 - excess capacity factor for drying beds

Output Design Parameters:

1 - bed area, sq. ft.

Notes:

1. Required bed area is computed as in Ref. C9.
2. Cost functions are from Ref. C1.
3. Energy consumption is from Ref. C3.

Process: Trickling Filter - Final Settler

Subroutine ID Number: 11

Input Design Parameters:

1 - effluent 5-day BOD, mg/l
2 - water temperature, degrees C
3 - hydraulic loading on filter (without recycle), mgd/acre (1040)
4 - specific surface area of the filter, sq. ft./cu. ft (935)
5 - effluent suspended solids, mg/l
6 - suspended solids concentration in sludge underflow from final settler (mg/l) (10000-40000)
7 - ratio of recycle flow to filter influent (14)
8 - overflow rate of final settler, gpd/sq. ft. (600-800)
9 - sludge production factor, lbs sludge/lb BOD removed (.4-.65)
10 - ratio of settled to unsettled effluent BOD (.5)
14 - excess capacity factor for recirculation pumps
15 - excess capacity factor for final settler
16 - excess capacity factor for filter

Output Design Parameters:

1 - surface area of final settler, sq. ft./1000
2 - volume of trickling filter, 1000 cu ft
3 - area of filter face, acres
4 - depth of filter, ft.

Notes:

1. Recycle of filter effluent and use of final settler are optional.
2. Filter is sized according to Ref. C10.
3. Cost functions are from Ref. C1.
4. Energy consumption is from Refs. C3 and C8.

Process: Chlorination - Dechlorination

Subroutine ID Number: 12

Input Design Parameters:

1 - dose of chlorine, mg/l (2-15)
2 - chlorine contact time, minutes (15-30)
3 - cost of chlorine, $/ton
4 - dose of sulfur dioxide for dechlorination, mg/l (2.5)
5 - cost of sulfur dioxide, $/ton
14 - excess capacity factor for the sulfur dioxide feed system
15 - excess capacity factor for the chlorine feed system
16 - excess capacity factor for the contact basin

Output Design Parameters:

1 - volume of the chlorine contact basin, cu. ft.
2 - amount of chlorine used, tons/yr.
3 - amount of sulfur dioxide used, tons/yr.

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C3.

Process: Flotation Thickening

Subroutine ID Number: 13

Input Design Parameters:

1 - solids recovery ratio (.95)
2 - suspended solids concentration of thickened sludge, mg/l
3 - overflow rate, gpd/sq. ft. (700-1200)
4 - solids loading rate, lb./day/sq. ft. (24-96)
5 - hours per week of operation

6 - dose of polymer, lb./ton
7 - cost of polymer, $/ton
16 - excess capacity factor

Output Design Parameters:

1 - surface area of each thickener used, sq. ft.
2 - number of thickeners used
3 - total surface area required, sq. ft.

Notes:

1. Thickeners are chosen from among a set of commercially available sizes.
2. Costs are taken from Ref. C1.
3. Energy consumption is from Ref. C8.

Process: Multiple Hearth Incineration

Subroutine ID Number: 14

Input Design Parameters:

1 - mass loading, lb./hr./sq. ft. of hearth area (2)
2 - number of multiple hearth incinerators (2)
3 - hours per week of operation
4 - number of start-up periods per week
5 - wind velocity, mph
6 - higher heat value for volatiles, BTU/lb. (10000)
7 - type of fuel used; 1 = fuel oil, 2 = natural gas, 3 = digestor gas
8 - cost of fuel oil, $/gal.
9 - cost of natural gas, $/1000 cu. ft.
10 - efficiency in converting BTU content of exhaust gas into equivalent kwh
16 - excess capacity factor

Output Design Parameters:

1 - total hearth area, sq. ft.
2 - total fuel usage, lb./yr.
3 - amount of dry solids incinerated, lb./day.
4 - cost of electrical power to operate the incinerator, $/yr.
5 - cost of fuel to operate the incinerator, $/yr.

Notes:

1. Hearth sizing and fuel requirements are computed as in Refs. C9 and C11 on the basis of exit gas temperature of 800°F.

2. Costs are from Ref. C11. Does not include air pollution control equipment or ash disposal.

3. Energy consumption is from Ref. C11.

4. Heat value of exhaust gas is computed as in Ref. C12 assuming ambient temperature of 60°F.

Process: Raw Wastewater Pumping

Suroutine ID Number: 15

Input Design Parameters:

1 - pumping head, ft. (10-30)
16 - excess capacity factor

Output Design Parameters:

1 - peak flow capacity of the raw wastewater pumping system, mgd

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C8.

Sludge Holding Tanks

Subroutine ID Number: 16

Input Design Parameters:

1 - dentention time, days
16 - excess capacity factor

Output Design Parameters:

1 - volume of holding tanks, cu. ft./1000

Notes:

1. Costs are from Ref. C1.

Process: Centrifugation

Subroutine ID Number: 17

Input Design Parameters:

3 - hours per week of operation
6 - cost of polymer, $/lb.
8 - minimum number of centrifuges to be used
9 - identification number of supplementary input tables

Supplementary Input Design Parameter Tables:

1 - solids recovery ratio (.5-.9)
2 - percent solids of centrifuged sludge (5-35)
3 - dose of conditioning polymer, lb/ton (0-15)
4 - sludge feed rate, gpm (10-200)

Output Design Parameters:

1 - design capacity of the centrifuges, gpm
2 - dry solids processed, tons/yr.
3 - capital recovery factor for centrifuges based on a 10 year lifetime
4 - size of each centrifuge used, gpm
5 - number of centrifuges used

Notes:

1. Supplementary input data tables consist of parameter values for the 15 categories of sludge types shown below and are entered into the program input by column.

	Raw	Limed	Digested	Digested + Elutriated	Heat Treated
Primary					
Secondary					
Primary + Secondary					

2. Determination of the number and sizes of centrifuges is described in Ref. C9.

3. Costs are from Ref. C1.

4. Energy consumption is based on 1 hp/gpm as quoted in Ref. C13.

Process: Aerobic Digestion

Subroutine ID Number: 18

Input Design Parameters:

4 - sludge temperature, degrees C
5 - process detention time, days (12-22)
6 - biomass decay rate coefficient at a sludge age of 1 day at 20°C, 1/days (.1-.5)
7 - true yield coefficient for 5-day BOD (.5-.7)
10 - maximum removal rate coefficient for nitrification, 1/day (7)
11 - oxygen transfer efficiency (.05-.08)
15 - excess capacity factor for blowers
16 - excess capacity factor for digester

Output Design Parameters:

1 - digester volume, cu. ft./1000
2 - size of air blower, cfm

Notes:

1. Complete mix, continuous flow operation is assumed.

2. Solids destruction is modeled as in Ref. C14. Adjustment of biomass decay rate to reflect solids retention time in both digester and activated sludge unit is from Ref. C6.

3. Costs are from Ref. C1.

4. Energy consumption is from Ref. C8.

Process: Truck Transport/Land Disposal of Sludge

Subroutine ID Number: 22

Input Design Parameters:

1 - working hours per year
2 - one-way hauling distance, miles
3 - amortization period for trucks, years
4 - fuel cost, $/gal.
5 - cost of land, $/acre
6 - program control; 0 = land spreading, 1 = landfilling
7 - storage period for liquid sludge, years (.1-.5)
8 - maximum allowable nitrogen application rate, lb./acre/yr. (600)
9 - land spreading site preparation cost, $/acre
10 - land spreading application cost, $/ton
15 - excess capacity factor for trucks
16 - excess capacity factor for sludge storage

Output Design Parameters:

1 - number of trips per year per truck
2 - number of trips per year by all trucks
3 - total number of trucks
4 - volume of sludge storage, cu. ft./1000
5 - amount of dry solids applied to land, tons/yr.
6 - land area required, acres
7 - equivalent annual interest cost on capital investment in land, $/yr.
8 - capital cost of land, $
9 - capital recovery factor for trucks

Notes:

1. Sludge spreading may involve either liquid or dewatered sludge. Only dewatered sludge may be landfilled. Dewatered sludge has a solids content of 15% or more.

2. Land used for sludge spreading has a resale value equal to its initial cost.

3. Costs and energy consumption of truck transport are from Ref. C15.

4. Costs for landfills are from Ref. C16.

5. Costs of storage lagoons are from Ref. C1.

6. Energy consumption for land spreading and landfilling is from Ref. C3.

Process: Lime Stabilization

Subroutine ID Number: 23

Input Design Parameters:

1 - lime dosage, lb./ton of dry solids (200-500)
2 - cost of lime, $/ton
16 - excess capacity factor

Output Design Parameters:

1 - lime addition rate, lb./day
2 - amount of sludge treated, tons of dry solids/day

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C3.

Process: Rotating Biological Contactor - Final Settler

Subroutine ID Number: 24

Input Design Parameters:

1 - effluent 5-day BOD, mg/l
2 - number of stages in series for the process (4)
3 - temperature of the wastewater, degrees C
4 - rate constant for BOD removal at 20°C, gpd/sq. ft. (6-9)
5 - rate constant for nitrification at 20°C, gpd/sq. ft. (4-5)
6 - overflow rate for final settler, gpd/sq. ft. (600-800)
7 - concentration of BOD at which nitrification begins, mg/l (20-30)
10 - sludge production factor, lb sludge/lb BOD removed

8 - concentration of waste solids from the final settler underflow, percent
9 - cost of installed concrete, \$/cu. yd.
15 - excess capacity factor for the final settler
16 - excess capacity factor for the rotating biological contactor

Output Design Parameters:

1 - loading rate for BOD removal adjusted for water temperature, gpd/sq. ft.
2 - loading rate for nitrification adjusted for water temperature, gpd/sq. ft.
3 - area per contactor stage, sq. ft.
4 - total active contactor area, sq. ft.
5 - number of stages required to achieve the BOD concentration at which nitrification begins
6 - number of remaining stages for nitrification
7 - fraction of influent BOD remaining in effluent
8 - percentage ammonia nitrogen removal
9 - overall hydraulic loading, gpd/sq. ft.
10 - surface area of final settler, sq. ft.
11 - solids wasting rate, lb. dry solids/day
12 - fraction of suspended solids remaining after settling
13 - number of 100,000 sq. ft. shafts per stage
14 - number of 100,000 sq. ft. shafts required
15 - materials and supplies cost, \$/yr.
16 - electrical power cost, \$/yr.
17 - labor cost, \$/yr.

Notes:

1. Waste stream transformation and sludge production is modeled as in Ref. C8.

2. Cost functions are from Ref. Cl.

3. Energy consumption is from Ref. C3 and C8.

Process: Primary Sedimentation - Activated Sludge - Waste Activated Sludge Returned to Primary Clarifier

Subroutine ID Number: 25

Input Design Parameters:

1 - option number assigned to primary clarifier unit

2 - option number assigned to activated sludge unit

Supplementary Input Design Parameters:

1 through 16 - see Primary Sedimentation subroutine

17 through 32 - see Activated Sludge subroutine

Output Design Parameters:

1 through 20 - see Activated Sludge subroutine

Notes:

1. See notes for Primary Sedimentation and Activated Sludge subroutines.

Process: Nonoxidative Heat Treatment

Subroutine ID Number: 26

Input Design Parameters:

4 - operating temperature, degrees C (150-220)
5 - hours per week of operation
6 - number of start-ups per week
7 - fuel cost, $/million BTU
8 - detention time for sludge holding tanks, days
9 - excess capacity factor for sludge holding tanks
16 - excess capacity factor for heat treatment

Output Design Parameters:

1 - capacity of heat treatment unit, gpm
2 - fraction of suspended COD remaining in effluent
3 - fraction of volatile suspended solids remaining in effluent
4 - annual heat requirement, million BTU/yr.

Notes:

