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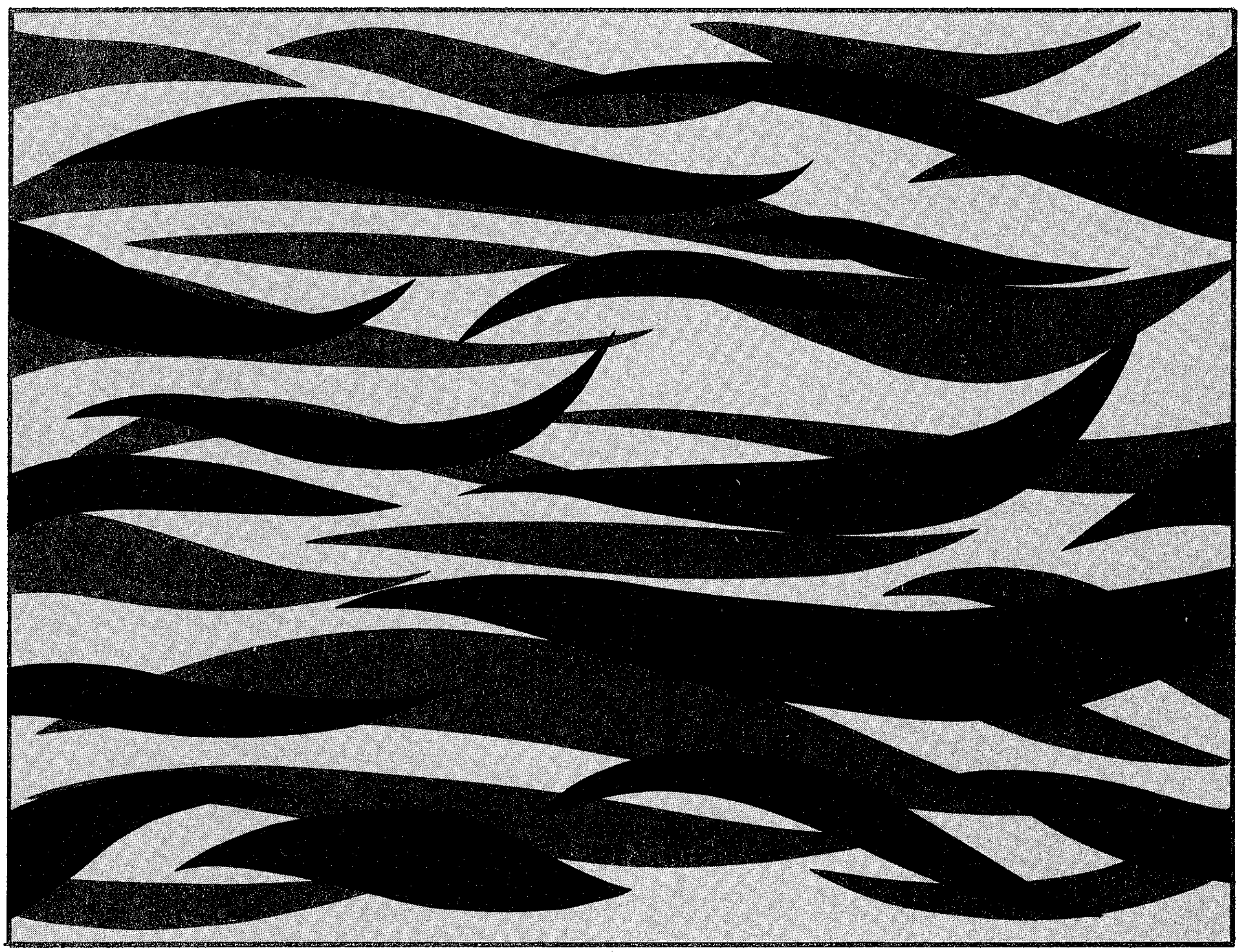

INSTITUTE OF WATER RESOURCES
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ABSTRACT

An efficient combination of private wastewater management and municipal treatment can be encouraged through municipal service charges based on actual treatment costs.

Charges for content are usually in the form of surcharges based on the weight of selected contaminants in excess of specified concentrations. A charge for volume and for the entire weight of each priced contaminant is recommended.

The selection of pricing parameters depends on the treatment process and wastewater characteristics. Biochemical oxygen demand (BOD) and suspended solids are major cost determinants for conventional primary and secondary treatment and are the most common pricing parameters. More comprehensive measures of content are needed for allocating the cost of more advanced treatment processes. BOD can be a major cost determinant and still not be an effective pricing parameter. BOD analysis of industrial wastewater should be either supplemented or replaced by other measures of organic content such as chemical oxygen demand.

Both federal cost recovery requirements and municipal accounts include a clear distinction between capital costs and operating and maintenance costs. Thus, separate cost allocations are necessary.

A component pricing method was developed for allocating actual costs in proportion to the marginal costs for volume and for each

priced contaminant. The component pricing system can be applied to capital cost as well as operating and maintenance cost.

A large portion of operating and maintenance cost is determined by facility size rather than actual use. Component prices to allocate operating and maintenance cost should be based on long-run marginal operating and maintenance costs. These marginal costs should be estimated with hypothetical changes in plant size rather than hypothetical changes in loading rates for a plant of fixed size.

Cost data and computer simulation models developed for preliminary design of water pollution control facilities can be used in estimating component marginal costs. The component pricing method of cost allocation is illustrated with a modified version of a digital simulation model developed by Richard G. Eilers and Robert Smith at the Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio. The example is for a treatment plant with activated sludge, anaerobic digestion, and vacuum filtration.

Some municipalities set prices for content equal to the short-run marginal costs of removing each major contaminant. Prices to recover only short-run marginal costs should be used only when excess capacity is available and is expected to be available for at least several years. A simulation model for estimating short-run marginal costs must not permit equipment capacities to vary with changes in the influent stream. Simulation models with fixed plant size are referred to as management models.

A management model was derived from the previously discussed design model. The operation of an existing treatment plant was simulated, and estimates of treatment effectiveness and costs were compared. Simulation results were encouraging, but additional comparison of simulation results with operating plants is recommended.

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PRICING OF INDUSTRIAL WASTEWATER TREATMENT SERVICES

I. Policies and Practices

Federal policy concerning the recovery of wastewater treatment cost from industrial discharges has developed in two quick steps. Federal cost recovery requirements for the approval of construction grants to municipalities were first established on July 1, 1970. These requirements pertained only to industrial users as a group. Any cost recovery system was acceptable if industrial users as a group paid an amount at least equal to the industrial share of operating and maintenance cost and the industrial portion of the local share of capital cost (U.S.D.I. [29], p. 1).*

Much more specific cost recovery requirements became effective March 1, 1973 (U. S. Public Law [35] and U.S.D.I. [29]). The new requirements for approval of construction grants specify that each industrial user must pay its proportionate share of operating and maintenance costs. The minimum portion of capital cost to be recovered was shifted from the local share to the much larger federal share.

Much of the current concern about the pricing of industrial wastewater treatment services relates to these federal requirements; however, attention should not be limited to required cost recovery. Prices which reflect municipal treatment cost encourage an efficient combination of waste control at the source and final treatment by the

* Numbers in brackets refer to References listed in full in Appendix D.

municipality. (For information on the response by industry to charges based on content as well as volume see Bubbis [2], pp. 1408-9, Shaw [22], pp. 46-47, and Elliott and Seagraves [8].)

The objective of this report is to present pricing systems which will encourage an efficient combination of private and municipal treatment of industrial wastewater. An efficient combination is defined as the combination of private and municipal treatment which meets specified quality standards at the least possible total cost. This economic concept of least-cost combination includes both complete private treatment of industrial wastewater and combined treatment of domestic sewage and industrial wastewater either with or without pretreatment. Use of the term "least-cost combination" does not imply a preference for pretreatment at the source and final treatment at a municipal facility. When faced with charges which fully recover municipal cost many industrial discharges may find that by-product recovery, private treatment, and water recycling are more economical than discharging to municipal sewers.

The selection of quality standards for effluents discharged to natural waters is outside the scope of this report. However, effluent standards have a direct relation to the pricing of industrial wastewater treatment services. More stringent effluent standards mean increased charges. Moreover, an increase in the number of regulated parameters could result in an increase in the number of priced contaminants.

This report includes only some of the numerous factors which influence decisions regarding joint treatment of industrial and domestic

wastewaters. Current federal policy requires industrial discharges to pay a proportionate share of operating and maintenance costs. Proportionate (average) cost pricing could result in separate treatment when combined treatment would be more economical. (For an excellent discussion of conceptual problems associated with cost allocation see Eckstein [4]). On the other hand, federal cost recovery requirements for capital cost apply only to the federal share of construction costs. Moreover, the legislation did not limit the repayment period and did not set an interest rate. A long repayment period and a low interest rate would encourage excessive discharges of industrial wastewater to municipal sewers. The division of cost between users and taxpayers seems to be based more on politics than on economics. This report is focused on the allocation of cost to be recovered from current dischargers.

A. Surcharges and Component Prices

With only a few exceptions wastewater treatment charges based on content are in the form of surcharges (Maystre and Geyer [11]; Public Works Engineers [17]; U.S.D.I. [29]). Surcharges usually apply to biochemical oxygen demand (BOD) and suspended solids in excess of a specified "normal" concentration for each contaminant. The level specified as normal varies from city to city usually within the range of 200 mg/l to 400 mg/l for both BOD and suspended solids. In most literature pertaining to wastewater treatment and in this report the term "suspended solids" is defined to include both settleable and unsettleable solids.

Specified normal concentrations appear to be based on averages for wastewater entering the municipal treatment plant just prior to the passage of the surcharge ordinance (Maystre and Geyer [11], p. 1282). Since the industrial portion of the wastewater entering municipal plants is often more concentrated than the domestic portion there is a tendency to undercharge industry.

An additional problem associated with the surcharge approach lies in the fact that an incentive to control wastes at the source is created only in the case of concentrations in excess of the level specified as normal. Parties discharging large volumes with waste concentrations at or just below the normal level have no economic incentive to reduce the quantity of contaminants discharged. The use of discounts or negative surcharges was suggested in 1947 by Wright [38], but no use of discounts has been reported in surveys of actual practice.

Some of the problems associated with surcharges can be avoided by charging for volume and for the entire weight of priced contaminants. This approach is used by the Metropolitan Sanitary District of Greater Chicago (Anderson and Sosewitz [1], p. 1591). Unless noted otherwise, all pricing systems and examples presented in this report will involve a charge for volume and for the entire weight of each priced contaminant. This approach will be referred to as "component pricing."

Use of surcharges partially sidesteps one question which must be faced directly when using component prices. Which industrial dischargers should be billed for content? With surcharges attention is focused only on sources with waste concentrations in excess of the

level specified as normal. With component prices the content from all sources must be considered. Individual sampling is feasible only for large sources based on either volume or content. A composite volume charge based on average contents of domestic sewage can be used for residential sources and for many commercial dischargers. Small sources of commercial and industrial wastewater can be grouped into user classes and charged on the basis of typical or average concentrations.

