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A MATHEMATICAL MODEL FOR PREDICTING WATER DEMAND, WASTE WATER DISPOSAL AND COST OF WATER AND WASTE WATER TREATMENT SYSTEMS IN DEVELOPING COUNTRIES

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
in partial fulfillment of the requirements for the
degree of
DOCTOR OF PHILOSOPHY

BY
MICHAEL IKUA MUIGA

Norman, Oklahoma
1975

A MATHEMATICAL MODEL FOR PREDICTING WATER DEMAND, WASTE WATER DISPOSAL AND COST OF WATER AND WASTE WATER TREATMENT SYSTEMS IN DEVELOPING COUNTRIES

Approved by

Geo. W Reid

Jim F Harp

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Dissertation Committee

ABSTRACT

This study uses mathematical modelling techniques to develop predictive equations for water supply and waste water disposal models in developing countries utilizing socio-economic, environmental and technological indicators. Predictive equations are developed for three regions (Africa, Asia and Latin America) for water demand, waste water amounts, and construction, operation and maintenance costs of slow sand filter, rapid sand filter, stabilization lagoon, aerated lagoon, activated sludge and trickling filter processes. The primary objective of this study was to provide engineers, planners and appropriate public officials in developing countries with an innovative technique for more effective development of in-country water resources.

Data analysis indicated that water demand is a function of population, income and a technological indicator (percentage of households connected to water supply) while waste water disposal was found to be a function of water demand, and two technological indicators (percentage of homes connected to public sewerage systems and percentage of household systems). The predictive equations for water treatment costs were found to be a function of a technological indicator (percentage cost of imported water supply materials), population, and the design capacity. The variables which gave the best correlation for waste water treatment costs were population, design capacity and the percentage of imported waste water disposal materials.

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CHAPTER I

INTRODUCTION

General

The increasing rapid urbanization and industrialization in developing countries is causing an ever more rapid rise in water pollution and in many areas has resulted in major public health hazards as well as in general deterioration of water resources.

The lack of a safe and adequate supply of potable water is a serious public health problem and along with an inadequate water supply for domestic, industries and irrigation retard economic progress of many developing countries.

In 1963, the World Health Organization (WHO) made a study (1) of water supplies in seventy-five developing countries and established that only thirty thirty precent of the inhabitants in the urban areas have piped water supply at home and less than ten percent of the total population were supplied with drinking water.

Again in 1970 the World Health Organization estimated less than ten percent of the rural inhabitants of developing countries were supplied with safe water (2).

The United Nations Conference on Human Environment held in Stockholm in July, 1972 (3) proposed that the proportion of the rural dwellers served with safe water should be increased from ten percent by the end of the United Nations Second Development Decade in 1980. The proposal pointed out that the majority of the people in developing countries still use, for drinking and domestic needs, untreated and in many cases polluted water from rivers, lakes, and other water bodies.

Expanding the population, industrialization and urbanization makes it more difficult to separate waste water from potable water. Industries and irrigated lands while conferring benefit to the people of these countries contribute directly or indirectly to the pollution of rivers, lakes and coastal waters, and as a result cause grave concern to the public's health, economics and aesthetics.

It is therefore highly desirable that effective water supplies and sewage disposal should be of the highest priority in order to obtain the maximum environmental, economic and social improvement of the people of developing countries. The improvement in the public health with the accompanying effect of general well-being and increased productivity are probably the most significant effects of improved water supplies and sewage disposal.

To prove statistically the effectiveness of the water supplies and sewage disposal in improving the health and social conditions of the people of developing countries would require medical examinations and laboratory tests for a particular community for many years. Fortunately with the World Health Organization, such a case history has been documented.

> A simply water supply system was installed in the Zaina area in the Central Province of Kenya, with the help of UNICEF and WHO, in 1961. This system is fed by gravity from a high level surface source of good physical quality and provides chlorinated piped water to 588 farms and four villages which had a total population of 3850 in 1961. By 1965, the system had been extended to supply water to 5800 persons. Prior to 1961, the source of water for domestic use and the considerable farm animal population was the Zaina River which flows in a gorge about 100 metres below the inhabited areas. Carrying water up the steep incline consumed a major portion of the time of the women.
>
> When the new system was installed in 1961, a complete survey of the health and social aspects of the area was made under the supervision of the Provincial Medical Officer. The survey collected detailed information on the incidence of illnesses and infections, housing conditions and general living standards. A similar study was made of a contral area located eight kilometers from Zaina and comparable to it in practically all characteristics except that it lacked an adequate community water supply. In 1965, after four years of operation of the Zaina water system, a resurvey was made of both areas.
>
> It was found that the Zaina community was in better health than four years earlier in terms of both total number of illnesses and duration of each illness. Using the same basis of comparison, the people of the control area were found to be in poorer health. A dramatic difference was found in the stool examination of children for ascariasis, the most common helminth infection in the area. The 1965 survey showed a decline of the disease in Zaina and an increase in the control area giving the latter a prevalence of six times that found in Zaina. The studies also showed that Zaina had made a greater economic advance than the control area. The easy availability of piped water and the release of women's energies for better housekeeping, care of children and vegetable gardening, has been the principal factor in the improvement of both health and well-being in Zaina (4).

Since the socio-economic and cultural conditions in developing countries are different from the United States, it is not known if the criteria used in developed countries for design of water supply will be of use for developing countries. It is felt, from the experience*

---

*This has been established by Professor George W. Reid through global contact with the Lower Cost Methods of Water and Waste Water Treatment Research Project in Developing Countries.

available, that it will not be of use, so this study was aimed at developing methods to estimate demand and costs for construction and maintenance of water and waste water system in developing countries.

The models developed are based on the assumption that economic, labor and resource conditions in developing countries are generally different from those in the highly industrialized countries, and that the methodology of the previously developed format might not be useful. However, very little information is known about water demand and costs in these countries and all present data on demand and cost of water and waste water are mainly available for the United States and industrial countries (10, 12, 23, 39, 45, 46, etc.). These do not include some of the developing countries variables which may drastically affect the costs of water and waste water systems (see Table 1).

Problem

The problem of this study arises from the need of reliable cost estimates of construction, operation, and maintenance of the water and waste water systems in developing countries. Economic, labor and resource conditions in developing countries are generally so different from those of industrialized countries that current technical solutions may not be applicable to developing countries. Conditions characteristic of many of developing countries include:

1. Limited financial resources (particularly foreign currency).
2. Limited manufacturing capacity.
3. Limited skilled labor but ample unskilled labor.

TABLE 1

U. S. Waste Water Treatment Cost vs. Developing Countries Waste Water Treatment Cost

		United States[5]		India[6]	
Process	Population	Construction dollars/capita	Operation and Maintenance $ per yr capita	Construction dollars/capita	Operation and Maintenance $ per yr capita
Waste Stabilization Lagoon	5,000	16.56	0.50	2.09	0.32
	10,000	10.89	0.39	1.84	0.25
	50,000	4.11	0.20	1.29	0.17
	100,000	2.70	0.14	1.25	0.14
	200,000	1.78	0.11	1.17	0.12

Source: [5] Smith and Eiler, Cost to Consumer for Collection and Treatment of Waste Water, United States Environmental Protection Agency July, 1970.

[6] Low Cost Waste Treatment, Central Public Health Engineering, Nagpur, India, 1972

4. Scarce engineering personnel for constructing and maintenance of water and waste water systems.

The determination of waste water processes cost is essential to the analysis of alternative costs in the development, use and management of water resources. Various cost models are required in assisting selection of the least cost process which also satisfies discharge standards. Selecting an alternative which has only seventy-five percent efficiency may be of economical importance, but not technologically practical because the discharge standard may require up to ninety-five percent treatment level. Therefore, both the economic and technical aspects of the alternative should be studied. Generally most of the waste water mathematical models which have been developed do not account for future technological and cultural changes and as such they may not give better cost alternatives because:

1. Relative prices of inputs may have changed requiring a different mix input for producing a particular level of clean effluent at least cost.
2. Technological breakthroughs that can substancially reduce cost may have been introduced.
3. Existing plants are likely to be an inefficient combination of technologies embodied in a series of additions.
4. Existing plants are not likely to be cost minimizers because they are not operated for profit.
5. Construction and operation costs change with time as a result of change in human values and environmental factors, both physical and economical.

Developing countries have limited resources, and to provide for water, it is essential to have a reasonable construction cost. There is a definite lack of information on construction costs data in developing countries. Present cost data and estimation equations are mainly available for the United States (10, 12, 23, 39, 45, 46) and do not include the variables which may drastically change the costs of water and waste water systems when applied in developing countries.

Many authors (10, 12, 23, 39, 45, 46) in the United States do not take into account the availability of the materials, equipment, and technical personnel when developing cost equations. Very few consider the influence of the environmental parameters to the total costs. An intensive search of the literature failed to find a single citation which considered all the significant factors and variables needed to develop a mathematical model(s) for predicting water supply and waste water disposal in developing countries.

Objective

The purpose of this study was to develop mathematical predictive equations for estimating water demand, per capita waste water disposal, and costs of water and waste water treatment in developing countries.

More specifically the purpose of this study is:

1. To provide administrators, engineers, and public officials in developing countries concerned with particular future water and waste water systems with reliable information which would allow them to assess the general level of water supply and waste water disposal prior to a detailed engineering determination of an estimated water demand, waste water disposal, and costs.

2. To establish per capita demand of domestic water and waste water disposal using socio-economic and environmental parameters of developing countries.

3. To provide financial guidance in making preliminary decisions concerning future water and waste water systems in developing countries.

4. To provide cost, processes, and resources inter-relationship.

5. To establish costs using socio-economic and environmental parameters of developing countries.

In summary, four sub-models were developed as follows. Eventually these will be grouped together as shown in Figure 1.

1. Water Demand Model for Developing Countries
2. Waste Water Disposal Model for Developing Countries
3. Cost of Water Treatment in Developing Countries
4. Cost of Waste Water Treatment in Developing Countries

The basic technique used in this study is the stepwise multiple regression technique. Predictive equations for water demand, waste water disposal, costs of water and waste water processes in developing countries are developed by using available cost data from Africa, Asia and Latin America on slow sand filters, rapid sand filters, stabilization ponds, aerated lagoons, activated sludge and trickling filter.

The equations for estimating water demand, waste water discharge, water and waste water costs by processes are in the following form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \; . \; . \; . + B_iX_i \quad \text{for } i = 1,2,3 \; . \; . \; . \; 22 \qquad (1)$$

where Y = independent variable to be estimated, e.g., water demand

X_i = dependent variables used in making estimates (Figure 1)

B_i = regression coefficients

Need of the Study and Justification

The United Nations has estimated that the developing countries have an annual population increase of more than two percent. Table II is a summary of the United Nations population projection (7).

FIGURE 1: RELATIONSHIP BETWEEN WATER - WASTE WATER DEMAND MODELS AND WATER - WASTE WATER COST MODELS FOR DEVELOPING COUNTRIES

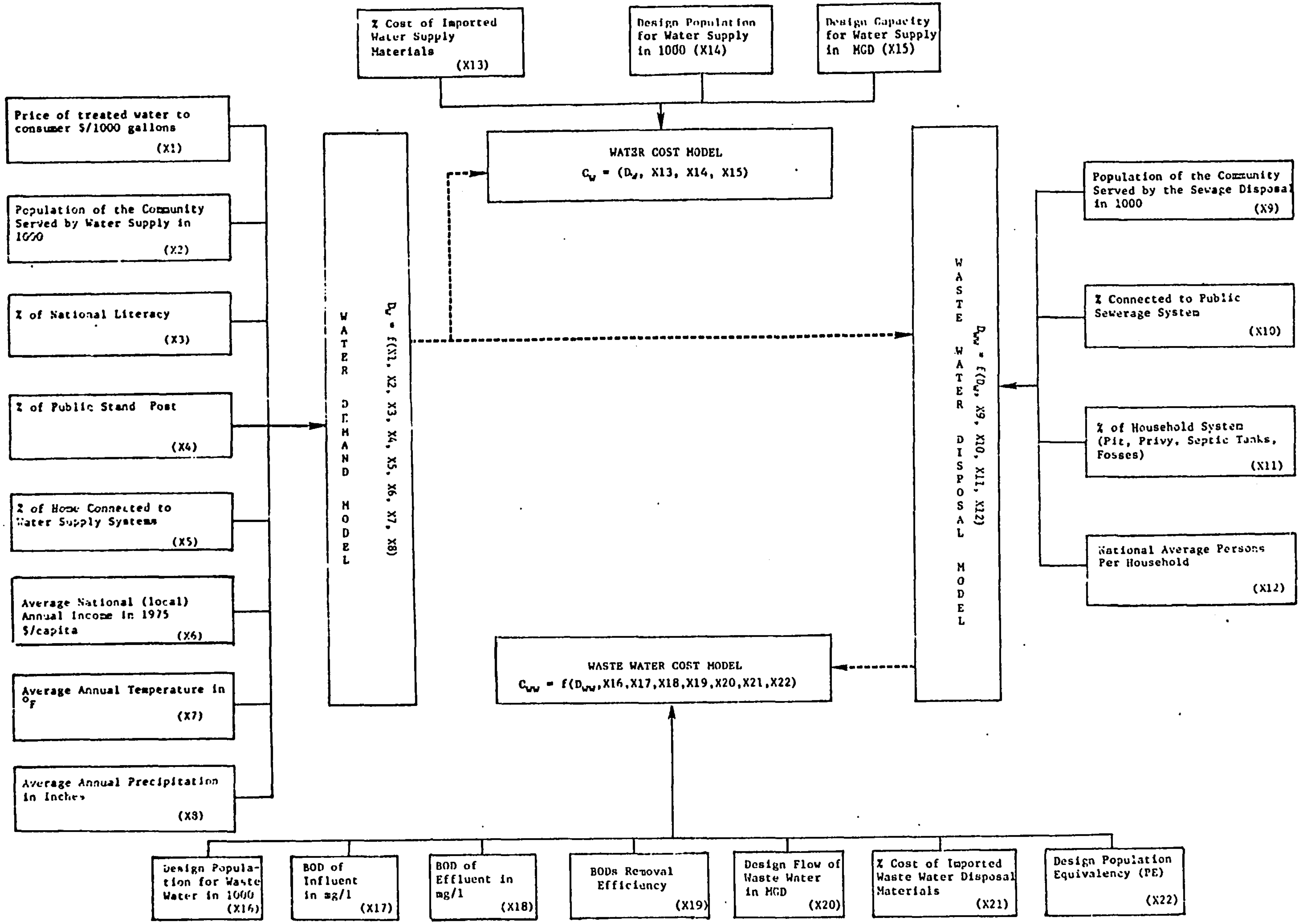

TABLE II

ESTIMATED POPULATION PROJECTIONS OF DEVELOPING COUNTRIES[7]

(In Millions)

	1950		1960		1970		1980		1990		2000	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
South Asia	111	587	154	711	238	888	370	1116	556	1355	793	1561
East Asia	74	500	120	567	191	635	294	185	433	707	602	690
Africa	30	187	48	221	77	268	125	332	203	413	320	498
Latin America & Oceania	50	89	81	104	129	119	201	134	304	148	440	157

Source: [7] United Nations, Urban and Rural, ESA/P/WP 33/Rev./New York, N.Y.

The increase in population will involve rising demand of water not only for domestic and industrial use but also for agriculture to grow more food for the underfed people of developing countries.

Consequently with the inevitable rise in water demand, more and more waste water will be discharged into rivers, lakes and the oceans causing health hazard not only to human beings, but to wild life as well.

Those countries within the tropics have never had a serious pollution problem with big rivers because seasonal flooding kept the water reasonably unpolluted (8). Nevertheless, during the dry season, waterborne diseases are always transmitted.

Since most of the industrial centers in developing countries are located near the rivers, lakes or sea (Nairobi-Athi River and Nairobi River; Kisumu-Kampala-Entebe-Lake Nyanza; Tunis, Istanbul, Nicosia-Mediterranean Sea) and only a small fraction of the waste water either from industrial or domestic areas is being treated, the final disposal of the rest is usually into these water bodies.

In the United States, Reid (9) has predicted that in the period 1980 and 2000 approximately 64 percent of the required stream flow for all purposes will be needed for dilution of wastes. Table III shows the distribution of the predicted required stream flow. This study could be applied to developing countries during this decade.

Therefore, if the waste water is not treated before discharging into water bodies the public health in developing countries may deteriorate further. Furthermore the cost of treating water for domestic use is likely to go higher. There is, therefore, a definite need for development of a technique that can be used for estimated water demand, per capita waste water disposal, and cost of treating water and waste water in developing countries.

TABLE III

Distribution of Required Stream Flow by Uses, United States, 1980 and 2000 [9]

Use		Percent of Total Flow	
		1980	2000
Agriculture		20.0	18.1
Mining		0.1	0.1
Manufacturing		1.7	3.0
Thermal Power		0.3	0.4
Municipal		0.7	0.8
Land Treatment		0.8	1.0
Fish and Wild Life Habitat		12.8	12.8
	Sub-total	36.4	36.2
Waste Dilution Flow		63.6	63.8
	Total	100.0	100.0

Source: [9] Reid, G. W., Water Requirements for Pollution Abatement, Committee Print No. 29, Water Resources Activities in the United States, U.S. Senate Committee on National Water Resources, July 1960.

CHAPTER II

LITERATURE REVIEW

The major aim of this study is to develop predictive equations for water demand, waste water disposal (per capita disposed daily), cost of water and waste water treatment in developing countries using socio-economic and environmental indicators. This chapter is a review of various studies and models related to this study.

Water Demand Models

A number of studies have been directed toward describing the demand of water. These involved the manipulation of water use information and related economic data to provide some projection of future demand.

Reid (10) has used economic, population, reconciliation and life style submodels in the form of the following predictive equation:

$$WD_t = (Pop_t)\ uu \left[\frac{ppct_t}{ppct_s}\right]^x \left[\frac{Inc_t}{Inc_s}\right]^y \left[\frac{Pop_t}{Pop_s}\right]^z \qquad (2\text{-}1)$$

where: WD_t = water demand at time t

uu = unit use

Pop_t = population at time t

ppc_t = precipitation at time t

Inc_t = income at time t

In another study, Wollman (11) describes methods for making estimates of water demand for the United States as an economic model rather than as a set of formal projections. He does this because several important factors are necessarily excluded either because the basic data are still lacking or because some inter-relationships are not well enough understood to be handled with any confidence.

In 1975, Reid and Muiga (12) presented an approach to develop an aggregate mathematical model for water demands in developing countries using socio-economic growth patterns. The authors used socio-economic inputs to identify four activity socio-technological levels. Levels representative of socio-economic development are in turn used to identify municipal, agricultural and industrial water requirements.

The most advanced statistical methods used have been correlation analysis and the development of estimating equations from the regression line. For example, Saki (13) developed a model for Tokyo, Japan using this method. He used four factors to give the following predictive equation:

$$I = 0.5674\ X_1 + 0.1606\ X_2 + 0.1149\ X_3 + 0.1571\ X_4 \ldots \qquad (2\text{-}2)$$

where: I = water demand in gallons per capita per day

X_1 = population

X_2 = personal income

X_3 = industrial production

X_4 = sales of goods

Further he expressed maximum consumption of water per day in Tokyo as the linear function below.

$$Y = 361.521 + 32.057\ I \ldots \qquad (2\text{-}3)$$

where: Y = water consumption for Tokyo

The formula coefficient correlation shows a value of 0.986 and the standard deviation of 0.012. This method expresses statistically better results than if each factor was used separately. Saki concluded that water consumption per capita appears to show a larger value in large cities.

An interesting and detailed field examination of domestic water use in East Africa (Kenya, Tanzania and Uganda) was carried out by White et. al. (14). Although no predictive equations were given, the study attempted to relate per capita use to income, educational level, family size, source of available water, cost, culture and natural environment. Daily per capita use was found to range from a minimum of 1.4 litres in a farming household to a maximum of 660 litres in an upper income suburb of Moshi, Tanzania. The mean per capita use for piped supplies shows a low of 30 litres per capita daily and a high of 254 litres, while for unpiped supplies the mean per capita showed a high of 21 litres and a low of 4 litres. White's study showed a minimum mean use per capita daily for an agricultural community of the order of 4.4 litres, varying to a maximum of 17.6 litres. Villages and urban areas using unpiped water showed a higher use, varying from a mean of 9.3 litres in a small farming village to 20.8 in an urban community where standpipe water is provided at no other cost than transport.