1. Reduction in BOD and volatile solids is based on operating temperature as described in Ref. C17.

2. Costs are from Ref. C18.

3. Energy consumption is from Ref. C19.

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APPENDIX D - PROGRAM LISTING

```
C                   EXECOP - MAIN
C
C       EXEC/OP - OPTIMIZATION VERSION OF EPA EXECUTIVE PROGRAM
C
C       SELECTS BEST COMBINATION OF UNIT PROCESSES FOR TREATING
C       WASTEWATER AND DISPOSING OF RESIDUAL SLUDGES.
C       SELECTION CRITERIA INCLUDES COST, ENERGY, LAND UTILIZATION,
C       AND A SUBJECTIVE PROCESS UNDESIREABILITY RATING.
C       PROGRAM CAN ALSO IDENTIFY UP TO 40 NEXT-BEST DESIGNS.
C
C               WRITTEN BY L. ROSSMAN, EPA, MERL, DECEMBER 1978
C
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3         CF,EER,EEP,ALAND
        COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2              NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3              IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
        COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2              IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3              ,EEPMAX(20)
        COMMON/TABLES/ DUMMY(600)
        DIMENSION CSIM(10),CSAVE(10)
        DIMENSION PSAVE(20,10)
        EQUIVALENCE (PSAVE(1,1),IPSAVE(1,1)),(JMIX,JSTRM(21))
C
C
C               INITIALIZE COUNTERS AND UPPER BOUND
C
        MITMAX=10
        MITER=1
        TUPE=0.
        TSE=0.
        NITSUM=0
        ZUB=1.E20
        NPHASE=1
C
        INP=5
        IO=5
C
C               CALL SUBROUTINE THAT READS IN INPUT
C
        ISW=0
        CALL INPUT(ISW)
C
C               INITIALIZE PLANT INFLOW AND RECYCLE PENALTIES
C
25      DO 30 I=1,20
        SMATX(I,1)=PINFLO(I)
        DO 30 K=1,10
        PSAVE(I,K)=0.
30      P(I,K)=0.
        P(2,5)=-10000.
        P(2,6)=-10000.
        TEPMAX=W(5)*TEPMAX
```

```
C
C             IF SYSTEM DESIGN IS FIXED, EVALUATE PERFORMANCE
C
      IF (ISW .EQ. 0) GO TO 40
      CALL SOLVE(TCS,CSIM,NITER)
      CALL OUTPUT(ISW,1,TCS,-1.,-1.)
      STOP
C
C             OPTIMIZATION PHASE
C             ------------------
C
C
40    WRITE(IO,400)
400   FORMAT(////,49X,'OPTIMIZATION PHASE'/49X,18('_'))
C
C             PERFORM SYSTEM OPTIMIZATION USING PENALTY TERMS TO
C             ACCOUNT FOR SLUDGE RECYCLE FLOWS.
C
45    IF(MITER.GT.MITMAX)GO TO 300
      TCO=1.01*ZUB
      CALL OPTIM(NPHASE,1,1.0,TCO,TCP,IFEAS)
      IF(IFEAS.GT.0)GO TO 90
      WRITE(IO,50)
50    FORMAT(/42X,' NO FEASIBLE DESIGN CAN BE FOUND'//)
      IF(MITER.EQ.1)STOP
      GO TO 300
C
C             FIND EXACT PERFORMANCE OF CANDIDATE OPTIMAL SYSTEM DESIGN
C
90    CALL SOLVE(TCS,CSIM,NITER)
      TSE=TSE+1.
      NITSUM=NITSUM+NITER
      WRITE(IO,100) MITER,TCS-TEPMAX
100   FORMAT(////52X,'DESIGN ',I3/52X,10('_')//
     2       39X,' EXACT SYSTEM VALUE',6X,F12.3)
      WRITE(IO,105) TCO-TEPMAX,TCP
105   FORMAT(39X,' APPROX. SYSTEM VALUE',4X,F12.3/
     2       39X,' PENALTY FROM RECYCLES',3X,F12.3)
C
C             IF TCS VALUE WAS REACHED ONCE BEFORE,STOP WITH CURRENT
C             UPPER BOUND AS OPTIMAL.
C
110   CONTINUE
      IF(MITER.EQ.1)GO TO 250
      J2=MITER-1
      DO 240 JJ=1,J2
      IF(CSAVE(JJ).EQ.TCS)GO TO 295
240   CONTINUE
C
C             PERFORM FEASIBILITY CHECK
C
250   IFEAS=1
      DO 230 K=1,10
      IF(CSIM(K).GT.RHS(K))IFEAS=0
230   CONTINUE
C
C             SAVE OBJECTIVE VALUE AND PRINT DESIGN OF CURRENT SYSTEM
C
      CALL OUTPUT(ISW)
      IF(IFEAS.EQ.0)WRITE(IO,235)
235   FORMAT(//42X,'*** SOLUTION IS NOT FEASIBLE ***')
      CSAVE(MITER)=TCS
      IF(IFEAS.EQ.0)GO TO 260
C
C             IF TCS LESS THAN CURRENT UPPER BOUND, REPLACE UPPER BOUND
C
      IF(ZUB.LE.TCS) GO TO 260
      ZUB=TCS
      DO 255 I=1,20
      DO 255 K=1,10
255   PSAVE(I,K)=P(I,K)
```

```
      MITMIN=MITER
260   MITER=MITER+1
      IF(MITER.GT.MITMAX)GO TO 300
C
C             COMPUTE NEW RECYCLE PENALTY  VALUES
C
      CALL PNALTY(CSIM)
C
C             RE-ARRANGE ENTRIES IN PROCESS LISTS SO THAT CANDIDATE
C             OPTIMAL PROCESS TRAIN APPEARS FIRST
C
      DO 290 J=1,NTPS
      L1=NPROC(J)
      DO 275 L=1,L1
      IF(KPROC(L,J).EQ.IPOPT(J))GO TO 285
275   CONTINUE
285   LSTAR=L
      IF(LSTAR.EQ.1)GO TO 290
      KSAVE=KPROC(LSTAR,J)
      L1=LSTAR-1
      DO 280 L=1,L1
      L2=LSTAR-L+1
      KPROC(L2,J)=KPROC(L2-1,J)
280   CONTINUE
      KPROC(1,J)=KSAVE
290   CONTINUE
C
C             BEGIN ANOTHER OPTIMIZATION ITERATION
      GO TO 45
C
295   WRITE(IO,305) JJ
305   FORMAT(/45X,'SAME SYSTEM AS DESIGN ',I3)
C
C             SENSITIVITY PHASE
C             -----------------
C
300   NPHASE=2
      IF(KMAX.LE.1) GO TO 360
      WRITE(IO,405)
405   FORMAT(////,49X,'SENSITIVITY PHASE'/49X,17('_'))
C
C             PERFORM SYSTEM OPTIMIZATION USING RECYCLE PENALTY VALUES
C             ASSOCIATED WITH OPTIMAL SYSTEM DESIGN (PSAVE) AND IDENTIFY
C             ALL DESIGNS WITHIN 'FACTOR' OF OPTIMUM.
C
      DO 310 I=1,20
      DO 310 K=1,10
310   P(I,K)=PSAVE(I,K)
      LIMIT=KMAX
      FACTOR=FACTR
      TCO=1.01*ZUB
      CALL OPTIM(NPHASE,LIMIT,FACTOR,TCO,TCP,IFEAS)
      IF(IFEAS.EQ.0)STOP
C
C             EVALUATE TRUE PERFORMANCE OF EACH DESIGN
C
      ZUB=100.E20
      DO 350 KS=1,LIMIT
      DO 330 J=1,NTPS
330   IPOPT(J)=IPSAVE(KS,J)
      JMIX=JMSAVE(KS)
      CALL SOLVE(TCS,CSIM,NITER)
      TSE=TSE+1.
      NITSUM=NITSUM+NITER
      WRITE(IO,100) KS,TCS-TEPMAX
      CALL OUTPUT(ISW)
      IF(ZUB.LE.TCS)GO TO 350
```

```
      ZUB=TCS
      MITMIN=KS
350   CONTINUE
360   WRITE(IO,370)MITMIN
370   FORMAT(//45X,'BEST DESIGN IS NUMBER ',I3)
C
C             COMPUTE SEARCH EFFICIENCY
C
      FEM=1.
      DO 380 J=1,NTPS
380   FEM=FEM*NPROC(J)
      FEM=FEM*NTPS*NITSUM/TSE
      SEFF=TUPE/FEM*100.
      WRITE(IO,390)SEFF
390   FORMAT(//33X,'SEARCH EFFORT WAS ',F8.4,'% OF TOTAL',
     2            ' ENUMERATION')
      WRITE(IO,395)
395   FORMAT(//47X,' * SLUDGE MIXING POINT')
      STOP
      END
C
C
C                     INPUT SUBROUTINE
C
      SUBROUTINE INPUT(ISW)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2            NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3            IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2            IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3            ,EEPMAX(20)
      COMMON/TABLES/ VACF1(3,5,5),VACF5(3,5,5),VACF6(3,5,5),VACF9(3,5,5)
     2     ,CENT1(3,5,5),CENT2(3,5,5),CENT5(3,5,5),CENT7(3,5,5)
      DIMENSION TITLE(40)
      EQUIVALENCE (JMIX, JSTRM(21))
C
C             READ IN JOB TITLE
C
      READ(INP,10)TITLE
10    FORMAT(40A2)
      WRITE(IO,15)
15    FORMAT(/49X,'EXECUTIVE PROGRAM'/46X,'(OPTIMIZATION VERSION)'
     2       /56X,'FOR'/33X,'PRELIMINARY SYNTHESIS OF WASTE ',
     3       'TREATMENT SYSTEMS')
      WRITE(IO,20)
20    FORMAT(//39X,'U.S. ENVIRONMENTAL PROTECTION AGENCY'/36X,
     2 'MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY'/39X,
     3 'SYSTEMS AND ECONOMIC ANALYSIS SECTION'/46X,
     4 'CINCINNATI, OHIO 45268')
      WRITE(IO,25) TITLE
25    FORMAT(////17X,40A2)
C
C             READ IN INFLUENT WASTE CHARACTERISTICS, EFFLUENT
C             DISCHARGE STANDARDS, AND ECONOMIC DATA.
C
      PINFLO(1)=1.
      PINFLO(20)=0.
      READ(INP,1) (PINFLO(I),I=2,19)
      READ(INP,1) (EFFSTD(I),I=1,5)
      READ(INP,1) CCI,WPI,RI,YRS,DHR,PCT,CKWH,RATIO,CF
      AF=RI*(1.+RI)**YRS/((1.+RI)**YRS-1.)
```

```
C
C              READ IN # WASTEWATER PROCESS STAGES,
C               # SECONDARY SLUDGE PROCESS STAGES,
C              # PRIMARY SLUDGE PROCESS STAGES, TOTAL # PROCESS UNITS,
C              SLUDGE RECYCLE STAGE, AND STABILIZATION STAGES FOR
C              SECONDARY AND PRIMARY SLUDGES.
C
      READ(INP,2)NWPS,NSSPS,NPSPS,NTPU,JRECYC
C
C              ESTABLISH SEGMENT ID NOS. FOR PROCESS STAGES AND ZERO OUT
C              LENGTH OF PROCESS LISTS.
C
      NTPS=NWPS+NPSPS+NSSPS
C
C              JSTRM CODE
C
C     1-2    = WASTEWATER PROCESSING STAGES
C     3-4    = SECONDARY SLUDGE PROCESSING STAGES
C     5-6    = PRIMARY SLUDGE PROCESSING STAGES
C     7-10   = SLUDGE STREAM FROM WASTEWATER TREATMENT
C    11-12   = SECONDARY SLUDGE RECYCLE STREAM
C    13-14   = PRIMARY SLLUDGE RECYCLE STREAM
C    15-17   = WASTEWATER, SECONDARY AND PRIMARY SLUDGE EFFLUENT STREAMS
C       20   = RECYCLE RETURN STAGE
C       21   = SECONDARY AND PRIMARY SLUDGE MIXING STAGE
C       22   = NULL PROCESS NUMBER
C
      JSTRM(1)=1
      JSTRM(2)=NWPS
      JSTRM(3)=JSTRM(2)+1
      JSTRM(4)=JSTRM(3)+NSSPS-1
      JSTRM(5)=JSTRM(4)+1
      JSTRM(6)=JSTRM(5)+NPSPS-1
      JSTRM(7)=JSTRM(6)+1
      JSTRM(10)=JSTRM(7)+NWPS-1
      JSTRM(11)=JSTRM(10)+1
      JSTRM(12)=JSTRM(11)+NSSPS-1
      JSTRM(13)=JSTRM(12)+1
      JSTRM(14)=JSTRM(13)+NPSPS-1
      JSTRM(15)=JSTRM(14)+1
      JSTRM(16)=JSTRM(15)+1
      JSTRM(17)=JSTRM(16)+1
      JSTRM(20)=JRECYC
      DO 30 J=1,NTPS
30    NPROC(J)=0
      N=0
C
C              READ IN STAGES ASSIGNED TO SLUDGE STREAMS FROM
C              WASTEWATER TREATMENT
C
      READ(INP,2) (JSIDE(I),I=1,NWPS)
      JJ=JSTRM(3)
      DO 32 I=JJ,NTPS
32    JSIDE(I)=JRECYC
C
C              READ IN INFORMATION ON ALTERNATIVE PROCESS UNITS
C
      DO 33 I=1,NTPS
33    EEPMAX(I)=0.
      WRITE(IO,35)
35    FORMAT(////47X,'PROCESS ALTERNATIVES'/47X,20('_'))
      WRITE(IO,40)
40    FORMAT(//' OPTION  PROCESS  STAGE  SIDESTREAM'/
     2  '   NO.      NO.      NO.   DESTINATION',37X,'REMARKS'
     3  ' ______  _______  _____  ___________',2X,80('_'))
```

```
      DO 60 K=1,NTPU
      READ(INP,3)J,N,IPROC,EMAX,UDR(N)
      IF (EMAX .GT. EEPMAX(J)) EEPMAX(J)=EMAX
      READ(INP,45)(TITLE(JJ),JJ=1,40)
45    FORMAT(40A2)
      WRITE(IO,50) N,IPROC,J,JSIDE(J), (TITLE(JJ),JJ=1,40)
50    FORMAT(1X,I4,3I8,9X,40A2)
      NPROC(J)=NPROC(J)+1
      KPROC(NPROC(J),J)=N
      IP(N)=IPROC
      IF(IPROC.EQ.0)JSTRM(22)=N
      IF(IPROC.EQ.0)GO TO 60
      READ(INP,1)(DMATX(I,N),I=1,16)
      IF(IPROC.EQ.7)GO TO 51
      IF(IPROC.EQ.17)GO TO 53
      IF(IPROC.EQ.25)GO TO 55
      GO TO 60
51    L=DMATX(11,N)
      READ(INP,1)((VACF1(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((VACF5(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((VACF6(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((VACF9(I,JJ,L),I=1,3),JJ=1,5)
      GO TO 60
53    L=DMATX(9,N)
      READ(INP,1)((CENT1(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((CENT2(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((CENT5(I,JJ,L),I=1,3),JJ=1,5)
      READ(INP,1)((CENT7(I,JJ,L),I=1,3),JJ=1,5)
      GO TO 60
55    NSAVE=DMATX(1,N)
      READ(INP,1) (DMATX(I,NSAVE),I=1,16)
      NSAVE=DMATX(2,N)
      READ(INP,1) (DMATX(I,NSAVE),I=1,16)
      GO TO 60
60    CONTINUE
C
C               READ IN SELECTION CRITERIA DATA
C
      DO 115 K=1,10
115   W(K)=0.
      WRITE(IO,120)
120   FORMAT(////48X,'SELECTION CRITERIA'/48X,18('_')//)
      WRITE(IO,125)
125   FORMAT(32X,'CRITERION',25X,'WEIGHT',11X,'LIMIT',
     2 /32X,9('_'),25X,6('_'),11X,5('_')/)
      READ(INP,1)(W(K),K=1,8)
      READ(INP,1)(RHS(K),K=1,8)
      WRITE(IO,130)(W(K),RHS(K),K=1,4)
130   FORMAT(25X,' 1.  INITIAL CONSTR. COST, M$   ',6X,2(F10.2,8X),
     2        /25X,' 2.  ANNUAL O & M COST, $/MG',9X,2(F10.2,8X),
     3        /25X,' 3.  TOTAL ANNUAL COST, $/MG',9X,2(F10.2,8X),
     4        /25X,' 4.  ENERGY CONSUMED, KWH/MG',9X,2(F10.2,8X))
      WRITE(IO,135)(W(K),RHS(K),K=5,8)
135   FORMAT(25X,' 5.  ENERGY PRODUCED, KWH/MG',9X,2(F10.2,8X),
     2        /25X,' 6.  NET ENERGY CONSUMED, KWH/MG',5X,2(F10.2,8X),
     3        /25X,' 7.  LAND REQUIRED, ACRES',12X,2(F10.2,8X),
     4        /25X,' 8.  UNDESIREABILITY INDEX',11X,2(F10.2,8X))
C
      WRITE(IO,200)
200   FORMAT(////51X,'ECONOMIC DATA'/51X,13('_')//)
      WRITE(IO,210) CCI,WPI,DHR,PCT
210   FORMAT(33X,' CONSTRUCTION COST INDEX',12X,F12.4/
     2         33X,' WHOLESALE PRICE INDEX',14X,F12.4/
     3         33X,' DIRECT HOURLY WAGE, $/HR',11X,F12.4/
     4         33X,' FRACTION CHARGED TO SUPERVISION',4X,F12.4)
```

```
      WRITE(IO,220) RATIO,CKWH,CF,RI,AF
220   FORMAT(33X,' COST ESCALATOR FOR MISC. FEES',6X,F12.4/
     2       33X,' COST OF ELECTRICITY, $/KWH',9X,F12.4/
     3       33X,' FUEL CONVERSION EFFICIENCY',9X,F12.4/
     4       33X,' DISCOUNT RATE',22X,F12.4/
     5       33X,' CAPITAL RECOVERY FACTOR',12X,F12.4)
      CCI=CCI/1.506
      WPI=WPI/1.122
C
C            INITIALIZE TARGET VALUES OF CRITERIA LIMITS
C
      TEPMAX=0.
      DO 160 J=1,NTPS
160   TEPMAX=TEPMAX+EEPMAX(J)
      RHS(5)=TEPMAX-RHS(5)
      RHS(6)=TEPMAX+RHS(6)
C
C            READ IN # NEXT BEST DESIGNS WANTED WITHIN 'FACTR' OF
C            OPTIMAL DESIGN.
C
      READ(INP,4) KMAX,FACTR
      FACTR=1.+FACTR
C
C            IF SYSTEM DESIGN IS TO BE FIXED, READ IN PROCESS UNIT NOS.
C            AND FIND MIXING STAGE FOR SECONDARY AND PRIMARY SLUDGES.
C
      READ(INP,2,END=80)(IPOPT(J),J=1,NTPS)
      ISW=1
      JT=JSTRM(4)
      JMIX=JSTRM(5)+NSSPS
70    IF (IP(IPOPT(JT)) .NE. 0) GO TO 80
      JMIX=JMIX-1
      JT=JT-1
      IF (JT .GT. JSTRM(2)) GO TO 70
      JMIX=JSTRM(5)
80    RETURN
1     FORMAT(8F10.0)
2     FORMAT(8I10)
3     FORMAT(3I10,2F10.0)
4     FORMAT(I10,F10.0)
      END
C
C
C            OUTPUT SUBROUTINE
C
      SUBROUTINE OUTPUT(ISW)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4       CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2             NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3             IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2             IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3             ,EEPMAX(20)
      DIMENSION CTOT(10)
C
C
      JMIX=JSTRM(21)
      WRITE(IO,20) (I,I=1,8)
20    FORMAT(//' STAGE  PROCESS  SLUDGE,',38X,'SELECTION CRITERIA'/
     2        '  NO.    OPTION   TONS/DAY',2X,8(6X,I1,4X)/
     3       1X,5('_'),2X,7('_'),2X,8('_'),2X,8(2X,9('_')))
```

```
      STOT=0.
      DO 30 K=1,10