B. Pricing Parameters

The fact that most existing charges for content are based on BOD and suspended solids does not mean that attention should be limited to these parameters. The BOD of individual sources of industrial wastewater is not always closely related to treatment cost even for conventional secondary treatment. Dispersed, nonbiodegradable, organic material can pass through secondary treatment processes and become an important cost determinant for tertiary treatment. The selection of pricing parameters depends on the wastewater characteristics and the treatment process.

The BOD of an individual industrial wastewater can be less than the associated BOD contribution to the mixture of domestic and industrial wastewater entering the municipal treatment plant. The ratio of carbon to nitrogen in an individual source of industrial wastewater is not always conducive to biological activity. Toxic materials in industrial wastewater can lower BOD test results. BOD analysis of industrial wastewater should be either supplemented with or replaced by other measures of organic content such as chemical oxygen demand (COD).

If BOD is an important design and operating parameter for a treatment plant, a relationship can be established between COD of each industrial wastewater and the impact of the particular industrial wastewater on the BOD of the mixture of wastewaters entering the treatment plant. Once such relationships are determined, charges based on BOD can be converted into charges based on COD.

Pricing methods presented in this report pertain only to industrial wastes compatible with treatment processes in actual operation. Pricing on the basis of volume and content is not a substitute for ordinances limiting the type and concentration of waste discharged to public sewerage systems.

The most effective parameters for relating treatment cost to wastewater content depend on the treatment process. COD appears to be a major cost determinant for some physical-chemical treatment systems (Skuckrow, Dawson, and Bonner [23], p. 25). Some processes relate directly to the removal of a particular contaminant. In these cases the contaminant should be priced on the basis of removal cost. For example, phosphorus should be one of the priced parameters if treatment processes include phosphorus removal.

The addition of an activated carbon process to conventional secondary treatment presents a new cost relationship. Dispersed, non-biodegradable organic matter which previously passed through the plant with little cost becomes a major cost determinant. Separate prices, each based on removal cost, could be levied for biodegradable and non-biodegradable organic materials. Likewise, separate prices could be

levied on settleable solids and dispersed solids. A less detailed accounting for the added cost of activated carbon treatment could be made by shifting the pricing parameters from BOD and suspended solids to COD and a more comprehensive measure of solids.

C. Cost Allocation

No surveys have been made of actual methods of allocating cost among volume and price contaminants. Indications of common practice are available from articles on methods of calculating surcharges (Joint Committee [10], Quirk [18], Roderick [19], Schroepfer [20], Symons [27], and Wright [38]). There are numerous reports on the method used in particular cities (Anderson and Sosewitz [1], Olliffe [15], Shaw [22], Symons and Crane [28], and Walter [37]). As a general practice capital cost for each treatment process is allocated among volume and priced contaminants. Two methods are used for the allocation of operating and maintenance cost. One method directly allocates various cost items, such as labor and electricity, among priced components. The more common approach allocates operating and maintenance cost among treatment processes and then among priced components.

The same basic method produces rather disparate results. There are wide differences in opinion regarding the basis for allocating the cost of individual processes. In an often-quoted article, Schroepfer [20], p. 1502, divided capital costs of final settling tanks evenly between volume and BOD. The Metropolitan Sanitary District of Greater Chicago allocated all capital costs of final settling tanks to volume

(Anderson and Sosewitz [1], p. 1592). The literature is filled with similar examples; some even more extreme. Capital costs of chlorine contact tanks have been allocated entirely to BOD in one case (Walter [37], p. 1107) and entirely to volume in another case (Roderick [19], p. 315). A possible basis for these differences in opinion is summarized in the following statement:

> "In rate making for wastewater treatment plant cost distribution two philosophies seem to prevail. The first may be termed a cost responsive or design parameter approach. This philosophy assigns the cost of each treatment unit to the specific loading parameter used in its design. An example of this basis of cost allocation would be the assignment of the cost of a primary clarifier to average flow in that the primary clarifier is sized using average flow as a design parameter. The second philosophy may be termed a functional approach. ... Using this approach the cost of a primary clarifier would be assigned to either suspended solids or to a combination of suspended solids and BOD. This assignment would be made in that the function of the primary clarifier unit is the removal of these wastewater loadings." (Quirk [18], pp. 29-30)

While the preceeding statement is consistent with observable practice, the literature contains many examples and little explanation. An intentional cost allocation on a basis not related to cost seems illogical. Function may have been over-emphasized through an erroneous focus on total cost. If the wastewater contained no suspended solids there would be no need for a primary clarifier. However, this obvious fact provides no basis for assigning the cost of the primary clarifier to suspended solids. Domestic sewage and most industrial wastewater include suspended solids. Function does not generally need to be considered in allocating the cost of treatment processes which would be used in the absence of industrial wastewater.

Attention should be given to function in the case of industrial wastes which necessitate special treatment processes. Where a special

process is required to remove an industrial contaminant the entire cost of the special process could be allocated among dischargers of that contaminant. The fact that costs of the special process are influenced by the volume of wastewater from other sources would not generally constitute a sound basis for requiring all dischargers to pay a volume charge for the special process. Specialized treatment processes necessitated by industrial contaminants introduce cost allocation problems requiring individual study and administrative judgement.

The cost-responsive approach cannot be easily implemented from municipal cost accounts. Costs are usually known for the entire treatment plant but not for individual treatment processes. Moreover, the costs of some treatment processes are determined by more than one wastewater characteristic. For example, aeration tank size and cost are influenced by both volume and BOD of the primary effluent. A cost-responsive, or marginal cost, basis for cost allocation requires cost estimates with volume and BOD in various proportions. Fortunately, cost data for an individual treatment plant can be supplemented with published cost data. Data developed to assist in the design of treatment facilities can be used to establish a relative distribution of costs among volume and priced contaminants. The relative distribution can be combined with actual cost to establish component prices for a particular treatment plant.

II. A Marginal Cost Basis for Allocating Cost

Both capital costs and operating maintenance costs can be allocated through a component pricing system. Component prices can be established through proportional adjustment of marginal cost associated with each economically important characteristic of the wastewater.

"Components" are defined as the volume of wastewater and the weight of each contaminant to be priced. Volume is priced on essentially the same basis as an individual contaminant. The marginal cost, price, and charge (price times quantity) for volume relate to the cost associated with an increase in the volume of water with no corresponding increase in the weight of contaminants. The selection of contaminants to be priced depends on the treatment process and the wastewater characteristics.

Both federal cost recovery requirements and municipal financing procedures include a clear distinction between capital costs, and operating and maintenance costs. Therefore, component prices for allocating capital cost should be based on marginal capital cost for individual wastewater components. Likewise, component prices for the allocation of operating and maintenance cost should be based on marginal operating and maintenance cost for each component. Conventional definitions of marginal cost do not include this distinction between capital cost and operating and maintenance cost. Marginal capital cost and marginal operating and maintenance cost are essential concepts in this study and must be defined precisely.

Marginal capital cost for the "i"th component is defined as the change in capital cost resulting from a one unit increase in the average

daily inflow of the "i"th component. Marginal capital costs are estimated in the following manner. The capital cost of the facility built is compared to the estimated capital costs for a series of hypothetical treatment plants each designed to accommodate a small increase in the quantity of one component. The estimated marginal capital cost for each component is the ratio of the increase in capital cost to the increase in quantity of the corresponding component.

Marginal operating and maintenance cost for the "i"th component is defined as the change in daily operating and maintenance cost resulting from a one unit increase in the average daily inflow of the "i"th component.

Cost equations developed by Smith [25], pp. 43-44, indicate that a large portion of operating and maintenance cost depend on facility size. Component prices can encourage an efficient combination of private and municipal treatment through time only if the component prices are based on a long-run concept of marginal operating and maintenance cost. Thus, long-run marginal operating and maintenance cost should be estimated with hypothetical changes in plant size rather than hypothetical changes in loading rates for a plant of fixed size.

The quantity of any component can be expressed in any unit of measurement provided the associated marginal cost and price are expressed in relation to the same unit. However, an introduction of units permits a less abstract presentation. Thus, costs and prices related to volume will be expressed in dollars per 1,000 gallons, while costs and prices for each contaminant will be expressed in dollars per pound.

The component pricing procedure applies to both capital and operating costs; however, the difference in relation to time requires some separate explanation. "Component service prices" are defined to be the component prices which will recover operating and maintenance cost. "Component capacity prices" are defined to be component prices which will recover capital costs to be charged to current discharges.

A. Component Service Prices

Component service prices to allocate operating and maintenance costs can be found with the following equation:

$$P_{oi} = MC_{oi} \; (C_o / \sum_{i=1}^{n} X_i \cdot MC_{oi}) \qquad \text{(Eq. 1)}$$

where

P_{oi} = service price for the "i"th component.

MC_{oi} = marginal operating and maintenance cost for the "i"th component.

C_o = average daily operating and maintenance cost.

X_i = daily quantity of the "i"th component from all sources.

n = number of components.

The daily service charge to each major industrial discharger can be calculated in the following manner:

$$C_{ok} = \sum_{i=1}^{n} P_{oi} \cdot X_{ki} \qquad \text{(Eq. 2)}$$

where:

C_{ok} = daily service charge to the "k"th waste discharger.

P_{oi} = service price for the "i"th component.

X_{ki} = daily quantity of the "i"th component from the "k" discharger.

n = number of components.

A monthly, rather than daily, service charge could be computed by using the monthly, rather than daily, quantity of each component.

Service charges for treating domestic sewage can be based on a composite service price expressed in dollars per 1,000 gallons of domestic sewage. The composite service price equivalent to a particular set of component service prices can be found with the following equation:

$$P_{od} = P_{ov} + \sum_{j=1}^{m} P_{oj} \cdot Y_{dj} \qquad \text{(Eq. 3)}$$

where:

P_{od} = composite service price for domestic sewage, \$/1,000 gal.

P_{ov} = component service price for volume, \$/1,000 gal.

P_{oj} = component service price for the "j"th contaminant, \$/lb.

Y_{dj} = pounds of the "j"th contaminant per 1,000 gallons of domestic sewage, lb/1,000 gal.

m = number of priced contaminants.

At first glance the component pricing system may appear to be substantially different from the usual practice of combining a charge for normal sewage with a surcharge for wastewater with above average content concentrations. Component prices can be expressed in terms of a normal charge and a surcharge. If dischargers large enough to merit individual sampling and billing are given discounts or "negative surcharges" for contaminant concentrations less than those in domestic sewage a surcharge system is equivalent to component pricing. The previously defined composite service price for domestic sewage is equivalent to the conventional charge rate, or price, for normal sewage. With

a normal charge and surcharge system the daily charge to each major industrial discharger could be computed with the following equation:

$$C_{ok} = P_{od} \cdot X_{kv} + \sum_{j=1}^{m} P_{oj} \cdot X_{kv} \cdot (Y_{kj} - Y_{dj}) \qquad \text{(Eq. 4)}$$

where:

C_{ok} = daily service charge to the "k"th waste discharger, \$/day.