In general, White et. al. (14) found that the per capita use, where water is not piped into the household is in large measure a function of income level, urban versus rural situation, and number of children within ethnic groups. Where water is piped into the household a major consumption in water occurs; the amount above that minimum is a function in considerable measure of cost, income level, family size and education. Finally, the study found that where domestic water demand in the urban areas is relatively price inelastic, price is of measurable significance.

The influence of the type of housing toward water demand in developing countries can be found in the Accra-Tema Study (15). The average daily domestic supply to Accra increased by about 11 percent from 1961 to 1963. In this period the population increase was about 9 percent whereas the increase in per capita use of water was about 2.5 percent. The average daily domestic supply to Tema increased during the same period by about 122 percent, the population increased by about 35 percent, whereas the increase in per capita consumption was about 60 percent. This was due mainly to the construction of high and medium grade housing with modern sanitary facilities. The study states that the factor accounting for the difference between the per capita consumption of Accra and Tema is that in Tema almost all the houses were connected to the distribution system and had an average daily domestic per capita consumption of 150 litres in 1963 whereas half of Accra's population lives in substandard housing and is served by street standpipes and the daily per capita consumption was only 48 litres.

In 1969, Lee (16) selected thirteen sites in Calcutta and New Delhi in an attempt to measure and define the relationship between economic development and the provision or need for public water supply systems through the examination of domestic water consumption. He concluded without giving any predictive equations the demand for domestic water supply is a function of accessibility to water, housing conditions, levels of income and water using habits.

Wolman (17) presented a basis to determine the amount of water used for various purposes in different countries throughout the world, along with the possibilities to forecast the amounts needed for domestic, municipal and other uses. Wolman concludes that the decision on quantitative requirements should be geared to the planner's objectives, and that responsibility for improved forecasting should lie jointly with the water project designer, the economist and the sociologist.

Hakes (18) pointed out that while there is little empirical evidence concerning the nature of price elasticity for water, he observed that a shift in water usage caused a thirty-six percent decline in domestic use of water in Boulder, Colorado after meter installation. He pointed out that within a metered system relatively small price changes may not lead to substantial changes in water demand. Howe and Linaweaver (19), while studying residential water demands using logarithmic demand models, incorporated several independent variables for both average domestic demand and sprinkling demand in the United States, suggested that sprinkling demand might be relatively elastic and that domestic demand might be relatively inelastic.

Price elasticity of demand, which is defined as the relative change in quantity demanded as response to a relative change in price if one assumes that the quantity demanded q is a function of price p is theoretically given as (19):

$$E_d = \frac{dq.p}{dp.q} = \frac{d(\log q)}{d(\log p)} \quad \dots\dots\dots\dots\dots\dots \quad (2\text{-}5)$$

where: E_d = demand function

Equation (2.5) can be described by the regression line

$$\text{Log } E_d = a + b \log p \quad \dots\dots\dots\dots\dots\dots \quad (2\text{-}6)$$

where: b = elasticity coefficient

Fourt (20) performed multiple linear regressions to find relationships between water usage and price, number of days in summer, rainfall, average number of persons per meter and the total population served.

In another study, Wong (21) worked with a set of twenty variables incorporated the water demand analysis reduced to a set of seven principal components. The most significant of these factors were: community size, per capita demand, price, standard of living and industrial depletion.

In 1937, Capen (22) developed the following equation for a well-metered water demand:

$$G = 54P^{0.125} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}7)$$

where: G = gallons per capita per day

P = population in thousands

Although Capen's equation (2-7) is good representative data from 52 cities he surveyed, to suggest that the population is the only variable relevant to domestic water demand is invalid.

In 1969, Meyer and Mangan (23) developed a model which is known as MAIN I for calculating water requirements by correlation with economic, social and climatic variables. Forecasts were completed for 141 Standard Metropolitan Statistical Areas (SMSA) and the final equation is given as follows:

$$E_{75i} = (W_{60i} \times 1.19X \frac{Y_{75i} - Y_{60i}}{Y_{60i}} + W_{60i}) \cdot P_{75i} \quad \ldots\ldots \quad (2\text{-}8)$$

where: E = total water use

W = per capita use

Y = per capita income

P = estimated population

i = SMSA number

60, 75 = 1960, 1975

Waste Water Models

The general relationship between per capita waste water disposal and socio-economic indicators has not been developed especially for the developing countries. Developing countries like India (24) recommend 30 gallons per capita per day for designing waste water treatment plants. This may not be valid for high income communities in India or other developing countries. In developed and developing countries the main types of water using appliances are washing machines, dishwashers and garbage disposals. On the other hand air conditioners, evaporative coolers and swimming pools may be important in some areas.

Durfar and Becker (25 attempted to classify domestic water use by function and postulated the following division of sub uses as shown in Figure 2.

Howe, Russell and Young (26) classified household water use as shown in Figure 3.

As the life sytle and economic conditions of developing countries changes, water demand will likely change as well as the amount of waste water disposed daily. So there is a need for a model which relates the per capita waste water disposed daily to socio-economic and environmental indicators. The per capita waste water disposed daily is needed for future waste water plants design in the developing countries.

In the United States and other industrial nations, it has been simply a matter of taking a percentage of per capita water demand for waste water systems designing. As such there are no empirical equations given for predicting per capita waste water disposed of daily.

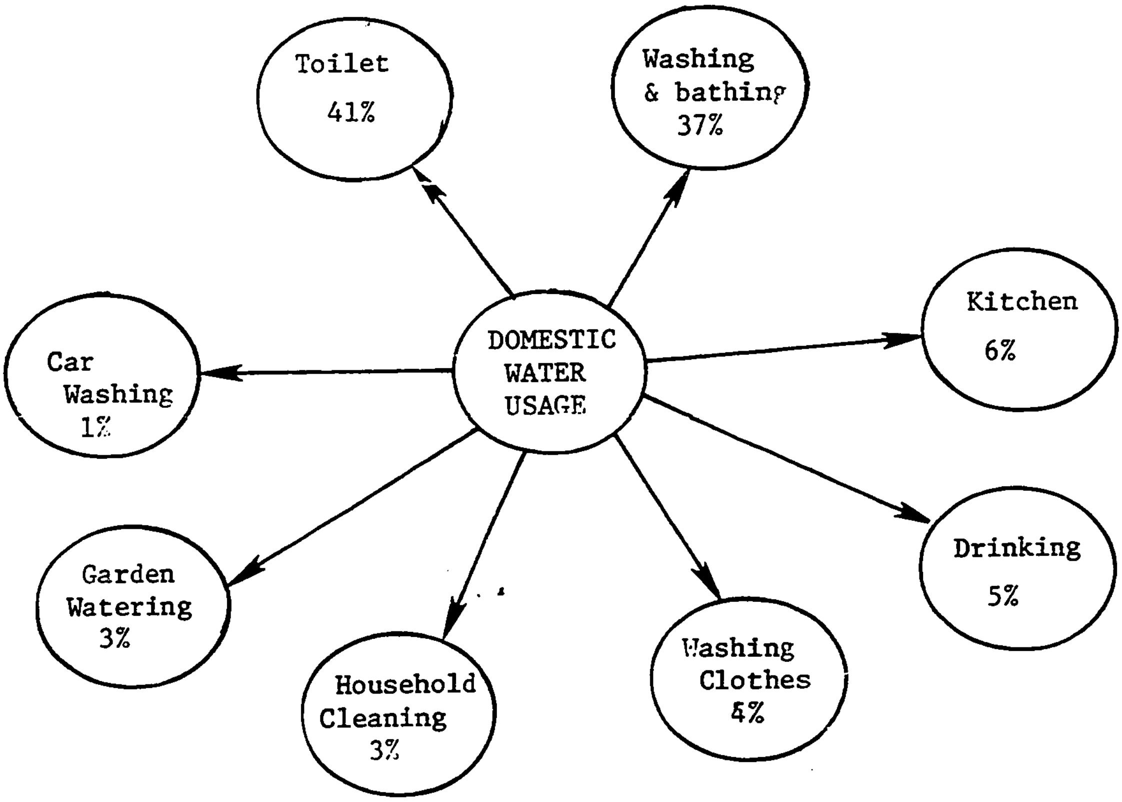

Figure 2: Domestic Water Usage

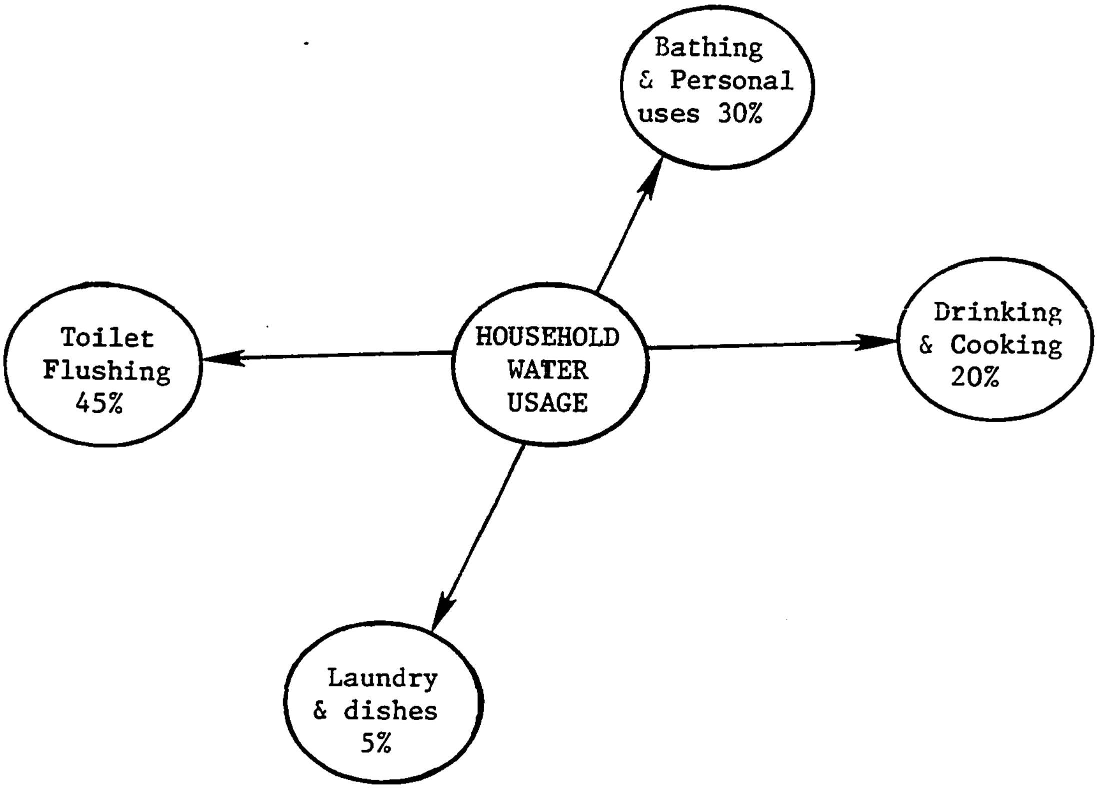

Figure 3: Classification of Household Water Usage

Water Treatment Cost Models

A water treatment plant like many other capital facilities, is usually constructed with a capacity that will satisfy the requirements over many years to come, instead of just immediate requirements. The main reason for this lies in economies of scale available only with a large plant that can be achieved in terms of investment or operating cost. To reflect possible scale effects, the investment cost of an industrial facility is often represented by a power function of capacity of the following form, first proposed by Chenery (27):

$$C = \alpha K^{\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}9)$$

where: C = investment cost in thousand dollars

K = design capacity in MGD

and β = coefficients

In equation (2-9) if we let K equal 1 MGD, C equals α . That means parameter α is equal to the investment cost of a plant with a capacity of 1 MGD. On the other hand, β determines the manner in which investment cost changes with capacity. Since β is a constant exponent of K , the investment cost increases with capacity at an increasing or decreasing rate depending on whether β is bigger or smaller than 1.

The World Health Organization Chronicle (28) gives the cost of construction and operation of water supply for villages of 2,000 - 10,000 and water demand of 68 litres per capita per day. Installation costs (without water treatment) range from seventy cents per person to forty-five cents for a driven well, with maintenance costs of seventy-two cents per capita per year for any well. Pipe water systems range from 8-14 dollars per capita with operation costs of 1.80 dollars per year.

Data were collected for 68 water systems gravity type without filtration in Central America (29) which were constructed between 1965 and 1969. These systems included piped house services and public fountains. Field studies using least squares analysis resulted in the following function:

$$C(Z) = 300{,}000\ Z^{0.83} \quad \ldots\ldots\ldots\ldots\ldots \quad (2\text{-}10)$$

where: C(Z) = Cost per million gallons per day

Z = million gallons per day

In 1974, a study (30) was carried out in West Africa to determine the main effects on the costs of consumed water at the public standpipes. The general formula is given by:

$$C_c = \frac{1}{1-w}\ C_b + \frac{(a + b)\ I_p + E_o + E_g)}{qc} \quad \ldots\ldots\ldots\ldots \quad (2\text{-}11)$$

where: C_c = costs of consumed water at stand pipe

W = wastage factor as part of the produced water at the standpipe in M^3
W = 0, no wastage
W = 1, all produced water is wasted

C_b = the general costs of production, transport and distribution for the entire water supply company (in the US $\$/M^3$)

I_p = investment costs of one standpipe (in US dollars)

aIp = annual costs of depreciation and interest for one standpipe (in US dollars)

bIp = annual costs of maintenance and spare parts for one standpipe (in US dollars)

E_o = annual costs of operation, management, revenue collecting, etc., for one standpipe(in US dollars)

E_g = annual costs of guard(in US dollars)

gc = total annual consumption at one standpipe in M^3

Koenig (31) reported the collection of data on some 30 surface-water treatment plants in unspecified locations. Using data on 21 of these plants he obtained the following investment cost function based on the 1964 price level:

$$C = 307Q_s^{0.68} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}12)$$

where: C = investment cost in thousand dollars

Q_s = design capacity in MGD

Ackermann (32) reported an investment cost function for the surface-water treatment plant, using data on 42 plants composed of plants reported by Keonig in 1968. Using the 1964 price level and the Handy-Whitman Utilities Indix for adjusting location differences, he reported the following function:

$$C = 267.0Q_s^{0.65} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}13)$$

In the same study, Ackermann produced an investment cost function for ground water treatment plants based on data related to 58 Illinois plants. He adjusted the original data to 1964 price levels, included in these data indirect costs covering engineering, legal, administrative, and other overhead items including interest during construction, and obtained the following function:

$$C = 115Q_s^{0.63} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}14)$$

In 1961 comprehensive per capita construction cost data were compiled (33) for six nations (Brazil, Ceylon, Costa Rica, India, Jamaica, and Nigeria) in all three major geographical regions of the developing countries. Summary of construction costs are presented in Table IV.

Black and Veatch (34) undertook a study to develop a manual to estimate cost of conventional water supplies in the United States. The costs were developed as a function of design flow only. The costs included all structures, basin, filters, wastewater facilities, plant equipment, tanks, piping, fencing and other materials necessary for a complete treatment plant. Table V gives some results of these findings.

Waste Water Treatment Cost Models

A number of studies (39, 43, 44, 46, 47) have been directed toward describing the cost of municipal waste treatment. The cost is usually expressed as a function of the design flow through the plant or the design population, and the expected level of waste removal efficiency. Recognizing the need for cost data, the US Public Health Service (USPHS) began a study of the construction costs of sewage treatment facilities. Howells and Bubois (35) made the first of such studies for USPHS. They based their study on the analysis of twenty small secondary sewage treatment plants in the upper midwest. They only considered construction, operation and maintenance costs. The costs of land, engineering, administrative and legal services were not included in the analysis. The

Table IV: Per Capita Construction Cost of Water Treatment in Developing Countries [33]

Continent	Country	Per Capita Construction Cost In United States Dollars	
		Reported	Adopted
Africa	Ghana	12.74	13
	Nigeria	8.65	10
Asia	Ceylon	42.00	42
	India	9.05	12
Latin America	Brazil	16.40	25
	Cost Rica	23.60	30
	Jamaica	30 - 50	40

Source: [33] Henderson, M. J., Report on Global Urban Water Supply Program Costs in Developing Nations 1961-1975, International Cooperation Administration Washington, D. C. 1961.

Table V: Cost of Water Supplies[34]

Design Capacity in MGD	Construction Cost in US $			Operations & Maintance $/1,000 gallons
	Well Supplies	Treatment Plants and Storage	Intake & Pumping Stations	
0.1	20,000	60,000	40,000	0.120
0.2	21,000	90,000	40,000	0.102
0.5	26,000	140,000	40,000	0.078
1.0	34,000	220,000	40,000	0.062
2.0	50,000	380,000	55,000	0.048
5.0	125,000	700,000	130,000	0.034
10.0	250,000	1,150,000	240,000	0.028
20.0	500,000	2,000,000	465,000	0.024
30.0	750,000	2,700,000	630,000	0.024
40.0	1,000,000	3,400,000	800,000	0.022
50.0	1,250,000	4,000,000	980,000	0.021
60.0	1,500,000	4,600,000	1,150,000	0.020
70.0	1,750,000	5,100,000	1,300,000	0.019
80.0	2,000,000	5,600,000	1,480,000	0.018
90.0	2,250,000	6,100,000	1,660,000	0.017
100.0	2,500,000	6,550,000	1,820,000	0.017

Source: [34] Black and Veatch, Consulting Engineers, Kansas City, Missouri, 1963 design population of the plants studied ranged from 600 to 12,500.

In 1964, the USPHS conducted yet another study (31). This study summarized the cost of 1,504 sewage treatment projects constructed under the Federal Government's Construction Grants program. A series of curves were developed relating the capital construction costs to the populations served by the plants, the design flows of the plants, and the design

Velz (37) made a study of the costs of waste water treatment plants. He obtained his data from the literature and the questionnaires he sent. His objectives was to relate the construction cost of a plant per million gallons per day of flow to the size of the plant. To estimate the total cost of a plant, Velz assumed that the bid price on the construction cost was about eighty to eighty-five percent of the total cost, excluding the costs of land, engineering and legal fees.

Wollman (38) used a multiple regression model to estimate the operation and maintenance costs of a waste water plant. The model was as follows:

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}15)$$

where: Y = the annual operation and maintenance cost per daily population equivalent (P.E.)

X_1 = treatment level in percent of BOD removal

X_2 = percent of total waste that is industrial

X_3 = population served by the sewage system

b_0, b_1, b_2, b_3 = regression coefficients

Application of systems analysis techniques to the preliminary design of a waste treatment plant was made by Logan and others (39). The cost data were obtained by visiting the plants. Models were developed to estimate the cost per MGD of the plant as a function of the design capacity of the palnt in MGD. The unit processes of the following treatment plants that were studied were:

1. Primary treatment plants;
2. High rate trickling filter plants;
3. Standard rate trickling filter plants; and
4. Activated sludge treatment plants.

Since the authors found many inconsistencies in the field data, they based their analysis on a series of theoretical designs under ideal conditions.

An effort was made by Eckenfelder (40) to assess the construction and operation costs of several types of industrial waste treatment plants. The author did not develop any model, although he presented graphs for estimating construction costs.

Part (41) approached the problem of estimating the construction cost of a plant by considering both the hydraulic and biological loadings of the plant. He assumed that the primany treatment plant costs can be represented by the capacity of the plant in terms of its hydraulic leading, since the hydraulic loading is an important parameter for a primary treatment plant design. However, the secondary treatment plant costs can best be represented by the capacity of the plant in terms of its organic loading. To convert the unit cost per capita to the unit cost per lb. of BOD, the author assumed 0.2 lb of 5 day BOD per person per day. Similarly, to convert the unit construction cost per MGD, he assumed 100 gallons per capita per day of waste flow.

Thoman and Jenkins (42) realized the regional differences in the construction costs. To account for these differences in costs, the authors partitioned the U.S. into twenty regions on a county line basis. Each of the regions corresponded to one of the twenty cities used in obtaining the US Average Engineering News Records - Cost Index (ENR-CI). They referred the costs to the year 1913 as the base year. Three models were developed for estimating the construction costs of:

1. Primary treatment plants;
2. Secondary treatment plants; and
3. Stabilization ponds.

The main variable in the models is the design population. The authors developed the following model.

$$Y = aX^b \qquad (2\text{-}16)$$

where: Y = cost of a plant per MGD of flow

X = size of the plant in terms of MGD of flow

a, b = constants

Diachishin (43) attempted to refine and update the work of Velz. He analyzed the cost data from 154 plants. He succeeded in developing separate models for primary treatment plants and secondary treatment plants. Diachishin used 1913 as the base year of construction rather than 1926 as used by Velz. The construction costs were adjusted by means of the ENR-C Index.