30    CTOT(K)=0.
C
      DO 120 J=1,NTPS
      SMIX=' '
      N=IPOPT(J)
      IPROC=IP(N)
      IF(IPROC.EQ.0)GO TO 110
      IF(J.GT.JSTRM(2))GO TO 50
      OS2=NTPS+J
      S2=SMATX(2,OS2)*SMATX(10,OS2)*8.33/2000.
      STOT=STOT+S2
      GO TO 60
C
50    S2=SMATX(2,J)*SMATX(10,J)*8.33/2000.
C
60    IF(J.EQ.JMIX)SMIX='*'
      WRITE(IO,90) J,SMIX,N,S2,(C(J,K),K=1,8)
90    FORMAT(2X,I2,A1,5X,I2,5X,F8.2,2X,8F11.2)
C
      DO 95 K=1,10
95    CTOT(K)=CTOT(K)+C(J,K)
      GO TO 120
110   IF(J.EQ.JMIX)JMIX=JMIX+1
120   CONTINUE
      WRITE(IO,130)
130   FORMAT(17X,8('_'),2X,8(2X,9('_')))
      WRITE(IO,140)STOT,(CTOT(K),K=1,8)
140   FORMAT(' SYSTEM VALUES    ',F8.2,2X,8F11.2)
      IF (ISW .EQ.0) GO TO 145
      WRITE(IO,190)
190   FORMAT(////40X,'PROCESS PERFORMANCE CHARACTERISTICS'/40X,35('_')
     2 //49X,'VOLUME FLOW, MGD'/49X,'CONCENTRATION, MG/L'/15X,
     4 'CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT',
     5 ' AND OUTPUT DESIGN DATA.'//)
      DO 260 J=1,NTPS
      N=IPOPT(J)
      IPROC=IP(N)
      IF(IPROC.EQ.0)GO TO 260
      IS1=J
      OS1=J+1
      IF(J.EQ.JSTRM(2))OS1=JSTRM(15)
      IF(J.EQ.JSTRM(4))OS1=JSTRM(16)
      IF(J.EQ.JSTRM(6))OS1=JSTRM(17)
      OS2=NTPS+J
      WRITE(IO,200) J,N
200   FORMAT(//46X,'STAGE ',I2,'   PROCESS OPTION ',I2/46X,28('_'))
      WRITE(IO,210)
210   FORMAT(/51X,'INPUT DESIGN DATA:')
      WRITE(IO,220) (DMATX(I,N),I=1,16)
220   FORMAT(8F12.3)
      WRITE(IO,230)
230   FORMAT(/51X,'OUTPUT DESIGN DATA:')
      WRITE(IO,240) (OMATX(I,N),I=1,20)
240   FORMAT(9F12.3)
      WRITE(IO,250)
250   FORMAT(/35X,'INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:'/
     2   9X,'Q',9X,'SOC',8X,'SNBC',9X,'SON',9X,'SOP',9X,
     3   'SFM',8X,'SBOD',9X,'VSS',9X,'TSS')
      WRITE(IO,240) (SMATX(I,IS1),I=2,10),(SMATX(I,OS1),I=2,10),
     2              (SMATX(I,OS2),I=2,10)
      WRITE(IO,255)
255   FORMAT(7X,'DOC',8X,'DNBC',10X,'DN',10X,'DP',9X,'DFM',9X,'ALK',
     2       8X,'DBOD',9X,'NH3',9X,'NO3')
      WRITE(IO,240) (SMATX(I,IS1),I=11,19),(SMATX(I,OS1),I=11,19),
     2              (SMATX(I,OS2),I=11,19)
```

```
260     CONTINUE
145     RETURN
        END
C
C
C                          SYSTEM SOLUTION SUBROUTINE
C
        SUBROUTINE SOLVE(TCS,CSIM,NITER)
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,FER,EEP,ALAND
        COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2               NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3               IPOPT(20),PINFLO(20),EFFSID(20),ISC(45),IDC(45)
        COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2               IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3               ,EEPMAX(20)
        DIMENSION CSIM(10),TRECYC(20),RECYC(20)
        DATA NITMAX/20/,EPS1/.001/,EPS2/.0001/
C
        DO 5 I=1,20
5       RECYC(I)=0.
        DELSUM=0.
        NITER=0
C
C              EVALUATE TOTAL SYSTEM PERFORMANCE WITH CURRENT VALUE
C              OF RECYCLE FLOW
C
90      NITER=NITER+1
        IF(NITER.GT.NITMAX) GO TO 100
        DO 10 I=1,20
        TRECYC(I)=RECYC(I)
10      SMATX(I,1)=PINFLO(I)
        SUMOLD=DELSUM
        CALL SYSTEM(TCS,CSIM,RECYC)
C
C              MIX RECYCLE FLOWS OFF OF SLUDGE UNITS TOGETHER
C
C       THE VALUE OF J SHOULD BE SET TO THE DIMENSION OF THE SECOND
C       INDEX OF SMATX(I,J).
35      J=45
        J1=JSTRM(3)
        J2=JSTRM(6)
        J3=JSTRM(20)
        CALL SMIX(J,J1,J2,J3)
        DO 40 I=2,20
40      RECYC(I)=SMATX(I,J)
C
C              CHECK FOR CONVERGENCE
C
        ISTOP=1
        DELSUM=0.
        DO 50 I=2,20
        DEL=ABS(RECYC(I)-TRECYC(I))
        DELSUM=DELSUM+DEL
        IF(DEL.GT.EPS1*RECYC(I)) ISTOP=0
50      CONTINUE
        IF(ABS(DELSUM-SUMOLD).LT.EPS2*DELSUM) GO TO 100
        IF(ISTOP.EQ.1) GO TO 100
        GO TO 90
C
C              CONVERGENCE IS ATTAINED.
C
100     RETURN
        END
```

```
C
C
C                 OPTIMIZATION SUBROUTINE
C
C         IMPLICIT ENUMERATION OPTIMIZATION PROCEDURE
C
      SUBROUTINE OPTIM(NPHASE,LIMIT,FACTOR,FMIN,PMIN,IFEAS)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2             NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3             IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2            IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3            ,EEPMAX(20)
      DIMENSION LSAVE(20),FSAVE(40),IPMIN(20)
      DIMENSION FTEMP(10),PTEMP(10),FJ(20,10),PJ(20,10)
      EQUIVALENCE (JLEFF,JSTRM(15)),(JSSEFF,JSTRM(16)),
     2            (JPSEFF,JSTRM(17)),(JMIX,JSTRM(21))
C
C
C                 BEGIN AT STAGE J = 1
C
      IFEAS=0
      KOUNT=0
      DO 5 K=1,10
      FJ(1,K)=0.
5     PJ(1,K)=0.
      JSTART=1
      JMIX=JPSEFF
C
C                 FIND NEXT OPTION IN PROCESS LIST AT STAGE J
C
15    J=JSTART
20    L=1
25    LSAVE(J)=L
      N=KPROC(L,J)
      IPROC=IP(N)
      IS1=J
      IS2=0
      OS1=J+1
      IF(J.EQ.JSTRM(2))OS1=JLEFF
      IF(J.EQ.JSTRM(4))OS1=JSSEFF
      IF(J.EQ.JSTRM(6))OS1=JPSEFF
      OS2=NTPS+J
      IF(J.EQ.JSTRM(3))GO TO 30
      IF(J.EQ.JSTRM(5))GO TO 40
      GO TO 60
C
C                 J=START OF SECONDARY SLUDGE PROCESSING.
C                 MIX SECONDARY SLUDGE STREAMS TOGETHER.
C
30    J1=JSTRM(1)
      J2=JSTRM(2)
      CALL SMIX(J,J1,J2,J)
      IDC(J)=1
      ISC(J)=0
      IF (SMATX(2,J) .GT. 0.) ISC(J)=2
      GO TO 80
C
C                 J=START OF PRIMARY SLUDGE-PROCESSING.
C                 MIX PRIMARY SLUDGE STREAMS TOGETHER.
C                 FIND MIXING POINT OF PRIMARY AND
C                 SECONDARY SLUDGES (JMIX).
```

```
C
40      J1=JSTRM(1)
        J2=JSTRM(2)
        CALL SMIX(J,J1,J2,J)
        IDC(J)=1
        ISC(J)=0
        IF (SMATX(2,J) .GT. 0.) ISC(J)=1
45      JT=JSTRM(4)
        JMIX=JSTRM(5)+NSSPS
50      IF(IP(IPOPT(JT)).NE.0)GO TO 60
        JMIX=JMIX-1
        JT=JT-1
        IF(JT.GT.JSTRM(2))GO TO 50
        JMIX=JSTRM(5)
        IF (J .EQ. JMIX) GO TO 65
C
60      IF(J.NE.JMIX .OR. L .GT. 1)GO TO 80
C
C               J=JMIX. MIX PRIMARY AND SECONDARY SLUDGES TOGETHER.
C
65      TEMP1=SMATX(2,JSSEFF)+SMATX(2,J)
        DO 70 I=3,20
        TEMP2=SMATX(2,J)*SMATX(I,J)+SMATX(2,JSSEFF)*SMATX(I,JSSEFF)
70      SMATX(I,J)=TEMP2/TEMP1
        SMATX(2,J)=TEMP1
        ISC(J)=ISC(J)+ISC(JSSEFF)
        IF (ISC(J) .EQ. 2) IDC(J)=IDC(JSSEFF)
        IF (ISC(J) .EQ. 3) IDC(J)=10*IDC(J)+IDC(JSSEFF)
C
C               EVALUATE SELECTION CRITERIA FOR CURRENT PROCESS AND ADD
C               TO SYSTEM VALUES. CHECK IF CONSTRAINTS ARE MET AND
C               CURRENT UPPER BOUND NOT EXCEEDED.
C
80      CONTINUE
        CALL UNIT(J,IPROC)
        PSUM=0.
        FSUM=0.
        DO 85 K=1,10
        FTEMP(K)=FJ(J,K)+C(J,K)
        PTEMP(K)=PJ(J,K)+CP(K)
        IF(K.EQ.5)FTEMP(K)=FJ(J,K)+EEPMAX(J)-C(J,K)
        IF(K.EQ.6)FTEMP(K)=FJ(J,K)+EEPMAX(J)+C(J,K)
        IF(FTEMP(K)+PTEMP(K).GT.RHS(K))GO TO 90
75      FSUM=FSUM+W(K)*FTEMP(K)
        PSUM=PSUM+W(K)*PTEMP(K)
85      CONTINUE
        IF(FACTOR*FMIN.LE.FSUM+PSUM)GO TO 90
C
C               ADD CURRENT PROCESS ALTERNATIVE TO SOLUTION AND UPDATE
C               SYSTEM CRITERIA VALUES.
C
        IPOPT(J)=N
        J=J+1
        DO 95 K=1,10
        FJ(J,K)=FTEMP(K)
95      PJ(J,K)=PTEMP(K)
        IF(J.LE.NTPS)GO TO 20
C
C               NEW TOTAL SYSTEM WAS ARRIVED AT. UPDATE UPPER BOUND.
C
        IFEAS=1
        FTOT=FSUM+PSUM
        IF(FTOT.GE.FMIN)GO TO 105
        FMIN=FTOT
        PMIN=PSUM
```

```
      JMMIN=JMIX
      DO 100 J=1,NTPS
100   IPMIN(J)=IPOPT(J)
C
C           IF THIS IS SENSITIVITY PHASE, INSERT NEW SOLUTION INTO LIST
C
105   IF(NPHASE.EQ.1)GO TO 180
      IF(KOUNT.EQ.0)GO TO 120
C
C        LOCATE POSITION OF LARGEST ENTRY IN LIST
      FMAX=0.
      DO 110 M=1,KOUNT
      IF(FTOT.EQ.FSAVE(M))GO TO 180
      IF(FSAVE(M).LE.FMAX)GO TO 110
      FMAX=FSAVE(M)
      KFMAX=M
110   CONTINUE
      IF(FTOT.GE.FMAX)GO TO 140
      IF(KOUNT.EQ.LIMIT)GO TO 130
C
C        LENGTH OF LIST IS LESS THAN LIMIT
120   KIN=KOUNT+1
      KOUNT=KIN
      GO TO 160
C
C        LENGTH OF LIST EQUALS LIMIT. REPLACE LARGEST ENTRY WITH
C        NEW SOLUTION.
130   KIN=KFMAX
      GO TO 160
C
C        NEW SOLUTION IS LARGER THAN LARGEST ENTRY IN LIST. IF LENGTH
C        OF LIST EQUALS LIMIT, REJECT NEW SOLUTION.
140   IF(KOUNT.EQ.LIMIT)GO TO 180
      FMAX=FTOT
      KFMAX=KOUNT+1
      GO TO 120
C
C        PLACE NEW SOLUTION INTO LIST.
160   FSAVE(KIN)=FTOT
      DO 170 J=1,NTPS
170   IPSAVE(KIN,J)=IPOPT(J)
      JMSAVE(KIN)=JMIX
180   CONTINUE
C
C
      J=NTPS
C
C           MOVE TO NEXT PROCESS OPTION AT CURRENT STAGE
C           IF NO MORE OPTIONS THEN MOVE BACK ONE STAGE
90    L=LSAVE(J)+1
      IF(L.LE.NPROC(J))GO TO 25
      J=J-1
      IF(J.GE.JSTART)GO TO 90
C
C           IF CANNOT MOVE BACK ANY MORE STAGES THEN STOP THE SEARCH
C
      JMIX=JMMIN
      DO 190 J=1,NTPS
190   IPOPT(J)=IPMIN(J)
      LIMIT=KOUNT
      RETURN
      END
C
C
```

```
C
C              SYSTEM EVALUATION SUBROUTINE
C
C
      SUBROUTINE SYSTEM(TCS,F,RECYC)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2             NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3             IPOPT(20),PINFLO(20),EFFSID(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2             IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3             ,EEPMAX(20)
      DIMENSION F(10),RECYC(20)
      EQUIVALENCE (JLEFF,JSTRM(15)),(JSSEFF,JSTRM(16)),(JPSEFF,
     2            JSTRM(17)),(JRECYC,JSTRM(20)),(JMIX,JSTRM(21))
C
      TCS=0.
      DO 5 K=1,10
    5 F(K)=0.
C
C              EVALUATE SELECTION CRITERIA FOR THE PROCESS SELECTED
C              AT EACH STAGE.
C
      DO 90 J=1,NTPS
      N=IPOPT(J)
      IPROC=IP(N)
      IS1=J
      IS2=0
      OS1=J+1
      IF(J.EQ.JSTRM(2))OS1=JLEFF
      IF(J.EQ.JSTRM(4))OS1=JSSEFF
      IF(J.EQ.JSTRM(6))OS1=JPSEFF
      OS2=NTPS+J
      IF(J.EQ.JRECYC)GO TO 10
      IF(J.EQ.JSTRM(3))GO TO 30
      IF(J.EQ.JSTRM(5))GO TO 40
      GO TO 60
C
C              J=RECYCLE MIXING POINT. MIX INFLUENT AND RECYCLE STREAMS.
C
   10 TEMP1=SMATX(2,J)+RECYC(2)
      DO 20 I=3,20
      TEMP2=SMATX(2,J)*SMATX(I,J)+RECYC(2)*RECYC(I)
   20 SMATX(I,J)=TEMP2/TEMP1
      SMATX(2,J)=TEMP1
      SMATX(1,J)=1.
      SMATX(20,J)=0.
      GO TO 80
C
C              J=START OF SECONDARY SLUDGE PROCESSING.
C              MIX SECONDARY SLUDGE STREAMS TOGETHER.
C
   30 J1=JSTRM(1)
      J2=JSTRM(2)
      CALL SMIX(J,J1,J2,J)
      IDC(J)=1
      ISC(J)=0
      IF (SMATX(2,J) .GT. 0.) ISC(J)=2
      GO TO 80
C
C              J=START OF PRIMARY SLUDGE PROCESSING.
C              MIX PRIMARY SLUDGE STREAMS TOGETHER.
C
```

```
40        J1=JSTRM(1)
          J2=JSTRM(2)
          CALL SMIX(J,J1,J2,J)
          IDC(J)=1
          ISC(J)=0
          IF (SMATX(2,J) .GT. 0.) ISC(J)=1
60        IF(J.NE.JMIX)GO TO 80
C
C                 J=MIXING POINT OF PRIMARY AND SECONDARY SLUDGES.
C
          TEMP1=SMATX(2,JSSEFF)+SMATX(2,J)
          DO 70 I=3,20
          TEMP2=SMATX(2,JSSEFF)*SMATX(I,JSSEFF)+SMATX(2,J)*SMATX(I,J)
70        SMATX(I,J)=TEMP2/TEMP1
          SMATX(2,J)=TEMP1
          ISC(J)=ISC(J)+ISC(JSSEFF)
          IF (ISC(J) .EQ. 2) IDC(J)=IDC(JSSEFF)
          IF (ISC(J) .EQ. 3) IDC(J)=10*IDC(J)+IDC(JSSEFF)
C
C                 DETERMINE PERFORMANCE OF PROCESS N AT STAGE J.
C
80        CALL UNIT(J,IPROC)
          DO 85 K=1,10
          IF(K.EQ.5)GO TO 81
          IF(K.EQ.6)GO TO 82
          F(K)=F(K)+C(J,K)
          GO TO 85
81        F(K)=F(K)+EEPMAX(J)-C(J,K)
          GO TO 85
82        F(K)=F(4)+F(5)
85        CONTINUE
90        CONTINUE
          DO 95 K=1,10
95        TCS=TCS+W(K)*F(K)
          RETURN
          END
C
C
C                 UNIT PROCESS EVALUATION SUBROUTINE
C
          SUBROUTINE UNIT(J,IPROC)
C
          INTEGER OS1,OS2
          COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1           INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2           ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3           CF,EER,EEP,ALAND
          COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2                 NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3                 IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
          COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2                 IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3                 ,EEPMAX(20)
          COMMON/TABLES/ VACF1(3,5,5),VACF5(3,5,5),VACF6(3,5,5),VACF9(3,5,5)
     2        ,CENT1(3,5,5),CENT2(3,5,5),CENT5(3,5,5),CENT7(3,5,5)
          DIMENSION SAVE(20)
          EQUIVALENCE (J2LP,JSTRM(2)),(JLEFF,JSTRM(15)),
     2     (JMIX,JSTRM(21)),(JSSEFF,JSTRM(16))
C
          TUPE=TUPE+1.
C
C                 INITIALIZE ERROR INDICATOR
C
          IAERF=0
C
```

```
C                INITIALIZE OUTPUT STREAMS AND SELECTION CRITERIA
C
      ISC(OS1)=ISC(IS1)
      IDC(OS1)=IDC(IS1)
      DO 5 I=1,20
      SMATX(I,OS1)=SMATX(I,IS1)
5     SMATX(I,OS2)=0.
      DO 15 II=1,5
      CCOST(II)=0.
      COSTO(II)=0.
      ACOST(II)=0.
15    CONTINUE
      DO 16 K=1,10
      CP(K)=0.
16    C(J,K)=0.
      EER=0.
      EEP=0.
      ALAND=0.
C
C               DETERMINE WHICH PROCESS SUBROUTINE TO CALL
C
      IF(IPROC.EQ.0)GO TO 560
      IF(SMATX(2,IS1).EQ.0.)GO TO 560
      GO TO(10,20,30,560,560,60,70,80,90,100,110,120,130,140,150,160,
     1      170,180,560,560,560,220,230,240,250,260),IPROC
      GO TO 560
C
C               PRELIMINARY TREATMENT
C
10    CALL PREL
      GO TO 500
C
C               PRIMARY SEDIMENTATION
C
20    CALL PRSET
      GO TO 500
C
C               ACTIVATED SLUDGE
C
30    IF (DMATX(1,N) .GT. .75*(SMATX(8,IS1)+SMATX(17,IS1)))
     2   GO TO 225
      CALL AERFS
      IF(IAERF)500,500,225
C
C               ANAEROBIC DIGESTION
C
60    CALL DIG
C
C        UPDATE SLUDGE DIGESTION CODE
      IDC(OS1)=3
      GO TO 500
C
C               VACUUM FILTRATION
C
C
C      DETERMINE SLUDGE TYPE
70    I1=ISC(IS1)
C