P_{od} = composite service price for domestic sewage, \$/1,000 gal.

X_{kv} = daily volume from the "k"th discharger, 1,000 gal/day.

P_{oj} = component service price for the "j"th contaminant, \$/lb.

Y_{kj} = pounds of the "j"th contaminant per 1,000 gallons of wastewater from the "k"th discharger, lb/1,000 gal.

Y_{dj} = pounds of the "j"th contaminant per 1,000 gallons of domestic sewage, lb/1,000 gal.

The conversion of component service prices into a combination of charges and surcharges may be helpful in introducing the component pricing system to persons familiar with surcharges. Attention can then be focused on the method of estimating component service prices without diversion into needless debates over imagined differences between component prices and surcharges. Direct use of component service prices, as shown in equation (2), would be much simpler than use of surcharges.

B. Component Capacity Prices

Component capacity prices to allocate capital cost can be found with the following equation:

$$P_{ci} = MC_{ci} \; (C_c / \sum_{i=1}^{n} X_i \cdot MC_{ci}) \qquad \text{(Eq. 5)}$$

where:

P_{ci} = capacity price for the "i"th component.

MC_{ci} = marginal capital cost for the "i"th component.

C_c = capital cost to be recovered from current users.

X_i = daily quantity of the "i"th component from all sources.

n = number of components.

The amount of capital cost to be recovered from each major industrial discharger can be calculated in the following manner:

$$C_{ck} = \sum_{i=1}^{n} P_{ci} \cdot X_{ki} \qquad \text{(Eq. 6)}$$

where:

C_{ck} = capital charge to the "k"th discharger.

P_{ci} = capacity price for the "i"th component.

X_{ki} = daily quantity of the "i"th component from the "k" discharger.

C. Adjustment for Peak Flows

The component pricing method has been stated in terms of average daily volume and content. Actual flow of industrial wastewater depends on the hour of the day, the day of the week, and the season of the year. The merits of detailed adjustment of charges to account for variations in flow depend on the particular situation.

Where industries operate only seasonally, capital cost and that portion of operating and maintenance cost dependent on facility size should be allocated on the basis of some measure of average flow during the operating season. Equation (5), which defines component capacity prices, can be revised by defining X_i and X_{ki} on the basis of daily averages during the season of maximum flow. Equation (1), which defines

component service prices, can be rewritten into two equations, one for operating and maintenance cost items dependent on facility size, and one for chemicals and other items not related to facility size.

Hourly and daily fluctuations in industrial wastewater discharge are often limited by municipal ordinances which set an upper limit on the ratio of maximum flow to average flow. Contaminant concentrations are also limited by ordinance. Within these limits special charges may be worth the effort in some cases. Large flows of short duration may require unusual operating procedures. Charges to cover these cost should probably be set through partial budgeting, or cost analysis, and levied as an addition to the general service charge.

III. Design and Cost Estimation Models

Estimation of component marginal costs is the key phase of the component pricing system. Marginal cost estimation through conventional design and cost estimation techniques would be time-consuming and expensive. Fortunately, component marginal costs can be estimated through mathematical simulation models. Programs are now available for most treatment processes in common use.

A major research project on the mathematical simulation of wastewater treatment processes has been conducted at the Advanced Waste Treatment Research Laboratory at Cincinnati, Ohio. (The project, along with other activities at the Cincinnati Laboratory, is now a part of the Office of Research and Monitoring of the United States Environmental Protection Agency.) The following reports on simulation have been published:

1. Smith, "Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer," March 1968. [25]

2. Smith, Eilers, and Hall, "Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," August 1968. [26]

3. Eilers and Smith, "Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," (preliminary copy), November 1970. [5]

4. Eilers and Smith, "User's Manual for Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," March 1973. [6] (The manual and the program on cards can be obtained from the National Technical Information Service.)

Cost estimation and pricing examples in this report are based on a modified version of the Eilers and Smith [5] program dated November

1970. The more recent program by Eilers and Smith [6] was not available when the component pricing examples were prepared. The program which became available in March 1973 includes 21 treatment processes. As additional data becomes available Eilers and Smith are revising the program and writing subroutines for additional treatment processes. Applications of the component pricing method should be made with the latest available program.

The cost estimation procedure in the March 1973 program is different from that in the previous simulation models. In the March 1973 program costs are estimated on the basis of data from Patterson and Banks [16]. Information on the new cost equations is also available in an April 1971 report by Eilers and Smith [7]. The new method of estimating operating and maintenance cost incorporates current wage rates. The cost of labor index which was added to the November 1970 program is not needed with the March 1973 program.

A. Basic Features

The Eilers and Smith [5] program can be used to estimate the quasi-steady-state performance and cost of conventional wastewater treatment processes. The simulation model consists of a MAIN (a calling program), a subroutine for each treatment process, a COST subroutine to compile cost estimates, and a PRINT subroutine. The simulation is created through the interaction of stream vectors and decision vectors. A stream vector consists of a stream identification number, volume of flow, and concentration of fifteen materials. The content of a stream vector is fully defined in Table 1. The contaminant concentrations

TABLE 1. Stream Vector

SMATX	Parameter	Program Symbol	Nominal Value
(1,I)	Stream Number	*	--
(2,I)	Volume Flow, mgd	Q	--
(3,I)	Solid Organic Carbon, mg/l	SOC	105.
(4,I)	Solid Nonbiodegradable Carbon, mg/l	SNBC	30.
(5,I)	Solid Organic Nitrogen, mg/l	SON	10.
(6,I)	Solid Organic Phosphorus, mg/l	SOP	2.
(7,I)	Solid Fixed Matter, mg/l	SFM	30.
(8,I)	Solid BOD, mg/l	SBOD	140.2
(9,I)	Volatile Suspended Solids	VSS	223.6
(10,I)	Total Suspended Solids, mg/l	TSS	253.6
(11,I)	Dissolved Organic Carbon, mg/l	DOC	43.
(12,I)	Dissolved Nonbiodegradable Carbon, mg/l	DNBC	11.
(13,I)	Dissolved Nitrogen, mg/l	DN	19.1
(14,I)	Dissolved Phosphorus, mg/l	DP	4.
(15,I)	Dissolved Fixed Matter, mg/l	DFM	500.
(16,I)	Alkalinity, mg/l	ALK	250.
(17,I)	Dissolved BOD, mg/l	DBOD	59.84

* designates the stream number

listed as nominal values in Table 1 are from Smith [25], pp. 7-9. Decision vectors are lists of numerical values which specify design criteria for treatment processes and for the COST subroutine. The decision vectors as a group are referred to as the decision matrix (DMATX). The decision vectors for all subroutines used in this report are shown in Table 2. Each operational subroutine (those simulating treatment processes) contain numerous coefficients and specify the relationship between input stream vectors and the relevant decision vector. Each operational subroutine calculates effluent stream vectors, size of needed structures and equipment, operating characteristics, and costs. Streams move from process to process as specified. Feedback streams are simulated by feedback loops. The MAIN includes an iterative system which continues to cycle until the content of the influent to the primary settler stabilizes within a specified tolerance (EPS). Once the prescribed tolerance is reached costs are summarized and the results are printed. Information printed includes: the stream characteristics between each treatment process, needed equipment size, operating characteristics, and costs.

B. Cost Data and Equations

Costs are estimated in the operational subroutines. The COST subroutine summarizes all cost data and makes common adjustments such as addition of an estimated engineering fee. Cost adjustments are not accompanied by changes in the name of the variable. Units are changed in one case. Operating and maintenance costs, COSTO(J,I), are estimated in thousands of dollars per year and are converted in the COST

TABLE 2. Decision Matrix (DMATX)
(N designates the process number)
(Program Symbols are Defined in Appendix A.)

Preliminary Treatment

DMATX	Program Symbol
(1,N)	DCAP*
(16,N)	ECF

Primary Settler

DMATX	Program Symbol
(1,N)	FRPS
(2,N)	URPS
(3,N)	APS *
(16,N)	ECF

Aerator-Final Settler

DMATX	Program Symbol
(1,N)	BOD of OS1
(2,N)	XMLSS
(3,N)	DEGC
(4,N)	CAER20
(5,N)	DO
(6,N)	AEFF20
(7,N)	URSS
(8,N)	GSS
(9,N)	VAER*
(10,N)	AFS *
(11,N)	BSIZEI*
(12,N)	ASRPSI*
(13,N)	ECF (Final Settler)
(14,N)	ECF (Sludge Return Pump)
(15,N)	ECF (Blowers)
(16,N)	ECF (Aerator)

Chlorination Tank

DMATX	Program Symbol
(1,N)	DCL2
(2,N)	TCL2
(3,N)	VCL2*
(4,N)	DACL2
(16,N)	ECF

Thickener

DMATX	Program Symbol
(1,N)	TRR
(2,N)	TSS of OS1
(3,N)	GTHD
(4,N)	GSTHD
(5,N)	ATHM*
(16,N)	ECF

Digester

DMATX	Program Symbol
(1,N)	TD
(2,N)	TDIG
(3,N)	VDIG*
(16,N)	ECF

Elutriation Tank

DMATX	Program Symbol
(1,N)	ERR
(2,N)	TSS of OS1
(3,N)	WRE
(4,N)	GED
(5,N)	GESD
(6,N)	AE *
(16,N)	ECF

Vacuum Filter

DMATX	Program Symbol
(1,N)	VFL
(2,N)	HVF
(3,N)	TSS
(4,N)	AVF*
(5,N)	LHVF
(16,N)	ECF

Cost Constants

DMATX	Program Symbol
(1,20)	CKWH
(2,20)	CCI
(3,20)	AF
(4,20)	CTRP
(5,20)	CTGO
(6,20)	CLAND
(7,20)	CFECL3
(8,20)	CCL2
(9,20)	CLI
(10,20)	WRVF
(11,20)	RVF

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* Denotes parameters which are predetermined only in the management program.

subroutine to cents per thousand gallons. Capital costs for each process, CCOST(J,I), always appear in thousands of dollars, while amortization costs, ACOST(J,I), are in cents per thousand gallons. For convenience final cost units are defined at the top of the table showing process characteristics and costs.

1. Capital cost

Capital costs in this report are estimated with the same equations used by Eilers and Smith [5]. Original sources and methods of derivation are reported in an earlier publication by Smith [25], pp. 37-43.

Capital cost for each treatment process is a function of either capactiy or some measure of size. Prior to cost estimation, capacities and sizes can be increased to allow excess capacity for periodic cleaning and maintenance. The deicsion matrix includes an excess capacity factor (ECF) for each treatment process. Since the previously calculated capacity or size is multiplied by ECF, 1.0 must be entered if there is no allowance for excess capacity.