Smith and Eiler (44) developed a log-log regression equation for predicting per capita, operation and maintenance costs of wastewater treatment plants. In their analysis they assumed cost was a function of flow and population. They did not take into consideration high BOD's produced by industries.

Their equation is in the form:

$$Y = aX^b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}17)$$

where: Y = capita costs of per capita operation and maintenance costs

X = population

a, b = constants

The estimating relationship of Smith and Eiler has been adjusted upward to 1973 dollars on the basis of an assumed 6.25% annual inflation rate.

In 1970, Shah and Reid made a study (45) to develop models for estimating the construction costs of waste treatment plants. Four variables were studied to predict the costs of a plant. They are:

1. Population Equivalent (PE);
2. Flow in million gallons per day;
3. BOD of the influent, mg/l; and
4. Efficiency of BOD removal.

The cost was evaluated in terms of:

1. 1957-59 dollars per design PE; and
2. 1957-59 dollars per MGD of design flow.

Five types of waste treatment plants were modeled:

1. Primary treatment plant;

2. Waste stabilization ponds;
3. Standard rate trickling filter;
4. High rate trickling filter; and
5. Activated sludge.

To account for possible regional differences in the construction costs of these plants, the authors like Thoman and Jenkins considered the US divided into twenty different regions on a county line basis. However, to adjust the cost data of treatment plants obtained from various parts of the country to a common base, the WPC-STP Index was used because it is based on information peculiar to waste water treatment plant construction.

The general form of the model was:

$$Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + e \quad \dots\dots\dots\dots \quad (2\text{-}18)$$

where: Y = construction cost of a plant in 1957-59 dollars per design MGD or per design PE

X_1 = design PE

X_2 = design flow in MGD

X_3 = design BOD influent in mg/l

X_4 = BOD removal efficiency.

$B_o, B_1, B_2 B_3 B_4$ = coefficients of regression

e = residual

It was felt that in some situations, the linear model may not be able to represent the cost of a waste treatment plant. Therefore, along with the linear form, the following non-linear forms of the model were tested as follows:

$$Y = B_o + \sum_{i=1}^{4} B_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}19)$$

$$\ln Y = B_o + \sum_{i=1}^{4} B_i \ln X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}20)$$

$$\frac{1}{\ln Y} = B_o + \sum_{i=1}^{4} B_i \ln X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}21)$$

$$\frac{1}{y} = B_o + \sum_{i=1}^{4} B_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2\text{-}22)$$

The variables, X_3 and X_4, the influent BOD and the BOD removal efficiency, were found to be "not significant" statistically, in the estimation of the construction costs of the waste treatment plants studied. The models developed are:

1. Primary treatment plants:

$$\ln Y'' = 12.42 + 0.3852\ X_2 \ldots\ldots \quad (2\text{-}23)$$

where: Y" = construction cost per design MGD, in 1957-59 dollars

2. Waste stabilization ponds:

$$\frac{1}{\ln Y''} = 0.1291 - 0.0044 \ln X_1 + 0.0073 \ln X_2 \quad (2\text{-}24)$$

$$\frac{1}{Y'} = 0.0511 + 0.0001\ X_1 - 0.0640\ X_2 \quad (2\text{-}25)$$

where: Y' = construction cost per design PE in 1957-1959 dollars.

3. Standard rate trickling filter:

$$\ln Y'' = 7.90 + 0.4007 \ln X_1 - 0.9568 \ln X_2 \quad (2\text{-}26)$$

4. High rate trickling filter:

$$\ln Y'' = 9.39 + 0.3357 \ln X_1 - 0.6443 \ln X_2 \qquad (2\text{-}27)$$

$$\ln Y'' = 9.39 - 0.6443 \ln X_1 + 0.3557 \ln X_2 \qquad (2\text{-}28)$$

5. Activated sludge treatment plants:

$$\ln Y'' = 8.53 + 0.4610 \ln X_1 - -.7375 \ln X_2 \qquad (2\text{-}29)$$

$$\ln Y' = 8.53 - 0.5389 \ln X_1 + 0.2634 \ln X_2 \qquad (2\text{-}30)$$

The models based upon this sample were developed for primary treatment plants:

$$\ln Y'' = 12.93509 - 0.09734 \ln X_2 - 2.09333 D_1 - 0.22875 D_2 \qquad (2\text{-}31)$$

Secondary treatment plants:

$$\ln Y'' = 11.99740 - 0.54917 \ln X_2 + 0.20309 \ln X_3 - 0.10770 D_1 - 0.10804 D_2 \qquad (2\text{-}32)$$

where: Y_p'' = construction cost per design MGD of primary industrial waste treatment plants in 1957-59 dollars

Y_s'' = construction cost per design MGD of secondary industrial waste treatment plants in 1957-59 dollars

X_2 = design flow in MGD

X_3 = design influent BOD in mg/1

$D_1 = 0$, $D_2 = 0$ for petroleum wastes

$D_1 = 1$, $D_2 = 0$ for pulp and paper wastes

$D_1 = 0$, $D_2 = 1$ for chemical wastes

Studies have been done on municipal sewege treatment construction costs for 291 projects built in Illinois between 1957 and 1968 (46). Least square regression analysis was used to relate design population equivalent to construction costs. Also regression equations for estimating lagoon land costs, plant operating costs, and land costs were developed in the general geometric form:

$$C = KP^n \quad \text{(2-23)}$$

where: C = either construction, operating or land costs

K = regression constant

P = sewage treatment capacity or average annual load treated

n = slope of the least square regression line

A new equation was also developed to account for future expansion of the plant in the form:

$$C = KP^nS^m \quad \text{(2-24)}$$

where: C = cost of new addition to old

K = a regression constant

P = capacity of new addition

S = capacity of existing plant

n,m = slope constants

The following are the summeries of the equations developed for Illinois:

Oxidation lagoon	$C_1 = 349P^{0.690}$	(2-25)
Primary digester	$C = 4290P^{-0.506}$	(2-26)
Primary vacuum	$C = 634P^{-0.362}$	(2-27)

Trickling filter digester $C = 1069P^{-0.362}$ (2-38)

Trickling filter Imoff $C = 738P^{-0.328}$ (2-39)

Activated Sludge (in place built) PE $\leq 10{,}000$

$C = 3746P^{-0.493}$ (2-40)

Activated Sludge (in place built) PE $\geq 10{,}000$

$C = 91P^{-0.09}$ (2-41)

Activated Sludge (factory built)

$C = 1298P^{-0.402}$ (2-42)

Lagoon land cost $C_2 = 22.1P^{0.877}$ (2-43)

Conventional plant operating cost

$C_0 = 23.3P_w^{-0.213}$ (2-44)

In conclusion then most of the mathematical models for water supply and waste water disposal have been developed (10, 11, 12, 23, 25, 33, 39) for the industrial countries. This current study therefore is an attempt to produce effective predictive equations for water demand waste water disposal, and cost of water and waste water treatment in developing countries rather than applying the industrial countries models.

CHAPTER III

DEVELOPMENT OF THE MATHEMATICAL MODEL

The major aim of this study was to develop prediction equations to estimate water demand, per capita waste water disposal, and cost of water and waste water treatment in developing countries. The development of a multiple correlation from the analysis of a series of regression equations is discussed in this chapter.

The objective of the multiple correlation is to provide a function that can be used to estimate dependent variables that can yield more accurate results than using the sample mean.

Sample data were analyzed both to determine an arithmetic mean value and to determine to what degree this value varies from the mean by calculating the standard deviation. The independent variables were individually analyzed by calculating linear correlation coefficients to determine which variables correlates best. The result of these analyses determine the order in which they were added to the regression equation. Regression equations were then developed starting with a linear equation, which utilized only the most significant independent variable to form a new equation until all the variables were utilized. The resultant regression equations were then analyzed, to determine how much more accurate the added new variables were.

Variables not significantly improving the correlation were deleted. Finally the F-test (defined by equation 3-16) of the significance was made to determine whether the degree of improvement in the accuracy of estimated values could reasonably be arrived at by chance or was statistically significant.

Correlation Coefficients

A good indication of the relationship between independent variables, and the relationship between individual independent variables and the dependent variable, is the value of the linear correlation coefficient (r) between the pair of variables.

The correlation coefficient between two random variables, x and y, with a joint distribution is defined as:

$$r = \frac{\Sigma\ (xy - \overline{xy})}{\left[\Sigma(x - \bar{x})^2\ \Sigma(y-\bar{y})^2\right]^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}1)$$

where: r = linear correlation coefficient of y vs. x

y = independent or dependent variable

x = independent of dependent variable

$\bar{y}$ = arithmetic mean y value

$\bar{x}$ = arithmetic mean x value

xy = produce of x and y

xy = arithemtic mean value of xy

The range of values of the correlation coefficients is from -1 to + 1. A non-zero simple correlation coefficient implies that there is an association between the observed values of the two variables and does not imply that there is a relationship between the two variables. Although independent variables are uncorrelated, that is, their correlation coefficient of zero can exist between variables that are independent. This occurs because only the linear relationship is explained by the correlation coefficient.

Correlation coefficients were used as one of the screening mechanisms to select those variables which appeared to explain the magnitudes of the dependent variables of water demand, waste water disposal, cost of water treatment and cost of waste water treatment.

Correlation coefficients were also used to determine which independent variables had a high association between their respective values and therefore the use of either variable in the regression equation would yield a similar regression equation in terms of parameters. On the other hand, correlation coefficients at each stage provide some knowledge in determining which variables may only appear to explain the changes in dependent variables. Such variables may only appear to explain the changes because of a high correlation with a variable that actually explains the relationship and which variables appear not to be an important factor in influencing dependent variables.

Dealing with more than two variables at a time allows the partial correlation coefficients to be used to measure the linearity between observation of two variables with all other coefficients held constant. A partial correlation coefficient is useful because it removes the influence of the other variables. By the use of simple correlation coefficients two variables may be correlated because of a common relationship with another variable and not a relationship between each other.

The partial correlation coefficient of x, and x_2 with x_3 held constant is defined as follows:

$$r_{21.3} = r_{12.3} = \frac{r_{12} - r_{13}\, r_{23}}{\left[(1-r_{13}^{2})(1-r_{23}^{2})\right]^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}2)$$

Multiple Regression

The problem of best-fitting a hyper plane to a set of joint observations on a dependent variable which is a linear function of several independent variables can be accomplished by the least squares principle. For any linear model, least squares minimizes the residual sum of squares and provides an unbiased, linear estimate with minimum variance of the parameters.

The use of matrices is convenient since the computations increase tremendously as the number of variables and observations increase. The use of a digital computer is essential if investigation of many possible predictive equations is desirable.

The k equations can be set out in matrix form where Y is a k by 1 vector of observations of a dependent variable, X is a n by (i + 1) matrix of independent variables which explains the dependent variable's value, B is a (i + 1) by 1 vector of unknown parameters to be estimated and E is a k by 1 vector of residuals. The intercept term, B_o, dictates that each of the elements of the first column of the matrix X (X_{10}, X_{20} . . . X_{ko}) is equal to one. Matrices representing a sample of k sets of observations on y and (i values of x) are:

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \cdot \\ \cdot \\ y_k \end{bmatrix} \quad X = \begin{bmatrix} x_{10} & x_{11} & \cdots & x_{1i} \\ x_{20} & x_{21} & \cdots & x_{2i} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ x_{ko} & x_{k1} & & x_{ki} \end{bmatrix} \quad B = \begin{bmatrix} B_o \\ B_1 \\ B_2 \\ \cdot \\ \cdot \\ B_k \end{bmatrix} \quad E = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ \cdot \\ \cdot \\ e_k \end{bmatrix}$$

Matrix formulation of the observation is:

$$Y = BX + E \qquad (3\text{-}3)$$

The residuals are described by the following matrix:

$$\begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ e_r \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_r \end{bmatrix} - \begin{bmatrix} x_{11} & x_{21} & \cdots & X_{ki} & b_1 \\ & & & & b_2 \\ \cdot & & & & \cdot \\ \cdot & & & & \cdot \\ x_{1r} & x_{2r} & \cdot & x_{kr} & b_k \end{bmatrix}$$

The matrix of the residual can be written as:

$$e = y - xb \qquad (3\text{-}4)$$

The sum of squared residuals, can be written as:

$$\phi = \sum_{i=1}^{n} e_i^{\,2} = \Sigma y_i - b_i\, X_{1i} - b_2\, X_{2i} - \ldots\ldots - b_k X_{ki})^2$$

$$\phi = y'y - 2b'x'y + b'x'xb \qquad (3\text{-}5)$$

with respect to each component of B and setting the resulting equations equal to zero provides a set of normal equations:

$$\frac{\delta\phi}{b_1} = 2(-\Sigma x_{1i}y_i + b_1\Sigma X_{1i}^2 + b_2\Sigma\, x_{1i}\, x_{2i} + . . .$$

$$+ b_k\Sigma\, x_{1i}\, x_{ki}) = 0$$

$$\frac{\delta\phi}{b_2} = 2\ (-\Sigma\, x_{2i}y_i + b_1\Sigma\, x_{2i}x_{1i} + b_2\Sigma\, x_{2i}^2 + . . .$$

$$+ b_k\Sigma x_{2i}x_{ki}) = 0$$

.

.

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$$\frac{\delta\phi}{b_k} = 2\ (-\ \Sigma\, x_{2i}y_i + b_1\Sigma x_{ri}x_{1i} + b_2\Sigma\, x_{ki}\, x_{2i} + . . .$$

$$+ b_k\ \Sigma\, x_{ki}^2) = 0$$

This set of normal equations is written in matrix form as:

$$\frac{\delta\phi}{\delta b} = -2X'Y + 2\ X'Xb = 0 \qquad . . . . \qquad (3\text{-}6)$$

which is equivalent to:

$$X'Xb = X'Y \qquad . . . . \qquad (3\text{-}7)$$

Stepwise Multiple Regression

Stepwise regression is a variation of multiple regression which provides a means of choosing independent variables which will provide the best prediction possible with fewest independent variables. This computation method was used in this study to provide the information necessary to select the next variable to be brought into the equation.

Typical stepwise regression uses a simple correlation matrix for the selection of the first independent variable, choosing the independent variable with the largest absolute value correlation coefficient with the dependent variable. The selection of subsequent variables in the typical stepwise regression is made by selecting from the independent variables the variable having the highest partial correlation coefficient with the response. The decision of acceptance or rejection of each newly added variable is based on the results of an overall and partial F-test. Then stepwise regression examines the contribution the previously added variables would have made if the newly added variable had been entered first. A variable once accepted into the regression equation may later be rejected by this method.

The only modification made to the typical stepwise regression procedure was that the variable's order of entry was determined by the results of screening procedures and studies by others and not a correlation matrix alone.

Examination of Residuals

The residual refers to the difference between the observed and regression equation value of the dependent variable. The basic assumptions made about the residuals when using least-squares regression analysis indicates that they are independent, have a constant variance and zero mean and if an F-test is used that they follow a normal distribution. The examination of residuals therefore should be directed to verifying the assumptions.

An other test for time sequence data is examination of the pattern of the signs of the residuals to determine if the observed arrangement is statistically unusual. A number of test runs accomplish this. Since the number of observations was for the most part not of sufficient size to be approximated by a normal distribution the actual cumulative distribution of the total number of runs shown by Draper and Smith (47). The probability of the observed number of runs, considered as the number of sign changes plus one, is obtained from this table and its occurrence evaluated as being random or non-random. If the cumulative probability is less than five percent the arrangement is assumed to be non-random.

An other test was done by comparing the observed values to the long term average, a positive sign was assigned values greater than the average and a negative sign was assigned to values less than the average. When the number of observations was greater than twenty a normal approximation to the actual distribution was used as suggested by Draper and Smith (47) where:

$$\mu = \frac{2\, n_1\, n_2}{n_1 + n_2} + 1 \quad \ldots\ldots\ldots\ldots \quad (3\text{-}8)$$

$$\sigma^2 = \frac{2\, n_1\, n_2 \quad 2\, n_1\, n_2 - (n_1 + n_2)}{(n_1 + n_2)^2\ (n_1 + n_2 - 1)} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}9)$$

$$Z = \frac{(u - \mu + \frac{1}{2})}{\sigma} \quad \ldots\ldots\ldots\ldots \quad (3\text{-}10)$$

with n_1 representing either the number of positive or negative residuals and n_2 being the number of residuals with a sign opposite of those chosen for n_1.

μ and σ^2 are the mean and variance of the discrete distribution of μ, the number of runs.

The residual mean square of the model has the expected value of the error variance, σ^2, only if the model is correct. If it is incorrect the residuals contain errors of two components, the variance error, which is random, and bias error, which is systematic. Generally, prior information on the expected error variance is not known, but if repeat measurements of the dependent variables are made with all independent variables retaining their same value for two or more observations they can be used to determine an estimate of the variance error. The other component of the residual error is bias error.

The procedure used to determine the variance error estimate of σ^2, S_{pe}^2 is outlined by Draper and Smith (47) and is as follows:

Suppose $Y_{11}, Y_{12}, \ldots, Y_{1n_1}$ are n_1 repeat observations
at X_1
$Y_{21}, Y_{22}, \ldots, Y_{kn_k}$ are n_k repeat observations
at X_k

The contribution to the pure error sum of squares from the X_1 reading is:

$$\sum_{u=1}^{n_1} (Y_{1u} - \bar{Y}_1)^2 = \sum_{u=1}^{n} Y_{iu}^2 - n_1 \bar{Y}_1^2 \quad \ldots\ldots\ldots\ldots\ldots \text{(3-11)}$$

where $\bar{Y}_1$ is the mean value of the $Y_{11}, Y_{12}, \ldots Y_{1n_1}$ observations.

Similar sum of squares calculations are made for each X_i. The total variance error sum of squares is:

$$\sum_{i=1}^{k} \sum_{m=1}^{n_i} (Y_{iu} - \overline{Y_i})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}12)$$

and the total degrees of freedom equals

$$\sum_{i=1}^{k} (n_i - 1) .$$

The mean square for the variance error is

$$S_{pe}^2 = \frac{\sum_{i=1}^{k} \sum_{u=1}^{n_i} (Y_{iu} - \overline{Y}_i)^2}{\sum_{i=1}^{k} n_i - k} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}13)$$

Selection of Best Equation

The square of the multiple correlation coefficient or the coefficient of multiple determination(R^2), the ratio of the sum of squares, is one possible criterion for selection of the best equation. However, the importance of an R^2 close to unity, its maximum value, may be misleading. This is particularly the case when only a small number of observations are used because the increase in the number of variables may have more of an influence on the accompnaying increase in R^2 than the related explanation contributed by the variables. The addition of another variable to a regression equation will never decrease R^2 because the regression sum of squares will either increase or remain the same and the total sum of squares will reamin unchanged.

Draper and Smith (47) point out that if a set of observations on a dependent variable has only four different values a four-parameter model will provide a perfect fit. One method which takes into consideration a number of observations and the number of parameters is the corrected coefficient of determination (R^{-2}) defined by Goldberger (48).

$$\bar{R}^2 = R^2 - \left(\frac{K}{N - K - 1}\right)(1 - R^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3-14)}$$

where: R^2 = coefficient of determination

K = number of variables

N = number of observations

$N-K-1$ = degrees of freedom

The corrected coefficient of determination does not always increase with the addition of a new variable to the regression equation. One of the techniques used to evaluate alternative equations was the corrected coefficient of determination.

The standard error of estimate, defined as the square root of the residual mean square, has incorporated into it consideration of the degrees of freedom of the residual and, therefore, is also a usalbe index for evaluating alternative regression equations.

The simple F - test, a ratio of the regression mean square to the residual mean square, is a measure of the equation's usefulness as a predictor. A significant F-value means only that the regression coefficients explain more of the variation in the data than would be expected by chance, under similar conditions, a specified percentage of the time.

It should be further noted that use of the F-test requires that the residuals are normally distributed. Normal distribution of water supply and waste water disposal data cannot be arbitrarily assumed to exist. However, normal distribution is not required for regression analysis.

The sequential F-test was used to determine if the addition of a new variable into the regression equation explained more of the variation than would be expected by chance. A 5 percent level of significance was used. The sequential or partial F-test as it is sometimes called is the ratio of the regression sum of squares explained by the addition of the new variable divided by the residual mean square (49).

This calculated value is termed F_c and is compared with published values of F-test to determine the probability that explained deviation is significant when compared with unexplained deviation.

$$F_c = (D_e/f_e)/(D_u/f_u) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}15)$$

where: F_c = calculated F value

D_e = explained deviation

D_u = unexplained deviation

f_e = degrees of freedom of D_e = NV

f_u = degrees of freedom of D_u = N - NV - L

NV = number of independent variables

N = number of samples

A plot of the residuals versus their associated fitted value of the dependent variable also yields information on any variation in variance as the magnitude of the fitted value increases.