C      DETERMINE TYPE OF STABILIZATION
      GO TO (71,71,73),I1
71    J1=IDC(IS1)
      J2=J1
      W1=1.
      W2=0.
      GO TO 74
73    IF(IDC(IS1).LT.10)GO TO 71
      J1=IDC(IS1)/10
      J2=IDC(JSSEFF)
```

```
      TEMP1=SMATX(2,JMIX)*SMATX(10,JMIX)
      TEMP2=SMATX(2,JSSEFF)*SMATX(10,JSSEFF)
      W2=TEMP2/TEMP1
      W1=1.-W2
C
C       DETERMINE PROCESS PARAMETERS
74    L=DMATX(11,N)
      DMATX(1,N)=W1*VACF1(I1,J1,L)+W2*VACF1(I1,J2,L)
      DMATX(5,N)=W1*VACF5(I1,J1,L)+W2*VACF5(I1,J2,L)
      DMATX(6,N)=W1*VACF6(I1,J1,L)+W2*VACF6(I1,J2,L)
      DMATX(9,N)=W1*VACF9(I1,J1,L)+W2*VACF9(I1,J2,L)
      CALL VACF
      GO TO 500
C
C             GRAVITY THICKENING
C
C       SAVE SECONDARY INFLUENT STREAM
80    IF(IS2.EQ.0)GO TO 82
      DO 81 I=2,20
81    SAVE(I)=SMATX(I,IS2)
C
C       DETERMINE SLUDGE TYPE
82    I1=ISC(IS1)
C
C       DETERMINE UNDERFLOW SOLIDS CONC. AND LOADING
      DMATX(2,N)=DMATX(4+I1,N)
      DMATX(4,N)=DMATX(7+I1,N)
      IF(DMATX(2,N).LT.SMATX(10,IS1))GO TO 560
      CALL THICK
      IF(IS2.EQ.0)GO TO 500
      DO 83 I=2,20
83    SMATX(I,IS2)=SAVE(I)
      GO TO 500
C
C             ELUTRIATION
C
C       SAVE FLOW OF SECOND INFLUENT STREAM
90    IS2=JLEFF
      SAVE(2)=SMATX(2,IS2)
C
C        DETERMINE SLUDGE TYPE
      I1=ISC(IS1)
C
C        DETERMINE UNDERFLOW CONC. AND LOADING
      DMATX(2,N)=DMATX(5+I1,N)
      DMATX(5,N)=DMATX(8+I1,N)
C
C       DO NOT ALLOW ELUTRIATION IF PRECEEDED BY LIME STABILIZATION
      IF(IDC(IS1).EQ.2)GO TO 225
      IF(IDC(IS1)/10.EQ.2)GO TO 225
      IF(IDC(JSSEFF).EQ.2)GO TO 225
      CALL ELUT
      SMATX(2,IS2)=SAVE(2)
      IDC(OS1)=4
      GO TO 500
C
C             SAND DRYING BEDS
C
C        CHECK TO SEE IF SLUDGE IS STABILIZED
100   IF (IDC(IS1) .LE. 1) GO TO 225
      IF (IDC(IS1) .LT.10) GO TO 105
      IF (IDC(IS1)/10 .LE. 1) GO TO 225
      IF (IDC(JSSEFF) .LE. 1)  GO TO 225
105   CONTINUE
```

```
C         CHECK THAT MINIMUM INFLUENT SOLIDS CONC. IS MET
        IF(SMATX(10,IS1)/10000.,LT.1.12)GO TO 225
C
C          FIND COST OF SLUDGE HOLDING TANKS
        SAVE(1)=DMATX(1,N)
        SAVE(16)=DMATX(16,N)
        DMATX(1,N)=DMATX(6,N)
        DMATX(16,N)=DMATX(7,N)
        CALL SHT
        CCOST(2)=CCOST(1)
        COSTO(2)=COSTO(1)
        DMATX(1,N)=SAVE(1)
        DMATX(16,N)=SAVE(16)
C
C          DETERMINE SLUDGE TYPE
        I1=ISC(IS1)
C
C          DETERMINE CAKE SOLIDS CONC.
        DMATX(1,N)=DMATX(2+I1,N)
        CALL SBEDS
C
C          FIND COST OF LAND
        CCOST(3)=DMATX(8,N)*ALAND
        GO TO 500
C
C               TRICKLING FILTER
C
110     IF (DMATX(1,N) .GT. .75*(SMATX(8,IS1)+SMATX(17,IS1)))
     2     GO TO 225
        CALL TRFS
        IF (IAERF .GT. 0) GO TO 225
        GO TO 500
C
C               CHLORINATION
C
120     CALL CHLOR
        GO TO 500
C
C               FLOTATION THICKENING
C
130     IF(IS2.GT.0)SAVE(2)=SMATX(2,IS2)
        CALL TFLOT
        IF(IS2.GT.0)SMATX(2,IS2)=SAVE(2)
        GO TO 500
C
C               INCINERATION
C
140     CALL MHINC
        DO 145 I=1,20
145     SMATX(T,OS1)=0.
        GO TO 500
C
C               RAW WASTEWATER PUMPING
C
150     CALL RWP
        GO TO 500
C
C               SLUDGE HOLDING TANKS
C
160     CALL SHT
        GO TO 500
C
C               CENTRIFUGATION
C
C        DETERMINE SLUDGE TYPE
170     I1=ISC(IS1)
```

```
C
C          DETERMINE TYPE OF STABILIZATION
           GO TO (171,171,173),I1
171        J1=IDC(IS1)
           J2=J1
           W1=1.
           W2=0.
           GO TO 174
173        IF(IDC(IS1).LT.10)GO TO 171
           J1=IDC(IS1)/10
           J2=IDC(JSSEFF)
           TEMP1=SMATX(2,JMIX)*SMATX(10,JMIX)
           TEMP2=SMATX(2,JSSEFF)*SMATX(10,JSSEFF)
           W2=TEMP2/TEMP1
           W1=1.-W2
C
C          DETERMINE PROCESS PARAMETERS
174        L=DMATX(9,N)
           DMATX(1,N)=W1*CENT1(I1,J1,L)+W2*CENT1(I1,J2,L)
           TEMP=W1*CENT2(I1,J1,L)+W2*CENT2(I1,J2,L)
           DMATX(2,N)=TEMP*1.E4
           DMATX(5,N)=W1*CENT5(I1,J1,L)+W2*CENT5(I1,J2,L)
           DMATX(7,N)=W1*CENT7(I1,J1,L)+W2*CENT7(I1,J2,L)
           CALL CENT
           GO TO 500
C
C                AEROBIC DIGESTION
C
C           FIND SRT OF ACTIVATED SLUDGE UNIT
180        DO 183 J1=1,J2LP
           L=IP(IPOPT(J1))
           IF(L.EQ.3)GO TO 185
           IF(L.EQ.25)GO TO 185
183        CONTINUE
           DMATX(3,N)=0.
           GO TO 186
185        DMATX(3,N)=DMATX(2,IPOPT(J1))
186        CONTINUE
           CALL AEROB
C
C          UPDATE SLUDGE STABILIZATION CODE
           IDC(OS1)=3
           GO TO 500
C
C                LAND DISPOSAL
C
220        IF(DMATX(6,N).EQ.1)GO TO 227
C
C          CHECK TO SEE THAT SLUDGE IS STABILIZED
           IF (IDC(IS1) .LE. 1) GO TO 225
           IF (IDC(IS1) .LT.10) GO TO 228
           IF (IDC(IS1)/10 .LE. 1) GO TO 225
           IF (IDC(JSSEFF) .LE. 1) GO TO 225
           GO TO 228
C
C           CHECK THAT SOLIDS IS OVER 15% IF LANDFILLING
227        TEMP=SMATX(10,IS1)*1.E-6
           IF(TEMP.LT.0.15)GO TO 225
C
C           CHECK IF FINAL DISPOSAL INCURS ANY COST
228        IF(DMATX(16,N).EQ.0.)GO TO 560
           CALL LANDD
```

```
      DO 229 I=1,20
229   SHATX(I,OS1)=0.
      GO TO 500
C
C       INFEASIBLE OPTION. MAKE OBJECTIVE VALUE VERY HIGH.
225   DO 226 K=1,10
226   C(J,K)=100.E20
      C(J,5)=0.
      RETURN
C
C             LIME STABILIZATION
C
230   CALL LIME
C
C       ADJUST SLUDGE STABILIZATION CODE
      IDC(OS1)=2
      GO TO 500
C
C             ROTATING BIOLOGICAL CONTACTOR
C
240   CALL RBC
      GO TO 500
C
C             PRIMARY SEDIMENTATION - ACTIVATED SLUDGE - WASTE
C             ACTIVATED SLUDGE RETURNED TO PRIMARY SETTLER
C
250   CALL PSASFS
      IF(IAERF.GT.0)GO TO 225
      GO TO 500
C
C             HEAT TREATMENT
C
C        FIND COST OF HOLDING TANK
260   IF(DMATX(8,N).EQ.0.)GO TO 261
      SAVE(1)=DMATX(1,N)
      SAVE(16)=DMATX(16,N)
      DMATX(1,N)=DMATX(8,N)
      DMATX(16,N)=DMATX(9,N)
      CALL SHT
      CCOST(3)=CCOST(1)
      COSTO(3)=COSTO(1)
      DMATX(1,N)=SAVE(1)
      DMATX(16,N)=SAVE(16)
C
C        CHECK IF SLUDGE DIGESTED AND FIND STREAM NOS. AT MIXING POINT
261   DMATX(3,N)=0.
      IF(IDC(IS1).EQ.3) DMATX(3,N)=1.
      I1=JMIX
      I2=JSSEFF
      IF(J.GE.JMIX)GO TO 262
      I1=J
      I2=0
      IF(J.GE.JSTRM(5))GO TO 262
      I1=0
      I2=0
262   DMATX(1,N)=I1
      DMATX(2,N)=I2
C
C        FIND COST OF THERMAL REACTOR
      CALL HEAT
C
      IDC(OS1)=5
      GO TO 500
C
```

```
C
C                SUM SUB-UNIT AMORTIZATION AND O&M COSTS.
C
500     DO 540 II=1,5
        CCOST(II)=CCOST(II)*CCI*RATIO
        COSTO(II)=COSTO(II)*RATIO
        IF(ACOST(II))520,510,520
510     ACOST(II)=CCOST(II)*AF/(3650.*PINFLO(2))
        GO TO 530
520     ACOST(II)=ACOST(II)*CCI*RATIO
530     C(J,3)=C(J,3)+ACOST(II)+COSTO(II)
        C(J,1)=C(J,1)+CCOST(II)
        C(J,2)=C(J,2)+COSTO(II)
540     CONTINUE
C
C                EVALUATE SELECTION CRITERIA
C
        C(J,1)=C(J,1)/1.E6
        C(J,2)=C(J,2)*10.
        C(J,3)=C(J,3)*10.
        C(J,4)=EER/PINFLO(2)
        C(J,5)=EEP/PINFLO(2)
        C(J,6)=C(J,4)-C(J,5)
        C(J,7)=ALAND
        C(J,8)=UDR(N)
C
C                EVALUATE PENALTIES FOR EACH CRITERION
C
        IF(J.LE.J2LP)GO TO 600
        DO 555 K=1,10
        CP(K)=P(2,K)*SMATX(2,OS2)
        TEMP1=SMATX(2,OS2)
        DO 550 I=3,19
        TEMP2=SMATX(I,OS2)
        IF(I.EQ.9)TEMP2=SMATX(9,OS2)-SMATX(3,OS2)-SMATX(5,OS2)-SMATX(6,OS2)
        IF(I.EQ.13)TEMP2=SMATX(13,OS2)-SMATX(18,OS2)-SMATX(19,OS2)
        IF(TEMP2.LE.0.)TEMP2=0.
550     CP(K)=CP(K)+(P(I,K)*TEMP1*TEMP2)
555     CONTINUE
        GO TO 600
C
C                PROCESS IS NULL PROCESS WITH ZERO COST
C
560     DO 570 I=1,20
        SMATX(I,OS1)=SMATX(I,IS1)
570     SMATX(I,OS2)=0.
        N=JSTRM(22)
        GO TO 600
C
C                CHECK EFFLUENT STANDARDS ON BOD, TSS, TKN, NO3, AND P
C
600     IF(J.NE.J2LP)RETURN
        IF(SMATX(8,JLEFF)+SMATX(17,JLEFF).GT.EFFSTD(1))GO TO 225
        IF(SMATX(10,JLEFF).GT.EFFSTD(2))GO TO 225
        IF(SMATX(5,JLEFF)+SMATX(18,JLEFF).GT.EFFSTD(3))GO TO 225
        IF(SMATX(10,JLEFF).GT.EFFSTD(4))GO TO 225
        IF(SMATX(14,JLEFF).GT.EFFSTD(5))GO TO 225
        RETURN
        END
C
```

```
C               PENALTY SUBROUTINE
C
C
C
      SUBROUTINE PNALTY(CSIM)
C
      COMMON SMATX(20,45),DUMMY1(2000),IDUMMY(58),
     2       DUMMY2(27)
      COMMON/PROC/ ID(225),JSTRM(22),JSIDE(20),P(20,10),IPOPT(20),
     2              PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
      DIMENSION TRECYC(20),DC(20,10),CRECYC(10),COPT(10),TSUM(10)
     2          ,CSIM(10),RECYC(20)
C
C
      DO 5 K=1,10
5     TSUM(K)=0.
      DO 10 I=2,20
      RECYC(I)=0.
      DO 10 K=1,10
      P(I,K)=0.
10    DC(I,K)=0.
C
C               EVALUATE SYSTEM PERFORMANCE WITH NO RECYCLES
C               MIX RECYCLE FLOWS TOGETHER
C
      CALL SYSTEM(TCS,COPT,RECYC)
      J=JSTRM(17)
      J1=JSTRM(3)
      J2=JSTRM(6)
      J3=JSTRM(20)
      CALL SMIX(J,J1,J2,J3)
      DO 15 I=2,20
15    TRECYC(I)=SMATX(I,J)
C
C               EVALUATE MARGINAL TREATMENT CRITERIA FOR RECYCLE
C               COMPONENTS BY FINDING CHANGE IN CRITERIA FOR TREATING EACH
C               COMPONENT SEPARATELY.
C
      Q1=TRECYC(2)
      Q2=.001*PINFLO(2)
      IF(TRECYC(2).LT.Q2)RETURN
      DO 200 I=2,18
      GO TO (200,20,200,40,50,60,70,80,200,200,200,120,200,140,200,
     2       140,170,190), I
      GO TO 200
C
C               Q
C
20    RECYC(2)=TRECYC(2)
      GO TO 180
C
C               SNBC
C
40    RECYC(2)=Q2
      RECYC(4)=TRECYC(4)*Q1/Q2
      RECYC(3)=RECYC(4)
      RECYC(9)=RECYC(4)
      RECYC(10)=RECYC(4)
      GO TO 180
C
C               SON
C
50    RECYC(2)=Q2
      RECYC(5)=TRECYC(5)*Q1/Q2
      RECYC(9)=RECYC(5)
      RECYC(10)=RECYC(5)
      GO TO 180
```

```
C               SOP
C
60      RECYC(2)=Q2
        RECYC(6)=TRECYC(6)*Q1/Q2
        RECYC(9)=RECYC(6)
        RECYC(10)=RECYC(6)
        GO TO 180
C
C               SFM
C
70      RECYC(2)=Q2
        RECYC(7)=TRECYC(7)*Q1/Q2
        RECYC(10)=RECYC(7)
        GO TO 180
C
C               SBOD
C
80      RECYC(2)=Q2
        RECYC(8)=TRECYC(8)*Q1/Q2
        RECYC(3)=RECYC(8)/1.87
        RECYC(9)=RECYC(8)/1.87
        RECYC(10)=RECYC(8)/1.87
        GO TO 180
C
C               OTHER VSS (NOT SOC, SON, OR SOP)
C
90      RECYC(2)=Q2
        RECYC(9)=(TRECYC(9)-TRECYC(3)-TRECYC(5)-TRECYC(6))*Q1/Q2
        RECYC(10)=RECYC(9)
        GO TO 180
C
C               DNBC
C
120     RECYC(2)=Q2
        RECYC(12)=TRECYC(12)*Q1/Q2
        RECYC(11)=RECYC(12)
        GO TO 180
C
C               OTHER DN (NOT NH3 OR NO3)
C
130     RECYC(2)=Q2
        RECYC(13)=(TRECYC(13)-TRECYC(18)-TRECYC(19))*Q1/Q2
        GO TO 180
C
C               DP AND ALK
C
140     RECYC(2)=Q2
        RECYC(I)=TRECYC(I)*Q1/Q2
        GO TO 180
C
C               DBOD
C
170     RECYC(2)=Q2
        RECYC(17)=TRECYC(17)*Q1/Q2
        RECYC(11)=RECYC(17)/1.87
        GO TO 180
C
C               NH3
C
190     RECYC(2)=Q2
        RECYC(18)=TRECYC(18)*Q1/Q2
        RECYC(13)=RECYC(18)
C
C
180     DO 185 II=2,20
185     IF(RECYC(II).LT.0.)RECYC(II)=0.
        CALL SYSTEM(TCS,CRECYC,RECYC)
```

```
      DO 186 K=1,10
      DC(I,K)=CRECYC(K)-COPT(K)
186   TSUM(K)=TSUM(K)+DC(I,K)
194   DO 195 II=2,20
195   RECYC(II)=0.
200   CONTINUE
C
C
      DO 210 I=1,20
210   RECYC(I)=TRECYC(I)
C
C             PENALTY = MARGINAL CHANGE IN CRITERION / MASS FLOW *
C                                        ADJUSTMENT FACTOR
C             ADJUSTMENT FACTOR = (CRITERION W/ RECYCLE - CRITERION W/O
C                                        RECYCLE) / SUM OF MARGINAL CHANGES
C
      DO 230 K=1,10
      IF(TSUM(K).EQ.0.)GO TO 230
      DEL=(CSIM(K)-COPT(K))/TSUM(K)
      P(2,K)=DC(2,K)*DEL/TRECYC(2)
      DO 220 I=3,20
      IF(TRECYC(I).EQ.0.)GO TO 220
      P(I,K)=DC(I,K)*DEL/(TRECYC(2)*TRECYC(I))
220   CONTINUE
C
C             CORRECT COMPUTED PENALTIES FOR OTHER VSS AND DN
C
      TEMP=TRECYC(9)-TRECYC(3)-TRECYC(5)-TRECYC(6)
      IF(TEMP.LE.0.)GO TO 225
      P(9,K)=P(9,K)*TRECYC(9)/TEMP
225   TEMP=TRECYC(13)-TRECYC(18)-TRECYC(19)
      IF(TEMP.LE.0.)GO TO 230
      P(13,K)=P(13,K)*TRECYC(13)/TEMP
230   CONTINUE
      RETURN
      END
C
C
C             STREAM MIXING SUBROUTINE
C
C
      SUBROUTINE SMIX(J,J1,J2,J3)
C
      COMMON SMATX(20,45),DUMMY1(2000),IDUMMY(58),
     2       DUMMY2(27)
      COMMON/PROC/ ID(223),NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     2             IPOPT(20),DUMMY(40),ISC(45),IDC(45)
C
      SMATX(1,J)=1.
      TEMP1=0.
      DO 10 JT=J1,J2
      IF (JSIDE(JT) .NE. J3) GO TO 10
      TEMP1=TEMP1+SMATX(2,JT+NTPS)
10    CONTINUE
      IF(TEMP1.EQ.0.)GO TO 50
      DO 30 I=3,20
      TEMP2=0.
      DO 20 JT=J1,J2
      IF (JSIDE(JT) .NE. J3) GO TO 20
      TEMP2=TEMP2+SMATX(2,JT+NTPS)*SMATX(I,JT+NTPS)
20    CONTINUE
30    SMATX(I,J)=TEMP2/TEMP1
40    SMATX(2,J)=TEMP1
      RETURN
50    DO 60 I=2,20
60    SMATX(I,J)=0.
      SMATX(2,J)=0.
      RETURN
      END
```

```
      SUBROUTINE PREL
C              PRELIMINARY TREATMENT
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      IPREL=DMATX(1,N)
      X=ALOG(SMATX(2,IS1)*DMATX(16,N))
      IF(IPREL) 30,20,30
   20 CCOST(1)=EXP(2.566569+.619151*X)*1000.
      GO TO 40
   30 CCOST(1)=EXP(3.259716+.619151*X)*1000.
   40 X=ALOG(SMATX(2,IS1))
      OHRS=EXP(6.398716+.230956*X+.164959*X**2-.014601*X**3)
      XMHRS=EXP(5.846098+.206513*X+.068842*X**2+.023824*X**3-
     . .004410*X**4)
      TMSU=EXP(7.235657+.399935*X-.224979*X**2+.110099*X**3-
     . .011026*X**4)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
        EER=EXP(2.64866+.532611*X-.034378*X**2+.007274*X**3)
        EER=EER+EXP(.47668+.256486*X-.051504*X**2+.02465*X**3)
        EER=EER+DMATX(1,N)*3.01*EXP(.249*X)
      RETURN
      END

      SUBROUTINE PRSET
C              PRIMARY SEDIMENTATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      HPWK=DMATX(3,N)