The capital cost equations are based on prices in St. Louis, Missouri, in January 1960. The COST subroutine includes a capital cost index (CCI) to adjust for price changes. The index is simply the ratio of current prices to base prices. Since the index entering the program is a ratio, any of several price or cost indices could be used. The "Sewage Treatment Plant Construction Cost Index", (U.S.D.I. [32]) is the most specific and is used in this report. This index was at 105.23 for the St. Louis region in January 1960.

After cost estimates are adjusted for inflation the individual items are summarized and are referred to as TCAP, which is subsequently multiplied by a capital cost ratio (CCR). CCR includes percentage adjustments for engineering cost (CENG), contractor's profit (CTRP), contingencies and omissions (CTGO), and land (CLAND). CENG is a function of TCAP, while the other allowances are specified in the decision matrix. The capital cost for each process, CCOST(J,I), is also adjusted by CCR.

Capital cost for each process is amortized and converted from thousands of dollars to cents per thousand gallons. An amortization factor (AF) is one of the cost constants in the decision matrix. The amortization factor converts capital cost to an annual equivalent for a given interest rate and expected service life. Total amortization cost for the entire system (TAMM) is found by summing the amortization cost (ACOST) for each process.

2. Operating and maintenance cost

Operating and maintenance costs include both direct cost and plant overhead. Costs directly attributed to individual processes include operating labor and supplies, maintenance labor and materials, power, and indirect labor costs (fringe benefits). Plant overhead is the cost of common services and supervision at the plant site. Major items are supervision, plant vehicles, laboratory, general supplies, maintenance of roads and grounds, telephone, and maintenance of the plant administrative building. The cost equation for each process

includes a share of plant overhead allocated on the basis of the percentage of total direct costs attributed to the process.

The costs of administrative services usually rendered away from the plant site are not included in the cost estimates. These services include billing, auditing, personnel management, legal counsel and engineering advice. An estimate of these off-site costs is needed in estimating actual treatment costs. However, general administrative costs need not be allocated to individual processes if marginal cost for each waste component is used only to establish a proportional basis for allocating actual costs.

In Eilers and Smith [5], vacuum filter operating and maintenance costs consist of chemical costs and a general estimate of other operating and maintenance costs based on the volume of filtrate. This method fails to account for the fact that labor costs depend on vacuum filter size as well as volume of filtrate. Finding little published data on vacuum filter operating and maintenance costs, we decided to collect data through a survey of the 28 water pollution control plants in Connecticut which use vacuum filters. Results of the survey and a new method of estimating vacuum filter operating and maintenance costs are presented in Appendix B.

Current prices are used for chlorine, electricity for blowers, and in estimating the cost of operating vacuum filters. Other operating and maintenance costs are estimated with equations based on either flow or size of facilities. These cost relationships were estimated originally on the basis of prices prevailing in June 1967 (Smith [24],

Table A-IV). Since wages typically amount to 60 percent or more of total operating and maintenance costs and some items are priced directly, relative wage rates appear to be a reasonable basis for adjusting for inflation.

For June 1967, the United States Department of Labor reported average hourly wages of $2.80 for nonsupervisory workers in water, steam and sanitary systems (U.S.D.L. [33], p. 78). Estimates of operating and maintenance costs which are not based directly on current prices are adjusted by the ratio of current hourly earnings of nonsupervisory workers to $2.80. This ratio is defined as the cost of labor index (CLI), which enters the program as DMATX (9,20). In this report operating and maintenance costs are adjusted to prices of January 1971 in order to facilitate comparisons to actual costs of fiscal 1971-72. The average hourly earnings of nonsupervisory workers in water, steam, and sanitary systems was $3.69 in January 1971 (U.S.D.L. [34], p. 90). The corresponding value for CLI is 1.318.

C. Corrections and Definitional Changes

In Eilers and Smith [5] only the volume and solids from the digester are used in sizing the elutriation tank. This seems inappropriate in view of the fact that the inflow of treated water for dilution of alkalinity is commonly three times the volume of the sludge. The sizing equations were revised to include volume and solids for both the sludge and the wash water.

Four variables were defined incorrectly in Eilers and Smith [5]. GPS, GSS, GTH, and GE, which are the flow loading rates for the primary

settler, final settler, thickener, and elutriation tank, were used in relation to inflow but were defined in relation to overflow. To be consistent with actual use GPS is redefined to be "Computed inflow to surface area ratio for the primary settler, gpd/sq ft." For the same reason, GSS is redefined as "Design inflow to surface area ratio for the final settler, gpd/sq ft." In this case the inflow is from the aerator and includes the return activated sludge as well as the overflow from the primary settler.

Definitional corrections for the thickener and the elutriation tank have been accompanied by changes to expand the amount of information printed. For both the thickener and the elutriation tank, surface area is calculated both on the basis of the design inflow to surface area ratio and on the basis of the design solids loading rate. For each process the greater of the two surface area values is used as the required surface area. Since there is some uncertainty about the proper values for the design criteria, loading rates for both solids and inflow are of interest. The elutriation and thickener subroutines have been modified to include calculation of loading rates on the basis of solids and inflow. One of the two loading rates will always be at the design limit. To avoid confusion between design and computed loading rates separate symbols were defined.

D. Adaptation to Specific Situations

The decision matrix includes enough variables to permit simulation of a rather wide range of situations. Additional adaptations can be made through modification of subroutines. Coefficients based on

average conditions can be replaced with coefficients based on specific conditions. Some parameters which are normally computed within the program can be set at predetermined levels. However, the latter type of modification must be made with caution and results should be analyzed carefully. The volume of output streams and of activated sludge returned to the aerator should always be computed within the program.

IV. Estimation of Long-Run Marginal Costs and Calculation of Component Prices

Estimation of long-run marginal costs for each component is accomplished with the following procedure. A simulation with a design model is made to estimate both capital cost and operating and maintenance cost for the wastewater stream to be treated. This base simulation is compared to hypothetical simulations each with an increase in the quantity of one component. (Adjustments to account for related characteristics are discussed in the following subsection.) Marginal costs are estimated by dividing changes in costs by changes in component quantities.

The following example is for a treatment system composed of:

1. preliminary treatment
2. primary settler
3. aerator-final settler
4. thickener
5. anaerobic digester
6. elutriation tank
7. vacuum filter
8. chlorination tank.

For this treatment system important cost determinants appear to be:

1.	volume	(Q)
2.	solid BOD	(SBOD)
3.	total suspended solids	(TSS)
4.	dissolved BOD	(DBOD).

There are some difficulties in estimating marginal costs for SBOD and for TSS. Biodegradable suspended solids are included in both parameters. Double counting would overprice SBOD and TSS and would underprice Q and DBOD. A portion of this bias is removed by estimating marginal costs for TSS from cost changes resulting from estimated increases in nonbiodegradable suspended solids. A portion of this bias

remains due to the fact that the transformation of marginal costs to prices and the calculation of charges are based on TSS rather than nonbiodegradable suspended solids. The remaining bias could be removed through measurement of nonbiodegradable suspended solids for major sources of industrial wastewater and for the stream entering the treatment plant. However, TSS is easily and commonly measured and will be used in transforming marginal costs to prices.

A. Specification of Hypothetical Streams

Base and hypothetical stream vectors for a component pricing example are shown in Table 3. The base is a 10 mgd flow with contents reported as typical by Smith [25], pp. 7-9.

In the hypothetical stream with increased water, contaminant concentrations, except DFM and ALK, were reduced to maintain the amount of each contaminant at the same quantity as in the base stream. DFM and ALK would probably not be reduced significantly by additions of water from the same source supplying water to waste dischargers. The concentration of each of the remaining thirteen contaminants was divided by 1.1 to offset the ten percent increase in volume.

The concentration of each contaminant to be priced is closely related to the concentration of at least one other contaminant. Adjustment of the concentration of these related contaminants is necessary for a realistic simulation.

An increase in DBOD should be accompanied by an increase in DOC. Since only the biodegradable portion of DOC should be increased, a ten

TABLE 3. Base and Hypothetical Stream Vectors for Component Pricing

SMATX		Base Stream	Hypothetical Streams			
Number	Symbol		Increased Water	Increased DBOD	Increased SBOD	Increased NBSS*
2	Q	10.	11.	10.	10.	10.
3	SOC	105.	95.4	105.	112.5	111.
4	SNBC	30.	27.3	30.	30.	36.
5	SON	10.	9.1	10.	10.	10.
6	SOP	2.	1.8	2.	2.	2.
7	SFM	30.	27.3	30.	30.	36.
8	SBOD	140.2	127.4	140.2	154.2	140.2
9	VSS	223.6	203.3	223.6	239.6	236.4
10	TSS	253.6	230.5	253.6	269.6	272.4
11	DOC	43.	39.1	46.2	43.	43.
12	DNBC	11.	10.1	11.	11.	11.
13	DN	19.1	17.4	19.1	19.1	19.1
14	DP	4.	3.6	4.	4.	4.
15	DFM	500.	500.	500.	500.	500.
16	ALK	250.	250.	250.	250.	250.
17	DBOD	59.84	54.4	65.82	59.84	59.84

* NBSS = nonbiodegradable suspended solids

percent increase in DBOD is accompanied by an increase in DOC equal to .1(DOC-DNBC).

An increase in SBOD requires an accompanying adjustment of SOC, VSS, and TSS. As in the case of DOC adjustment, a ten percent in SBOD is accompanied by an increase in SOC equal to .1(SOC-SNBC). The adjustment of VSS to accompany a ten percent increase in SBOD is estimated by the following equation:

$$\Delta VSS = .10(VSS)(SOC-SNBC)/SOC \qquad \text{(Eq. 7)}$$

For the simulation with a ten percent increase in SBOD, TSS was increased by an amount equal to ΔVSS.

A hypothetical stream with an increase in nonbiodegradable suspended solids (NBSS) is used in estimating marginal costs for TSS. NBSS is estimated by the following equation:

$$NBSS = SFM + VSS\ (SNBC/SOC) \qquad \text{(Eq. 8)}$$

Since NBSS is somewhat less than half of TSS a twenty percent increase in NBSS is used in estimating marginal costs. In this example a twenty percent increase in NBSS results in a seven percent increase in TSS. The hypothetical stream for estimating marginal costs for TSS is derived from the base stream through the following changes in SFM, VSS, TSS, SNBC, and SOC:

$$\Delta SFM = .20(SFM) \qquad \text{(Eq. 9)}$$

$$\Delta VSS = .20(VSS)(SNBC/SOC) \qquad \text{(Eq. 10)}$$

$$\Delta TSS = \Delta SFM + \Delta VSS \qquad \text{(Eq. 11.)}$$

$$\Delta SNBC = .20(SNBC) \qquad \text{(Eq. 12)}$$

$$\Delta SOC = \Delta SNBC \qquad \text{(Eq. 13)}$$

B. Calculation of Marginal Costs and Component Prices

Cost estimates for the base stream and for each hypothetical stream are made with the same decision matrix. The program has the capacity to make successive, independent simulations for up to ten different streams with the same decision matrix. Computer and printer time can be saved by using this multiple entry feature.