Preparation of the residuals into unit normal deviate form and comparison of the resulting residuals distribution allows another examination of the residuals. Using this technique approximately 95 percent of the unit normal deviations would be expected to be within -1.96 to +1.96. If the residuals are assumed to have a normal distribution, their units normal deviate form should satisfy the above criterion.

Using the criterias discussed in this Chapter and Chapter IV data were analyzed. Residual mean squares (RESMS) are presented in Chapter V, Tables X, XI, XII and XIII.

CHAPTER IV

METHODS OF DATA COLLECTION AND PROCESSING

To gather the proper data the developing countries were divided into these major regions: Africa, Asia, and Latin America.

A questionnaire was designed in such a way that the questions supplied the required variables (see Chapter I). Such variables like population equivalent (PE) and percent biochemical oxygen demand (BOD) removal were not included. The following formula was used to calculate PE:

$$P.E = \frac{8.33\ QL}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}1)$$

where

Q = Average flowing wastewater treatment plant in MGD

L = Average 5 days BOD of the waste in Mg/1

b = was assumed to be 0.17 of BOD per capita per day

The other variable, BOD removal efficiency was calculated using the following formula

$$X_{19} = \frac{(BOD_i - BOD_e)\,100}{BOD_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}2)$$

where

X_{19} = Percentage removal

$BOD_i = X_{17}$ = 5 days BOD influent

$BOD_e = X_{18}$ = 5 days BOD efluent

Questionnaires were sent to Africa in March, 1974, the Far East, Middle East and Latin America in May, 1974.

The questionnaires were sent to Ministries of Health and City Governments, Water Development Boards, in addition to being sent to the following agencies:

(1) Regional Office for Mediterranean, World Health Organization, Alexandria, Egypt;

(2) Regional Office for Africa, World Health Organization, Brazaville, Congo;

(3) Regional Office for the Pacific, World Health Organization, Manila, Philippines;

(4) Regional Office for the Far East, World Health Organization, New Delhi, India

(5) Pan American Center for Engineering and Environmental Sciences, Lima, Peru;

(6) American University of Beirut, Beirut, Lebanon;

(7) University of Nairobi, Nairobi, Kenya;

(8) Asian Institute of Technology, Bangkok, Thailand;

(9) Middle East Technical University, Ankara, Turkey.

Accompanying the questionnaire (Tables VI, VII, VIII) a letter and summary and the summary of Professor George W. Reid's* research project on Low Cost Methods of Water and Wastewater Treatment in Less Developed countries was included. Due to the problems of handling overseas mail and the problems which may rise in data collection, it was decided to send one questionnaire

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*"Lower Cost Methods of Water and Waste Water Treatment in Less Developed Countries," sponsored by U.S.A.I.D. (1973-76).

TABLE VI: QUESTIONNAIRE USED IN MODEL SURVEY

QUESTIONNAIRE FOR
WATER AND WASTE STUDIES
FOR DEVELOPING COUNTRIES
BUREAU OF WATER RESOURCES AND ENVIRONMENTAL SCIENCES RESEARCH
UNIVERSITY OF OKLAHOMA
NORMAN, OKLAHOMA 73069
U.S.A.
April 1974

1. Please supply flowing data as shown in the tables for water treatment processes. Indicate if the flow is in metric system or English (MGD), and if the cost is in local currency or in U.S. equivalent dollars.
2. Have you ever had any problem with operational and maintenance of your plants?__________Yes __________No
   If yes, which one and how did you overcome it?____________________
   ____
3. What is the estimated daily water demand in gallons per capita per day (gpcd)__________________in litres per day____________________.
4. What is the estimated wastewater demand (discharge)*___________(gpcd) or litres__________________
5. What is the average annual local temperature* in °F_______or °C______.
6. What is the average annual precipitation in inches*__________________.
7. Estimated price of treated water per 1000 gallons*__________________.
8. Estimated national average of persons in each household______________.
9. Estimate percent of household system (septic tank, privy, etc.)*______ ______________.

10. Estimate percent connected to public sewerage system* ______________.

11. Estimate percent cost of impoarted materials for sewage treatment to the total cost* ____________________________.

12. Estimate percent cost of imported materials for water treatment to the total cost* _________________.

13. Average annual income in local currency ______________ or U. S. dollars ______________.

14. Estimate percent of national literacy _______________.

15. Estimate percent of public stand post* ____________________________.

16. Estimate percent number of home connected water supply* ____________.

Please do not hesitate to send any information on water and waste treatment in your country which you feel might be of help in our studies.

Would you like to have a final report of the study? ______ yes ______ no

Name and Title of individual completing questionnaire ____________________

____

Address ____

___________________________________ Date _______________________________

* If local data are not available, give national data.

TABLE VII - WATER TREATMENT PROCESSES

(AID - UNIVERSITY OF OKLAHOMA LDC PROJECT)

Name of the Country____________________________

Name of City or Town							
Population							
Year Construction Completed							
Type of Treatment Plant (e.g. slow sand filter or rapid sand filter)							
Population Served***							
Design Capacity Million Gallons per Day (MGD)							
Construction Cost (in local currency or U.S. dollars)***							
Operation & Maintenance Cost/Year (in local currency or U.S. dollars)***							

* If design capacity is in metric system please indicate

** Please indicate currency

*** Is population served (population of the city) same as design population? Yes________ No________ If no, what is the numbers________________________

TABLE VIII. WASTEWATER TREATMENT PROCESSES

(AID - UNIVERSITY OF OKLAHOMA LDC PROJECT)

Name of the Country ______________________________

Name of City or Town							
Population							
Year Construction Completed							
Type of Treatment Plant (e.g. Lagoon Activated Sludge, etc.)							
Population Served***							
Flow into Treatment Plant							
5 Days BOD of Inffluent							
5-Day BOD of Effluent							
Construction Cost (in local currency or U.S. Dollars)***							
Operation & Maintenance Cost per Year (in local currency or U. S. dollars)***							

to local government offices (capita city or provincial city) and one to those national government agencies dealing with water supply and waste water disposal.

In sampling there always exists the risk, in making an estimate from data, that a particular sample is not truly representative of the universal population under study. The risk can be minimized by the application of probability sampling methods and appropriate estimation techniques, and also by taking a larger sample than originally called for (50).

Stratified random sampling, as used in this study requires that the samplier have prior knowledge about the population with respect to various categories or strata.

The sampling process involves a number of assumptions about variables in the universe, as follows:

1. The dependent variable is a random series with a probability distribution.
2. The independent variables are either fixed constantly random series with probability distribution.
3. The dependent and independent variables are random series each with a normal distribution, and, hence, there is joint multivariable normal distribution.
4. Further assumptions are required for the stochastic variable, for testing and estimation.

The multicolinearity is defined as the intercorrelation among independent variables. When independent variables are intercorrelated, it is difficult to disentangle them in order to get precise and separate estimates of their relative effects upon the dependent variable. On the other hand, as the correlation between independent variables increases, estimates move further away from their association parameters. As such, the larger the multicolinearity, the larger the sampling errors, and the smaller the reliability and the precision of the estimates. Two of the very few things which can be done to minimize the multicollinearity are:

1. Specify variables in the model which are known to be related;
2. Check for variables in the model which have the same meaning and eliminate them.

A variable represents a number of values in an analysis characterized by a fluctuation in its size or magnitude. Variables are classified as dependent ($Y_1 \ldots Y_n$) or independent ($X_1 \ldots X_n$). If two variables are so related that when X is given, Y can be determined, then Y is said to be a function of X.

Thus the general statement for any fucntional relation for a single independent variable is given by:

$$Y = f(X) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (4\text{-}3)$$

and for more than one independent variables is given by:

$$Y = f(X_1, X_2, \ldots X_n) \qquad \ldots\ldots\ldots\ldots\ldots \qquad (4\text{-}4)$$

To estimate the sample size of this study the Newman allocation method (51) was used. The sample size n is defined by the following:

$$n_s = \frac{N_s S_s \cdot n}{\Sigma(N_s S_s)}$$

where . . . . (4-5)

n_s= Sample size required for the Sth stratum

S_s= Sample estimate of the standard deviation

n = Number of observation required

N_s= The size of the Sth stratum

An estimated variance within each stratum was necessary to compute the sample size. In this study a random size between 25 and 35 was used to estimate the variance of each stratum and finally n is computed by the following (52):

$$n = \frac{(\Sigma N_s S_s)}{\Sigma N_s S_s^2 + N^2 V^2} \quad . . . . \quad (4\text{-}6)$$

where: N = total population size

V = desired variance

V^2 is defined by the following:

$$V^2 = \frac{d^2}{t^2} \quad . . . . \quad (4\text{-}7)$$

where: d = half width of the required confidence interval

t = level of reliability

Using the required precision and the estimates of the variances, the number of observations required were computed. As indicated before the questionnaire was designed carefully in such a way that it would give the required variables or the information to be used to calculate unknown variables. Table IX shows the number of the questionnaires sent and the percent received from each three principle regions. Also on Table IX is

TABLE IX: DISTRIBUTION OF THE COUNTRIES SURVEYED AND SAMPLE DISTRIBUTION

Region / Country	AFRICA			ASIA		LATIN AMERICA	
	East and Central	West	North	Far East	Middle East	Central and West Indies	South
Zaire	●						
Kenya	●						
Zambia	●						
Malawi	●						
Nigeria		●					
Ghana		●					
Uganda	●						
Sudan	●						
Ivory Coast		●					
Central Africa	●						
Libya			●				
Egypt			●				
Morocco			●				
Tunisia			●				
Algeria			●				
Cameroon	●						
Ethiopia	●						
Somali	●						
Malagasy	●						
Liberia		●					
Sierra Leone		●					
Gabon	●						
Mozambique	●						
Rwanda	●						
Mali		●					
Singapore				●			
South Korea				●			
Burma				●			
Taiwan				●			
Pakistan				●			
Philippines				●			
Afghanistan				●			
Viet Nam				●			
Laos				●			
Cyprus					●		
Iran					●		
Saudi Arabia					●		
Syria					●		
India				●			
Indonesia				●			
Thailand				●			
Lebon					●		
Jordan					●		
Turkey					●		
Barbados						●	
Panama						●	
Jaimaca						●	
Venezuela							●
Guyana							●
Paraquay							●
Uruquay							●
Argentina							●
Mexico						●	
Costa Rica						●	
Trinidad-						●	
Tobago						●	
Puerto Rico						●	
El Salvador						●	
Haiti						●	
Guatemala						●	
Brazil							●
Colombia							●
Peru							●
Chile							●
Bolivia							●
Number of questionnaires sent	50			59		40	
Number of questionnaires received	43			40		25	
% of the questionnaires received	86			67		62	
Sample number needed	90			75		65	
Sample number received	60			40		32	
Sample number from Literature	43			38		25	

the data found in the literature survey*. Using these sample data the partial regression coefficients for the following linear equations were computed for each submodel. The form which gave the best fit was used as the predictive equation.

The following forms of equations were tested to establish the best predictive equation.

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}8)$$

$$\ln Y = b_0 + \sum_{i=1}^{k} b_i \ln X_i \quad \ldots\ldots\ldots\ldots\ldots \quad (4\text{-}9)$$

$$\frac{1}{\ln Y} = b_0 + \sum_{i=1}^{k} b_i \ln X_i \quad \ldots\ldots\ldots\ldots\ldots \quad (4\text{-}10)$$

$$\ln Y = b_0 + \sum_{i=1}^{k} b_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}11)$$

$$\frac{1}{Y} = b_0 + \sum_{i=1}^{k} b_i X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4\text{-}12)$$

where: Y = dependent variable like Dw, Dww, Cw, Cww in this study

X_i = independent variables like X_1, X_2 . . . X_{22}

b_i = partial regression coefficient

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* A visit was made to AID - Reference Center in Washington, D. C., to the Pan American Health Organization (PAHO) office, to the World Bank and to the United Nations, Office of Energy and Natural Resources in May of 1975.

CHAPTER V

RESULT OF DATA ANALYSIS

After receiving the data as a result of mail and literature surveys, multiple regression analysis were performed. As previously indicated in Chapter Iv, the questionnaires were both sent to the national and local agencies dealing with water supply and waste disposal. Other questionnaires were also sent to WHO regional offices and several universities. The data from literature surveys were tested against the mail surveyed data before final analysis was performed.

Many of the questionnaires received did not include BOD information. Some countries reported in the questionnaires that waste water disposal was not yet developed and thus they could not supply data on waste water disposal.

Predictive Equations

To develop the predictive equations for water demand, waste water disposal, cost of water and waste water treatment, multiple regression analysis was used. Regression equations using all possible and reasonable combination of variables were developed. Variables used in the regression for both four models are shown on Figure 1 in Chapter I. The criteria discussed in Chapter III, were used to develop and evaluate the predictive equations. The sequential F-test using five percent significant level, the coefficient of determination (R^2) and other criterias discussed in Chapter III were used to evaluate regression equations. The discussion of the equations derived for water demand, waste water disposal, cost of water and waste water treatment in developing countries is presented below.

Water Demand Model

In developed countries where data are abundant and where water demand information is readily available, the problem associated with evaluating the design capacity is usually not too serious. Since a large proportion of water supply is in the nature of expansion rather than new supply, it is usually possible to analyze meter records to obtain indications of per capita water demand.

Such is not the case, however, in developing countries. These systems are generally new and hence historical demand records do not exist. In this situation what is often done is to use per capita demand which has been found to exist in developed countries. These rough estimates which are often inappropriate for specific design situations since socio-economic conditions of a community in a developed country are often significantly different from those of a community in a developing country. Furthermore water systems in developing countries primarily serve domestic needs, while systems in developed countries additionally meet large commercial and town irrigation demands.

Therefore, because of the difference in planning conditions, it is generally recognized that developed countries criteria will not produce optimal designs in developing countries.

The primary concern of this part of the model was to develop water demand predictive equations utilizing socio-economic, environmental and technological variables from developing countries. Data from developing countries were analyzed using eight independent variables as shown in Figure 1, Chapter I. The sequential F-test indicated the non-significance of variable X_1. Furthermore there was no improvement of the regression equations with the temperature (X_7) and precipitation (X_8).

There was a good correlation between water usage with variables X_2, X_5, and X_6. In the United States, the Reid study (9) showed precipitation, income, population and the lifestyle as the indicators of water usage.

Equations for predicting water demand for three regions (Africa, Asia, and Latin America) are presented below.

$$D_{w.af} = 22.0341 + 0.0973\,X_2 \qquad (*)\ (**) \quad R^2 = 0.953 \qquad (5\text{-}1)$$

$$\begin{aligned} D_{w.af} &= 12.7200 + 0.0683\,X_2 \\ &\quad + 0.0142\,X_6 \qquad (*)\ (**) \quad R^2 = 0.968 \qquad (5\text{-}2) \end{aligned}$$

$$D_{w.as} = 7.1476 + 0.0827\,X_2 \qquad (*)\ (**) \quad R^2 = 0.902 \qquad (5\text{-}3)$$

$$\begin{aligned} D_{w.as} &= 6.6817 + 0.04597\,X_2 \qquad (*)\ (**) \quad R^2 = 0.953 \\ &\quad + 0.2204\,X_5 + 0.0263\,X_6 \qquad (*)\ (**) \quad R^2 = 0.968 \qquad (5\text{-}4) \end{aligned}$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$D_{w.la} = 15.3981 + 0.0663\ X_2 \qquad (*)\ (**)\quad R^2 = 0.810 \qquad (5\text{-}5)$$

$$D_{w.la} = 13.7401 + 0.0645\ X_2 + 0.0682\ X_5 + 0.0330\ X_6 \qquad (*)\ (**)\quad R^2 = 0.897 \qquad (5\text{-}6)$$

where: $D_{w.af}$ = Water demand in Africa in gallons per capita per day (gpcd)

$D_{w.as}$ = Water demand in Asia in gpcd

$D_{w.la}$ = Water demand in Latin America in gpcd

X_2 = Population of the community served by water supply in thousands

X_5 = Percentage of home connected to water supply systems

X_6 = Average national annual income in U. S. dollars

Waste Water Disposal Model

To obtain optimum design of waste water treatment plants, the amount of sewage provided must be estimated. Developed countries use seventy-five percent of water demand as a criteria for designing waste water plants. This criteria may be not applicable to developing countries. Before design can be undertaken, the amount of sewage must be provided. So the primary purpose of this part of the model was to develop predictive equations for predicting the amount of sewage produced per capita per day.

Sample sizes of 49, 55, and 46 were used in this model. Variables X_9 and X_{12} were non-significance. Good correlation between per capita waste water disposal and variables D_w, X_{10} and X_{11} were obtained. Applying the sequential F-test, equations (5-7), (5-8), (5-9), (5-10),(5-11) and (5-12) contained the accepted variables.

Equations for predicting per capita waste water discharged daily are given as follows:

$$D_{ww.af} = 0.2840 + 0.6670\ D_w \qquad (*)\ (**)\quad R^2 = 0.890 \qquad (5\text{-}7)$$

$$D_{ww.af} = 0.6442 + 0.4614\ D_w + 0.0079\ X_{10} - 0.0341\ X_{11} \qquad (*)\ (**)\quad R^2 = 0.960 \qquad (5\text{-}8)$$

$$D_{ww.as} = 0.7266 + 0.7399\ D_w \qquad (*)\ (**)\quad R^2 = 0.908 \qquad (5\text{-}9)$$

$$D_{ww.as} = 0.993 + 0.4614\ D_w + 0.0047\ X_{10} \qquad (*)\ (**)\quad R^2 = 0.952 \qquad (5\text{-}10)$$

$$D_{ww.la} = 0.1652 + 0.7508\ D_w \qquad (*)\ (**)\quad R^2 = 0.990 \qquad (5\text{-}11)$$

$$D_{ww.la} = 0.1835 + 0.6164\ D_w - 0.0368\ X_{11} \qquad (*)\ (**)\quad R^2 = 0.999 \qquad (5\text{-}12)$$

where: $D_{ww.af}$ = Waste water disposal in Africa in gallons per capita per day (gpcd)

$D_{ww.as}$ = Waste water disposal in Asia in gpcd

$D_{ww.la}$ = Waste water disposal in Latin America in gpcd

D_w = Water demand in gallons per capita per day

X_{10} = Percentage connected to public sewerage system

X_{11} = Percentage of household system

Water Treatment Cost Model

Costs data on water construction, operation, and maintenance were analyzed after all the cost has been projected to U.S. dollars using

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

International Financial Statistics (51) and then projected to 1975 U.S. dollars assuming 6½% annual inflation. An examination of the correlation matrix indicated a high correlation between D_w and X_{15} and therefore only one variable was used in each regression equation. Both equation predicting construction cost per capita (C'_w) and per MGD (C''_w) designed were evaluated. Also operation and maintenance cost per capita (C'''_w) per year and per MGD per year (C''''_w) were evaluted for both slow and rapid sand filter processes.

A sequential F-test justified the acceptance of each variable into the regression equations. In all regions good correlations were obtained using water demand (D_w), technological indicator (X_{13}), population (X_{14}) and design capacity (X_{15}). The logarithmic transformation of variables gave the best fit.