      SMATX(2,OS2)=DMATX(1,N)*SMATX(2,IS1)/DMATX(2,N)
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      TEMP1=(1.-DMATX(1,N))*SMATX(2,IS1)/SMATX(2,OS1)
      TEMP2=DMATX(1,N)*SMATX(2,IS1)/SMATX(2,OS2)
      DO 10 I=3,10
      SMATX(I,OS1)=TEMP1*SMATX(I,IS1)
   10 SMATX(I,OS2)=TEMP2*SMATX(I,IS1)
        SMATX(20,OS1)=TEMP1*SMATX(20,IS1)
        SMATX(20,OS2)=TEMP2*SMATX(20,IS1)
      DO 20 I=11,19
      SMATX(I,OS2)=SMATX(I,IS1)
   20 SMATX(I,OS1)=SMATX(I,OS2)
      GPS=-2780.*ALOG(DMATX(1,N))-551.7
      APS=SMATX(2,IS1)*1000./GPS*DMATX(16,N)
      X=ALOG(APS)
      CCOST(1)=EXP(3.716354+.389861*X+.084560*X**2-.004718*X**3)*
     . 1000.
      X=ALOG(APS/DMATX(16,N))
      OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      PGPM=SMATX(2,OS2)*116666.7/HPWK*DMATX(15,N)
      X=ALOG(PGPM)
      CCOST(2)=EXP(2.237330+.207628*X+.026479*X**2)*1000.
      X=ALOG(PGPM/DMATX(15,N))
      OHRS=EXP(4.945155+.419391*X)
      XMHRS=EXP(3.993365+.444966*X)
      TMSU=EXP(4.433129+.642272*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=GPS
      OMATX(2,N)=APS
      OMATX(3,N)=PGPM
```

```
          X=ALOG(APS/DMATX(16,N))
          EER=EXP(2.92248+.396798*X+.062424*X**2)
          X=ALOG(SMATX(2,IS1))
          EER=EER+EXP(1.70697+.293587*X+.075918*X**2-
     2                 .002995*X**3)
      RETURN
      END
        SUBROUTINE AERFS
C
C                 ACTIVATED SLUDGE - FINAL SETTLER
C
        REAL MLSS,MLVSS,MLISS,MLASS,MLRSS
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,EER,EEP,ALAND
C
        IAERF=0
        BODLIM=DMATX(1,N)
        TSSLIM=DMATX(2,N)
        MLVSS=DMATX(3,N)
        RTURN=DMATX(4,N)
        CS   =DMATX(5,N)
        CY   =DMATX(6,N)
        CK   =DMATX(7,N)
        CB1  =DMATX(8,N)
        CKN  =DMATX(9,N)
        AEFF =DMATX(10,N)
        GSS  =DMATX(11,N)
        HEAD =DMATX(12,N)
C
C    COMPUTE INFLUENT CONC. OF BOD AND SOLIDS
        BOD1=SMATX(8,IS1)+SMATX(17,IS1)
        MLASS=0.
        MLRSS=SMATX(4,IS1)*SMATX(9,IS1)/SMATX(3,IS1)
        MLISS=SMATX(7,IS1)
C
C    USE METHOD OF FALSE POSITION TO FIND THE SRT AND BOD2 THAT
C    WILL RESULT IN BODEFF = BODLIM.
C    STEP1 - FIND AN SRT THAT GIVES BODEFF .GT. BODLIM
        SRT=3.
        CB=CB1*SRT**-.415
        BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
        INDEX=1
        GO TO 25
101     X1=SRT
        Y1=BODEFF-BODLIM
        IF(Y1.LE.0.)GO TO 30
C
C    STEP 2 - FIND AN SRT THAT GIVES BODEFF .LT. BODLIM
        SRT=6.
5       CB=CB1*SRT**-.415
        BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
        INDEX=2
        GO TO 25
102     X2=SRT
        Y2=BODEFF-BODLIM
        IF(Y2.LE.0.)GO TO 15
        SRT=SRT+3.
        IF(SRT.GT.21.)GO TO 1000
        GO TO 5
C
C    STEP 3 - INTERPOLATE BETWEEN X1 AND X2 TO ESTIMATE A NEW SRT
15      SRT=(X2*Y1-X1*Y2)/(Y1-Y2)
        CB=CB1*SRT**-.415
        BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
        INDEX=3
        GO TO 25
103     IF(ABS(BODEFF-BODLIM).LE.0.001*BODLIM)GO TO 30
```

```
C
C     STEP 4 - DISCARD OLD POINT THAT IS ON SAME SIDE OF BODLIM AS IS THE
C               CURRENT BODEFF AND RETURN TO STEP 3
          IF(Y1*(BODEFF-BODLIM).LE.0.)GO TO 20
          Y1=Y2
          X1=X2
20        Y2=BODEFF-BODLIM
          X2=SRT
          GO TO 15
C
C     COMPUTE HRT, SETTLER EFFICIENCY, AND BODEFF
25        HRT=SRT/MLVSS*(MLRSS+CY*(BOD1-BOD2)/(1.+CB*SRT)*(1.+.2*CB*SRT))
          XRSS=TSSLIM/(MLVSS+MLISS*SRT/HRT)
          BODEFF=BOD2+.97*.8*XRSS*SRT/HRT*CY*(BOD1-BOD2)/(1.+CB*SRT)
          GO TO (101,102,103), INDEX
C
C     COMPUTE CONC. OF SOLIDS IN AERATOR
30        MLASS=SRT/HRT*CY*(BOD1-BOD2)/(1.+CB*SRT)
          MLRSS=.2*CB*MLASS*SRT+SRT/HRT*MLRSS
          MLISS=SRT/HRT*MLISS
          MLSS=MLVSS+MLISS
C
C     FIND WASTE SLUDGE SOLIDS CONC. AND FLOW RATE
          SMATX(10,OS1)=TSSLIM
          SMATX(10,OS2)=MLSS/RTURN*(1.+RTURN-HRT/SRT)
          SMATX(2,OS2)=SMATX(2,IS1)*(MLSS*(1.+RTURN)-SMATX(10,OS1)-
      2                SMATX(10,OS2)*RTURN)/(SMATX(10,OS2)-SMATX(10,OS1))
          SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
C
C     COMPUTE CONC. OF SOLIDS SPECIES IN OVERFLOW
          SMATX(4,OS1)=XRSS*(.2*CB*MLASS*SRT/2.46+SMATX(4,IS1)*SRT/HRT)
          SMATX(4,OS1)=SMATX(4,OS1)+XRSS*.2*MLASS/2.46
          SMATX(3,OS1)=SMATX(4,OS1)+XRSS*.8*MLASS/2.46
          SMATX(5,OS1)=XRSS*(.12*MLASS+.06*MLRSS)
          SMATX(6,OS1)=XRSS*.025*MLASS
          SMATX(7,OS1)=XRSS*MLISS
          SMATX(8,OS1)=BODEFF-BOD2
          SMATX(9,OS1)=XRSS*MLVSS
          SMATX(20,OS1)=XRSS*MLASS
C
C     COMPUTE CONC. OF SOLID SPECIES IN UNDERFLOW
          R=SMATX(10,OS2)/SMATX(10,OS1)
          DO 40 I=3,9
40        SMATX(I,OS2)=SMATX(I,OS1)*R
          SMATX(20,OS2)=SMATX(20,OS1)*R
C
C     COMPUTE DISSOLVED C, N, P, AND FIXED MATTER
          SMATX(11,OS1)=SMATX(12,IS1)+BOD2/BOD1*(SMATX(11,IS1)-SMATX(12,IS1))
          SMATX(12,OS1)=SMATX(12,IS1)
          SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)-SMATX(5,OS1)*SMATX(2,OS1)/
      2   SMATX(2,IS1)-SMATX(5,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
          SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)-SMATX(6,OS1)*SMATX(2,OS1)/
      2   SMATX(2,IS1)-SMATX(6,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
          SMATX(15,OS1)=SMATX(15,IS1)
C
C     CHECK FOR NITRIFICATION (SRT .GE. 5 DAYS)
          IF(SRT.LT.5.)GO TO 50
          IF(SRT*.05*CKN.LE.1.)GO TO 50
          SMATX(18,OS1)=1.*(1./((SRT*.05*CKN)-1.))
          SMATX(19,OS1)=SMATX(13,OS1)-SMATX(18,OS1)
          GO TO 60
50        SMATX(19,OS1)=SMATX(19,IS1)
          SMATX(18,OS1)=SMATX(13,OS1)-SMATX(19,OS1)
C
C     ADJUST ALKALINITY AND DISSOLVED BOD
60        SMATX(16,OS1)=SMATX(16,IS1)-7.14*(SMATX(19,OS1)-SMATX(19,IS1))
          SMATX(17,OS1)=BOD2
          DO 70 I=11,19
70        SMATX(I,OS2)=SMATX(I,OS1)
```

```
C
C     SIZE THE AERATION TANK
          VAER=HRT*SMATX(2,IS1)*DMATX(16,N)
          X=ALOG(VAER*1000./7.48)
          CCOST(1)=EXP(2.414380+.175682*X+.084742*X**2-.002670*X**3)*1000.
          COSTO(1)=0.
C
C     COMPUTE AIR REQUIREMENTS
          ARCFD=(1.5-1.42*CY)*SMATX(2,IS1)*(BOD1-BOD2)*8.33
          ARCFD=ARCFD+1.42*CB*.8*MLASS*VAER*8.33
          ARCFD=ARCFD+4.6*(SMATX(19,OS1)-SMATX(19,IS1))*SMATX(2,IS1)*8.33
          ARCFD=ARCFD/AEFF/.232/.075
          BSIZE=ARCFD/1440.*DMATX(15,N)
          CFPGL=ARCFD/1.E6/SMATX(2,IS1)
          X=ALOG(BSIZE/1000.)
          CCOST(2)=EXP(4.145454+.633339*X+.031939*X**2-.002419*X**3)*1000.
          X=ALOG(BSIZE/1000./DMATX(15,N))
          OHRS=EXP(6.900586+.323725*X+.059093*X**2-.004926*X**3)
          XMHRS=EXP(6.169937+.294853*X+.175999*X**2-.040947*X**3+
        2           .003300*X**4)
          HP=BSIZE/DMATX(15,N)*8.1*144./(33000.*.8)
          XKW=.8*HP
          XKWPY=XKW*24.*365.
          ECOST=XKWPY*CKWH
          SCOST=EXP(.62138+.482047*X)*1000.
          TMSU=ECOST+SCOST*WPI
          COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C     COMPUTE RETURN SLUDGE PUMPING REQUIREMENTS
          QR=RTURN*SMATX(2,IS1)*DMATX(14,N)
          X=ALOG(QR)
          CCOST(3)=EXP(3.481553+.377485*X+.093349*X**2-.006222*X**3)*1000.
          X=ALOG(QR/DMATX(14,N))
          OHRS=EXP(6.097269+.253066*X-.193659*X**2+.078201*X**3-
        2           .006680*X**4)
          XMHRS=EXP(5.911541-.013158*X+.076643*X**2)
          IF (QR-1.44) 72,74,74
   72     PEFF=.7
          GO TO 80
   74     IF (QR-10.08) 76,78,78
   76     PEFF=.74
          GO TO 80
   78     PEFF=.83
   80     YKWPY=QR*1.E6*HEAD/1440./3690./PEFF/.9*.7457*24.*365.
          ECOST=YKWPY*CKWH
          SCOST=EXP(5.051743+.301610*X+.197183*X**2-.017962*X**3)
          TMSU=ECOST+SCOST*WPI
          COSTO(3)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C     COMPUTE FINAL SETTLER REQUIREMENTS
          AFS=SMATX(2,OS1)*1000./GSS*DMATX(13,N)
          AFS2=.04*SMATX(2,IS1)*(1.+RTURN)*MLSS/1000.*(SMATX(10,OS2)/1000.)**.6
          IF(AFS2.GT.AFS)AFS=AFS2
          X=ALOG(AFS)
          CCOST(4)=EXP(3.716354+.389861*X+.084560*X**2-.004718*X**3)*1000.
          X=ALOG(AFS/DMATX(13,N))
          OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
          XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
          TMSU=EXP(5.669881+.750799*X)
          COSTO(4)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
C
```

```
C    FILL IN OUTPUT MATRIX VALUES
          OMATX(1,N) =BOD1
          OMATX(2,N) =SRT
          OMATX(3,N) =XRSS
          OMATX(4,N) =AFS
          OMATX(5,N) =CK
          OMATX(6,N) =CB
          OMATX(7,N) =VAER
          OMATX(8,N) =VAER
          OMATX(9,N) =MLASS
          OMATX(10,N)=0.
          OMATX(11,N)=MLRSS
          OMATX(12,N)=.2*CB*SRT*MLASS
          OMATX(13,N)=MLISS
          OMATX(14,N)=BOD1-BOD2
          OMATX(15,N)=RTURN
          OMATX(16,N)=CKN
          OMATX(17,N)=ARCFD
          OMATX(18,N)=BSIZE
          OMATX(19,N)=CFPGL
          OMATX(20,N)=QR
C
C    COMPUTE ENERGY REQUIREMENTS
          EER=XKWPY/365.+YKWPY/365.
          EER=EER+EXP(2.8248+.30093*X+.022308*X**2+.0035144*X**3)
          RETURN
 1000     IAERF=1
          RETURN
          END


      SUBROUTINE DIG
C             SINGLE STAGE ANAEROBIC DIGESTION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      C1DIG=.28/EXP(.036*(35.-DMATX(2,N)))
      C2DIG=700.*EXP(.10*(35.-DMATX(2,N)))
      DIG12=SMATX(3,IS1)-SMATX(4,IS1)+SMATX(11,IS1)-SMATX(12,IS1)
        TD=DMATX(1,N)
        DIG13=C2DIG/(C1DIG*TD-1.)
 20     TEMP1=(DIG12-DIG13)/(SMATX(3,IS1)+SMATX(11,IS1))
      SMATX(2,OS1)=SMATX(2,IS1)
      SMATX(3,OS1)=SMATX(4,IS1)+.75*DIG13
      SMATX(4,OS1)=SMATX(4,IS1)
      SMATX(5,OS1)=(1.-TEMP1)*SMATX(5,IS1)
      SMATX(6,OS1)=(1.-TEMP1)*SMATX(6,IS1)
      SMATX(7,OS1)=SMATX(7,IS1)
      SMATX(8,OS1)=(SMATX(3,OS1)-SMATX(4,OS1))*1.87
      SMATX(9,OS1)=SMATX(3,OS1)*2.38
      SMATX(10,OS1)=SMATX(9,OS1)+SMATX(7,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+.25*DIG13
      SMATX(12,OS1)=SMATX(12,IS1)
      SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)*.65*TEMP1
      SMATX(14,OS1)=SMATX(14,IS1)+TEMP1*SMATX(6,IS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)+(SMATX(13,OS1)-SMATX(13,IS1))*3.57
      SMATX(17,OS1)=(SMATX(11,OS1)-SMATX(12,OS1))*1.87
      SMATX(18,OS1)=SMATX(18,IS1)
      SMATX(19,OS1)=SMATX(19,IS1)
        SMATX(20,OS1)=SMATX(20,IS1)*.75*DIG13/(SMATX(3,IS1)-
     2                SMATX(4,IS1))
      CH4=163.85*(DIG12-DIG13)*SMATX(2,IS1)
      CO2=249.9*(DIG12-DIG13)*SMATX(2,IS1)-CH4
      VDIG=SMATX(2,IS1)*TD*1000./7.48*DMATX(16,N)
      X=ALOG(VDIG)
      IF(VDIG-20.) 22,25,25
```

```
22 CCOST(1)=EXP(4.594215+.127244*X-.004001*X**2)*1000.
   GO TO 28
25 CCOST(1)=EXP(7.679634-1.949689*X+.402610*X**2-.018211*X**3)*
  . 1000.
28 X=ALOG(VDIG/DMATX(16,N))
   IF(VDIG-20.) 30,40,40
30 OHRS=EXP(6.163803+.166305*X-.012470*X**2)
   XMHRS=EXP(5.726981+.113674*X)
   TMSU=EXP(6.531623+.198417*X+.021660*X**2)
   GO TO 50
40 OHRS=EXP(9.129250-1.816736*X+.373282*X**2-.017290*X**3)
   XMHRS=EXP(8.566752-1.768137*X+.363173*X**2-.016620*X**3)
   TMSU=EXP(8.702803-1.182711*X+.282691*X**2-.013672*X**3)
50 COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
   OMATX(1,N)=C1DIG
   OMATX(2,N)=C2DIG
   OMATX(3,N)=VDIG
   OMATX(4,N)=CH4
   OMATX(5,N)=CO2
   E1=9.589*VDIG/DMATX(16,N)
   TDIG=1.8*DMATX(2,N)+32.
   CAP=SMATX(2,IS1)*8.33*1.E6*(TDIG-60.)
   XX=ALOG(CAP/1000./24.)
   E2=.75*24.*.7457*EXP(2.00069-1.02649*XX+.127492*XX**2)
   E3=.000293*CAP*CF/.75
   E4=VDIG/DMATX(16,N)*62500.*DMATX(3,N)*.000293*CF/.75
   EER=E1+E2+E3+E4
   EEP=CH4*600.*.000293*DMATX(4,N)
 RETURN
 END

 SUBROUTINE VACF
C        VACUUM FILTRATION
 INTEGER OS1,OS2
 COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
. INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
. ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
. CF,EER,EEP,ALAND
 FECL3=DMATX(5,N)
 CAO=DMATX(6,N)
 CFECL=DMATX(7,N)
 CCAO=DMATX(8,N)
 DPOLY=DMATX(9,N)
 CPOLY=DMATX(10,N)
   SAVE1=SMATX(7,IS1)
   SAVE2=SMATX(10,IS1)
 SMATX(7,IS1)=SMATX(7,IS1)+(FECL3+CAO+DPOLY)*SMATX(10,IS1)/2000.
 SMATX(10,IS1)=SMATX(10,IS1)+(FECL3+CAO+DPOLY)*SMATX(10,IS1)/2000.
 SMATX(10,OS2)=DMATX(3,N)
 WP=88./(SMATX(10,IS1)/10000.)**.123
 SMATX(10,OS1)=(100.-WP)*10000.
 SMATX(2,OS1)=(SMATX(2,IS1)*SMATX(10,IS1))/(SMATX(10,OS1)-
. SMATX(10,OS2))
 SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
 TEMP2=SMATX(10,OS1)/SMATX(10,IS1)
 TEMP3=SMATX(10,OS2)/SMATX(10,IS1)
 DO 10 I=3,9
 SMATX(I,OS1)=TEMP2*SMATX(I,IS1)
10 SMATX(I,OS2)=TEMP3*SMATX(I,IS1)
   DO 20 I=11,19
   SMATX(I,OS1)=SMATX(I,IS1)
20 SMATX(I,OS2)=SMATX(I,IS1)
   SMATX(20,OS1)=SMATX(20,IS1)*TEMP2
   SMATX(20,OS2)=SMATX(20,IS1)*TEMP3
 SF=SMATX(10,IS1)/10000.
 SC=100.-WP
 FVF=DMATX(1,N)/11.99/(1./SF-1./SC)
 AVF=SMATX(10,IS1)*SMATX(2,IS1)*58.31/FVF/DMATX(2,N)*DMATX(16,N)
 IVACF=1.
 PSDD=SMATX(10,IS1)*SMATX(2,IS1)*8.33
```

```
      X=ALOG(AVF)
      CCOST(1)=EXP(3.288028+.194537*X+.038313*X**2)*1000.
      X=ALOG(PSDD*365./2000.)
      IF(IVACF) 40,30,40
   30 OHRS=EXP(6.069419-.009894*X+.042699*X**2)
      GO TO 50
   40 OHRS=EXP(3.714368+.850848*X-.074615*X**2+.005085*X**3)
   50 XMHRS=EXP(4.306110-.093695*X+.047738*X**2)
      SUPP=EXP(-3.113515+.718466*X)*1000.
      CHEM=PSDD*365./2000.*(FECL3*CFECL+CAO*CCAO+DPOLY*CPOLY)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+SUPP*WPI+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=WP
      OMATX(2,N)=AVF
      OMATX(3,N)=PSDD
        X=ALOG(AVF/DMATX(16,N))
        EER=EXP(3.21323+.378196*X+.036877*X**2)
        EER=EER+PSDD*(FECL3*.44+CAO*.36+DPOLY*.14)/2000.
        X=ALOG(SMATX(2,IS1)*SMATX(10,IS1)*8.33/2000.)
        EER=EER+EXP(2.3018+.36033*X+.089968*X**2-
     2              .0057516*X**3)
        SMATX(7,IS1)=SAVE1
        SMATX(10,IS1)=SAVE2
      RETURN
      END


      SUBROUTINE THICK
C              GRAVITY THICKENING
      INTEGER OS1,OS2