The decision matrix for this pricing example is shown in Table 4.

The amount of capital cost to be recovered from current users (C_c) is $3,024,070 in the example shown in Table 5. This amount is the total capital cost estimated for the base stream. In an actual use of the component pricing system C_c would be the actual amount to be allocated. The relationship between C_c and actual capital cost would depend on the amount of excess capacity, local pricing objectives, and the specific interpretation of federal cost recovery requirements.

In the pricing example, daily operating and maintenance cost (C_o in Table 6) is $511.86. This is the simulation estimate of daily operating and maintenance cost for the base stream. In an actual application of the component pricing system C_o would be the actual amount of operating and maintenance cost.

Component prices (P_{ci} and P_{oi}) in Tables 5 and 6 are presented only to illustrate the method. The marginal cost estimates (MC_{ci} and MC_{oi}) could be used in setting prices if wastewater and treatment plant

TABLE 4. Decision Matrix for Component Pricing Example

Preliminary Treatment

DMATX	Program Symbol	Value
(1,N)	DCAP*	--
(16,N)	ECF	1.0

Primary Settler

DMATX	Program Symbol	Value
(1,N)	FRPS	.50
(2,N)	URPS	100.
(3,N)	APS*	--
(16,N)	ECF	2.0

Aerator-Final Settler

DMATX	Program Symbol	Value
(1,N)	BOD of OS1	15.
(2,N)	XMLSS	2000.
(3,N)	DECG	20.
(4,N)	CAER20	1.0
(5,N)	DO	1.0
(6,N)	AERR20	.075
(7,N)	URSS	8.0
(8,N)	GSS	1310.
(9,N)	VAER*	--
(10,N)	AFS*	--
(11,N)	BSIZEI*	--
(12,N)	ASRPSI*	--
(13,N)	ECF (F.S.)	2.0
(14,N)	ECF (S.R.P.)	2.0
(15,N)	ECF (B.)	1.5
(16,N)	ECF (A.)	1.2

Chlorination Tank

DMATX4	Program Symbol	Value
(1,N)	DCL2	8.0
(2,N)	TCL2	30.
(3,N)	VCL2*	--
(4,N)	DACL2	365.
(16,N)	ECF	1.0

Thickener

DMATX	Program Symbol	Value
(1,N)	TRR	.95
(2,N)	TSS of OS1	60000.
(3,N)	GTHD	750.
(4,N)	GSTHD	9.0
(5,N)	ATHM*	--
(16,N)	ECF	1.5

Digester

DMATX	Program Symbol	Value
(1,N)	TD	30.
(2,N)	TDIG	33.
(3,N)	VDIG*	--
(16,N)	ECF	2.0

Elutriation Tank

DMATX	Program Symbol	Value
(1,N)	ERR	.76
(2,N)	TSS of OS1	60000.
(3,N)	WRE	3.0
(4,N)	GED	800.
(5,N)	GESD	9.0
(6,N)	AE*	--
(16,N)	ECF	1.5

Vacuum Filter

DMATX	Program Symbol	Value
(1,N)	VFL	10.
(2,N)	HVF	36.7
(3,N)	TSS	200.
(4,N)	AVF*	--
(5,N)	LHVF	1.4
(16,N)	ECF	1.0

Cost Constants

DMATX	Program Symbol	Value
(1,20)	CKWH	.0176
(2,20)	CCI	1.431
(3,20)	AF	.06744
(4,20)	CTRP	.10
(5,20)	CTGO	.15
(6,20)	CLAND	0.0
(7,20)	CFECL3	.08
(8,20)	CCL2	.075
(9,20)	CLI	1.318
(10,20)	WRVF	3.69
(11,20)	RVF	.005

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*Denotes parameters which are predetermined only in the management program

TABLE 5. Calculation of Component Capacity Prices

Component	Base X_i	ΔX_i	ΔC_{ci}	MC_{ci}	P_{ci}
	(thou gal)	(thou gal)	($)	($/thou gal)	($/thou gal)
Water	10,000	1,000	64,570	65.	52.
	(lb)	(lb)	($)	($/lb)	($/lb)
Dissolved BOD	4,994.	499.	51,910.	104.	84.
Solid BOD	11,700.	1,170.	88,920.	76.	61.
Total SS	21,164.	1,569.	125,620.	80.	65.

$$MC_{ci} = \Delta C_{ci}/\Delta X_i$$

$$P_{ci} = M_{ci}\ (C_c/\ \sum_{i=1}^{4} X_i \cdot MC_{ci})$$

where

X_i = daily quantity of the "i"th component

ΔX_i = a hypothetical increase in X_i

ΔC_{ci} = change in capital cost expected to result from ΔX_i

MC_{ci} = marginal capital cost for the "i"th component

P_{ci} = capacity price for the "i"th component

C_c = capital cost to be recovered from current users = $3,024,070.

TABLE 6. Calculation of Component Service Prices

Component	Base X_i	ΔX_i	ΔC_{oi}	MC_{oi}	P_{oi}
	(thou gal)	(thou gal)	($)	($/thou gal)	($/thou gal)
Water	10,000.	1,000.	11.12	.0111	.0113
	(lb)	(lb)	($)	($/lb)	($/lb)
Dissolved BOD	4,994.	499.	10.31	.0206	.0210
Solid BOD	11,700.	1,170.	14.49	.0124	.0126
Total SS	21,164.	1,569.	10.06	.0067	.0068

$$MC_{oi} = \Delta C_{oi} / \Delta X_i$$

$$P_{oi} = MC_{oi} \; (C_o / \sum_{i=1}^{4} X_i \cdot MC_{oi})$$

where:

X_i = daily quantity of the "i"th component

ΔX_i = a hypothetical increase in X_i

ΔC_{oi} = change in daily operating and maintenance cost expected to result from ΔX_i

MC_{oi} = marginal operating and maintenance cost for the "i"th component

P_{oi} = service price for the "i"th component

C_o = average daily operating and maintenance cost = $511.86.

characteristics are similar to those in the example. Since marginal cost estimates are used only to establish the relative distribution of costs, differences in plant size and in the general price level are of limited significance. Actual rather than simulation values must be used for X_i, C_c, and C_o. Marginal cost estimates in Tables 5 and 6 should be used with extreme caution. If data and computer facilities are available, MC_{ci} and MC_{oi} should be estimated for each application of the component pricing system.

V. Estimation of Short-Run Marginal Costs

Short-run marginal costs establish a floor below which prices should never be set. Lower prices would always fail to encourage an efficient combination of waste control at the source and final treatment by the municipality. Prices should be based on short-run marginal cost only when excess capacity is available and is expected to be available for at least several years.

Federal cost recovery requirements for facilities with federal grants approved July 1, 1970, through April 30, 1973, do not rule out the possibility of short-run marginal cost pricing to individual dischargers. The requirements for that period apply only to industrial users as a class (U.S.D.I. [29], p. 1). Various systems of charges and taxes are acceptable if industrial users as a group pay an amount at least equal to the industrial share of total operating and maintenance cost and the industrial portion of the local share of capital cost.

A simulation model for estimating short-run marginal costs must not permit equipment capacities and sizes to vary with changes in the influent stream. Models with fixed plant size will be referred to as management models. In a management model the size of installed facilities for each unit process is included in the decision matrix. Detention times, loading rates, stream characteristics between unit processes, and operating and maintenance costs are estimated for influent wastewater streams of specified volume and content. Major characteristics of a management model derived from the design model in Eilers and Smith [5] are presented in the following section of this report.

The procedure for estimating short-run marginal costs with a management model is similar to the procedure previously presented for estimating long-run marginal costs with a design model. The process of defining hypothetical streams and the method of calculating the simulation estimate of marginal costs are the same as with the design model. Similarity of the two procedures ceases at this point. Pricing to recover only short-run marginal costs does not involve an allocation of actual costs. However, simulation estimates of short-run marginal costs should be related to actual costs through proportional adjustments.

Component marginal costs estimated with a management model can be adjusted to actual operating conditions and costs with the following equations:

$$MC_{ai} = MC_{si}(C_a/C_s) \qquad \text{(Eq. 14)}$$

where

MC_{ai} = adjusted estimate of marginal cost for the "i"th component.

MC_{si} = simulation estimate of marginal cost for the "i"th component.

C_a = actual operating and maintenance cost per day.

C_s = simulation estimate of daily operating and maintenance cost.

The adjusted estimates of component marginal costs can be used as component prices if the pricing objective is to recover only short-run marginal costs.

Content-related charges to recover short-run marginal cost from a few dischargers can be estimated directly rather than through hypothetical streams and component marginal costs. Daily operating and maintenance cost with and without each major source of industrial wastewater can be estimated with a management model. Simulation cost estimates can be adjusted to actual cost conditions in the following manner:

$$\Delta C_{ak} = \Delta C_{sk}(C_a/C_s) \qquad \text{(Eq. 15)}$$

where:

ΔC_{ak} = adjusted estimate of the increase in cost resulting from treatment of wastewater from the "k"th discharger.

ΔC_{sk} = simulation estimate of the increase in cost resulting from treatment of wastewater from the "k"th discharger.

C_a = actual operating and maintenance cost per day.

C_s = simulation estimate of daily operating and maintenance cost.

While recommended only for treatment plants with a large amount of excess capacity, the short-run marginal cost method of pricing may serve an additional purpose. Many municipalities still finance wastewater treatment from general revenues without even a charge based on volume. A minimum charge for volume and content would be a step toward lower treatment cost, less water use, and less pollution.

VI. A Management Model

In practice, sewage treatment plants often receive flows substantially different from the design capacity. In growing communities newly constructed plants typically begin operation with flows no more than half of design capacity and are often overloaded before expansion or replacement. A model which can simulate the operation of a specific treatment plant provides a convenient method for estimating the impact of a particular industrial wastewater flow on treatment effectiveness and costs.

The management model discussed in this report was derived from the Eilers and Smith [5] design model after modifications presented in Section III and Appendix B. The decision matrix was expanded to include the size of installed facilities. Given treatment plant and wastewater characteristics the program estimates detention times, loading rates, stream characteristics between processes, and operating and maintenance costs.

The management program was derived from the design program with no change in basic relationships. The SPLIT, MIX, and COST subroutines and the MAIN are exactly the same as in the design program.

The preliminary treatment subroutine in the management program is the same as in the design program except that capital cost is based on design capacity (DCAP) rather than incoming flow.

In the design program detention times in the digester and the chlorination tank are predetermined, and volumes are calculated on the basis of flow. The relationship is simply reversed in the management program.

The design program does not relate either volume or solids loading rate to treatment efficiency for either the thickener or the elutriation tank. Thus, conversion from design to management is simple. The surface area of each tank is read from the decision matrix and sizing equations are removed.