The best fit equations for predicting construction, operation and maintenance costs for slow sand filter are as follows:

$$\ell_n C'_{w.af} = 2.6436 + 0.0988\, \ell_n D_w - 0.20651\, \ell_n X_{14} \qquad (*)\ (**)\quad R^2 = 0.810 \qquad (5\text{-}13)$$

$$\ell_n C''_{w.af} = 3.4537 + 0.0089\, \ell_n D_w - 0.1321\, \ell_n X_{14} \qquad (*)\ (**)\quad R^2 = 0.806 \qquad (5\text{-}14)$$

$$\ell_n C'''_{w.af} = 0.4346 + 0.0160\, \ell_n D_w - 0.3628\, \ell_n X_{14} \qquad (*)\ (**)\quad R^2 = 0.756 \qquad (5\text{-}15)$$

---

* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$\ell_n C''''_{w.af} = 1.6217 - 0.6203 \ell_n X_{15} \quad (*) \; (**) \; R^2 = 0.865 \qquad (5\text{-}16)$$

$$\begin{aligned} \ell_n C'_{w.as} &= 2.7436 + 0.0088 \ell_n D_w \\ &\quad - 0.1065 \ell_n X_{14} \quad (*) \; (**) \; R^2 = 0.887 \qquad (5\text{-}17) \end{aligned}$$

$$\begin{aligned} \ell_n C''_{w.as} &= 3.6044 + 0.0100 \ell_n X_{13} \\ &\quad - 0.1065 \ell_n X_{15} \quad (*) \; (**) \; R^2 = 0.876 \qquad (5\text{-}18) \end{aligned}$$

$$\ell_n C'''_{w.as} = 0.5017 - 0.0751 \ell_n X_{14} \quad (*) \; (**) \; R^2 = 0.770 \qquad (5\text{-}19)$$

$$\begin{aligned} \ell_n C''''_{w.as} &= 2.1243 - 0.1018 \ell_n X_{14} \\ &\quad - 0.4891 \ell_n X_{15} \quad (*) \; (**) \; R^2 = 0.902 \qquad (5\text{-}20) \end{aligned}$$

$$\begin{aligned} \ell_n C'_{w.la} &= 2.5461 + 0.0096 \ell_n X_{13} \\ &\quad - 0.3628 \ell_n X_{14} \quad (*) \; (**) \; R^2 = 0.640 \qquad (5\text{-}21) \end{aligned}$$

$$\ell_n C''_{w.la} = 3.7997 - 0.0799 \ell_n X_{14} \quad (*) \; (**) \; R^2 = 0.592 \qquad (5\text{-}22)$$

$$\ell_n C'''_{w.la} = 0.3559 - 0.1511 \ell_n X_{14} \quad (*) \; (**) \; R^2 = 0.804 \qquad (5\text{-}23)$$

$$\begin{aligned} \ell_n C''''_{w.la} &= 1.6751 + 0.0016 \ell_n X_{13} \\ &\quad - 0.6315 \ell_n X_{15} \quad (*) \; (**) \; R^2 = 0.579 \qquad (5\text{-}24) \end{aligned}$$

where: $C'_{w.af}$ = Per capita construction cost in Africa in U.S. dollars

$C''_{w.af}$ = Per MGD construction cost in Africa in thousand U.S. dollars

$C'''_{w.af}$ = Per capita operation and maintenance cost in Africa in U.S. dollars per year

$C''''_{w.af}$ = Per MGD operation and maintenance cost in Africa in thousand U.S. dollars per year

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$C'_{w.as}$ = Per capita construction cost in Asia in U.S. dollars

$C''_{w.as}$ = Per MGD construction cost in Asia in thousand U.S. dollars

$C'''_{w.as}$ = Per capita operation and maintenance cost in Asia in U.S. dollars per year

$C''''_{w.as}$ = Per MGD operation and maintenance cost in Asia in thousand U.S. dollars per year

$C'_{w.la}$ = Per capita construction cost in Latin America in U.S. dollars

$C''_{w.la}$ = Per MGD construction cost in Latin America in thousand U.S. dollars

$C'''_{w.la}$ = Per capita operation and maintenance cost in Latin America in U.S. dollars per year

$C''''_{w.la}$ = Per MGD operation and maintenance cost in Latin America in thousand U.S. dollars per year

D_w = Water demand in gallons per capita per day

X_{13} = Percentage cost of imported water supply materials

X_{14} = Design population for water supply in 1000

X_{15} = Design capacity for water supply in Million Gallons per Day (MGD)

Equations for predicting construction, maintenance and operation costs of rapid sand filter are as follows:

$$\ell_n C'_{w.af} = 3.1325 + 0.0024\, \ell_n D_w - 0.885\, \ell_n X_{14} \qquad (*)\ (**)\ R^2 = 0.902 \qquad (5\text{-}25)$$

$$\ell_n C''_{w.af} = 5.8975 + 0.0097\, \ell_n X_{13} - 0.0127\, \ell_n X_{14} \qquad (*)\ (**)\ R^2 = 0.859 \qquad (5\text{-}26)$$

$$\ell_n C'''_{w.af} = 1.9229 + 0.0396\, \ell_n D_w - 0.2596\, \ell_n X_{14} \qquad (*)\ (**)\ R^2 = 0.953 \qquad (5\text{-}27)$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination.

$$\begin{aligned}\ell_n C''''_{w.af} &= 4.7581 + 0.023\ \ell_n X_{13}\\ &\quad - 0.0370\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.865 \qquad (5\text{-}28)\end{aligned}$$

$$\begin{aligned}\ell_n C'_{w.as} &= 3.3160 + 0.0017\ \ell_n X_{13}\\ &\quad - 0.0901\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.870 \qquad (5\text{-}29)\end{aligned}$$

$$\begin{aligned}\ell_n C''_{w.as} &= 6.3884 + 0.0065\ \ell_n X_{13}\\ &\quad - 0.0380\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.877 \qquad (5\text{-}30)\end{aligned}$$

$$\begin{aligned}\ell_n C'''_{w.as} &= 2.7466 + 0.0088\ \ell_n D_w\\ &\quad - 0.2065\ \ell_n X_{14} \qquad (*)\ (**)\ R^2 = 0.940 \qquad (5\text{-}31)\end{aligned}$$

$$\begin{aligned}\ell_n C''''_{w.as} &= 5.0991 + 0.0248\ \ell_n X_{13}\\ &\quad - 0.0553\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.902 \qquad (5\text{-}32)\end{aligned}$$

$$\begin{aligned}\ell_n C'_{w.la} &= 3.4597 + 0.0021\ \ell_n X_{13}\\ &\quad - 0.0901\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.876 \qquad (5\text{-}33)\end{aligned}$$

$$\begin{aligned}\ell_n C''_{w.la} &= 6.1328 + 0.0027\ \ell_n X_{14}\\ &\quad - 0.0236\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.960 \qquad (5\text{-}34)\end{aligned}$$

$$\begin{aligned}\ell_n C'''_{w.la} &= 2.0127 + 0.0238\ \ell_n X_{13}\\ &\quad - 0.3007\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.897 \qquad (5\text{-}35)\end{aligned}$$

$$\begin{aligned}\ell_n C''''_{w.la} &= 4.7829 + 0.0448\ \ell_n X_{13}\\ &\quad - 0.0530\ \ell_n X_{15} \qquad (*)\ (**)\ R^2 = 0.968 \qquad (5\text{-}36)\end{aligned}$$

where: $C'_{w.af}$ = Per capita construction cost in Africa in U. S. dollars

$C''_{w.af}$ = Per MGD construction cost in Africa in thousand U.S. dollars

$C'''_{w.af}$ = Per Capita operation and maintenance cost in Africa in U. S. dollars per year

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$C''''_{w.af}$ = Per MGD operation and maintenance cost in Africa in thousand U.S. dollars per year

$C'_{w.as}$ = Per capita construction cost in Asia in U.S. dollars

$C''_{w.as}$ = Per MGD construction cost in Asia in thousand U.S. dollars

$C'''_{w.as}$ = Per capita operation and maintenance cost in Asia in U.S. dollars per year

$C''''_{w.as}$ = Per MGD operation and maintenance cost in Asia in thousand U.S. dollars per year

$C'_{w.la}$ = Per capita construction cost in Latin America in U.S. dollars

$C''_{w.la}$ = Per MGD construction cost in Latin America in thousands U.S. dollars

$C'''_{w.la}$ = Per capita operation and maintenance cost in Latin American in U.S. dollars per year

$C''''_{w.la}$ = Per MGD operation and maintenance cost in Latin America in thousand U.S. dollars per year

D_w = Water demand in gallons per capita per day

X_{13} = Percentage cost of imported water supply materials

X_{14} = Design population for water supply in 1000

X_{15} = Design capacity for water supply in million gallons per day (MGD)

Waste Water Treatment Cost Model

The last set of predictive equations were developed for construction, operation and maintenance costs of waste water treatment for the three regions using eight independent variables as shown previously on Figure 1 in Chapter 1. Variables X_{17}, X_{18}, X_{19} and X_{22} were non-significant since most of the waste water plants did not provide influent and effluent BOD values. The variables X_{16} and X_{20} gave the best correlation for all the waste water treatment processes (stabilization lagoon, aerated lagoon, activated sludge and trickling filter). The technological indicator (X_{21}) appeared in the regression equations of advanced waste water treatment processes (aerated lagoon, activated sludge, and trickling filter) especially in the operation and the maintenance equations.

The conclusion is that in the developing countries machines such as aerators, motors, and chemicals have to be imported for these high technology processes. Therefore, in developing countries where land is cheaper the stabilization lagoons or other land type processes are the appropriate technology. Using the F-test and R^2 as criterias the following equations were developed.

The best fit equations for predicting construction, operation and maintenance costs of stabilization lagoon are:

$$\ell_n C'_{ww.af} = 1.3955 - 0.1845\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.980 \qquad (5\text{-}37)$$

$$\ell_n C''_{ww.af} = 4.0770 - 0.0440\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.826 \qquad (5\text{-}38)$$

$$\ell_n C'''_{ww.af} = -\ 0.2532 - 0.2837\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.917 \qquad (5\text{-}39)$$

$$\begin{aligned}\ell_n C''''_{ww.af} &= 2.0967 - 0.2683\ \ell_n X_{16} \\ &\quad - 0.0345\ \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.864 \qquad (5\text{-}40)\end{aligned}$$

$$\ell_n C'_{ww.as} = 1.5304 - 0.2152\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.806 \qquad (5\text{-}41)$$

$$\ell_n C''_{ww.as} = 4.9849 - 0.2594\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.980 \qquad (5\text{-}42)$$

$$\ell_n C'''_{ww.as} = -0.3274 - 0.1846\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.788 \qquad (5\text{-}43)$$

$$\ell_n C''''_{ww.as} = 2.2242 - 0.0035\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.784 \qquad (5\text{-}44)$$

$$\ell_n C'_{ww.la} = 1.7880 - 0.0979\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.810 \qquad (5\text{-}45)$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$\ell_n C''_{ww.la} = 4.6571 - 0.0079 \ell_n X_{16} - 0.0043 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.960 \qquad (5\text{-}46)$$

$$\ell_n C'''_{ww.la} = 0.2597 - 0.0879 \ell_n X16 \quad (*)\ (**)\ R^2 = 0.806 \qquad (5\text{-}47)$$

$$\ell_n C''''_{ww.la} = 2.5720 - 0.2160 \ell_n X_{16} - 0.0024 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.848 \qquad (5\text{-}48)$$

Equations for predicting construction, operation and maintenance costs of aerated lagoon are as follows:

$$\ell_n C'_{ww.af} = 1.4768 - 0.1132 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.990 \qquad (5\text{-}49)$$

$$\ell_n C''_{ww.af} = 4.8764 - 0.0025 \ell_n X_{16} - 0.1214 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.861 \qquad (5\text{-}50)$$

$$\ell_n C'''_{ww.af} = 0.1136 - 0.1435 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.865 \qquad (5\text{-}51)$$

$$\ell_n C''''_{ww.af} = 3.7754 - 0.2854 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.853 \qquad (5\text{-}52)$$

$$\ell_n C'_{ww.as} = 1.6395 - 0.1565 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.898 \qquad (5\text{-}53)$$

$$\ell_n C''_{ww.as} = 5.0595 - 0.0475 \ell_n X_{16} - 0.2105 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.988 \qquad (5\text{-}54)$$

$$\ell_n C'''_{ww.as} = 0.3561 - 0.0955 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.958 \qquad (5\text{-}55)$$

$$\ell_n C''''_{ww.as} = 3.9509 - 0.2170 \ell_n X_{20} + 0.0032 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.853 \qquad (5\text{-}56)$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$\ell_n C'_{ww.la} = 1.7581 - 0.1461 \ell_n X_{16} \qquad (5\text{-}57)$$

$$\ell_n C''_{ww.la} = 5.4210 - 0.1645 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.956 \qquad (5\text{-}58)$$

$$\ell_n C'''_{ww.la} = 0.21149 - 0.1600 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.921 \qquad (5\text{-}59)$$

$$\ell n\, C''''_{ww.la} = 4.023 - 0.3659 \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.948 \qquad (5\text{-}60)$$

Equations for predicting construction, operation and maintenance cost of activated sludge are as follows:

$$\ell_n C'_{ww.af} = 3.0051 - 0.3090 \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.984 \qquad (5\text{-}61)$$

$$\begin{aligned} \ell_n C''_{ww.af} &= 6.5907 - 0.3020 \ell_n X_{20} \\ &\quad + 0.0021 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.917 \qquad (5\text{-}62) \end{aligned}$$

$$\begin{aligned} \ell_n C'''_{ww.af} &= 1.5225 - 0.3307 \ell_n X_{16} \\ &\quad + 0.0032 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.960 \qquad (5\text{-}63) \end{aligned}$$

$$\ell_n C''''_{ww.af} = 5.1250 - 0.3355 \ell_n X_{20} \qquad (5\text{-}64)$$

$$\begin{aligned} \ell_n C'_{ww.as} &= 2.8597 - 0.2890 \ell_n X_{16} \\ &\quad + 0.0201 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.937 \qquad (5\text{-}65) \end{aligned}$$

$$\begin{aligned} \ell_n C''_{ww.as} &= 5.7594 - 0.2645 \ell_n X_{16} \\ &\quad + 0.2644 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.902 \qquad (5\text{-}66) \end{aligned}$$

$$\begin{aligned} \ell_n C'''_{ww.as} &= 1.7534 - 0.4269 \ell_n X_{16} \\ &\quad + 0.0021 \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.948 \qquad (5\text{-}67) \end{aligned}$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$\begin{aligned}\ell_n C''''_{ww.as} &= 4.9224 - 0.2754\ \ell_n X_{16} \\ &\quad + 0.0021\ \ell_n X_{21} \qquad (*)\ (**)\ R^2 = 0.948 \qquad (5\text{-}68)\end{aligned}$$

$$\ell_n C'_{ww.la} = 2.8967 - 0.2709\ \ell_n X_{16} \qquad (*)\ (**)\ R^2 = 0.940 \qquad (5\text{-}69)$$

$$\begin{aligned}\ell_n C''_{ww.la} &= 7.2754 - 0.0035\ \ell_n X_{16} \\ &\quad - 0.3575\ \ell_n X_{20} \qquad (*)\ (**)\ R^2 = 0.968 \qquad (5\text{-}70)\end{aligned}$$

$$\ell_n C'''_{ww.la} = 1.7526 - 0.4002\ \ell_n X_{16} \qquad (*)\ (**)\ R^2 = 0.887 \qquad (5\text{-}71)$$

$$\begin{aligned}\ell_n C''''_{ww.la} &= 5.6075 - 0.0073\ \ell_n X_{16} \\ &\quad - 0.3902\ \ell_n X_{20} \qquad (*)\ (**)\ R^2 = 0.865 \qquad (5\text{-}72)\end{aligned}$$

Equations for predicting construction, operation and maintenance cost of trickling filter are as follows:

$$\ell_n C'_{ww.af} = 3.1058 - 0.2546\ \ell_n X_{16} \qquad (*)\ (**)\ R^2 = 0.938 \qquad (5\text{-}73)$$

$$\ell_n C''_{ww.af} = 7.2400 - 0.5503\ \ell_n X_{20} \qquad (*)\ (**)\ R^2 = 0.966 \qquad (5\text{-}74)$$

$$\ell_n C'''_{ww.af} = 1.5591 - 0.3105\ \ell_n X_{16} \qquad (*)\ (**)\ R^2 = 0.910 \qquad (5\text{-}75)$$

$$\begin{aligned}\ell_n C''''_{ww.af} &= 5.1240 - 0.3355\ \ell_n X_{20} \\ &\quad + 0.0024\ \ell_n X_{21} \qquad (*)\ (**)\ R^2 = 0.958 \qquad (5\text{-}76)\end{aligned}$$

$$\begin{aligned}\ell_n C'_{ww.as} &= 3.0021 - 0.3410\ \ell_n X_{16} \\ &\quad + 0.0124\ \ell_n X_{21} \qquad (*)\ (**)\ R^2 = 0.966 \qquad (5\text{-}77)\end{aligned}$$

$$\ell_n C''_{ww.as} = 7.0453 - 0.5709\ \ell_n X_{20} \qquad (*)\ (**)\ R^2 = 0.940 \qquad (5\text{-}78)$$

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$$\ell_n C'''_{ww.as} = 1.8641 - 0.3507\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.913 \qquad (5\text{-}79)$$

$$\ell_n C''''_{ww.as} = 5.2594 - 0.2659\ \ell_n X_{16} + 0.0211\ \ell_n X_{21} \quad (*)\ (**)\ R^2 = 0.896 \qquad (5\text{-}80)$$

$$\ell_n C'_{ww.la} = 3.3345 - 0.2491\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.929 \qquad (5\text{-}81)$$

$$\ell_n C''_{ww.la} = 6.9852 - 0.3294\ \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.958 \qquad (5\text{-}82)$$

$$\ell_n C'''_{ww.la} = 1.7543 - 0.2009\ \ell_n X_{16} \quad (*)\ (**)\ R^2 = 0.937 \qquad (5\text{-}83)$$

$$\ell_n C''''_{ww.la} = 5.975 - 0.2956\ \ell_n X_{20} \quad (*)\ (**)\ R^2 = 0.900 \qquad (5\text{-}84)$$

where: $C'_{ww.af}$ = Per capita construction cost in Africa in U.S. dollars

$C''_{ww.af}$ = Per MGD construction cost in Africa in thousands U.S. dollars

$C'''_{ww.af}$ = Per capita operation and maintenance cost in Africa in U.S. dollars per year

$C''''_{ww.af}$ = Per MGD operation and maintenance cost in thousands U.S. dollars per year

$C'_{ww.as}$ = Per capita construction cost in Asia in U.S. dollars

$C''_{ww.as}$ = Per MGD construction cost in Asia in thousands U.S. dollars

$C'''_{ww.as}$ = Per capita operation and maintenance cost in Asia in U. S. dollars per year

$C''''_{ww.as}$ = Per MGD operation and maintenance cost in Asia in thousands U.S. dollars per year

$C'_{ww.la}$ = Per capita construction cost in Latin America in U.S. dollars

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

$C''_{ww.la}$ = Per MGD construction cost in Latin America in thousands U. S. dollars

$C'''_{ww.la}$ = Per capita operation and maintenance cost in Latin America in U.S. dollars per year

$C''''_{ww.la}$ = Per MGD operation and maintenance cost in Latin America in thousands U.S. dollars per year

X_{16} = Design population for waste water in 1000

X_{20} = Design flow of waste water plant in MGD

X_{21} = Percent of cost of imported waste water disposal materials

Of the various forms of equations described in Chapter IV, the non-logarithmic linear form resulted in better predictive equations in water demand and waste water disposal models with higher R^2 and satisfied the sequential F-test criteria. The log - log linear form gave better predictive equations in water and waste water treatment cost models. In almost all cases, the rapid sand filter construction, operation and maintenance costs were correlated with variable X_{13} while activated sludge and trickling filter were correlated with variable X_{21}. This shows that a great abundance of materials have to be imported for constructing, operating and maintaining these high technology processes.

In Tables X, XI, XII, and XIII correlation matrices, degrees of freedom, deviations, residual mean squares (RESMS) are given for estimating standard errors of estimated expected values with ninty-five percent confidence interval.

Table XIV shows typical construction, operation and maintenance costs of slow sand and rapid sand filters for selected socio-economic and technological conditions using the predictive equations. Table XV gives comparison costs of waste water treatment processes for the study done in India (6) and the predictive equations developed as a result of this study.