      DIMENSION SMAT(20)
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 2 I=1,20
    2 SMAT(I)=0.
      IF(IS2) 7,7,4
    4 DO 6 I=1,20
    6 SMAT(I)=SMATX(I,IS2)
    7 SMATX(10,OS1)=DMATX(2,N)
      SMATX(2,OS1)=DMATX(1,N)*(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*
     . SMAT(10))/SMATX(10,OS1)
      TEMP=DMATX(4,N)/DMATX(3,N)*1000000./8.33
      IF(IS2) 9,8,9
    8 WRT=0.
      GO TO 10
    9 WRT=(SMATX(10,IS1)-TEMP)/(TEMP-SMAT(10))
      SMATX(2,IS2)=WRT*SMATX(2,IS1)
      SMAT(2)=SMATX(2,IS2)
   10 SMATX(2,OS2)=SMATX(2,IS1)+SMAT(2)-SMATX(2,OS1)
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10)
      SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
      TEMP=TEMP/(SMATX(2,IS1)+SMAT(2))
      TEMP1=SMATX(10,OS1)/TEMP
      TEMP2=SMATX(10,OS2)/TEMP
      DO 15 I=3,9
      TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMAT(2)*SMAT(I))/
     . (SMATX(2,IS1)+SMAT(2))
      SMATX(I,OS1)=TEMP1*TEMP3
   15 SMATX(I,OS2)=TEMP2*TEMP3
        TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMAT(2)*SMAT(20))/
     2        (SMATX(2,IS1)+SMAT(2))
        SMATX(20,OS1)=TEMP1*TEMP3
        SMATX(20,OS2)=TEMP2*TEMP3
```

```
      DO 20 I=11,19
      SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMAT(I)*SMAT(2))/
     . (SMATX(2,IS1)+SMAT(2))
   20 SMATX(I,OS2)=SMATX(I,OS1)
      ATH1=(SMATX(2,OS2)+SMATX(2,OS1))*1000000./DMATX(3,N)*DMATX(16,N)
      IF(IS2) 40,25,40
   25 ATH2=SMATX(2,IS1)*SMATX(10,IS1)*8.33/DMATX(4,N)*DMATX(16,N)
      IF(ATH1-ATH2) 30,40,40
   30 ATHM=ATH2
      GO TO 50
   40 ATHM=ATH1
   50 X=ALOG(ATHM/1000.)
      CCOST(1)=EXP(3.725902+.397690*X+.075742*X**2-.001977*X**3-
     . .000296*X**4)*1000.
      X=ALOG(ATHM/1000./DMATX(16,N))
      IF(EXP(X)-1.) 60,70,70
   60 OHRS=350.
      XMHRS=190.
      TMSU=250.
      GO TO 80
   70 OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
   80 COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=ATHM
      OMATX(2,N)=WRT
        X=ALOG(ATHM/DMATX(16,N))
        EER=EXP(5.50543-1.59789*X+.206121*X**2-.005617*X**3)
      RETURN
      END


      SUBROUTINE ELUT
C              ELUTRIATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      SMATX(10,OS1)=DMATX(2,N)
        SAVE=SMATX(2,IS2)
      SMATX(2,IS2)=DMATX(3,N)*SMATX(2,IS1)
      AE1=(SMATX(2,IS1)+SMATX(2,IS2))*1000000./DMATX(4,N)
      AE2=SMATX(2,IS1)*SMATX(10,IS1)*8.33/DMATX(5,N)
        AE2=AE2+(SMATX(2,IS2)*SMATX(10,IS2)*8.33/DMATX(5,N))
      IF(AE1-AE2) 20,20,10
   10 AE=AE1*DMATX(16,N)
      GO TO 30
   20 AE=AE2*DMATX(16,N)
   30 SMATX(2,OS1)=DMATX(1,N)*SMATX(2,IS1)*SMATX(10,IS1)/SMATX(10,OS1)
      SMATX(2,OS2)=SMATX(2,IS1)+SMATX(2,IS2)-SMATX(2,OS1)
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMATX(2,IS2)*SMATX(10,IS2)
      SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
      TEMP=TEMP/(SMATX(2,IS1)+SMATX(2,IS2))
      TEMP1=SMATX(10,OS1)/TEMP
      TEMP2=SMATX(10,OS2)/TEMP
      DO 40 I=3,9
      TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMATX(2,IS2)*SMATX(I,IS2))/
     . (SMATX(2,IS1)+SMATX(2,IS2))
      SMATX(I,OS1)=TEMP1*TEMP3
   40 SMATX(I,OS2)=TEMP2*TEMP3
        TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMATX(2,IS2)*SMATX(20,IS2))/
     2          (SMATX(2,IS1)+SMATX(2,IS2))
        SMATX(20,OS1)=TEMP1*TEMP3
        SMATX(20,OS2)=TEMP2*TEMP3
```

```
      DO 50 I=11,19
      SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMATX(I,IS2)*SMATX(2,IS2))
     . /(SMATX(2,IS1)+SMATX(2,IS2))
   50 SMATX(I,OS2)=SMATX(I,OS1)
      X=ALOG(AE/1000.)
      CCOST(1)=EXP(3.725902+.397690*X+.075742*X**2-.001977*X**3-
     . .000296*X**4)*1000.
      X=ALOG(AE/1000./DMATX(16,N))
      IF(EXP(X)-1.) 60,70,70
   60 OHRS=350.
      XMHRS=190.
      TMSU=250.
      GO TO 80
   70 OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
   80 COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=AE
        X=ALOG(AE/DMATX(16,N))
        EER=EXP(5.50543-1.59789*X+.206121*X**2-.005617*X**3)
        SMATX(2,IS2)=SAVE
      RETURN
      END


      SUBROUTINE SBEDS
C             SAND DRYING BEDS
      INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      SMATX(2,OS2)=SMATX(2,IS1)
      SMATX(10,OS2)=DMATX(2,N)
      TEMP=SMATX(10,OS2)/SMATX(10,IS1)
      DO 10 I=3,9
   10 SMATX(I,OS2)=TEMP*SMATX(I,IS1)
        SMATX(20,OS2)=TEMP*SMATX(20,IS1)
        DO 20 I=11,19
   20 SMATX(I,OS2)=SMATX(I,IS1)
      SF=SMATX(10,IS1)/10000.
      SC=DMATX(1,N)*100.
      FSB=(29.84*SF-33.3)/SC
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)*249.9
      ASB=TEMP/FSB*DMATX(16,N)
      PSDD=SMATX(10,IS1)*SMATX(2,IS1)*8.33
        SMATX(10,OS1)=DMATX(1,N)*1.E6
        TEMP=SMATX(10,OS1)/SMATX(10,IS1)
        SMATX(2,OS1)=SMATX(2,IS1)/TEMP
        DO 30 I=3,9
30      SMATX(I,OS1)=TEMP*(SMATX(I,IS1)-SMATX(I,OS2))
        SMATX(20,OS1)=TEMP*(SMATX(20,IS1)-SMATX(20,OS2))
        DO 40 I=11,19
40      SMATX(I,OS1)=SMATX(I,IS1)
      X=ALOG(ASB/1000.)
      CCOST(1)=EXP(1.971125+.083841*X+.146751*X**2-.007718*X**3)*
     . 1000.
      X=ALOG(PSDD*365./2000.)
      OHRS=EXP(6.345052-.476780*X+.101319*X**2)
      XMHRS=EXP(4.290089-.098293*X+.075453*X**2)
      TMSU=EXP(.693148+1.000000*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=ASB
        GPM=SMATX(2,IS1)*1.E6/1440.
        EER=(.4355*GPM*SF**1.116)*293.*CF/365.
        ALAND=ASB*2.2E-5
      RETURN
      END
```

```
      SUBROUTINE TRFS
C
C             TRICKLING FILTER - FINAL SETTLER
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4       CF,EER,EEP,ALAND
C
      IAERF=0
C
      BOD5=DMATX(1,N)
      DEGC=DMATX(2,N)
      HQ=DMATX(3,N)
      SAREA=DMATX(4,N)
      TSS7=DMATX(6,N)
      RR=DMATX(7,N)
      GSS=DMATX(8,N)
      YIELD=DMATX(9,N)
      SRATIO=DMATX(10,N)
      TSS5=4.5+.51*BOD5
      IF (TSS5 .GT. DMATX(5,N)) GO TO 200
C
C             COMPUTE REMOVAL EFFICIENCY OF FILTER TO MEET BOD LIMIT
      BOD2=SMATX(8,IS1)+SMATX(17,IS1)
      BOD4=BOD5/SRATIO
      F=BOD4/BOD2
20    IF (F .GT. 1. .OR. F .LT. 0.) GO TO 200
C
C             COMPUTE FILTER AREA AND DEPTH
      BETA=.0245*1.035**(DEGC-20.)
      XN=.91-6.45/SAREA
      A=ALOG((1.+F*RR)/(F+F*RR))/BETA/SAREA
      RHQ=((RR+1.)*HQ)**XN
      DEPTH=RHQ*A
      IF (DEPTH .LE. 30.) GO TO 10
      DEPTH=30.
      RHQ=30./A
      HQ=(1./(RR+1.))*RHQ**(1./XN)
10    FAREA=SMATX(2,IS1)/HQ*43560.
C
C             COMPUTE SLUDGE PRODUCTION
      PDSD=DMATX(9,N)*(BOD2-BOD5)*SMATX(2,IS1)*8.33
C
C             COMPUTE FLOW RATES IN EFFLUENT AND SLUDGE STREAMS
      SMATX(2,OS2)=PDSD/TSS7/8.33
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      SMATX(10,OS1)=4.5+.51*BOD5
      SMATX(10,OS2)=TSS7
C
C             COMPUTE CONC. OF SOLID SPECIES IN EFFLUENT
      R=TSS5*SMATX(2,IS1)/(TSS5*SMATX(2,OS1)+TSS7*SMATX(2,OS2))
      SMATX(4,OS1)=R*SMATX(4,IS1)
      SMATX(8,OS1)=(SMATX(10,OS1)-4.5)*.897
      SMATX(3,OS1)=SMATX(8,OS1)*1.6/2.7+SMATX(4,OS1)
      SMATX(5,OS1)=.1*SMATX(3,OS1)
      SMATX(6,OS1)=.01*SMATX(3,OS1)
      SMATX(7,OS1)=R*SMATX(7,IS1)
      SMATX(9,OS1)=SMATX(10,OS1)-SMATX(7,OS1)
C
C             COMPUTE CONC. OF DISSOLVED SPECIES IN EFFLUENT
      SMATX(17,OS1)=BOD5-SMATX(8,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+SMATX(17,OS1)*1.6/2.7
```

```
      SMATX(12,OS1)=SMATX(12,IS1)
      TEMP=SMATX(2,OS1)/SMATX(2,IS1)
      TEMP=TEMP+SMATX(2,OS2)/SMATX(2,IS1)*SMATX(10,OS2)/SMATX(10,OS1)
      SMATX(13,OS1)=SMATX(5,IS1)+SMATX(13,IS1)-TEMP*SMATX(5,OS1)
      SMATX(14,OS1)=SMATX(6,IS1)+SMATX(14,IS1)-TEMP*SMATX(6,OS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      BODLD=BOD2*SMATX(2,IS1)*8.33/FAREA/DEPTH/1000.
      RN=1.-EXP(-.05*BODLD)
      SMATX(18,OS1)=RN*SMATX(18,IS1)
      SMATX(19,OS1)=(1.-RN)*SMATX(18,IS1)+SMATX(19,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)-10.*(SMATX(18,IS1)-SMATX(18,OS1))
      SMATX(20,OS1)=0.
C
C           COMPUTE CONC. OF SPECIES IN SLUDGE STREAM
      R1=SMATX(10,OS2)/SMATX(10,OS1)
      DO 50 I=3,9
50    SMATX(I,OS2)=R1*SMATX(I,OS1)
      DO 70 I=11,19
70    SMATX(I,OS2)=SMATX(I,OS1)
      SMATX(20,OS2)=0.
C
C           COMPUTE FILTER COSTS
95    VOL=FAREA*DEPTH*DMATX(16,N)
      X=ALOG(VOL/1000.)
      CCOST(1)=EXP(2.924951+.036285*X+.114673*X**2-
     2             .004587*X**3)*1000.
      X=ALOG(SMATX(2,IS1)/HQ*43560./1000.)
      OHRS=EXP(4.536510-.095731*X+.173718*X**2-.010114*X**3)
      XMHRS=EXP(4.312739-.052122*X+.157473*X**2-.010245*X**3)
      TMSU=EXP(5.105946+.465100*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
C
C           COMPUTE SETTLER COSTS
      AFS=SMATX(2,IS1)*1.E6/GSS*DMATX(15,N)
      X=ALOG(AFS/1000.)
      CCOST(2)=EXP(3.716354+.389861*X+.08456*X**2-.004718*X**3)
     2             *1000.
      X=ALOG(AFS/1000./DMATX(15,N))
      OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.569881+.750799*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
C
C           COMPUTE PUMPING REQUIREMENTS
110   QP=1.78*(SMATX(2,IS1)*(1.+RR))**.92
      X=ALOG(QP*DMATX(14,N))
      CCOST(3)=EXP(4.004828+.519499*X+.082262*X**2-.006492*X**3)
     2             *1000.
      X=ALOG(SMATX(2,IS1)*(1.+RR))
      OHRS=EXP(6.097269+.253066*X-.193659*X**2+.078201*X**3
     2             -.00668*X**4)
      XMHRS=EXP(5.911541-.013158*X+.076643*X**2)
      IF (SMATX(2,IS1)-1.44) 120, 130, 130
120   PEFF=.7
      GO TO 160
130   IF (SMATX(2,IS1)-10.08) 140, 150, 150
140   PEFF=.74
```

```
      GO TO 160
150   PEFF=.83
160   YRKW=SMATX(2,IS1)*(1.+RR)*1.E6*(DEPTH+6.)
      YRKW=YRKW/1440./3960./PEFF/.9*.7457*24.*365.
      ECOST=YRKW*CKWH
      SCOST=EXP(5.851743+.30161*X+.197183*X**2-.017962*X**3)
      TMSU=ECOST+SCOST*WPI
      COSTO(3)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C             FILL IN OUTPUT MATRIX VALUES
      OMATX(1,N)=AFS/1000.
      OMATX(2,N)=VOL/1000.
      OMATX(3,N)=FAREA/43560.
      OMATX(4,N)=DEPTH
C
C             COMPUTE ENERGY AND LAND CONSUMPTION
      EER=YRKW/365.
      X=ALOG(AFS/1000./DMATX(15,N))
      EER=EER+EXP(2.8248+.30093*X+.022308*X**2+.0035144*X**3)
170   ALAND=FAREA/43560.
      RETURN
200   IAERF=1
      RETURN
      END


      SUBROUTINE CHLOR
C             CHLORINATION - DECHLORINATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DCL2=DMATX(1,N)
      TCL2=DMATX(2,N)
      CCL2=DMATX(3,N)
      DSO2=DMATX(4,N)
      CSO2=DMATX(5,N)
      BVOL=SMATX(2,IS1)*TCL2/1.44/7.48*1000.*DMATX(16,N)
      X=ALOG(BVOL/1000.)
      CCOST(1)=EXP(2.048061+.521909*X-.002674*X**2+.004159*X**3)*
     . 1000.
      COSTO(1)=0.
      CUSE=SMATX(2,IS1)*DCL2*8.33*365./2000.
      SUSE=SMATX(2,IS1)*DSO2*8.33*365./2000.
      FACTR=CUSE/(CUSE+SUSE)
      X=ALOG(CUSE*2000./365.*DMATX(15,N)+SUSE*2000./365.*DMATX(14,N))
      XCOST=EXP(2.264294-.044271*X+.065029*X**2-.002536*X**3)*1000.
      CCOST(2)=FACTR*XCOST
      X=ALOG(CUSE+SUSE)
      OHRS=EXP(4.538517+.543669*X)
      XMHRS=EXP(3.752071-.224812*X+.158849*X**2-.006064*X**3)
      TMSU=EXP(6.126105+.287016*X)
      OC=FACTR*OHRS
      XC=FACTR*XMHRS
      TMSUC=CUSE*CCL2+FACTR*TMSU
      COSTO(2)=((OC+XC)*DHR*(1.+PCT)+TMSUC)/SMATX(2,1)/3650.
      IF(DSO2) 10,10,20
   10 CCOST(3)=0.
      COSTO(3)=0.
      GO TO 30
   20 CCOST(3)=XCOST-CCOST(2)
      OS=OHRS-OC
      XS=XMHRS-XC
      TMSUS=SUSE*CSO2+(1.-FACTR)*TMSU
      COSTO(3)=((OS+XS)*DHR*(1.+PCT)+TMSUS)/SMATX(2,1)/3650.
```

```
   30 DO 40 I=2,20
   40 SMATX(I,OS1)=SMATX(I,IS1)
      OMATX(1,N)=BVOL
      OMATX(2,N)=CUSE
      OMATX(3,N)=SUSE
        PCL2D=OMATX(1,N)*SMATX(2,IS1)*8.33
        X=ALOG(PCL2D)
        EER=1.5*CUSE*2000./365.
        IF(DMATX(4,N).GT.0.)GO TO 50
        EER=EER+EXP(-.071827+.44044*X+.076407*X**2-.003003*X**3)
        GO TO 60
50      EER=EER+EXP(-.259363+.69229*X+.025652*X**2)
60      EEP=0.
      RETURN
      END


       SUBROUTINE TFLOT
C               FLOTATION THICKENING
       INTEGER OS1,OS2
       DIMENSION Y(12),SMAT(20)
       COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
       DATA Y/25.,50.,100.,150.,200.,250.,300.,400.,500.,600.,800.,1000./
       DO 5 I=1,20
     5 SMAT(I)=0.
       IF(IS2) 20,20,10
    10 DO 15 I=1,20
    15 SMAT(I)=SMATX(I,IS2)
    20 SMATX(10,OS1)=DMATX(2,N)
       SMATX(2,OS1)=DMATX(1,N)*(SMATX(2,IS1)*SMATX(10,IS1)+
     . SMAT(2)*SMAT(10))/SMATX(10,OS1)
       ATH1=(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10))*
     . 8.33/DMATX(4,N)*168./DMATX(5,N)
       IF(IS2) 30,25,30
    25 ARCY=0.
       GO TO 35
    30 ARCY=.00288*ATH1
       SMATX(2,IS2)=ARCY
    35 SMAT(2)=ARCY
       SMATX(2,OS2)=SMATX(2,IS1)+SMAT(2)-SMATX(2,OS1)
       ATH2=SMATX(2,OS2)*1000000./DMATX(3,N)*168./DMATX(5,N)
       IF(ATH1-ATH2) 40,50,50
    40 ATHM=ATH2*DMATX(16,N)
       GO TO 60
    50 ATHM=ATH1*DMATX(16,N)
    60 TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10)
       SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
       TEMP=TEMP/(SMATX(2,IS1)+SMAT(2))
       TEMP1=SMATX(10,OS1)/TEMP
       TEMP2=SMATX(10,OS2)/TEMP
       DO 70 I=3,9
       TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMAT(2)*SMAT(I))/
     . (SMATX(2,IS1)+SMAT(2))
       SMATX(I,OS1)=TEMP1*TEMP3
    70 SMATX(I,OS2)=TEMP2*TEMP3
         TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMAT(2)*SMAT(20))/
     2          (SMATX(2,IS1)+SMAT(2))
         SMATX(20,OS1)=TEMP1*TEMP3
         SMATX(20,OS2)=TEMP2*TEMP3
       DO 80 I=11,19
       SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMAT(I)*SMAT(2))
     . /(SMATX(2,IS1)+SMAT(2))
    80 SMATX(I,OS2)=SMATX(I,OS1)
```

```
      ATHM1=ATHM
      XN=0.
      XX=0.
      K=0
      DO 100 I=1,12
      IF(ATHM-Y(I)) 90,90,95
   90 ATHM=Y(I)
      GO TO 110
   95 IF(I-12) 100,96,100
   96 ATHM=Y(12)
  100 CONTINUE
  110 IF(ATHM-25.) 120,120,130
  120 ATHM=25.
      XN=1.
      GO TO 180
  130 IF(ATHM1-1000.) 170,170,140
  140 XN=ATHM1/1000.
      K=XN
      XX=K
      IF((XN-XX)*1000.-500.) 150,150,160
  150 XN=XX+.5
      GO TO 180
  160 XN=XX+1.