In the design program the number of hours per week of vacuum filter operation (HVF) is predetermined; the size of the vacuum filter (AVF) varies in proportion to the volume per week of filtrate. In the management program AVF is fixed, and HVF depends on the volume per week of filtrate. HVF is found through a rearrangement of the statement which calculates AVF in the design program.

Conversion of the primary settler and aerator-final settler subroutines from design to management was somewhat complex. In both of these subroutines treatment effectiveness is functionally related to facility size through several equations. Explanation of the conversion procedures are presented in Appendix C.

Since the management program was derived from the design program, the accuracy of the conversion could be verified with comparative simulations. Facility sizes generated by a design simulation with no allowance for excess capacity were used as input data for a management simulation. The comparative simulations produced final and interprocess streams with characteristics differing by no more than the specified iteration tolerance.

VII. Comparison of Simulation Results with an Operating Plant

The design program can be conveniently compared to an operating plant only if the plant is operating at or near design capacity. In the management program treatment effectiveness is based on flow rates in relation to the actual size of facilities. Since the same basic relationships and parameters are used in both programs, the management version can be used for checking the accuracy of both programs.

An activated sludge plant in Branford, Connecticut, was selected for an empirical check on coefficients in the simulation models. The Branford plant with a capacity of 1.5 mgd was operating at 85 to 90 percent of capacity without excessive groundwater infiltration and with no significant amount of industrial wastewater. The plant was achieving expected efficiencies in removal of BOD and suspended solids. Thus, the Branford plant seemed to be an ideal base for checking the programs.

The decision matrix for simulating the Branford treatment plant (Table 7) is not an exact description of the plant. The Branford plant has no elutriation tank. The digester volume in Table 7 is the total for two digesters, which are used in series with no mixing in the secondary digester. The plant superintendent estimates that an average of 5,000 gallons per day of sludge is pumped from the thickener to the digesters. Sludge withdrawals average approximately 2,500 gallons per day, leaving an equal volume to overflow to the primary settler. Both raw and digested sludge have solids concentrations of approximately 50,000 mg/l. Since half of the liquid overflows with no significant amount of solids the digestion process appears to achieve a fifty

percent reduction in total solids. The digester subroutine in the simulation model has no provision for separating outflow into sludge and supernatant. However, this separation can be accomplished by assuming the existence of an elutriation tank with the wash water ratio (WRE) set at zero.

Simulation results for Branford are very encouraging. Computed and actual stream vectors for the primary and final effluents are shown in Table 8. The simulation estimate of operating and maintenance cost seems reasonable in relation to actual cost. The 1970-71 budget for the treatment plant, sewer maintenance, and pumping stations totaled \$72,576. A simulation with prices adjusted to levels prevailing in January 1971 estimated operating and maintenance cost for the treatment plant at \$55,644 per year. Estimated capital cost, adjusted to the date of construction, was \$618,560, with no allowance for land cost. Actual capital cost was \$992,920, excluding land cost and engineering fees.

Simulation models provide a fast and convenient method of generating cost information for pricing industrial wastewater treatment services. However, simulation models should be used with caution. Results are no more reliable than the facts and assumptions in the models. In this regard simulation is no different from conventional design and budgeting procedures. Additional comparison of simulation results with operating plants is recommended.

TABLE 7. Decision Matrix for the Branford Sewage Treatment Plant

Preliminary Treatment

DMATX	Program Symbol	Value
(1,N)	DCAP	1.5
(16,N)	ECF	1.0

Primary Settler

DMATX	Program Symbol	Value
(1,N)	FRPS	*
(2,N)	URPS	61.
(3,N)	APS	1.126
(16,N)	ECF	1.0

Aerator-Final Settler

DMATX	Program Symbol	Value
(1,N)	BOD of OS1	*
(2,N)	XMLSS	2000.
(3,N)	DEGC	20.
(4,N)	CAER20	1.0
(5,N)	DO	1.0
(6,N)	AERR20	.05
(7,N)	URSS	8.0
(8,N)	GSS	*
(9,N)	VAER	.397
(10,N)	AFS	1.849
(11,N)	BSIZEI	1111.
(12,N)	ASRPSI	1.0
(13,N)	ECF (F.S.)	1.0
(14,N)	ECF (S.R.P.)	1.0
(15,N)	ECF (B.)	1.0
(16,N)	ECF (A.)	1.0

Chlorination Tank

DMATX4	Program Symbol	Value
(1,N)	DCL2	6.0
(2,N)	TCL2	*
(3,N)	VCL2	.0408
(4,N)	DACL2	153.
(16,N)	ECF	1.0

Thickener

DMATX	Program Symbol	Value
(1,N)	TRR	.95
(2,N)	TSS of OS1	50000.
(3,N)	GTHD	*
(4,N)	GSTHD	*
(5,N)	ATHM	267.
(16,N)	ECF	1.0

Digester

DMATX	Program Symbol	Value
(1,N)	TD	*
(2,N)	TDIG	33.
(3,N)	VDIG	75.72
(16,N)	ECF	1.0

Elutriation Tank

DMATX	Program Symbol	Value
(1,N)	ERR	.76
(2,N)	TSS of OS1	50000.
(3,N)	WRE	0.0
(4,N)	GED	*
(5,N)	GESD	*
(6,N)	AE	267.
(16,N)	ECF	1.0

Vacuum Filter

DMATX	Program Symbol	Value
(1,N)	VFL	4.9
(2,N)	HVF	*
(3,N)	TSS	200.
(4,N)	AVF	150.
(5,N)	LHVF	1.4
(16,N)	ECF	1.0

Cost Constants

DMATX	Program Symbol	Value
(1,20)	CKWH	.0176
(2,20)	CCI	1.13
(3,20)	AF	.06744
(4,20)	CTRP	.1
(5,20)	CTGO	.15
(6,20)	CLAND	0.0
(7,20)	CFECL3	.08
(8,20)	CCL2	.075
(9,20)	CLI	1.318
(10,20)	WRVF	3.69
(11,20)	RVF	.005

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*Denotes values which are computed in the management program.

TABLE 8. Actual and Computed Stream Vectors for the Branford Sewage Treatment Plant

Parameters		Raw sewage	Primary effluent computed	Primary effluent actual	Final effluent computed	Final effluent actual
1.	Q	1.27	1.280	1.27	1.27	1.27
2.	SOC	74.	36.	--	4.1	--
3.	SNBC	27.	13.	--	1.6	--
4.	SON	9.	4.4	6.	0.7	0.4
5.	SOP	0.5	0.24	0.13	.04	0
6.	SFM	65.	31.	28.	2.7	3.
7.	SBOD	142.	67.	73.	5.1	0
8.	VSS	175.	84.	62.	9.8	3.
9.	TSS	240.	130.	90.	17.4	6.
10.	DOC	50.	50.	--	29.6	--
11.	DNBC	27.	27.	--	27.	--
12.	DN	28.	32.	31.	29.2	20.
13.	DP	17.	17.	12.	17.2	11.8
14.	DFM	215.	215.	280.	215.	270.
15.	ALK	100.	116.	95.	104.	102.
16.	DBOD	90.	89.	46.	4.8	7.

Samples drawn on 5/21/71

Appendix A

Program Symbols and Definitions

Computer Symbols	Definitions and Comments
ACOST(J,I)	Amortization cost for the Jth process, cents per 100 gallons
AE	Surface area of the elutriation tank, sq ft
AEFF	Efficiency of diffusers in aerator corrected for water temperature and dissolved oxygen deficit
AEFF20	Efficiency of diffusers in aerator at zero dissolved oxygen at 20°C (see: Smith [25], p. 23)
AF	Amortization factor
AFS	Surface area of the final settler, thousands of sq ft
ARCFD	Air requirements for the aerator, standard cu ft/day
ALK	Concentration of alkalinity as $CaCO_3$, mg/l
APS	Surface area of the primary settler, thousands of sq ft
ASMAX	Current maximum value of MLASS, mg/l mass.
ASMIN	Current minimum value for MLASS, mg/l mass.
ASRPS	Required size of activated sludge return pumps, million gallons per day
ASRPSI	Installed size of activated sludge return pumps, million gallons per day
ATH1	Surface area of the thickener required to meet the design inflow rate, sq ft
ATH2	Surface area of the thickener required to meet the design solids loading rate, sq ft
ATHM	Surface area of the thickener, sq ft
AVF	Area of the vacuum filter, sq ft

Computer Symbols	Definitions and Comments
BOD	Input value for the demand value of 5-day BOD in the final effluent from the aeration or trickling filter process, mg/l
BOD2	Influent 5-day BOD to the aeration process, mg/l
BSIZE	Required size of blower for supplying air to the aerator, cubic feet per minute
BSIZE	Installed size of blower for supplying air to the aerator, cubic feet per minute
C1DIG	Rate constant for digester (see: Smith [25], p. 28)
C2DIG	Rate constant for digester (see: Smith [25], p. 28)
CAER	Rate constant for sizing the aerator corrected for water temperature (see: Smith [25], p. 11)
CAER20	Rate constant used for sizing the aerator when water temperature is 20°C (see: Smith [25], p. 11)
CAIRP	Cost of electrical power for operating blowers, dollars per year
CCHEM	Cost of ferric chloride, dollars per year
CCI	Capital cost index to account for the variation of construction cost with time
CCL2	Cost of chlorine, dollars per pound
CCOST(J,I)	Capital cost for the Jth process, thousands of dollars
CCR	Capital cost ratio: CCR = 1. + CENG + CTRP + CLAND + CTGO
CEDR	Rate at which active solids are destroyed by natural causes in the aerator, fraction per day <u>mass</u>
CENG	Cost of engineering services expressed as a fraction of the total capital cost
CFECL3	Cost of ferric chloride, dollars per pound

Computer Symbols	Definitions and Comments
CFPGL	Air requirement for the aerator, standard cu ft/gallon of sewage entering the system
CH4	Standard cubic feet of methane produced in the digester each day, standard cu ft/day methane
CKWH	Cost of electrical power, dollars per kilowatt-hour
CLAND	Cost of land expressed as a fraction of the total capital cost
CLI	Cost of labor index: the ratio of current hourly wages to $2.80, the average wage rate for nonsupervisory water, steam and sanitary works in June 1967
CNIT	Rate constant used in the nitrification calculation (see: Smith [25], pp. 18-21)
CO2	Standard cubic feet of carbon dioxide produced in the digester each day, standard cu ft/day CO_2
COSTO(J,I)	Operating and maintenance cost for the Jth process, cents per 1,000 gallons
CTGO	Cost of contingencies and omissions expressed as a fraction of the total capital cost
CTRP	Contractor's profit expressed as a fraction of the total capital cost
DACL2	Length of chlorination season, days per year
DBOD	Dissolved BOD concentration, mg/l
DCAP	Design capacity of plant, millions of gallons per day
DCL2	Dose of chlorine, mg/l
DEGC	Water temperature in aerator, degrees centrigrade
DFM	Dissolved inorganic species, mg/l mass
DMATX(J,I)	Decision matrix vector for the Jth process
DN	Dissolved nitrogen concentration, mg/l nitrogen