TABLE X

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WATER DEMAND MODEL

		CORRELATION MATRIX C_{ij}						DEVIATIONS				
		C_{22}	C_{55}	C_{66}	C_{25}	C_{26}	C_{56}	X_2	X_5	X_6	Resms	N
WATER DEMAND MODEL	$D_{w.af}$	0.0002	-0.0005	0.0001	0.0016	0.0000	-0.0012	$X_2-(1050)$	$X_5-(-19)$	$X_6-(-500)$	0.2231	89
	$D_{w.a}$	0.0000	0.0015	0.0000	-0.0001	0.0000	0.0002	$X_2-(875)$	$X_5-(-38)$	$X_6-(-350)$	0.2001	70
	$D_{w.la}$	0.0000	0.0022	0.0000	-0.0001	0.0001	-0.0001	$X_2-(+25)$	$X_5-(-49)$	$X_6-(-55)$	0.1167	65

Standard error of estimated expected values:

$$S_{D_{w.af}}=\pm t_{.95,df}\left[\text{Resms}\left(\frac{1}{n}+C_{22}X^2{}_2+C_{66}X^2{}_6+2C_{26}X_2X_6\right)\right]^{\frac{1}{2}}$$

df=N-V-1
=89-2-1
=86

$$S_{D_{w.as}}=\pm t_{.95,df}\left[\text{Resms}\left(\frac{1}{n}+C_{22}X^2{}_2+C_{55}X^2{}_5+C_{66}X^2{}_6+2C_{25}X_2X_5+2C_{26}X_2X_6+2C_{56}X_5X_6\right)\right]^{\frac{1}{2}}$$

df=66

$$S_{D_{w.la}}=\pm t_{.95,df}\left[\text{Resms}\left(\frac{1}{n}+C_{22}X^2{}_2+C_{55}X^2{}_5+C_{66}X^2{}_6+2C_{25}X_2X_5+2C_{26}X_2X_6+2C_{56}X_5X_6\right)\right]^{\frac{1}{2}}$$

df=61

TABLE XI

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WASTE WATER DISPOSAL

		CORRELATION MATRIX C_{ij}						DEVIATIONS			Resms	N
		C_{ww}	$C_{10\ 10}$	$C_{11\ 11}$	$C_{w\ 10}$	$C_{w\ 11}$	$C_{10\ 11}$	d_w	X_{10}	X_{11}		
WASTE WATER DISPOSAL MODEL	$D_{ww.af}$	0.0024	0.0016	0.0000	-0.000	0.000	0.0001	$D_w-(6.5)$	$X_{10}-(4.5)$	$X_{11}-(7.5)$	0.2368	49
	$D_{ww.as}$	0.0032	0.0000	0.0003	0.0050	0.0011	0.0000	$D_w-(-4.5)$	$X_{10}-(-11.2$	$X_{11}-(13.9$	0.1274	55
	$D_{ww.la}$	0.0100	0.0022	0.0002	0.0009	0.0002	0.0000	$D_w-(4.8)$	$X_{10}-(-2.3)$	$X_{11}-(-3.9$	0.4509	46

Standard errors of estimated expected values

$S_{D_{ww.af}} = \pm t_{.95,df}\left[\mathrm{Resms}\left(\frac{1}{n}+C_{ww}d^2_w+C_{10\ 10}X^2_{10}+C_{11\ 11}X^2_{11}+2C_{w\ 10}d_wX_{10}+2C_{w\ 11}d_wX_{11}+2C_{10\ 11}X_{10}X_{11}\right)\right]^{\frac{1}{2}}$ df=45

$S_{D_{ww.as}} = \pm t_{.95,df}\left[\mathrm{Resms}\left(\frac{1}{n}+C_{ww}d^2_w+C_{10\ 10}X^2_{10}+C_{11\ 11}X^2_{11}+2C_{w\ 10}d_wX_{10}+2C_{w\ 11}d_wX_{11}+2C_{10\ 11}X_{10}X_{11}\right)\right]^{\frac{1}{2}}$ df=51

$S_{D_{ww.la}} = \pm t_{.95,df}\left[\mathrm{Resms}\left(\frac{1}{n}+C_{ww}d^2_w+C_{10\ 10}X^2_{10}+C_{11\ 11}X^2_{11}+2C_{w\ 10}d_wX_{10}+2C_{w\ 11}d_wX_{11}+2C_{10\ 11}X_{10}X_{11}\right)\right]^{\frac{1}{2}}$ df=42

TABLE XII

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WATER TREATMENT COST MODEL

		Correlation Matrix					c_{ij}					Deviations				Resms	N
		C_{ww}	$C_{13\ 13}$	$C_{14\ 14}$	$C_{15\ 15}$	$C_{w\ 13}$	$C_{w\ 14}$	$C_{w\ 15}$	$C_{13\ 14}$	$C_{13\ 15}$	$C_{14\ 15}$	d_w	x_{13}	x_{14}	x_{15}		
SLOW SAND FILTER	$C'_{ww.af}$	0.0005	0.0000	0.0040	0.0000	0.0001	0.0021	0.0003	0.0000	0.0006	0.0000	$\ln D_w-(-30)$	$\ln X_{13}-(-10)$	$\ln X_{14}-(-200)$	$\ln X_{15}-(-11)$	0.1750	65
	$C''_{ww,af}$	0.0003	0.0000	0.0031	0.0041	0.0010	0.0001	0.0000	0.0001	0.0000	0.0021	$\ln D_w-(-30)$	$\ln X_{13}-(-10)$	$\ln X_{14}-(-200)$	$\ln X_{15}-(-11)$	0.2650	65
	$C'''_{ww.af}$	0.0010	0.0011	0.0110	0.0000	0.0011	0.0010	0.0061	0.0018	0.0011	0.0044	$\ln D_w-(-30)$	$\ln X_{13}-(-10)$	$\ln X_{14}-(-200)$	$\ln X_{15}-(-11)$	0.1270	65
	$C''''_{ww.af}$	0.0006	0.0000	0.0127	0.0002	0.0021	0.0006	0.0021	0.0000	0.0000	0.0009	$\ln D_w-(-30)$	$\ln X_{13}-(-10)$	$\ln X_{14}-(-200)$	$\ln X_{15}-(-11)$	0.1350	65
	$C'_{ww.as}$	0.0000	0.0110	0.0101	0.0004	0.0000	0.0008	0.0013	0.0161	0.0016	0.0000	$\ln D_w-(+4.5)$	$\ln X_{13}-(-6)$	$\ln X_{14}-(-29)$	$\ln X_{15}-(-9)$	0.3450	49
	$C''_{ww.as}$	0.0001	0.0021	0.0000	0.0011	0.0001	0.0061	0.0005	0.0111	0.0000	0.0003	$\ln D_w-(+4.5)$	$\ln X_{13}-(-6)$	$\ln X_{14}-(-29)$	$\ln X_{15}-(-9)$	0.3050	49
	$C'''_{ww,as}$	0.0002	0.0003	0.0006	0.0031	0.0101	0.0000	0.0030	0.0016	0.0009	0.0004	$\ln D_w-(+4.5)$	$\ln X_{13}-(-6)$	$\ln X_{14}-(-29)$	$\ln X_{15}-(-9)$	0.2603	49
	$C''''_{ww.as}$	0.0009	0.0004	0.0104	0.0006	0.0000	0.0001	0.0008	0.0000	0.0006	0.0000	$\ln D_w-(+4.5)$	$\ln X_{13}-(-6)$	$\ln X_{14}-(-29)$	$\ln X_{15}-(-9)$	0.1017	49
	$C'_{ww.la}$	0.0013	0.0201	0.0000	0.0004	0.0003	0.0000	0.0000	0.0016	0.0021	0.0211	$\ln D_w-(-6.7)$	$\ln X_{13}-(-18)$	$\ln X_{14}-(-45)$	$\ln X_{15}-(-14)$	0.1920	39
	$C''_{ww.la}$	0.0030	0.0000	0.0600	0.0000	0.0001	0.0061	0.0037	0.0000	0.0111	0.0031	$\ln D_w-(-6.7)$	$\ln X_{13}-(-18)$	$\ln X_{14}-(-45)$	$\ln X_{15}-(-14)$	0.2001	39
	$C'''_{ww,la}$	0.0050	0.0000	0.0011	0.0041	0.0041	0.0004	0.0081	0.0061	0.0000	0.0046	$\ln D_w-(-6.7)$	$\ln X_{13}-(-18)$	$\ln X_{14}-(-45)$	$\ln X_{15}-(-14)$	0.1021	39
	$C''''_{ww.la}$	0.0031	0.0111	0.0009	0.0000	0.0011	0.0031	0.0000	0.0031	0.0000	0.0039	$\ln D_w-(-6.7)$	$\ln X_{13}-(-18)$	$\ln X_{14}-(-45)$	$\ln X_{15}-(-14)$	0.1450	39
RAPID SAND FILTER	$C'_{ww.af}$	0.0000	0.0034	0.0000	0.0034	0.0041	0.0004	0.0000	0.0041	0.0011	0.0006	$\ln D_w-(-5)$	$\ln X_{13}-(-25)$	$\ln X_{14}-(-15)$	$\ln X_{15}-(-8)$	0.1060	48
	$C''_{ww.af}$	0.0021	0.0017	0.0008	0.0000	0.0001	0.0036	0.0101	0.0064	0.0061	0.0031	$\ln D_w-(-5)$	$\ln X_{13}-(-25)$	$\ln X_{14}-(-15)$	$\ln X_{15}-(-8)$	0.1260	48
	$C'''_{ww,af}$	0.0000	0.0016	0.0000	0.0010	0.0011	0.0008	0.0003	0.0000	0.0094	0.0041	$\ln D_w-(-5)$	$\ln X_{13}-(-25)$	$\ln X_{14}-(-15)$	$\ln X_{15}-(-8)$	0.1102	48
	$C''''_{ww.af}$	0.0090	0.0000	0.0131	0.0000	0.0021	0.0031	0.0001	0.0011	0.0010	0.0000	$\ln D_w-(-5)$	$\ln X_{13}-(-25)$	$\ln X_{14}-(-15)$	$\ln X_{15}-(-8)$	0.1507	48
	$C'_{ww.as}$	0.0000	0.0000	0.0006	0.0020	0.0011	0.0000	0.0009	0.0004	0.0001	0.0061	$\ln D_w-(-12)$	$\ln X_{13}-(-3)$	$\ln X_{14}-(-23)$	$\ln X_{15}-(-4.4)$	0.1801	58
	$C''_{ww.as}$	0.0210	0.0000	0.0000	0.0009	0.0101	0.0008	0.0001	0.0061	0.0000	0.0031	$\ln D_w-(-12)$	$\ln X_{13}-(-3)$	$\ln X_{14}-(-23)$	$\ln X_{15}-(-4.4)$	0.2007	58
	$C'''_{ww,as}$	0.0121	0.0031	0.0401	0.0304	0.0000	0.0000	0.0021	0.0041	0.0116	0.0000	$\ln D_w-(-12)$	$\ln X_{13}-(-3)$	$\ln X_{14}-(-23)$	$\ln X_{15}-(-4.4)$	0.19007	58
	$C''''_{ww.as}$	0.0000	0.0131	0.0016	0.0000	0.0071	0.0009	0.0040	0.0009	0.0109	0.0017	$\ln D_w-(-12)$	$\ln X_{13}-(-3)$	$\ln X_{14}-(-23)$	$\ln X_{15}-(-4.4)$	0.1609	58
	$C'_{ww.la}$	0.0000	0.0090	0.0000	0.0008	0.0061	0.0000	0.0081	0.0000	0.0008	0.0049	$\ln D_w-(-4)$	$\ln X_{13}-(-15)$	$\ln X_{14}-(-6.5)$	$\ln X_{15}-(-3.9)$	0.1340	45
	$C''_{ww.la}$	0.0001	0.0061	0.0071	0.0000	0.0031	0.0101	0.0061	0.0211	0.0045	0.0000	$\ln D_w-(-4)$	$\ln X_{13}-(-15)$	$\ln X_{14}-(-6.5)$	$\ln X_{15}-(-3.9)$	0.1445	45
	$C'''_{ww,la}$	0.0010	0.0000	0.0008	0.0001	0.0041	0.0031	0.0031	0.0017	0.0008	0.0094	$\ln D_w-(-4)$	$\ln X_{13}-(-15)$	$\ln X_{14}-(-6.5)$	$\ln X_{15}-(-3.9)$	0.1501	45
	$C''''_{ww.la}$	0.0030	0.0008	0.0000	0.0204	0.0000	0.0017	0.0112	0.0016	0.0106	0.0105	$\ln D_w-(-4)$	$\ln X_{13}-(-15)$	$\ln X_{14}-(-6.5)$	$\ln X_{15}-(-3.9)$	0.1906	45

Sample equation for estimating standard error of estimated expected value for Slow Sand Filter

$$S\ln C'_{w.af} = \pm t_{.95,df}\left[Resms\left(\frac{1}{n}+C_{ww}d^2_w+C_{14\ 14}X^2_{14}+C_{w\ 14}d_wX_{14}\right)\right]^{\frac{1}{2}} \qquad df=62$$

TABLE XIII

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WASTE WATER TREATMENT COST MODEL

		CORRELATION MATRIX C_{ij}						DEVIATIONS				
		$C_{16\ 16}$	$C_{20.20}$	$C_{21\ 21}$	$C_{16\ 20}$	$C_{16\ 21}$	$C_{20\ 21}$	X_{16}	X_{20}	X_{21}	Resms	N
STABILIZATION LAGOON	$C'_{ww.af}$	0.0001	0.0021	0.0000	0.0011	0.0000	0.0008	$\ln X_{16}-(-30)$	$\ln X_{20}-(-13)$	$\ln X_{21}-(-5)$	0.2462	44
	$C'^{I}_{ww.af}$	0.0003	0.0101	0.00101	0.0020	0.0011	0.0031	$\ln X_{16}-(-30)$	$\ln X_{20}-(-13)$	$\ln X_{21}-(-5)$	0.3001	44
	$C'^{II}_{ww.af}$	0.0000	0.0060	0.0000	0.0041	0.0090	0.0101	$\ln X_{16}-(-30)$	$\ln X_{20}-(-13)$	$\ln X_{21}-(-5)$	0.1107	44
	$C'^{III}_{ww.af}$	0.0024	0.0000	0.0610	0.0000	0.0031	0.0009	$\ln X_{16}-(-30)$	$\ln X_{20}-(-13)$	$\ln X_{21}-(-5)$	0.1709	44
	$C'_{ww.as}$	0.0036	0.0211	0.0101	0.0000	0.0000	0.0035	$\ln X_{16}-(-5)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-2.5)$	0.3107	50
	$C'^{I}_{ww.as}$	0.0003	0.0060	0.0000	0.0201	0.0000	0.0004	$\ln X_{16}-(-5)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-2.5)$	0.4041	50
	$C'^{II}_{ww.as}$	0.0008	0.0107	0.0101	0.0000	0.0071	0.0000	$\ln X_{16}-(-5)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-2.5)$	0.5011	50
	$C'^{III}_{ww.as}$	0.0000	0.0009	0.0006	0.0009	0.0004	0.0006	$\ln X_{16}-(-5)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-2.5)$	0.1701	50
	$C'_{ww.la}$	0.0004	0.0003	0.0310	0.0003	0.0003	0.0009	$\ln X_{16}-(-39)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-4.4)$	0.2071	38
	$C'^{I}_{ww.la}$	0.0027	0.0002	0.0016	0.0005	0.0011	0.0044	$\ln X_{16}-(-39)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-4.4)$	0.1179	38
	$C'^{II}_{ww.la}$	0.0010	0.0004	0.0000	0.0007	0.0085	0.0030	$\ln X_{16}-(-39)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-4.4)$	0.2011	38
	$C'^{III}_{ww.la}$	0.0009	0.0006	0.0000	0.0003	0.0031	0.0001	$\ln X_{16}-(-39)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-4.4)$	0.3101	38
AERATED LAGOON	$C'_{ww.af}$	0.0000	0.0007	0.0301	0.0006	0.0400	0.0111	$\ln X_{16}-(+3)$	$\ln X_{20}-(-4)$	$\ln X_{21}-(-7.7)$	0.1309	34
	$C'^{I}_{ww.af}$	0.0037	0.0000	0.0107	0.0003	0.0301	0.0201	$\ln X_{16}-(+3)$	$\ln X_{20}-(-4)$	$\ln X_{21}-(-7.7)$	0.1907	34
	$C'^{II}_{ww.af}$	0.0101	0.0060	0.0203	0.0000	0.0061	0.0104	$\ln X_{16}-(+3)$	$\ln X_{20}-(-4)$	$\ln X_{21}-(-7.7)$	0.1601	34
	$C'^{III}_{ww.af}$	0.0061	0.0000	0.0000	0.0061	0.0001	0.0013	$\ln X_{16}-(+3)$	$\ln X_{20}-(-4)$	$\ln X_{21}-(-7.7)$	0.2107	34
	$C'_{ww.as}$	0.0021	0.0009	0.0007	0.0111	0.0000	0.0009	$\ln X_{16}-(-45)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-6.6)$	0.1109	41
	$C'^{I}_{ww.as}$	0.0203	0.0040	0.0065	0.0006	0.0081	0.0007	$\ln X_{16}-(-45)$	$\ln X_{20}-(-5)$	$\ln X -(-6.6)$	0.1607	41
	$C'^{II}_{ww.as}$	0.0007	0.0011	0.0000	0.0304	0.0000	0.0004	$\ln X_{16}-(-45)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-6.6)$	0.3401	41
	$C'^{III}_{ww.as}$	0.0000	0.0020	0.00701	0.0000	0.0101	0.0020	$\ln X_{16}-(-45)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-6.6)$	0.5007	41
	$C'_{ww.la}$	0.0009	0.0016	0.0010	0.0061	0.0000	0.0010	$\ln X_{16}-(-19)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(+0.4)$	0.4000	36
	$C'^{I}_{ww.la}$	0.0010	0.0000	0.0009	0.0401	0.0007	0.0071	$\ln X_{16}-(-19)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(+0.4)$	0.3015	36
	$C'^{II}_{ww.la}$	0.0060	0.0016	0.0000	0.0056	0.0046	0.0010	$\ln X_{16}-(-19)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(+0.4)$	0.2109	36
	$C'^{III}_{ww.la}$	0.0011	0.0000	0.0201	0.0000	0.0111	0.0203	$\ln X_{16}-(-19)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(+0.4)$	0.2001	36

TABLE XIII- Continued

		$C_{16\,16}$	$C_{20\,20}$	$C_{21\,21}$	$C_{16\,20}$	$C_{16\,21}$	$C_{20\,21}$	X_{16}	X_{20}	X_{21}	Resms	N
ACTIVATED SLUDGE	$C'_{ww.af}$	0.0101	0.0021	0.0000	0.0209	0.0000	0.0071	$\ln X_{16}-(-9)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-2)$	0.1241	26
	$C''_{ww.af}$	0.0034	0.0103	0.0002	0.0004	0.0344	0.0031	$\ln X_{16}-(-9)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-2)$	0.2017	26
	$C'''_{ww.af}$	0.0000	0.0045	0.0061	0.0000	0.0611	0.0041	$\ln X_{16}-(-9)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-2)$	0.1009	26
	$C''''_{ww.af}$	0.0301	0.0009	0.0007	0.0000	0.0081	0.0008	$\ln X_{16}-(-9)$	$\ln X_{20}-(-5)$	$\ln X_{21}-(-2)$	0.3000	26
	$C'_{ww.as}$	0.0000	0.0000	0.0003	0.0110	0.0004	0.0003	$\ln X_{16}-(-31)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(-7)$	0.4011	32
	$C''_{ww.as}$	0.0203	0.00701	0.0008	0.0309	0.00000	0.0041	$\ln X_{16}-(-31)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(-7)$	0.1107	32
	$C'''_{ww.as}$	0.0011	0.0301	0.0009	0.0220	0.0010	0.0008	$\ln X_{16}-(-31)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(-7)$	0.2111	32
	$C''''_{ww.as}$	0.0035	0.0404	0.0001	0.0030	0.0060	0.0004	$\ln X_{16}-(-31)$	$\ln X_{20}-(-3)$	$\ln X_{21}-(-7)$	0.3044	32
	$C'_{ww.la}$	0.0008	0.00504	0.0204	0.0016	0.0034	0.0009	$\ln X_{16}-(-75)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-.9)$	0.3066	34
	$C''_{ww.la}$	0.0000	0.00305	0.0207	0.0019	0.0007	0.0044	$\ln X_{16}-(-75)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-.9)$	0.1070	34
	$C'''_{ww.la}$	0.0061	0.00701	0.0093	0.0017	0.0008	0.0000	$\ln X_{16}-(-75)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-.9)$	0.17011	34
	$C''''_{ww.la}$	0.0209	0.0000	0.0000	0.0015	0.0007	0.0017	$\ln X_{16}-(-75)$	$\ln X_{20}-(-9)$	$\ln X_{21}-(-.9)$	0.1003	34
TRICKLING FILTER	$C'_{ww.af}$	0.0301	0.0006	0.0300	0.0014	0.0003	0.0008	$\ln X_{16}-(-48)$	$\ln X_{20}-(+3)$	$\ln X_{21}-(-1)$	0.1604	29
	$C''_{ww.af}$	0.0000	0.0020	0.0401	0.0014	0.0110	0.0000	$\ln X_{16}-(-48)$	$\ln X_{20}-(+3)$	$\ln X_{21}-(-1)$	0.1909	29
	$C'''_{ww.af}$	0.0010	0.0900	0.0000	0.0000	0.0030	0.0000	$\ln X_{16}-(-48)$	$\ln X_{20}-(+3)$	$\ln X_{21}-(-1)$	0.1070	29
	$C''''_{ww.af}$	0.0029	0.0000	0.0004	0.0031	0.0000	0.0031	$\ln X_{16}-(-48)$	$\ln X_{20}-(+3)$	$\ln X_{21}-(-1)$	0.4081	29
	$C'_{ww.as}$	0.0000	0.0020	0.0003	0.0041	0.0004	0.0041	$\ln X_{16}-(-11)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-8)$	0.1701	35
	$C''_{ww.as}$	0.0071	0.0040	0.0061	0.0090	0.0031	0.0031	$\ln X_{16}-(-11)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-8)$	0.1633	35
	$C'''_{ww.as}$	0.0002	0.0004	0.0031	0.0030	0.0007	0.0071	$\ln X_{16}-(-11)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-8)$	0.1401	35
	$C''''_{ww.as}$	0.0034	0.0007	0.0045	0.0004	0.0040	0.0001	$\ln X_{16}-(-11)$	$\ln X_{20}-(-14)$	$\ln X_{21}-(-8)$	0.5016	35
	$C'_{ww.la}$	0.0000	0.0011	0.0009	0.0005	0.0000	0.0109	$\ln X_{16}-(-65)$	$\ln X_{20}-(-7)$	$\ln X_{21}-(-5)$	0.4907	38
	$C''_{ww.la}$	0.0061	0.0031	0.0000	0.0009	0.0000	0.0009	$\ln X_{16}-(-65)$	$\ln X_{20}-(-7)$	$\ln X_{21}-(-5)$	0.3771	38
	$C'''_{ww.la}$	0.0000	0.0008	0.0000	0.0004	0.0070	0.000	$\ln X_{16}-(-65)$	$\ln X_{20}-(-7)$	$\ln X_{21}-(-5)$	0.3094	38
	$C''''_{ww.la}$	0.0000	0.0000	0.0107	0.0016	0.0021	0.107	$\ln X_{16}-(-65)$	$\ln X_{20}-(-7)$	$\ln X_{21}-(-5)$	0.5901	38