      GO TO 180
  170 ATHM=ATHM/2.
      XN=2.
  180 X=ALOG(ATHM)
      CCOST(1)=EXP(1.717538+.453735*X)*1000.*XN
      X=ALOG(ATHM/DMATX(16,N)*XN)
      OHRS=EXP(4.992517-.325053*X+.084026*X**2)
      XMHRS=EXP(4.832373-.336504*X+.083020*X**2)
      HPD=EXP(-1.254959+.852347*X)
        ELEC=HpD*.746*365.*CKWH*DMATX(5,N)/7.
      PWAS=(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10))*8.33
      POLC=PWAS*365./2000.*DMATX(6,N)*DMATX(7,N)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+ELEC+POLC)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=ATHM
      OMATX(2,N)=XN
      OMATX(3,N)=ATHM1
        EER=HPD*.746*DMATX(5,N)/7.
      RETURN
      END


      SUBROUTINE MHINC
C           MULTIPLE HEARTH INCINERATION
      INTEGER OS1,OS2
      DIMENSION SFHA(59)
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DATA SFHA/85.,98.,112.,125.,126.,140.,145.,166.,187.,193.,208.,
     . 225.,256.,276.,288.,319.,323.,351.,364.,383.,411.,452.,510.,560.,
     . 575.,672.,760.,845.,857.,944.,988.,1041.,1068.,1117.,1128.,1249.,
     . 1260.,1268.,1400.,1410.,1483.,1540.,1580.,1591.,1660.,1675.,
     . 1752.,1849.,1875.,1933.,2060.,2084.,2090.,2275.,2350.,2464.,
     . 2600.,2860.,3120./
      PSDO=SMATX(10,IS1)*SMATX(2,IS1)*8.33
      FHAT=58.31*SMATX(2,IS1)*SMATX(10,IS1)/DMATX(3,N)/DMATX(1,N)*
     . DMATX(16,N)
      XX=FHAT/DMATX(2,N)
      DO 20 I=1,59
      IF(XX-SFHA(I)) 10,10,20
   10 FHA=SFHA(I)
      GO TO 30
   20 CONTINUE
```

```
      FHA=3120.
 30   IF(FHA-200.) 40,40,50
 40   CYT=18.
      GO TO 100
 50   IF(FHA-1700.) 60,60,70
 60   CYT=13.+.024*FHA
      GO TO 100
 70   IF(FHA-2300.) 80,80,90
 80   CYT=.09*(FHA-1100.)
      GO TO 100
 90   CYT=108.
100   PASH=(SMATX(10,IS1)-SMATX(9,IS1))/SMATX(9,IS1)
      HASH=68.*PASH
      PWAT=(1000000.-SMATX(10,IS1))/SMATX(9,IS1)
      HWSL=1404.3*PWAT
      SAERA=64.03*FHA**.51
      VSPH=SMATX(9,IS1)*SMATX(2,IS1)*58.31/DMATX(3,N)
      HC=1.735*(1.+.374*DMATX(5,N))
      QTRAN=(1.279+HC)*100.*SAERA*DMATX(2,N)/VSPH
      QCOOL=267.*FHA*DMATX(2,N)/VSPH
      QNET=2725.+HASH+HWSL+QCOOL+QTRAN-DMATX(6,N)+246.
      IF(QNET) 105,105,106
105   QNET=0.
106   TEMP=SMATX(9,IS1)*SMATX(2,IS1)*8.33*365.
      QNET=QNET*TEMP
      YSBH=8.*CYT/9.+8736.-52.*DMATX(3,N)*7./9.
      YHUH=10.*CYT/9.+52.*CYT*DMATX(4,N)/9.
      QHUP=YHUH*1913.*FHA*DMATX(2,N)
      QSB=YSBH*315.*FHA*DMATX(2,N)
      QTOT=QHUP+QSB+QNET
      IF(DMATX(7,N)-1.) 130,130,140
130   WFYR=QTOT/15019.
      FCOST=WFYR/7.481*DMATX(8,N)
      GO TO 180
140   IF(DMATX(7,N)-2.) 150,150,160
150   WFYR=QTOT/15581.
      FCOST=WFYR/45.8*DMATX(9,N)
      GO TO 180
160   IF(DMATX(7,N)-3.) 170,170,180
170   CFDG=QTOT/8967./.9695
      FCOST=0.
180   TYR=SMATX(10,IS1)*SMATX(2,IS1)*1.52
      WTON=554.24/FHA**.3572
      ECOST=WTON*TYR*CKWH
      DPTON=FCOST/(PSDD*365./2000.)
      X=ALOG(PSDD/24.*DMATX(16,N))
      CCOST(1)=EXP(2.377364+.598986*X)*1000.
      X=ALOG(PSDD*365./2000.*(SMATX(9,IS1)/SMATX(10,IS1)))
      OHRS=EXP(3.402537+1.215130*X-.157203*X**2+.009771*X**3)
      XMHRS=EXP(3.906553+.702471*X-.088337*X**2+.006827*X**3)
      TMSU=EXP(7.864729-.338816*X+.054026*X**2)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI+ECOST+FCOST)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=FHA
      OMATX(2,N)=WFYR
      OMATX(3,N)=PSDD
      OMATX(4,N)=ECOST
      OMATX(5,N)=FCOST
      OMATX(6,N)=CFDG
        EER=ECOST/CKWH/365.+QTOT/365.*.000293*CF
        FS=SMATX(10,IS1)/1.E6
        FV=SMATX(9,IS1)/SMATX(10,IS1)
        WS=(1.-FS)/(FS*FV)
        EX=-((QNET-2725.)-2113.)/1223.
        IF(EX.LT..5)EX=.5
        IF(EX.GT.1.5)EX=1.5
        QPDVS=(800.-60.)*(.505*WS+2.55+2.09*EX)
        IF=DMATX(7,N)
        GO TO (190,200,210),IF
190     F1=4.136
        F2=WFYR
```

```
      GO TO 220
  200 F1=5.63
      F2=WFYR
      GO TO 220
  210 F1=3.151
      F2=CFDG*.0695
  220 QPD=QPDVS*SMATX(9,IS1)*SMATX(2,IS1)*8.33
      QPD=QPD+(800.-60.)/365.*F1*F2
      EEP=QPD*.000293*DMATX(10,N)
    RETURN
    END


      SUBROUTINE RWP
C             RAW WASTEWATER PUMPING
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      HEAD=DMATX(1,N)
      QP=1.78*SMATX(2,IS1)**.92
      X=ALOG(QP*DMATX(16,N))
      CCOST(1)=EXP(4.004828+.519499*X+.082262*X**2-.006492*X**3)*
     . 1000.
      X=ALOG(SMATX(2,IS1))
      OHRS=EXP(6.097269+.253066*X-.193659*X**2+.078201*X**3-
     . .006680*X**4)
      XMHRS=EXP(5.911541-.013158*X+.076643*X**2)
      IF(SMATX(2,IS1)-1.44) 20,30,30
   20 PEFF=.70
      GO TO 60
   30 IF(SMATX(2,IS1)-10.08) 40,50,50
   40 PEFF=.74
      GO TO 60
   50 PEFF=.83
   60 YRKW=SMATX(2,IS1)*1000000.*HEAD/1440./3960./PEFF/.9*.7457*24.*365.
      ECOST=YRKW*CKWH
      SCOST=EXP(5.851743+.301610*X+.197183*X**2-.017962*X**3)
      TMSU=ECOST+SCOST*WPI
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
      OMATX(1,N)=QP
        EER=YRKW/365.
      RETURN
      END
      SUBROUTINE SHT
C             SLUDGE HOLDING TANKS
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      VSHT=SMATX(2,IS1)*DMATX(1,N)*1000./7.48*DMATX(16,N)
      X=ALOG(VSHT)
      CCOST(1)=EXP(2.625751+.484180*X+.000613*X**2+.002252*X**3)*
     . 1000.
      V1=SMATX(2,IS1)*DMATX(1,N)*1000./7.48
      X=ALOG(V1)
      OHRS=EXP(5.727345+.000762*X+.098701*X**2-.006786*X**3)
      XMHRS=EXP(4.506628+.214662*X+.071402*X**2-.004681*X**3)
      TMSU=EXP(5.479939+.299282*X+.106008*X**2-.008658*X**3)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=VSHT
        EER=0.
      RETURN
      END
```

```
      SUBROUTINE CENT
C             CENTRIFUGATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
        DIMENSION CPDATA(4,2)
        DATA CPDATA/.73,.8,.43,.41,1.6,1.48,.81,.74/
      HPWK=DMATX(3,N)
      XCEN=1.
      POLY=DMATX(5,N)
      CPOLY=DMATX(6,N)
      GPMN=DMATX(7,N)
      CNMIN=DMATX(8,N)
        SAVE1=SMATX(7,IS1)
        SAVE2=SMATX(10,IS1)
      SMATX(7,IS1)=SMATX(7,IS1)+POLY*SMATX(10,IS1)/2000.
      SMATX(10,IS1)=SMATX(10,IS1)+POLY*SMATX(10,IS1)/2000.
      DSOL=SMATX(10,IS1)*SMATX(2,IS1)*8.33*365./2000.
      SMATX(10,OS2)=((1.-DMATX(1,N))/(1.-DMATX(1,N)*SMATX(10,IS1)/
     . DMATX(2,N)))*SMATX(10,IS1)
      TEMP1=DMATX(2,N)/SMATX(10,IS1)
      TEMP2=SMATX(10,OS2)/SMATX(10,IS1)
      SMATX(10,OS1)=DMATX(2,N)
      SMATX(2,OS1)=(SMATX(10,IS1)-SMATX(10,OS2))*SMATX(2,IS1)/
     . (SMATX(10,OS1)-SMATX(10,OS2))
      SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
      DO 11 I=3,9
      SMATX(I,OS1)=TEMP1*SMATX(I,IS1)
   11 SMATX(I,OS2)=TEMP2*SMATX(I,IS1)
        SMATX(20,OS1)=TEMP1*SMATX(20,IS1)
        SMATX(20,OS2)=TEMP2*SMATX(20,IS1)
      DO 21 I=11,19
      SMATX(I,OS1)=SMATX(I,IS1)
   21 SMATX(I,OS2)=SMATX(I,IS1)
      CN=CNMIN
      CGPM=SMATX(2,IS1)*116666.7/HPWK*DMATX(16,N)/CN
      GPMM=SMATX(2,IS1)*1000000./1440.
      CSIZE=.275*GPMN
      IF(CGPM-CSIZE) 8,8,2
    2 CSIZE=.350*GPMN
      IF(CGPM-CSIZE) 12,12,4
    4 CSIZE=.590*GPMN
      IF(CGPM-CSIZE) 16,16,6
    6 CSIZE=GPMN
      NCN=CGPM/CSIZE
      CN=NCN+1
      GO TO 20
    8 IF(GPMM-CSIZE*(CN-1.)) 24,24,10
   10 CN=CN+1.
      GO TO 8
   12 IF(GPMM-CSIZE*(CN-1.)) 26,26,14
   14 CN=CN+1.
      GO TO 12
   16 IF(GPMM-CSIZE*(CN-1.)) 28,28,18
   18 CN=CN+1.
      GO TO 16
   20 IF(GPMM-CSIZE*(CN-1.)) 30,30,22
   22 CN=CN+1.
```

```
      GO TU 20
   24 CCOST(1)=78500.*(1.-.044*(CN-2.))*CN
      GO TO 32
   26 CCOST(1)=98000.*(1.-.044*(CN-2.))*CN
      GO TO 32
   28 CCOST(1)=140000.*(1.-.044*(CN-2.))*CN
      GO TO 32
   30 CCOST(1)=160000.*(1.-.044*(CN-2.))*CN
   32 AFC=RI*(1.+RI)**10./((1.+RI)**10.-1.)
      ACOST(1)=CCOST(1)*AFC/SMATX(2,1)/3650.
      X=ALOG(DSOL)
      IF(XCEN) 40,34,40
   34 OHRS=EXP(7.621517-.476977*X+.071516*X**2)
      GO TO 50
   40 OHRS=EXP(7.264153-.466246*X+.069552*X**2)
   50 XMHRS=EXP(5.997115-.493809*X+.070892*X**2)
      SUPP=EXP(-2.822519+.700948*X)*1000.
      CHEM=DSOL*POLY*CPOLY
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+SUPP*WPI+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=CGPM
      OMATX(2,N)=DSOL
      OMATX(3,N)=AFC
      OMATX(4,N)=CSIZE
      OMATX(5,N)=CN
        SMATX(7,IS1)=SAVE1
        SMATX(10,IS1)=SAVE2
        EER=GPMM*.7457*24.
      RETURN
      END



        SUBROUTINE AEROB
C
C                AEROBIC DIGESTION
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,EER,EEP,ALAND
C
        SRT=DMATX(3,N)
        DEGC=DMATX(4,N)
        DTA=DMATX(5,N)
        CB1 =DMATX(6,N)
        CY  =DMATX(7,N)
        TSS1=DMATX(8,N)
        TSS2=DMATX(9,N)
        CKN =DMATX(10,N)
        AEFF=DMATX(11,N)
C
C   COMPUTE INFLUENT BIOMASS, REFRACTORIES,  AND BOD
        XASSIN=SMATX(20,IS1)
        XRSSIN=SMATX(4,IS1)/SMATX(3,IS1)*SMATX(9,IS1)-.2*XASSIN
        SIN=SMATX(8,IS1)+SMATX(17,IS1)-.97*.8*XASSIN
C
C
C   FIND EFFLUENT SOLIDS CONC.
        CB=CB1*(SRT+DTA)**-.415*(1.05)**(DEGC-20.)
        XASS=(XASSIN+CY*SIN)/(1.+.8*CB*DTA)
        XRSS=XRSSIN+.2*CB*XASS*DTA
        TSS=SMATX(7,IS1)+XASS+XRSS
C
```

```
C   FIND FLOW RATES IN OUTPUT STREAMS
        IF(TSS2.EQ.0.)GO TO 60
        IF(TSS2.GT.TSS)GO TO 60
        SMATX(10,OS1)=TSS1
        SMATX(10,OS2)=TSS2
        SMATX(2,OS1)=SMATX(2,IS1)*(TSS-TSS2)/(TSS1-TSS2)
        SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
        RSS=TSS1/TSS
        GO TO 70
60      SMATX(10,OS1)=TSS
        SMATX(10,OS2)=0.
        SMATX(2,OS1)=SMATX(2,IS1)
        SMATX(2,OS2)=0.
        RSS=1.
C
C   DETERMINE EFFLUENT SOLIDS CONC.
70      SMATX(4,OS1)=RSS*(SMATX(4,IS1)+.4*(XRSS-XRSSIN)-.4*.2*(XASSIN-XASS))
        SMATX(3,OS1)=SMATX(4,OS1)+RSS*.4*.8*XASS
        SMATX(5,OS1)=RSS*(.06*XRSS+.12*XASS)
        SMATX(6,OS1)=RSS*(.025*XASS)
        SMATX(7,OS1)=RSS*SMATX(7,IS1)
        SMATX(8,OS1)=RSS*.97*.8*XASS
        SMATX(9,OS1)=RSS*(XASS+XRSS)
        SMATX(20,OS1)=RSS*XASS
        R=SMATX(10,OS2)/SMATX(10,OS1)
        DO 80 I=3,9
80      SMATX(I,OS2)=SMATX(I,OS1)*R
        SMATX(20,OS2)=SMATX(20,OS1)*R
C
C   DETERMINE EFFLUENT CONC. OF SOLUBLE C, N, P, AND FIXED MATTER
        SMATX(12,OS1)=SMATX(12,IS1)
        SMATX(11,OS1)=SMATX(12,OS1)
        SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)-SMATX(5,OS1)*SMATX(2,OS1)/
     2  SMATX(2,IS1)-SMATX(5,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
        SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)-SMATX(6,OS1)*SMATX(2,OS1)/
     2  SMATX(2,IS1)-SMATX(6,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
        SMATX(15,OS1)=SMATX(15,IS1)
C
C   CHECK FOR NITRIFICATION
        IF(SRT+DTA.LT.5.) GO TO 90
        IF(CKN.EQ.0.) GO TO 90
        CKN=CKN*1.05**(DEGC-20.)
        SMATX(18,OS1)=1./((SRT+DTA)*.05*CKN-1.)
        SMATX(19,OS1)=SMATX(13,OS1)-SMATX(18,OS1)
        GO TO 100
90      SMATX(19,OS1)=SMATX(19,IS1)
        SMATX(18,OS1)=SMATX(13,OS1)-SMATX(19,OS1)
C
C   ADJUST ALKALINITY AND SOLUBLE BOD
100     SMATX(16,OS1)=SMATX(16,IS1)-7.14*(SMATX(19,OS1)-SMATX(19,IS1))
        IF(SMATX(16,OS1).LT.20.)SMATX(16,OS1)=20.
        SMATX(17,OS1)=1.
        IF(SMATX(2,OS2).EQ.0.) GO TO 120
        DO 110 I=11,19
110     SMATX(I,OS2)=SMATX(I,OS1)
        GO TO 140
120     DO 130 I=11,19
130     SMATX(I,OS2)=0.
C
C   SIZE DIGESTOR
140     VAER=DTA*SMATX(2,IS1)*DMATX(16,N)*1000./7.48
        X=ALOG(VAER)
        CCOST(1)=EXP(2.414380+.175682*X+.084742*X**2-.002670*X**3)*1.E3
        COSTO(1)=0.
C
```

```
C    COMPUTE AIR REQUIREMENTS
          ACFM=(1.5-1.42*CY)*SMATX(2,IS1)*SIN*8.33
          CB=CB1*(1.05**(DEGC-20.))*(SRT+DTA)**-.415
          ACFM=ACFM+1.42*CB*.8*XASS*VAER*1.E3*7.48*8.33/1.E6
          ACFM=ACFM+4.6*(SMATX(19,OS1)-SMATX(19,IS1))*SMATX(2,IS1)*8.33
          ACFM=ACFM/AEFF/.232/.075/1440.*DMATX(15,N)
          IF(20.*VAER*DMATX(15,N).GT.ACFM)ACFM=20.*VAER*DMATX(15,N)
          X=ALOG(ACFM/1000.)
          CCOST(2)=EXP(4.145454+.633339*X+.031939*X**2-.002419*X**3)*1.E3
          XX=ACFM/1000./DMATX(15,N)
          X=ALOG(XX)
          IF(XX.GE.1.)GO TO 150
          OHRS=850.
          XMHRS=350.
          GO TO 160
150       OHRS=EXP(6.900586+.323725*X+.059093*X**2-.004926*X**3)
          XMHRS=EXP(6.169937+.294853*X+.17599*X**2-.040947*X**3+.0033*X**4)
160       HP=ACFM/DMATX(15,N)*8.1*144./(33000.*.8)
          XKW=.8*HP
          XKWPY=XKW*24.*365.
          ECOST=XKWPY*CKWH
          SCOST=1000.*EXP(.62138+.482047*X)
          TMSU=ECOST+SCOST*WPI
          COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C    ASSIGN VALUES TO OUTPUT MATRIX
          OMATX(1,N)=VAER
          OMATX(2,N)=ACFM
          OMATX(3,N)=0.
          OMATX(4,N)=0.
C
C    COMPUTE ENERGY REQUIREMENTS
          EER=XKWPY/365.
          RETURN
          END


C
C                  LAND DISPOSAL SUBROUTINE
C
        SUBROUTINE LANDD
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,EER,EEP,ALAND
        DIMENSION CAPAC(6),TRUCK(6),OPER(6),TMPG(6)
        DATA CAPAC/1200.,2500.,5500.,10.,15.,30./
        DATA TRUCK/25000.,42000.,55000.,25000.,42000.,50000./
        DATA OPER/.2,.25,.3,.2,.25,.3/
        DATA TMPG/4.5,4.5,3.5,4.5,4.5,3.5/
C
        WHPY=DMATX(1,N)
        DIST=DMATX(2,N)
        YRSL=DMATX(3,N)
        FCOST=DMATX(4,N)
        SP=DMATX(7,N)
        TNMAX=DMATX(8,N)
        ECFT=DMATX(15,N)
        AFCTR=RI*(1.+RI)**YRSL/((1.+RI)**YRSL-1.)
C
```

```
C                  COMPUTE HAULING COSTS
C
        SLV=0.
        JSTYPE=0
        WS=(SMATX(10,IS1)+SMATX(15,IS1))*SMATX(2,IS1)*8.33
        WW=SMATX(2,IS1)*8.33E6-WS
        IF(WS/(WS+WW).GE.0.15) JSTYPE=1
        IF(JSTYPE.EQ.1)GO TO 10
        ASV=SMATX(2,IS1)*365.E6
        J1=0
        GO TO 20
10      ASV=(WS+WW)*365./55./27.
        J1=3
20      CT=1.E20
        ARS=25.
        IF(DIST.GT.20.)ARS=(25.*20./DIST)+(35.*(DIST-20.)/DIST)
        AHPT=(2.*DIST/ARS)+.75
        TPTPY=WHPY/AHPT
        DO 30 KTYPE=1,3
        TPY=ASV/CAPAC(J1+KTYPE)
        NT=TPY/TPTPY*ECFT+.9999999
        ATM=TPY*2.*DIST
        FUEL=ATM/TMPG(J1+KTYPE)
        TMHPY=AHPT*TPY*1.1
        CC=NT*TRUCK(J1+KTYPE)*WPI*118.2/150.2