Computer Symbols	Definitions and Comments
DNBC	Dissolved non-biodegradable carbon concentration, mg/l carbon
DO	Concentration of dissolved oxygen in the aerator, mg/l oxygen
DOC	Dissolved organic carbon concentration, mg/l carbon
DOPER	Daily operating and maintenance cost for the entire system, dollars per day
DOSAT	Saturation value for dissolved oxygen in the aerator at one-half the water depth, mg/l oxygen
DP	Dissolved phosphorus concentration, mg/l phosphorus
ECF	Excess capacity factor
EPS	Iteration tolerance for recycling systems
ERR	Solids recovery ratio for elutriation
FECL3	Concentration of ferric chloride used for sludge conditioning, mg/l $FeCL_3$
FOOD	5-day BOD synthesized to active solids in the aerator each day, mg/l oxygen
FRPS	Fraction of solids entering the primary settler which is removed from the main stream and sent to the thickener
GE	Computed inflow to surface aera ratio for elutriation, gpd/sq ft
GED	Design inflow to surface area ratio for elutriation, gpd/sq ft
GES	Computed solids loading rate for elutriation, lb/day/sq ft
GESD	Design solids loading rate for elutriation, lb/day/sq ft
GPS	Computed inflow to surface area ratio for the primary settler, gpd/sq ft

Computer Symbols	Definitions and Comments
GSS	Design inflow to surface area ratio for the final settler, gpd/sq ft
GSTHD	Design solids loading rate for the thickener, lb/day/sq ft
GTH	Computed inflow to surface area ratio for the thickener, gpd/sq ft
GTHD	Design inflow to surface area ratio for the thickener, gpd/sq ft
HVF	Hours of vacuum filter operation, hours per week
III	Integer input to the program thaj controlls the recycling in the system
IPROC	Integer input to the program that is used to identify the type of process
IS1	Input stream number 1 to a process
IS2	Input stream number 2 to a process
K	Integer input to the program that controls the recycling in the system
LHVF	Labor hours per hour of vacuum filter operation, ratio

MLSS, MLBSS, MLDSS, MLISS, MLNBSS, AND MLSS are respectively the equivalents of XMLAS, MXLBSS, XMLDSS, XMLIS, XMLNB, AND XMLSS.

N	Process number assigned to a particular process in the system by the program user
NAME(I)	Integer input vector that is used to print process names as part of the final output
NCASE	Integer input to the program that specifies the number of cases to be executed by the program
NIS	Integer input to the program that specifies the number of influent and guess streams to be read by the program

Computer Symbols	Definitions and Comments
NN(I)	Integer inputs to the program that specify the stream numbers of the influent and guess streams to be read by the program
OMATX(J,I)	Output matrix vector for the Jth process
OS1	Output stream number 1 from a process
OS2	Output stream number 2 from a process
Q	Volume of flow, mgd
RTURN	Sludge return ratio for the aerator
RVF	Ratio of vacuum filter annual repair cost to the capital cost of the vacuum filter, ratio
SBOD	Solid 5-day BOD concentration, mg/l oxygen
SFM	Solid inorganic matter concentration, mg/l mass
SMATX(I,J)	Stream matrix vector for the Jth stream
SNBC	Solid non-biodegradable carbon concentration, mg/l carbon
SOC	Solid carbon concentration, mg/l carbon
SON	Solid nitrogen concentration, mg/l nitrogen
SOP	Solid phosphorus concentration, mg/l phosphorus
TA	Time in the aerator, days
TAMM	Total amortization cost for the entire system, cents per 1,000 gallons
TCAP	Total capital cost for the entire system, thousands of dollars
TCL2	Chlorine contact time, minutes
TCOST(I,J)	Total treatment cost for the Ith process, cents per 1,000 gallons
TD	Digester detention time, days

Computer Symbols	Definitions and Comments
TDIG	Sludge temperature in digester, degrees centrigrade
TMATX(I,J)	Temporary stream matrix vector for the Jth stream that is used internally by the program for the recycling iteration
TOPER	Total operating and maintenance cost for the entire system, cents per 1,000 gallons
TOTAL	Total treatment cost for the entire system, cents per 1,000 gallons
TRR	Solids recovery ratio for the thickener
TSS	Total suspended solids concentration, mg/l mass
URPS	Ratio of solids concentration in OS2 (underflow stream) from the primary settler to the solids concentration in IS1 to the primary settler
URSS	Ratio of solids concentration in OS2 (underflow stream) from the aerator-final settler to the total solids concentration in the aerator
VAER	Volume of the aerator, millions of gallons
VCL2	Volume of the chlorinator, millions of gallons
VDIG	Volume of the digester, thousands of cu ft
VFL	Vacuum filter loading, gallons of filtrate per hour per sq ft
VNIT	Volume of the aerator required to achieve nitrification, millions of gallons
VSS	Volatile suspended solids concentration, mg/l mass
WP	Percentage of moisture in the filtered sludge
WRE	Wash water ratio for elutriation
WRVF	Wage rate of vacuum filter operators, dollars per hour
XMLAS (MLASS)	Concentration of active solids held in the aerator, mg/l mass

Computer Symbols	Definitions and Comments
XMLBS (MLBSS)	Concentration of unmetabolized biodegradable solids held in the aerator, mg/l mass
XMLDS (MLDSS)	Concentration of non-biodegradable solids in the aerator caused by destruction of active solids by natural causes, mg/l mass
XMLIS (MLISS)	Concentration of inert inorganic solids in the aerator caused by inorganic solids in the influent stream, mg/l mass
XMLNB (MLNBSS)	Concentration of non-biodegradable organic solids in the aerator, mg/l mass
XMLSS (MLSS)	Total concentration of solids in the aerator, mg/l mass
XRSS	Ratio of solids concentration of OS1 (overflow stream) from the aerator-final settler to the total solids concentration in the aerator

Appendix B

Vacuum Filter Operating and Maintenance Costs

Since most treatment processes must operate continuously, capacity of the process is a function of plant capacity and design. However, vacuum filter size and hours of operation are subject to a wide range of choice. In general, the smaller the plant the fewer hours per week of vacuum filter operation. Plants of 1 mgd design capacity usually have a vacuum filter of sufficient size to permit operation no more than sixteen to 24 hours per week. In plants of 50 mgd two or three shifts per day may be economical.

In Eilers and Smith [5] the fraction of the time the vacuum filters are operated (TVF) is a part of the decision matrix. The size of the vacuum filter and capital cost are directly related to TVF. However, neither capacity nor TVF is used in the estimation of operating and maintenance costs. Chemical costs are a linear function of sludge volume, while other operating and maintenance costs are estimated through an equation which provides for average cost to decline with increases in volume.

We needed a somewhat more detailed estimating procedure which would account directly for labor, electricity, and repair costs. Finding little published data on labor costs, we decided to collect information on vacuum filter operating costs through a survey of the 28 water pollution control plants in Connecticut which use vacuum filters. All 28 plant managers cooperated in the survey which included questions on

plant size, type of sludge, method of conditioning, operating characteristics, repair costs, and labor for operation and routine maintenance.

Survey data provided a basis for calculating the ratio of man-hours to machine operating hours for 24 vacuum filters. Man-hours included labor for starting, operation, shutdown, cleaning, and routine maintenance. The ratio of man-hours to operating hours ranged from 0.14 to 4.57; however, twelve of the 24 ratio values were between 1.0 and 1.5. No relationship between vacuum filter size and the ratio of man-hours to machine hours was indicated by the survey results. The ratio of labor hours to hours of vacuum filter operation (LHVF) enters the program as DMATX(5,N). A value of 1.4 is used in this report. The hourly wage rate for vacuum operators (WRVF) enters the program as DMATX(10,20).

The cost of electricity for operation of a vacuum filter is calculated from the number of operating hours and the surface area of the filter. Fair, Geyer and Okum [9], pp. 36-17, estimated power requirements of drum filters, including associated pneumatic and hydraulic equipment to be .125 hp per sq ft of filter area. Assuming an average of .746 kw per hp, electricity requirements are estimated to be .093 kw per sq ft of filter area.

The survey requested an estimate of the average annual repair costs (parts and labor by persons other than regular employees). The 28 plants surveyed had a total of 32 vacuum filters. Cost data were not available for eight filters. Zero average annual repair costs were

reported for sixteen filters. This seems unlikely and suggests that some respondents may have reported a lack of repair cost within the last year. One filter was reported to be currently under repair for an estimated cost of $400, the first major repair in eighteen years of service. Another one over 30 years old had been rebuilt recently at a cost of $4,685. Six reports of non-zero average annual repair costs ranged from $25 to $500 and averaged $230. The six reports of non-zero average cost were for filter sizes ranging from 50 to 200 sq ft and averaging 118 sq ft.

In considering possible relationships between repair costs and vacuum filter size a hypothesis that repair costs are proportional to capital cost seems logical. Survey results provide no basis for either supporting or rejecting this hypothesis. Repair costs are assumed to be in proportion to capital cost. The ratio of annual repair cost to capital cost (RVF) enters the program as DMATX(11,20). In this report RVF is set at .005. With this value the annual repair cost for a vacuum filter of 100 sq ft is estimated at $250, which can be compared to an estimate of $436 for a 200 sq ft filter.

In the design program the number of hours per week of vacuum filter operation (HVF) is a part of the decision matrix. The size of the filter (AVF) is calculated from the daily volume of filtrate removed from the sludge, SMATX(2,OS2). In the management program AVF is predetermined, and HVF depends on SMATX(2,OS2).

The entire discussion of annual vacuum filter operating cost, COSTO(N,1), can be summarized in the following statement:

```
COSTO(N,1) = (52.*(HVF*LHVF*WRVF+AVF*.093*CKWH)+CCHEM)/1000.
+DMATX(11,20)*CCOST(N,1)
```

Appendix C

Technical Notes on the Management Program

Conversion of the design program into a management form was complex enough to merit detailed explanation only for the primary settler and the aerator-final settler subroutines.

1. Primary Settler

In the design program primary settler operating characteristics are a function of two design parameters. The fraction of solids entering the primary settler which is removed from the main stream (FRPS) enters the program as DMATX(1,N). The ratio of solids concentration in the primary sludge to solids concentration in the incoming stream (URPS) enters the program as DMATX(2,N). The computed inflow rate to surface area ratio (GPS) is based on FRPS. Surface area of the primary settler (APS) is a function of GPS, SMATX(2,IS1) and ECF.

In the management program GPS is calculated from SMATX(2,IS1) and APS. FRPS is based on the following relationship from Smith [25], p. 10.

FRPS=.82*EXP(-GPS/2780). (Eq. 1)

The volume and content of sludge and overflow streams are calculated from the volume and content of the incoming stream in relation to FRPS and URPS.