Sample equation for estimating standard error of estimated expected value for stabilization lagoon

$$S_{\ln C''_{ww.af}} = \pm t_{.95,df} \left[Resms \left(\frac{1}{n} + C_{16\,16} X^2_{16} + C_{20\,20} X^2_{20} + C_{16\,20} X_{16} X_{20} \right) \right]^{\frac{1}{2}} \qquad df=41$$

TABLE XIV

ESTIMATED COST OF WATER TREATMENT IN DEVELOPING COUNTRIES

Type of Treatment Process	Water Demand in Gallons per Capita per Day	% Cost of Imported Water Supply Materials	Design Population	Design Capacity in MGD	Estimate of Mean Construction Cost in $ per capita			Estimate of Mean Operation and Maintenance Cost in $ per capita per yr		
					AFRICA	ASIA	LATIN AMERICA	AFRICA	ASIA	LATIN AMERICA
SLOW SAND FILTER	5	5	5,000	5	11.82	13.28	9.34	1.39	1.46	1.12
	25	25	30,000	5	9.57	11.13	6.59	1.23	1.28	0.85
	45	5	55,000	5	8.95	10.48	5.85	1.18	1.22	0.78
	65	45	105,000	25	8.12	9.82	5.15	1.13	1.16	0.71
	85	5	155,000	25	7.69	9.44	4.77	1.10	1.13	0.66
	105	25	180,000	25	7.62	9.31	4.64	1.08	1.10	0.65
RAPID SAND FILTER	5	5	5,000	5	19.96	23.89	27.58	4.80	11.34	4.79
	25	25	30,000	5	17.10	20.38	23.54	3.21	7.94	2.91
	45	5	55,000	5	16.23	19.25	22.32	2.81	7.04	2.45
	65	45	105,000	25	15.34	18.23	21.07	2.41	6.18	2.03
	85	5	155,000	25	14.83	17.54	20.35	2.20	5.72	1.82
	105	25	180,000	25	14.64	17.34	20.09	2.13	5.55	1.75

TABLE X V

ESTIMATED COST OF WASTE WATER TREATMENT IN ASIA USING OU-AID AND CPHERI NAGPUR STUDIES

Type of Treatment Process	Design Population	Design Flow in MGD	% Cost of Imported Waste Water Dispol Material	Estimate of Mean Construction Cost in $ per capita		Estimate of Mean Operation and Maintenance Cost in $ per capita per y	
				ASIA OU-AID Study	INDIA Nagpur Study	ASIA OU-AID Study	INDIA Nagpur Study[6]
STABILIZATION LAGOON	5,000	0.15	--	3.27	2.09	0.54	0.32
	10,000	0.30	--	2.81	1.84	0.47	0.25
	50,000	1.50	--	1.99	1.29	0.35	0.17
	100,000	3.00	--	1.71	1.25	0.31	0.14
	200,000	6.00	--	1.48	1.17	0.27	0.12
AERATED LAGOON	5,000	0.15	--	4.00	2.54	1.22	0.69
	10,000	0.30	--	3.59	2.18	1.15	0.60
	50,000	1.50	--	2.79	2.00	0.98	0.48
	100,000	3.00	--	2.50	1.81	0.92	0.44
	200,000	6.00	--	2.25	1.60	0.86	0.40
ACTIVATED SLUDGE	5,000	0.15	25	10.99	--	2.92	--
	10,000	0.30	25	9.00	--	2.17	--
	50,000	1.50	25	5.65	--	1.09	--
	100,000	3.00	25	4.62	--	0.81	--
	200,000	6.00	25	3.79	--	0.61	--
TRICKLING FILTER	5,000	0.15	25	12.09	8.65	3.66	1.89
	10,000	0.30	25	9.55	8.54	2.88	1.55
	50,000	1.50	25	5.51	3.85	2.58	0.86
	100,000	3.00	25	4.33	3.51	2.29	0.70
	200,000	6.00	25	3.43	2.22	1.00	0.51

[6] Low Cost Waste Treatment, Central Public Health Engineering Research Institute, Nagpur, India, 1972

CHAPTER VI

SUMMARY AND CONCLUSIONS

Because of the explosive acceleration of urbanization (7) in many developing countries in recent decades, the typical experience is that a public service which may have been adequate at one time deteriorates as consumers are connected to a system at a faster rate than the system's capacity is increased. Once a system is operating above capacity, the quality of service deteriorates for all the consumers connected to it

Urban communities of any size without adequate piped water and sewerage are not viable and thus seriously compromise national development prospects. Individuals need for a minimum amount of water for drinking and preparing food is paramount toward the growth of developing countries. A water supply contributes significantly to a city's existance by providing the only satisfactory method of removal of human wastes. Inadequate central sewerage not only raises problems of public health and aesthetics, but usually leads to higher costs in water treatment. In developing countries, cities which do not have sewerage systems have to haul away most of their waste by truck. This is increasingly expensive and unsatisfactory as a solution because disposal is becoming more and more complex. Since waterborne sewerage systems are normally the most effective means of urban waste disposal and water and sewerage facilities they should be considered as part of any integrated system in developing countries.

It is not enough to take into account the capital costs only, since in water and sewage treatment the operation and maintenance costs due to power and chemicals can be substantially different from process to process.

To provide engineers, planners, economists, and public officials charged with planning and development of water resources in developing countries with a management tool, equations were derived to predict water demand, waste water disposal and cost of water and waste water treatment. These equations were derived by the use of the multiple regression analysis technique.

In general, water demand was found to be a function of population, income and a technology indicator (percentage of households connected to the water supply systems or having piped water). There was a weak association of water demand to the price of water to the consumers (X_1). Indeed people who purchase water tend to use larger amounts. The consumption of water percapita appeared to show a larger value in larger population scale.

The per capita waste water disposal daily was found to be a function of water demand and two technological indicators (percent connected to public sewerage system and percent of household system(X_{10}, X_{11})). The analysis of the data showed that the amount of waste water increased daily with the increase of per capita consumption of water and the increase of the waste water disposal system, while in-house waste disposal processes showed a decrease in per capita waste water disposed of daily.

For estimating construction, operation and maintenance costs of water treatment processes, regression equations with two independent variables gave the best predictive equations in log-log form. Both population, design flow and a technology indicator (percentage cost of imported waste water disposal materials) showed good relationship with cost of water treatment.

Out of the eight independent variables used to derive the waste water cost model, only three were found to be significant. These were population, design capacity and the percentage cost of imported waste water disposal materials. The stabilization lagoon was found to be the cheapest sewage treatment process where the land was available, while mechanical aerated lagoons were second in terms of cost. Conventional treatment processes (activated sludge and trickling filter) were found to be the most expensive processes of sewage treatment in developing countries.

The following summarizes the research needed to evaluate and strengthen the models developed in this study:

(1) It is possible that these models could be refined by inclusion of additional socio-cultural data. This will need field work in one or two countries as case studies.

(2) Two case studies of water demand are needed which may include more detailed data than could be obtained by mail survey.

   (a) One country should be selected among the arid areas of the Middle East, for example, Saudi Arabia;

   (b) Another country in tropical regions, for example, Zaire.

(3) More mathematical models should be developed which reflect the total water resources planning in the developing countries using the conditions of developing countries.

(4) There is a need to develop water quality standards for developing countries.

(5) Cost-effectiveness studies of water supply and waste water disposal should be carried out especially comparing benefits acquired from treated water and sewerage facilties to other public work sectors.

(6) Efforts should be made to apply these models in actual planning situations.

Thus the use of the predictive equations presentedin this study give reliable estimates of water demand, waste water disposal, and cost of water and waste water treatment systems in the developing countries. Appendices A, B, C, D, E, F, G and H present a computer print-out of the mean water demand, waste disposal, and cost of water and waste water treatment systems of selected socio-economic and technological conditions of developing countries.

In conclusion, perhaps the best way to visualize the use of the derived equations is to look at the following practical applications of the equations.

Sample Problem 1

Water supply and waste water disposal processes are being considered to be built in Kijiji City in Tanzania. The population of the city is 5,000. Because of the availability of process resources a slow sand filter is under consideration to be built. However, due to the availability of cheap land a stabilization lagoon is recommended for waste water disposal. Water demand is unknown and the average national income per capita per year is $250. The following analyzes the cost of both processes.

Solution

1. Slow Sand Filter Costs

Using equation (5-2) to estimate water demand

$D_{w.af} = 19.7200 + 0.0683\ X_2 + 0.0142\ X_6$

where: $X_2 = 5$ (thousand)

$X_6 = 250$

$:D_{w.af} = 19.7200 + 0.0683(5) + 0.0142(250)$

$= 23.61$ gpcd

Now using equation (5-13) to estimate construction cost

$\ell_n\ C'_{.waf} = 2.6436 + 0.0988\ \ell_n\ D_w - 0.2065\ \ell_n\ X_{14}$

$= 2.6436 + 0.0988\ \ell_n\ 23.61 - 0.20651\ \ell_n\ 5$

$= 2.6436 + 0.3123 - 0.3323$

$= 2.6236$

Anti log of 2.6236 = 13.78 dollars

Using equation (5-15) to estimate operation and maintenance cost

$\ell_n\ C'''_{w.af} = 0.4346 + 0.0160\ \ell_n\ D_w - 0.3628\ \ell_n\ X_{14}$

$= 0.4346 + 0.0160\ \ell_n\ 23.61 - 0.3628\ \ell_n\ 5$

$= -\ 0.0987$

Anti log of -0.0987 = 1.51 dollars

Per capita per year O & M = 1.51 dollars

Design capacity = $23.61 \times 5000/10^6$

$= 0.108$ MGD

Total construction cost = 68900 U.S. dollars

Total O & M cost per year = 7550 U.S. dollars/year

2. Stabilization Lagoon Costs

Using equation (5-7) to estimate per capita waste water discharge

$D_{ww.af} = 1.2840 + 0.6670\ D_{w}$

Using calculated $D_{w.af} = 23.61$

$D_{ww.af} = 0.2840 + 0.6670\ (23.61)$

$= 16$

Now using equation (5-37) to estimate construction cost

$\ell_n\ C'_{ww.af} = 1.3955 - 0.1845\ (1.6094)$

$= 1.0985$

Anti log of 1.0985 = 3.00

:per capita construction cost = 3.00 U.S. dollars

Now using equation (5-39) to estimate operation and maintenance cost

$\ell_n\ C''_{ww.af} = -0.2532 - 0.2837\ \ell_n\ X_{16}$

$= -0.2532 - 0.2837\ \ell_n\ 5$

$= -0.2532 - 0.2837\ (1.6094)$

$= -0.7097$

Anti log of 0.7097 = 0.4917

Per capita/year O & M = 0.4917

Design capacity = $\frac{19.03 \times 5000}{106}$ = 0.095 MGD

Total construction cost = 3.00 x 5000 = 15,000 U.S. dollars

Total O & M cost per year = 0.49 x 5000 = 2450 U.S. dollars/year

Sample Problem 2

The City of Istanbul, Turkey, is proposing to build stabilization lagoons for three suburbs or one central activated sludge plant. Due to the geographical location of these cities the cost of transporting the waste water by gravity flow is minimal. Also land is cheap in this city.

The per capita income of the city is estimated to be 250 U.S. dollars per year. Twenty percent of the cost of waste water materials must be imported to construct and operate activated sludge. The design population is the same as the population of the communities shown on Figure 3.

A recommendation is sought for the Istanbul Planning Commissioners in terms of the mean lower cost process (three stabilization lagoons or one central activated sludge).

Solution

Using equation (5-41)

Construction Cost of Stabilization Lagoon 1

$$\ell_n C'_{ww.as} = 1.5303 - 0.2152\, \ell_n X_{16}$$

$$= 1.5303 - 0.2152\, \ell_n 100$$

$$= 1.5303 - 0.9910 = 0.5393$$

Anti log of 0.5393 = 1.71 U. S. dollars

Operation and Maintenance Cost of Stabilization Lagoon 1

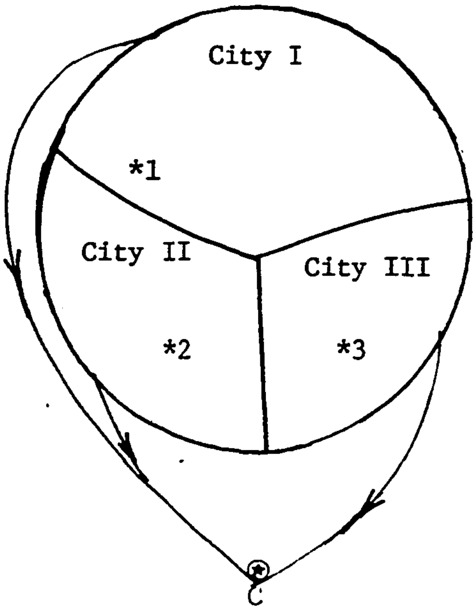
$$\ell_n C''_{ww.as} = -0.3274 - 0.1846\, \ell_n 100$$

$$= -0.3274 - 0.8501$$

$$= -1.1775$$

Anti log -1.1775 = 0.30 dollars/capita/year

Figure 4: Sample Problem 2



City I, Population = 100,000
City II, Population = 25,000
City III, Population = 75,000

* Location of Stabilization Lagoons

C Location of Activated Sludge

→ Transportation of waste water to Central Point C

<u>Construction Cost of Stabilization Lagoon 2</u>

$$\ell_n C'_{ww.as} = 1.5202 - 0.2152 \ \ell_n 25$$

: construction cost per capita = 2.31 dollars

<u>Construction Cost of Stabilization Lagoon 3</u>

$$\ell_n C'_{ww.as} = 1.5303 - 0.2152 \ \ell_n 75$$

: construction cost per capita = 1.82 dollars

Using equation (5-43)

$$\ell_n C'''_{ww.as} = -0.3274 - 0.1846 \ \ell_n X_{16}$$

Operation and Maintenance Cost of Stablization Lagoon 2

$$\ell_n C'''_{ww.as} = -0.3274 - 0.1846\ \ell_n\ 25$$

$$= -0.3274 - 0.8501$$

$$= -1.1775$$

Anti log -0.9216 = 0.40 dollars/capita/year

Operation and Maintenance Cost of Stablization Lagoon 3

$$\ell_n C'''_{ww.as} = -0.3274 - 0.1846\ \ell_n\ 75$$

$$= -1.12$$

Anti log -1.12 = 0.32 dollars/capita/year

Construction cost of Centralized Activated Sludge using equation(5-64)

$$\ell_n C'_{ww.as} = 2.8597 - 0.2890\ \ell_n X_{16} + 0.0201\ \ell_n X_{21}$$

(where: X_{16} is the total population of 3 cities and X_{21} is 20%)

$$\ell_n C'_{ww.as} = 2.8597 - 0.2890\ \ell_n\ (100 + 25 + 75) + 0.0201\ \ell_n\ 20$$

$$= 2.8597 - 1.5312 + 0.0602$$

$$= 1.3887$$

Anti log 1.3887 = 4.01 dollars/capita

Operation and Maintenance Cost for the Centralized Activated Sludge using Equation 5-66).

$$\ell_n C'''_{ww.as} = 1.7332 - 0.4269\ \ell_n X_{16} + 0.0021\ \ell_n X_{21}$$

$$= 1.7332 - 2.2618 + 0.0062$$

$$= 0.5222$$

Anti log 0.5222 = 0.59 dollars/capita/year

Total Construction Cost for three Stabilization Lagoons

= 1.71 (100,000) + 2.21 (25,000) + 1.82 (75,000)

= 171,000 + 57,750 + 136,500 = 365,250 dollars

Total O & M Cost per Year for three Stablization Lagoons

= 0.30 (100,000) + 0.40 (25,000) + 0.32 (75,000)

= 30,000 + 10,000 + 24,000

= 64,000 dollars

Total Construction Cost for Activated Sludge

= 4.01 (200,000)

= 802,000 dollars

Total O & M Cost per year for Activated Sludge

= 0.59 (200,000)

= 118,000 dollars

Total Construction Cost for three stabilization lagoons = 365,250 dollars
Operation and Maintenance per year cost for three lagoons = 64,000 dollars
Total Construction cost for activated sludge = 802,000 dollars
Total O & M cost per year for activated sludge = 118,000 dollars

Therefore three stabilization lagoons would be the recommendations to give to the Commissioners.

Sample Problem 3

An activated sludge plant is to be constructed in a city in Brazil. To make a decision on how big the plant should be requires the mean design capacity in MGD. The projected population of the city is 500,000 and per capita income per year is approximately 1,500 U.S. dollars. It is estimated presently that 30% of the homes are connected to water supply systems. Percentage of household sewage systems is estimated to be 15.

Solution

Using equations (5-6) and (5-12)

$$D_{w.1a} = 13.7401 + 0.0645\ X_2 + 0.0682\ X_5 + 0.0330\ X_6$$

$$= 13.7401 + 0.0645\ (500) + 0.0682\ (15) + 0.0330\ (1500)$$

$$= 97.5351 \text{ gpcd}$$

Per capita waste water disposal is estimated by equation (5-12)

$$D_{ww.1a} = 0.1835 + 0.6164\ D_w - 0.0368\ X_{11}$$

using the calculated $D_{w.1a}$ and $X_{11} = 15$

$$D_{ww.1a} = 0.1835 + 0.6164\ (97.5351) - 0.0368\ (15)$$

$$= 59.7521 \text{ gpcd}$$

$$\text{Design Capacity} = \frac{59.7521 \times 500{,}000 \text{ MGD}}{10^6}$$

$$= 29.87 \text{ MGD}$$

The following two sample problems are presented as illustrative of (a) a country wide problem and (b) a major city problem.

Sample Problem 4

The Governments of Kenya, Mexico and Taiwan want to establish small towns into the interior. The projected population for each town (Kijiji

Kipya, Nuevo Pueblo and Hsin Tsein) is to be 5,000. Both water and waste water treatment plants must be built simultaneously. Recommendations are needed for the mean costs of slow sand filter and aerated lagoon.

The following historical data exists for each region:

(1) Average annual income for Kenya is 500 dollars;

(2) Average annual income for Mexico is 550 dollars;

(3) Average annual income for Taiwan is 1100 dollars;

(4) Percentage homes connected to water supply for Mexico is approximately 40;

(5) Percentage homes connected to water supply for Taiwan is approximately 65;

(6) Assume design population is same as population of the towns;

(7) Since there are no sewerage systems X_{10} and X_{11} are assumed to be zero;

(8) It is further assumed that 20% cost of materials for building and operating activated sludge, trickling filters and rapid sand filters for each country will be imported.