        CA=CC*.85*AFCTR+.15*CC*RI
        CO=FUEL*FCOST+ATM*OPER(J1+KTYPE)*WPI*117.5/170.3
        CO=CO+TMHPY*DHR*(1.+PCT)
        IF(CA+CO.GE.CT)GO TO 30
        CT=CA+CO
        CCOST(2)=CC
        ACOST(2)=CA
        COSTO(2)=CO
        EER=FUEL
        OMATX(1,N)=TPY/NT
        OMATX(2,N)=TPY
        OMATX(3,N)=NT
30      CONTINUE
        EER=EER*140000.*.000293*CF/365.
C
C          ADD ON FACILITY COSTS
        IF(JSTYPE.EQ.1)GO TO 25
        Q=ASV/1.E6
        C1=20015.*Q**.32
        C2=19950.*Q**.40
        C3=  936.*Q**.22
        C4=  900.*Q**.3
        GO TO 28
25      Q=ASV/1.E3
        IF(Q.LT.15.)GO TO 26
        C1=13849.*Q**.32
        GO TO 27
26      C1=32387.
27      C2=17700.*Q**.40
        C3=  936.*Q**.22
        C4=  900.*Q**.3
28      CCOST(2)=CCOST(2)+C1
        ACOST(2)=(ACOST(2)+C1*AF)/SMATX(2,1)/3650.
        TMSU=C2*CKWH+C3*WPI
        COSTO(2)=(COSTO(2)+(C4*DHR*(1.+PCT)+TMSU))
        COSTO(2)=COSTO(2)/SMATX(2,1)/3650.
        EER=EER+C2/365.
C
```

```
C               COMPUTE STORAGE COSTS
C
      TONS=WS*365./2000.
      IF(DMATX(6,N).GT.0.)GO TO 60
      ALAND=SMATX(2,IS1)*(SMATX(5,IS1)+SMATX(13,IS1))*3040./TNMAX
      IF(JSTYPE.EQ.1)GO TO 50
      SLV=SP*365.*SMATX(2,IS1)*1.E6/7.48/1.E3*DMATX(16,N)
      IF(SLV.LE.0.)GO TO 40
      X=ALOG(SLV)
      CCOST(1)=EXP(.375449+.394996*X+.014726*X**2)*1000.
40    IF(TONS.LE.0.)GO TO 50
      X=ALOG(TONS)
      OHRS=EXP(6.567594-.971759*X+.095689*X**2)*SP
      XMHRS=EXP(-2.087393+2.395831*X-.340388*X**2+
     2       .017499*X**3)*SP
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT))/SMATX(2,1)/3650.
C
C               COMPUTE LAND AND APPLICATION COSTS
C
50    CCOST(3)=ALAND*DMATX(9,N)
      COSTO(3)=(ALAND*DMATX(5,N)*RI+TONS*DMATX(10,N))/SMATX(2,1)/3650.
      IF(JSTYPE.EQ.1)GO TO 55
      EER=EER+180.*SMATX(2,IS1)*293.*CF
      GO TO 70
55    EER=EER+71.43*ASV/1000.*293.*CF/365.
      GO TO 70
C
C               COMPUTE LANDFILL COSTS
C
60    WTPD=TONS/365.+WW/2000.
      ALAND=3.75E-3*WTPD*365.
      CCOST(3)=ALAND*DMATX(5,N)+1.E4*(WTPD**.74)*1.506/2.4
      COSTO(3)=9480.*(WTPD**.625)*1.192/1.7/SMATX(2,1)/3650.
      EER=EER+18.*ASV/1000.*293.*CF/365.
C
C               FILL IN OUTPUT DATA
C
70    OMATX(4,N)=SLV
      OMATX(5,N)=TONS
      OMATX(6,N)=ALAND
      OMATX(7,N)=ALAND*DMATX(5,N)*RI
      IF(DMATX(6,N).GT.0.)OMATX(7,N)=0.
      OMATX(8,N)=ALAND*DMATX(5,N)
      OMATX(9,N)=AFCTR
      RETURN
      END


      SUBROUTINE LIME
C             LIME ADDITION TO SLUDGE
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DLIME=DMATX(1,N)
      CLIME=DMATX(2,N)
      DTON=(SMATX(10,IS1)+SMATX(15,IS1))*SMATX(2,IS1)*8.33/2000.
      PPDL=DLIME*DTON*DMATX(16,N)
      DO 10 I=2,6
   10 SMATX(I,OS1)=SMATX(I,IS1)
      SMATX(7,OS1)=SMATX(7,IS1)+PPDL/8.33/SMATX(2,IS1)
      SMATX(8,OS1)=SMATX(8,IS1)
      SMATX(9,OS1)=SMATX(9,IS1)
      SMATX(10,OS1)=SMATX(10,IS1)+PPDL/8.33/SMATX(2,IS1)
        SMATX(20,OS1)=0.
```

```
      DO 20 I=11,19
   20 SMATX(I,OS1)=SMATX(I,IS1)
      X=ALOG(PPDL)
      CCOST(1)=EXP(-1.800487+.670797*X)*1000.
      X=ALOG(PPDL/DMATX(16,N))
      OHRS=0.
      XMHRS=EXP(6.060054+.197073*X)
      CHEM=PPDL*365.*CLIME/2000.
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=PPDL
      OMATX(2,N)=DTON
        EER=EXP(2.077+.001*1.32*DLIME+.7*ALOG(DTON*2000.))/
     2        365.+.36*PPDL
      RETURN
      END


      SUBROUTINE RBC
C           ROTATING BIOLOGICAL CONTACTOR - FINAL SETTLER
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5), DHR,PCT,WPI,CCI,RI,AF,RATIO ,CKWH,
     . CF,EER,EEP,ALAND
      BOD=DMATX(1,N)
      XNSTG=DMATX(2,N)
      DEGC=DMATX(3,N)
      QPABI=DMATX(4,N)
      QPANI=DMATX(5,N)
      GSS=DMATX(6,N)
      BODN=DMATX(7,N)
      TSS=DMATX(8,N)
      CPDY=DMATX(9,N)
        YIELD=DMATX(10,N)
      QPAB=DMATX(4,N)*1.04**(DMATX(3,N)-20.)
      QPAN=DMATX(5,N)*1.04**(DMATX(3,N)-20.)
      RBOD=DMATX(1,N)/(SMATX(17,IS1)+SMATX(8,IS1))
      TEMP1=ALOG(RBOD)/DMATX(2,N)
      TEMP2=1./EXP(TEMP1)-1.
      APSTG=SMATX(2,IS1)*1000000.*TEMP2/QPAB
        NTRN=APSTG*DMATX(16,N)/1.E5
        NTRN=NTRN+1
        NSHFT=NTRN*XNSTG
        XNTRN=NTRN
        XSHFT=NSHFT
        AREA=XSHFT*1.E5
        PDSD=YIELD*(SMATX(8,IS1)+SMATX(17,IS1)-BOD)*SMATX(2,IS1)*8.33
      TEMP3=1./(1.+QPAB*APSTG/SMATX(2,IS1)/1000000.)
      RBOD=DMATX(7,N)/(SMATX(17,IS1)+SMATX(8,IS1))
      FNSTG=ALOG(RBOD)/ALOG(TEMP3)
      RNSTG=XNSTG-FNSTG
      RNH3=(1./(1.+QPAN*APSTG/SMATX(2,IS1)/1000000.))**RNSTG
      SMATX(18,OS1)=SMATX(18,IS1)*RNH3
      SMATX(2,OS2)=PDSD/DMATX(8,N)/10000./8.33
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      SMATX(10,OS1)=4.5+.51*DMATX(1,N)
      SMATX(10,OS2)=DMATX(8,N)*10000.
      SMATX(8,OS1)=(SMATX(10,OS1)-4.5)*.897
      SMATX(17,OS1)=DMATX(1,N)-SMATX(8,OS1)
      SMATX(19,OS1)=SMATX(18,IS1)-SMATX(18,OS1)
      URSS=SMATX(2,IS1)/(SMATX(2,OS1)+SMATX(2,OS2)*SMATX(10,OS2)/
     . SMATX(10,OS1))
      SMATX(4,OS1)=URSS*SMATX(4,IS1)
      SMATX(3,OS1)=SMATX(8,OS1)*1.6/2.7+SMATX(4,OS1)
      SMATX(5,OS1)=.1*SMATX(3,OS1)
```

```
      SMATX(6,OS1)=,01*SMATX(3,OS1)
      SMATX(7,OS1)=URSS*SMATX(7,IS1)
      SMATX(9,OS1)=SMATX(10,OS1)-SMATX(7,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+SMATX(17,OS1)*1,6/2,7
      SMATX(12,OS1)=SMATX(12,IS1)
        TEMP=SMATX(2,OS1)/SMATX(2,IS1)
        TEMP=TEMP+SMATX(2,OS2)/SMATX(2,IS1)*SMATX(10,OS2)/SMATX(10,OS1)
        SMATX(13,OS1)=SMATX(5,IS1)+SMATX(13,IS1)-TEMP*SMATX(5,OS1)
        SMATX(14,OS1)=SMATX(6,IS1)+SMATX(14,IS1)-TEMP*SMATX(6,OS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)-10,*(SMATX(18,IS1)-SMATX(18,OS1))
        SMATX(20,OS1)=0,
        SMATX(20,OS2)=0,
      TEMP4=SMATX(10,OS2)/SMATX(10,OS1)
      DO 60 J=3,9
   60 SMATX(J,OS2)=TEMP4*SMATX(J,OS1)
      DO 70 J=11,19
   70 SMATX(J,OS2)=SMATX(J,OS1)
      AFS=SMATX(2,OS1)*1000000,/DMATX(6,N)*DMATX(15,N)
      PREM=(SMATX(18,IS1)-SMATX(18,OS1))*100,/SMATX(18,IS1)
      QPAT=SMATX(2,IS1)*1000000,/APSTG/XNSTG
      IF(NSHFT-20) 80,80,90
   80 CCOST(1)=(28500,+45,*DMATX(9,N))*NSHFT*1,506/2,1215
      GO TO 100
   90 CCOST(1)=(23000,+45,*DMATX(9,N))*NSHFT*1,506/2,1215
  100 X=ALOG(AREA/1000,/DMATX(16,N))
      OHRS=EXP(1,323670+,524215*X+,023076*X**2)
      XMHRS=EXP(-,124185+,840104*X+,007757*X**2)
      COSTL=(OHRS+XMHRS)*DHR*(1,+PCT)
      COSTM=(CCOST(1)-45,*DMATX(9,N)*NSHFT*1,506/2,1215)*,02
      COSTE=NSHFT*5,*,746*24,*365,*CKWH
      TMSU=COSTM+COSTE
      COSTO(1)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU)/SMATX(2,1)/3650,
      X=ALOG(AFS/1000,)
      CCOST(2)=EXP(3,716354+,389861*X+,084560*X**2-,004718*X**3)*
       1000,
      X=ALOG(AFS/1000,/DMATX(15,N))
      OHRS=EXP(5,846565+,254813*X+,113703*X**2-,010942*X**3)
      XMHRS=EXP(5,273419+,228329*X+,122646*X**2-,011672*X**3)
      TMSU=EXP(5,669881+,750799*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU*WPI)/SMATX(2,1)/3650,
      OMATX(1,N)=QPAB
      OMATX(2,N)=QPAN
      OMATX(3,N)=APSTG
      OMATX(4,N)=AREA
      OMATX(5,N)=FNSTG
      OMATX(6,N)=RNSTG
      OMATX(7,N)=RATIO
      OMATX(8,N)=PREM
      OMATX(9,N)=QPAT
      OMATX(10,N)=AFS
      OMATX(11,N)=PDSD
      OMATX(12,N)=URSS
      OMATX(13,N)=XNTRN
      OMATX(14,N)=XSHFT
      OMATX(15,N)=COSTM
      OMATX(16,N)=COSTE
      OMATX(17,N)=COSTL
        EER=COSTE/365,/CKWH
        EER=EER+EXP(2,8248+,30093*X+,022308*X**2+
     2              ,0035144*X**3)
      RETURN
      END
```

```
C
      SUBROUTINE PSASFS
C
C     PRIMARY SEDIMENTATION, ACTIVATED SLUDGE, WAS RETURNED TO PRIMARY
C     CLARIFIER.
C
      INTEGER OS1,OS2,OS11,OS12,OS21,OS22,OS1SAV,OS2SAV
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      DIMENSION TRECYC(20),CTEMP(5),TEMPO(5),ATEMP(5)
C
C            SAVE STREAM AND PROCESS ID NUMBERS
C
      NITER=1
      IS1SAV=IS1
      OS1SAV=OS1
      OS2SAV=OS2
      NSAVE=N
      N1=DMATX(1,N)
      N2=DMATX(2,N)
      EPS=.001
      NITMAX=20
      IS11=OS2+1
      OS11=OS2+2
      OS12=OS2
      OS21=OS1
      OS22=OS2+3
      DO 10 I=2,20
      SMATX(I,OS22)=0.
   10 TRECYC(I)=0.
C
C            MIX STREAM IS1SAV WITH OS22
C
   20 TEMP1=SMATX(2,OS22)+SMATX(2,IS1SAV)
      DO 30 I=3,20
      TEMP2=SMATX(2,OS22)*SMATX(I,OS22)
      TEMP2=TEMP2+SMATX(2,IS1SAV)*SMATX(I,IS1SAV)
   30 SMATX(I,IS11)=TEMP2/TEMP1
      SMATX(2,IS11)=TEMP1
C
C            EVALUATE PROCESS PERFORMANCES
C
      N=N1
      IS1=IS11
      OS1=OS11
      OS2=OS12
      DO 40 I=1,5
      CCOST(I)=0.
      COSTO(I)=0.
   40 ACOST(I)=0.
      CALL PRSET
      DO 45 I=1,5
      CTEMP(I)=CCOST(I)
      TEMPO(I)=COSTO(I)
   45 ATEMP(I)=ACOST(I)
      EERTMP=EER
      N=N2
      IS1=OS11
      OS1=OS21
      OS2=OS22
      DO 50 I=1,5
      CCOST(I)=0.
      ACOST(I)=0.
   50 COSTO(I)=0.
      CALL AERFS
      IF(IAERF.GT.0)GO TO 1000
```

```
      DO 55 I=1,5
      CCOST(I)=CCOST(I)+CTEMP(I)
      COSTO(I)=COSTO(I)+TEMPO(I)
55    ACOST(I)=ACOST(I)+ATEMP(I)
      EER=EER+EERTMP
C
C              COMPARE RECYCLE STREAM OS22 WITH TRECYC
C
      DO 60 I=2,20
      IF(ABS(SMATX(I,OS22)-TRECYC(I))-SMATX(I,OS22)*EPS)60,60,70
60    CONTINUE
      GO TO 90
C
C              CONVERGENCE NOT ATTAINED. INCREMENT ITERATION COUNT.
C              SAVE STREAM OS22 IN TRECYC. REPEAT ANOTHER ITERATION.
C
70    NITER=NITER+1
      IF(NITER.GT.NITMAX)GO TO 1000
      DO 80 I=2,20
80    TRECYC(I)=SMATX(I,OS22)
      GO TO 20
C
C              CONVERGENCE ATTAINED.
C
90    N=NSAVE
      DO 100 I=1,20
100   OMATX(I,N)=OMATX(I,N2)
      RETURN
C
C              ITERATION LIMIT EXCEEDED OR MLASS CANNOT BE ATTAINED.
C
1000  IAERF=1
      GO TO 90
      END



      SUBROUTINE HEAT
C
C              HEAT TREATMENT SUBROUTINE
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2        INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3        ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4        CF,EER,EEP,ALAND
C
      I1=DMATX(1,N)
      I2=DMATX(2,N)
      IDIG=DMATX(3,N)
      TEMP=DMATX(4,N)
C
C     FIND FRACTION OF SLUDGE FROM PRIMARY TREATMENT
      IF(IDIG.GT.0)GO TO 30
      IF(I1.EQ.0) GO TO 10
      IF(I2.EQ.0) GO TO 20
      FPRI=1.-SMATX(2,I2)*SMATX(10,I2)/SMATX(2,I1)/SMATX(10,I1)
      GO TO 30
10    FPRI=0.
      GO TO 30
20    FPRI=1.
C
C     COMPUTE EFFLUENT STREAM CHARACTERISTICS
30    AS=1.3255-.00457*TEMP
      AP=1.8112-.00596*TEMP
      AD=1.9698-.00709*TEMP
      BS=1.5855-.00657*TEMP
      BP=1.8455-.00657*TEMP
      BD=1.9855-.00757*TEMP
      GND=.00163*TEMP+.1755
      GD=.00163*TEMP+.0755
```

```
      ALPHA=(1-IDIG)*(FPRI*AP+(1.-FPRI)*AS)+IDIG*AD
      BETA=(1-IDIG)*(FPRI*BP+(1.-FPRI)*BS)+IDIG*BD
      GAMMA=(1-IDIG)*GND+IDIG*GD
      SMATX(2,OS1)=SMATX(2,IS1)
      SMATX(3,OS1)=SMATX(3,IS1)*BETA
      SMATX(4,OS1)=SMATX(3,OS1)*SMATX(4,IS1)/SMATX(3,IS1)
      SMATX(5,OS1)=SMATX(5,IS1)*BETA
      SMATX(6,OS1)=SMATX(6,IS1)*BETA
      SMATX(7,OS1)=SMATX(7,IS1)
      SMATX(8,OS1)=SMATX(8,IS1)*ALPHA
      SMATX(9,OS1)=SMATX(9,IS1)*BETA
      SMATX(10,OS1)=SMATX(7,OS1)+SMATX(9,OS1)
      SMATX(11,OS1)=SMATX(11,IS1)+(SMATX(3,IS1)-SMATX(3,OS1))
      SMATX(12,OS1)=SMATX(11,OS1)*(1.-GAMMA)
      SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)*(1.-BETA)
      SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)*(1.-BETA)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)+(SMATX(13,OS1)-SMATX(13,IS1))*3.57
      SMATX(17,OS1)=SMATX(17,IS1)+SMATX(8,IS1)*SMATX(3,IS1)/
     2              (SMATX(3,IS1)-SMATX(4,IS1))*(1.-ALPHA)*GAMMA
      SMATX(18,OS1)=SMATX(13,OS1)*(.00274*TEMP-.307)
      SMATX(19,OS1)=SMATX(19,IS1)
      SMATX(20,OS1)=BETA*SMATX(20,IS1)
C
C     EVALUATE COST AND ENERGY REQUIREMENTS
      GPM=SMATX(2,IS1)*116666.7/DMATX(5,N)*DMATX(16,N)
      X=ALOG(GPM)
      CCOST(1)=EXP(5.9096-.050119*X+.073395*X**2)*1000.*.60873
      OHRS=EXP(8.4281-.084636*X+.05961*X**2)
      OHRS=OHRS*DMATX(5,N)*52./8000.
      XMHRS=.25*OHRS
      TMSU=EXP(8.8497-.13093*X+.073644*X**2)*.6643*WPI
      XKWPY=.007*GPM/DMATX(16,N)*60.*DMATX(5,N)*52.
      ECOST=XKWPY*CKWH
      QTOT=(TEMP-20.)*.25*15./.75*GPM/DMATX(16,N)*60.*DMATX(5,N)*52.
      HPD=DMATX(5,N)/DMATX(6,N)
      IF(HPD.LT.8.)FK=2000.
      IF(HPD.LT.16.)FK=1500.
      IF(HPD.LT.24.)FK=1000.
      IF(HPD.GE.24.)FK=0.
      SPY=DMATX(6,N)*52.
      QTOT=QTOT+(12.*2000.+FK*(SPY-12.))*GPM/DMATX(16,N)*60.
      FCOST=FUEL*DMATX(7,N)/1.E6
      TMSU=TMSU+ECOST+FCOST
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
      EER=XKWPY/365.+QTOT/365.*.000293*CF
C
C     FILL IN VALUES OF OUTPUT MATRIX
      OMATX(1,N)=GPM
      OMATX(2,N)=ALPHA
      OMATX(3,N)=BETA
      OMATX(4,N)=QTOT/1.E6
      RETURN
      END
```

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(Please read Instructions on the reverse before completing)

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16. ABSTRACT

A computer-aided design procedure for the preliminary synthesis of wastewater treatment and sludge disposal systems is developed. It selects the components in the wastewater treatment and sludge disposal trains from a list of candidate process units with fixed design characteristics so that criteria on effluent quality, cost, energy, land utilization, and subjective undesireability are best satisfied. The computational procedure uses implicit enumeration coupled with a heuristic penalty method that accounts for the impact of return sidestreams from sludge processing. The programmed version of the design procedure, called EXEC/OP, has been interfaced with the unit process subroutines contained in a previously EPA developed system evaluation program known as EXECUTIVE. A number of case study design problems are presented to demonstrate the versatility of EXEC/OP. Included among these is a preliminary cost/energy-effectiveness analysis for a hypothetical design problem containing over 15,000 alternative system configurations.

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