An observed or estimated value for FRPS can be used instead of the calculated value. This can be accomplished by setting FRPS equal to DMATX(1,N) rather than calculating FRPS from GPS.

2. Aerator-final Settler

Volume of the aerator (VAER) and surface area of the final settler (AFS) are predetermined in the management model. Treatment efficiency is a function of the size of these facilities. These relationships are essentially the reverse of those in the design model.

In the design program VAER is based on SMATX(2,IS1) and time in the aerator (TA). TA is calculated by the statement:

```
TA=(BOD2-DMATX(1,N))/DMATX(1,N)*CAER*SA*24)
```
(Eq. 2)

where:

```
BOD2=SMATX(8,IS1)+SMATX(17,IS1)
CAER=.18*1.047**(DMATX(3,N)-28)
```

In the management program TA is found by the statement:

```
TA=VAER/SMATX(2,IS1)
```
(Eq. 3)

BOD of OS1 is a calculated value in the management program. BOD of OS1 is stored and used as DMATX(1,N) to facilitate comparison with the design program. With CAER and SA the same as in the design program and with TA available from statement (2), DMATX(1,N) can be found through a rearrangement of equation (2).

```
DMATX(1,N)=BOD2/(TA*CAER*SA*24.+1.)
```
(Eq. 4)

Once calculated the value for DMATX(1,N) is used in exactly the same way as in the design program.

The inflow to surface area ratio for the final settler (GSS) is DMATX(8,N) in the design program. In the management program GSS is calculated from the volume per day of inflow to the final settler (Q4)

and the surface area of the final settler (AFS). Q4 is the sum of SMATX(2,IS1) and the flow of secondary sludge returned to the aerator (Q6). Q6 depends on settling efficiency which is a function of GSS. Calculations are initiated by setting Q4 equal to 1.15*SMATX(2,IS1). DMATX(8,N) is approximated by the following statement:

DMATX(8,N)=1.15*SMATX(2,IS1)*1000./DMATX(10,N) (Eq. 5)

The approximated value for DMATX(8,N) is used until the point at which new values are estimated for Q6 and Q4. GSS is calculated on the basis of the new Q4. If the absolute value of the difference between DMATX(8,N) and GSS exceeds .03*GSS, DMATX(8,N) is set equal to GSS and calculations starting with the first use of DMATX(8,N) are repeated. The tolerance of three percent is arbitrary and could be reduced to increase precision.

The management model does not relate treatment effectiveness to the installed capacity of either air blowers or activated sludge return pumps. The respective capacity needs BSIZE and ASRPS are estimated and printed. The needed capacities must be compared with installed capacities when interpreting simulation results. In the management program installed capacities BSIZI and ASRPSI are used only for estimating capital cost.

Appendix D

References

[1] Anderson, Norval E. and Ben Sosewitz, "Chicago Industrial Waste Surcharge Ordinance," Journal of the Water Pollution Control Federation, Vol. 43, No. 8, (Aug. 1971), 1591-1599.

[2] Bubbis, N. S., "Industrial Waste Control in Metropolitan Winnipeg," Journal of the Water Pollution Control Federation, Vol. 35, No. 11, (Nov. 1963), pp. 1403-1413.

[3] Downing, Paul B., The Economics of Urban Sewage Disposal, (Frederick A. Praeger, New York, 1969), 195 pages.

[4] Eckstein, Otto, Water-Resource Development -- The Economics of Project Evaluation, "The Allocation of Joint Costs," Chapter IX, (1958), Harvard University Press, pp. 259-272.

[5] Eilers, Richard G. and Robert Smith, "Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," WP-20-9, U. S. Department of the Interior, FWQA, Cincinnati, (a preliminary copy), Nov. 1970.

[6] Eilers, Richard G., and Robert Smith, "User's Manual for Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," Environmental Protection Agency, Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio, March 1973. (The user's manual and the program on cards can be obtained from the National Technical Information Service.)

[7] Eilers, Richard G. and Robert Smith, "Wastewater Treatment Plant Cost Estimating Program," Environmental Protection Agency, Water Quality Office, Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio, 1971.

[8] Elliott, Ralph D. and James A. Seagraves, "The Effects of Sewer Surcharges on the Level of Industrial Wastes and the User of Water by Industry," Report No. 70, Water Resources Research Institute of the University of North Carolina, Raleigh, N.C., (Aug. 1972), 53 pages.

[9] Fair, G. M., J. C. Geyer, and D. A. Okun, Water and Wastewater Engineering, Volume 2, Water Purification and Wastewater Treatment and Disposal, (John Wiley & Sons, New York, 1968).

[10] Joint Committee of the American Society of Civil Engineers, et. al., "Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works," Ohio State Law Journal, Vol. 12, No. 2, (Spring 1951), pp. 151-276.

[11] Maystre, Yves and John C. Geyer, "Charges for Treating Industrial Wastewater in Municipal Plants," Journal of the Water Pollution Control Federation, Vol. 42, No. 7, (July 1970), pp. 1278-1291.

[12] Michel, Robert L., "Costs and Manpower for Municipal Wastewater Treatment Plant Operation and Maintenance, 1965-1968," Journal of the Water Pollution Control Federation, Vol. 42, No. 11, (Nov. 1970), pp. 1884-1908.

[13] Michel, Robert L., Albert L. Pelmoter, and Ralph C. Palange, "Operation and Maintenance of Municipal Waste Treatment Plants," Water Pollution Control Federation, Volume 41, No. 3, Part 1, (March 1969), pp. 335-354.

[14] Milliman, Jerome W., "Beneficiary Charges: Toward a Unified Theory," Public Prices for Public Products, ed. by Selma J. Mushkin, (The Urban Institute, Washington, D.C., 1972), Chap. 2, pp. 27-51.

[15] Olliffe, Joseph J., "Sewer Service Charges and Surcharges," Journal of the Water Pollution Control Federation, Vol. 35, No. 5, (May 1968), pp. 607-613.

[16] Patterson, W. L. and R. F. Banker, (Black & Veatch Consulting Engineers), "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities," U. S. Environmental Protection Agency, Waste Pollution Control Research Series, 17090 DAN 10/71, Oct. 1971, 251 pages.

[17] Public Works Engineers, "Industrial Waste Disposal Charges in Cities over 5,000 Population," American Public Works Association, Special Reports No. 18-S, (Jan. 1955), pp. 1-70.

[18] Quirk, Thomas P., "Economic Decision Marking for Participation in Joint Industrial-Municipal Treatment Systems," presented at a National Symposium on Costs of Water Pollution Control sponsored by the Research Triangle Universities and the U. S. Environmental Protection Agency, Hilton Innc, Raleigh, N.C., (April 6 & 7, 1972), 28 pages.

[19] Roderick, Ralph E., "Rate Structures for Industry," Journal of the Federation of Water Pollution Control, Vol. 34, No. 4, (April 1962), pp. 311-319.

[20] Schroefer, George J., "Determination of Fair Sewage Service Charges for Industrial Waste," Sewage and Industrial Wastes, Volume 23, No. 12, (Dec. 1951), pp. 1492-1515.

[21] Seagraves, J. A., "Surcharges for Industrial Wastes," A paper prepared for the 20th Southern Water Pollution Control Conference,

April 2, 1971, at Chapel Hill, North Carolina, (School of Public Health, University of North Carolina, Chapel Hill, N. C.), pp. 148-161.

[22] Shaw, Ray E. Jr., "Experience with Waste Ordinance and Surcharges at Greensboro, N.C.," Journal of the Water Pollution Control Federation, Vol. 42, No. 1, (Jan. 1970), pp. 45-50.

[23] Shuckrow, Alan J., Gaynor W. Dawson, and William F. Bonner, "Physical-Chemical Treatment of Combined and Municipal Sewage," U. S. Environmental Protection Agency, Environmental Protection Technology Series, EPA-R2-73-149, Feb. 1973, 178 pages.

[24] Smith, Robert, "Cost of Conventional and Advanced Treatment of Wastewater," U. S. Department of the Interior, F.W.P.C.A., Cincinnati, 1968.

[25] Smith, Robert, "Preliminary Design and Simulation of Conventional Wastewater Renovations Systems Using the Digital Computer," WP-20-9, U. S. Department of the Interior, F.W.P.C.A., Cincinnati, 1968.

[26] Smith, Robert, Richard G. Eilers, and Ella D. Hall, "Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems," WP-20-14, U. S. Department of the Interior, F.W.P.C.A., Cincinnati, 1968.

[27] Symons, James M., "Rate Formulas for Industrial Wastes," Water and Sewage Works, Vol. 101, No. 12, (Dec. 1954), pp. 540-545.

[28] Symons, George E. and Frederick W. Crane, "Special Sewer Service Charges for Industrial Wastes," Water Works and Sewage, Vol. 91, No. 3, (March 1944), pp. 114-115.

[29] U. S. Department of the Interior, Environmental Protection Agency, Office of Water Programs, "Federal Guidelines: Equitable Recovery of Industrial Waste Treatment Costs in Municipal Systems," Oct. 1971.

[30] U. S. Department of the Interior, Environmental Protection Agency, "Proposed Rules--User Charges and Industrial Cost Recovery," Federal Register, Vol. 38, No. 98, (Tues. May 22, 1973), pp. 13524-13526.

[31] U. S. Department of the Interior, Federal Water Pollution Control Administration, "The Cost of Clean Water and its Economic Impact," Sewarage Charges, Volume III, (January 10, 1968), 103 pages.

[32] U. S. Department of the Interior, Federal Water Pollution Control Administration, "Sewer and Sewage Treatment Plant Construction

Cost Index," Dec. 1967, 59 pages, (includes the method of computation and data for 1930-1967). National and regional cost indices are published monthly by the U.S.D.I., Environmental Protection Agency, Office of Water Programs, Division of Facilities Construction and Operation, Evaluation and Resource Control Branch.

[33] U. S. Department of Labor, Bureau of Labor Statistics, "Employment and Earnings," Vol. 14, No. 2, (Aug. 1967).

[34] U. S. Department of Labor, Bureau of Labor Statistics, "Employment and Earnings," Vol. 17, No. 9, (March 1971).

[35] U. S. Public Law 92-500, "Federal Water Pollution Control Act Amendments of 1972," 92nd Congress, S.2770, Oct. 18, 1972. "Title II -- Grants for Construction of Treatment Works," pp. 18-29 of PL 92-500.

[36] Unterberg, W., R. J. Sherwood, and G. R. Schneider, "Computerized Design and Cost Estimation for Multiple-Hearth Sludge Incinerators," U. S. Environmental Protection Agency, Water Pollution Control Research Series, 17070 EBP, July 1971, 165 pages.

[37] Walter, C. Richard, "Determination of Charges and Surcharges for Waste Treatment," Journal of the Water Pollution Control Federation, Vol. 35, No. 9, (Sept. 1963), pp. 1105-1111.

[38] Wright, Robert, "Sewage Service Charges," Agricultural & Mechanical College of Texas, Bulletin No. 98, (1947), 74 pages.