Solution

Using equations (5-2), (5-4), (5-13), (5-15), (5-17), (5-19), (5-21) and (5-23), construction, operation and maintenance costs of the slow sand filter for each country

$$
\begin{aligned}
\ell_n C'_{w.af} &= 2.6436 + 0.0988\ \ell_n D_w - 0.20651\ \ell_n X_{14} \\
&= 2.6436 + 0.0988\ \ell_n (12.72 + 0.0683\ X_2 + 0.0142\ X_6) \\
&\quad - 0.20651\ X_{14} \\
&= 2.6436 + 0.0988\ \ell_n (12.72 + 0.0683\ (5) + 0.0142\ (500)) \\
&\quad - 0.20651\ \ell_n 5
\end{aligned}
$$

$= 2.6080$

Anti log 2.6080 = 13.57 dollars/capita

$\ell_n C'''_{w.af} = 0.4346 + 0.0160\ \ell_n D_w - 0.3628\ \ell_n X_{14}$

$= 0.4346 + 0.0160\ \ell_n\ (12.72 + 0.0683\ X_2 + 0.0142\ X_6)$
$- 0.3628 \ell_n X_{14}$

$= 0.4346 + 0.0160\ \ell_n\ (12.72 + 0.0683\ (5) + 0.0142\ (500)\ )$
$- 0.3628\ \ell_n (5)$

$= 0.4346 + 0.0480 - 0.5838$

$= -0.1012$

Anti log -0.1012 = 0.90 dollars/capita/year

$\ell_n C'_{w.as} = 2.7436 + 0.0088\ \ell_n\ (6.6817 + 0.04597\ (5) + 0.2204\ (65)$
$+ 0.0263\ (1100)\ ) - 0.1065\ \ell_n\ (5)$

$= 2.7436 + 0.0344 - 0.1711$

$= 2.6069$

Anti log 2.6069 = 13.55 dollars/capita

$\ell_n C'''_{w.as} = 0.5017 - 0.0751\ \ell_n\ (5)$

$= 0.3809$

Anti log 0.3809 = 1.46 dollars/capita/year

$\ell_n C'_{w.la} = 2.5461 + 0.0096\ \ell_n\ (5)$

$= 2.5292$

Anti log 2.5292 = 12.54 dollars/capita

$\ell_n\ C'''_{w.la} = 0.3559 - 0.1511\ \ell_n\ (5)$

$= 0.1127$

Anti log 0.1127 = 1.12 dollars/capita/year

Using equations (5-49), (5-51), (5-53), (5-55), (5-57), and (5-59) construction, operation and maintenance costs of aerated lagoon for each country.

$$\ell_n C'_{ww.af} = 1.4768 - 0.1132\ \ell_n X_{16}$$
$$= 1.4758 - 0.1132\ \ell_n (5)$$
$$= 1.29462$$

Anti log 1.29462 = 3.65 dollars/capita

$$\ell_n C'''_{ww.af} = 0.1136 - 0.1435\ \ell_n X_{16}$$
$$= 0.1136 - 0.1435\ \ell_n (5)$$
$$= 0.1173$$

Anti log 0.1173 = 0.89 dollars/capita/year

$$\ell_n C'_{ww.as} = 1.6395 - 0.1565\ \ell_n X_{16}$$
$$= 1.6395 - 0.1565\ \ell_n (5)$$
$$= 1.3876$$

Anti log 1.3876 = 4.01 dollars/capita

$$\ell_n C'''_{ww.as} = 0.3561 - 0.0955\ \ell_n X_{16}$$
$$= 0.3561 - 0.0955\ \ell_n (5)$$
$$= 0.2024$$

Anti log 0.2024 = 1.22 dollars/capita/year

$$\ell_n C'_{ww.la} = 1.7581 - 0.1461\ \ell_n X_{16}$$
$$= 1.7581 - 0.1461\ \ell_n (5)$$
$$= 1.523$$

Anti log 1.523 = 4.59 dollars/capita

$$\ell_n C'''_{ww.la} = 0.21149 - 0.1600\, \ell_n X_{16}$$

$$= 0.21149 - 0.1600\, \ell_n (5)$$

$$= -0.0460$$

Anti log -0.0460 = 0.96 dollars/capita/year

Total Construction Cost for Slow Sand Filter in Kenya = 13.57 (5000)

= 67,850 dollars

Total Operation and Maintenance Cost for Slow Sand Filter in Kenya = 0.90 (5000)

= 4,500 dollars/year

Total Construction Cost for Aerated Lagoon in Kenya = 3.65 (5000)

= 18,250 dollars

Total Operation and Maintenance Cost for Aerated Lagoon in Kenya = 0.89 (5000)

= 4,450 dollars/year

Total Construction Cost for Slow Sand Filter in Taiwan = 13.55 (5000)

= 67,750 dollars

Total Operation and Maintenance Cost for Slow Sand Filter in Taiwan = 1.46 (5000)

= 7,300 dollars/year

Total Construction Cost for Aerated Lagoon in Taiwan = 4.01 (5000)

= 20,050 dollars

Total Operation and Maintenance Cost for Aerated Lagoon in Taiwan = 1.22 (5000)

= 6,100 dollars/year

Total Construction Cost for Slow Sand Filter in Mexico = 12.54 (5000)

= 62,700 dollars

Total Operation and Maintenance for Slow Sand Filter in Mexico = 1.12 (5000)

= 5,600 dollars/year

Total Construction Cost for Aerated Lagoon in Mexico = 4.59 (5000)

= 22,950 dollars

Total Operation and Maintenance Cost for Aerated Lagoon in Mexico = 0.96 (5000)

= 4,800 dollars/year

Sample Problem 5

The City of Nairobi is considering building water supply and waste water processes for ten urban sections. A central rapid sand filter at point P is being considered. Since the elevation of point P is higher than all the sections treated water can be transported by gravity flow. Also the source of water is only 1/8 mile from point P. A central trickling filter at point C must be constructed. Since point C is lower than all the sections, it will cost minimum to transport raw waste water to point C. It is estimated that it will cost the City 2% more of the total construction to build transportation systems from point P to the 10 sections of the city and also 1% to build a transportation system from the ten sections to point C. The per capita annual income of the city is 500 dollars per year. Thirty percent cost of the materials for building and operating rapid sand filters must be imported and fifteen percent for trickling filter. Assume design population is the same as population of the city.

Recommend to the city maximum and minimum construction costs of building a central rapid sand filter at point P and a trickling filter at point C.(Figure 5)

Solution

Construction cost of a central rapid sand filter at point P using equations (5-2) and(5-25).

$$\ell_n C'_{w.af} = 3.1324 + 0.0024\ \ell_n D_w - 0.885\ \ell_n X_{14}$$

$$= 3.1325 + 0.0024\ \ell_n (12.72 + 0.0683\ X_2 + 0.0142\ X_6)$$

$$- 0.885\ \ell_n X_{14}$$

$$= 3.1325 + 0.0024\ \ell_n (12.72 + 0.0683(637) + 0.0142(500))$$

$$- 0.885\ \ell_n (637)$$

$$= 2.5721$$

Anti log 2.5721 = 13.09 dollars/capita

Using Table XII to estimate standard error of estimated value with 95 confidence interval and 45 degrees of freedom (df)

$$S\ell_n C'_{w.af} = \pm t_{.95,df} \Big[\text{Resms} \Big(\frac{1}{n} + C_{ww}\, d^2_w$$

$$+ C_{14\,14} x^2_{14} + C_{w14}\, d_w\, x_{14} \Big) \Big]^{\frac{1}{2}}$$

$$= \pm 2.021 \Big[0.1060 \Big(\frac{1}{48} + 0.0000 \big(\ell_n D_w - (-5)\big)^2$$

$$+ 0.0000 \big(\ell_n X_{14} - (-15)\big)^2$$

$$+ 0.0004 \big(\ell_n D_w - (-5)\big)\big(\ell_n X_{14} - (-15)\big) \Big]^{\frac{1}{2}}$$

$$= \pm 2.021 \left[0.1060 \left(\frac{1}{48} + 0.0004 (\ell_n 63.321 + 5)(\ell_n 637 + 15) \right] ^{\frac{1}{2}}$$

$$= \pm 2.021 \left[0.1060 \ (0.0317) \right] ^{\frac{1}{2}}$$

$$= \pm 2.021 \ (0.05796)$$

$$= \pm 0.11713$$

Anti log 0.11713 = ± 1.12 dollars/capita

Construction cost of a central trickling filter at point C using equation (5-73)

$$\ell_n C'_{ww.af} = 3.1058 - 0.2546 \ \ell_n X_{16}$$

$$= 0.1058 - 0.2546 \ \ell_n 637$$

$$= 3.1058 - 1.6438$$

$$= 1.462$$

Anti log 1.462 = 4.31 dollars/capita

Using Table XIII to estimate standard error of estimated value with 95 confidence interval and 27 degrees of freedom (df)

$$S\ell_n C'_{ww.af} = \pm 2.052 \left[0.1604 \left(\frac{1}{29} + 0.0301 (\ell_n 637 + 48)^2 \right) \right] ^{\frac{1}{2}}$$

$$= \pm 2.052 \left[0.1604 \ (1.3176) \right] ^{\frac{1}{2}}$$

$$= \pm 0.9433$$

Anti log 0.9433 = ± 2.57 dollars/capita

Minimum Total Construction Cost for Central Rapid Sand Filter at point P including 2% cost of transportation systems (Figure 5) = (13.09 - 1.12) 637,000 + (13.09 - 1.12) (0.02)(637,000)

= 7,777,387.80 dollars

Maximum Total Construction Cost = (13.90 + 1.12) 637,000 +(13.90 + 1.12) (0.02) (637,000)

= 9,232,805.40 dollars

Minimum Total Construction Cost for Central Trickling Filter at point C including 1% cost of transporation systems (Figure 5) = (4.31 - 2.57) 637,000 + (4.31 - 2.57) (0.01) (637,000)

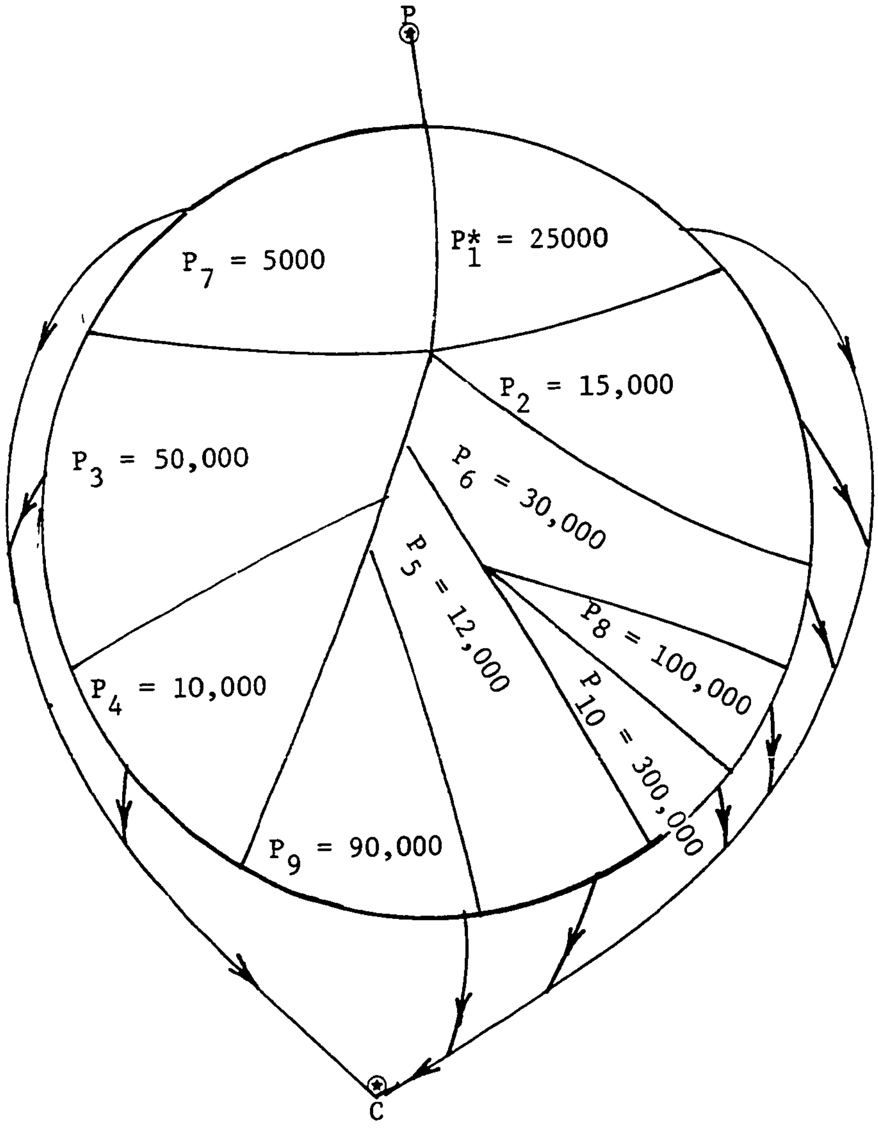
= 1,119,463.80 dollars

Maximum Total Construction Cost = (4.31 + 2.57) (637,000) + (4.31 + 2.57) (0.01) (637,000)

= 4,426,385.60 dollars

Figure 5

Sample Problem 5



$*P_{1-10}$ = Population

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APPENDICES

APPENDIX A

ESTIMATED MEAN WATER DEMAND IN GALLONS PER CAPITA PER DAY FOR SELECTED CONDITIONS

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
5	5	75	21	10	17
5	5	325	25	17	25
5	5	575	28	23	33
5	5	825	32	30	42
5	5	1075	35	36	50
5	5	1325	39	43	58
5	5	1575	42	49	66
5	5	1825	46	56	75
5	5	2075	50	63	83
5	5	2325	53	69	91
5	5	2575	57	76	99
5	5	2825	60	82	108
5	5	3075	64	89	116
5	5	3325	67	95	124
5	5	3575	71	102	132
5	5	3825	74	109	141
5	25	75	21	14	18
5	25	325	25	21	27
5	25	575	28	28	35
5	25	825	32	34	43
5	25	1075	35	41	51
5	25	1325	39	47	60
5	25	1575	42	54	68
5	25	1825	46	60	76
5	25	2075	50	67	84
5	25	2325	53	74	93
5	25	2575	57	80	101
5	25	2825	60	87	109
5	25	3075	64	93	117
5	25	3325	67	100	126
5	25	3575	71	106	134
5	25	3825	74	113	142
5	45	75	21	19	20
5	45	325	25	25	28
5	45	575	28	32	36
5	45	825	32	39	44
5	45	1075	35	45	53
5	45	1325	39	52	61
5	45	1575	42	58	69
5	45	1825	46	65	77
5	45	2075	50	71	86
5	45	2325	53	78	94
5	45	2575	57	85	102
5	45	2825	60	91	110
5	45	3075	64	98	119
5	45	3325	67	104	127
5	45	3575	71	111	135
5	45	3825	74	117	143
5	65	75	21	23	21
5	65	325	25	30	29
5	65	575	28	36	37
5	65	825	32	43	46
5	65	1075	35	50	54
5	65	1325	39	56	62
5	65	1575	42	63	71
5	65	1825	46	69	79
5	65	2075	50	76	87
5	65	2325	53	82	95
5	65	2575	57	89	104
5	65	2825	60	96	112
5	65	3075	64	102	120
5	65	3325	67	109	128
5	65	3575	71	115	137

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
5	65	3825	74	122	145
5	85	75	21	28	22
5	85	325	25	34	31
5	85	575	28	41	39
5	85	825	32	47	47
5	85	1075	35	54	55
5	85	1325	39	60	64
5	85	1575	42	67	72
5	85	1825	46	74	80
5	85	2075	50	80	88
5	85	2325	53	87	97
5	85	2575	57	93	105
5	85	2825	60	100	113
5	85	3075	64	107	121
5	85	3325	67	113	130
5	85	3575	71	120	138
5	85	3825	74	126	146
40	5	75	24	12	19
40	5	325	27	18	27
40	5	575	31	25	36
40	5	825	34	31	44
40	5	1075	38	38	52
40	5	1325	41	44	60
40	5	1575	45	51	69
40	5	1825	48	58	77
40	5	2075	52	64	85
40	5	2325	55	71	93
40	5	2575	59	77	102
40	5	2825	63	84	110
40	5	3075	66	90	118
40	5	3325	70	97	126
40	5	3575	73	104	135
40	5	3825	77	110	143
40	25	75	24	16	21
40	25	325	27	23	29
40	25	575	31	29	37
40	25	825	34	36	45
40	25	1075	38	42	54
40	25	1325	41	49	62
40	25	1575	45	55	70
40	25	1825	48	62	78
40	25	2075	52	69	87
40	25	2325	55	75	95
40	25	2575	59	82	103
40	25	2825	63	88	111
40	25	3075	66	95	120
40	25	3325	70	101	128
40	25	3575	73	108	136
40	25	3825	77	115	144
40	45	75	24	20	22
40	45	325	27	27	30
40	45	575	31	34	38
40	45	825	34	40	47
40	45	1075	38	47	55
40	45	1325	41	53	63
40	45	1575	45	60	71
40	45	1825	48	66	80
40	45	2075	52	73	88
40	45	2325	55	80	96
40	45	2575	59	86	104
40	45	2825	63	93	113
40	45	3075	66	99	121
40	45	3325	70	106	129
40	45	3575	73	112	137
40	45	3825	77	119	146
40	65	75	24	25	23

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
40	65	325	27	31	31
40	65	575	31	38	40
40	65	825	34	45	48
40	65	1075	38	51	56
40	65	1325	41	58	65
40	65	1575	45	64	73
40	65	1825	48	71	81
40	65	2075	52	77	89
40	65	2325	55	84	98
40	65	2575	59	91	106
40	65	2825	63	97	114
40	65	3075	66	104	122
40	65	3325	70	110	131
40	65	3575	73	117	139
40	65	3825	77	123	147
40	85	75	24	29	25
40	85	325	27	36	33
40	85	575	31	42	41
40	85	825	34	49	49
40	85	1075	38	56	58
40	85	1325	41	62	66
40	85	1575	45	69	74
40	85	1825	48	75	82
40	85	2075	52	82	91
40	85	2325	55	88	99
40	85	2575	59	95	107
40	85	2825	63	102	115
40	85	3075	66	108	124
40	85	3325	70	115	132
40	85	3575	73	121	140
40	85	3825	77	128	148
75	5	75	26	13	21
75	5	325	29	20	30
75	5	575	33	26	38
75	5	825	37	33	46
75	5	1075	40	40	54
75	5	1325	44	46	63
75	5	1575	47	53	71
75	5	1825	51	59	79
75	5	2075	54	66	87
75	5	2325	58	72	96
75	5	2575	61	79	104
75	5	2825	65	86	112
75	5	3075	69	92	120
75	5	3325	72	99	129
75	5	3575	76	105	137
75	5	3825	79	112	145
75	25	75	26	18	23
75	25	325	29	24	31
75	25	575	33	31	39
75	25	825	37	37	48
75	25	1075	40	44	56
75	25	1325	44	50	64
75	25	1575	47	57	72
75	25	1825	51	64	81
75	25	2075	54	70	89
75	25	2325	58	77	97
75	25	2575	61	83	105
75	25	2825	65	90	114
75	25	3075	69	97	122
75	25	3325	72	103	130
75	25	3575	76	110	138
75	25	3825	79	116	147
75	45	75	26	22	24
75	45	325	29	29	32

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
75	45	575	33	35	41
75	45	825	37	42	49
75	45	1075	40	48	57
75	45	1325	44	55	65
75	45	1575	47	61	74
75	45	1825	51	68	82
75	45	2075	54	75	90
75	45	2325	58	81	98
75	45	2575	61	88	107
75	45	2825	65	94	115
75	45	3075	69	101	123
75	45	3325	72	107	131
75	45	3575	76	114	140
75	45	3825	79	121	148
75	65	75	26	26	25
75	65	325	29	33	34
75	65	575	33	40	42
75	65	825	37	46	50
75	65	1075	40	53	59
75	65	1325	44	59	67
75	65	1575	47	66	75
75	65	1825	51	72	83
75	65	2075	54	79	92
75	65	2325	58	86	100
75	65	2575	61	92	108
75	65	2825	65	99	116
75	65	3075	69	105	125
75	65	3325	72	112	133
75	65	3575	76	118	141
75	65	3825	79	125	149
75	85	75	26	31	27
75	85	325	29	37	35
75	85	575	33	44	43
75	85	825	37	51	52
75	85	1075	40	57	60
75	85	1325	44	64	68
75	85	1575	47	70	76
75	85	1825	51	77	85
75	85	2075	54	83	93
75	85	2325	58	90	101
75	85	2575	61	97	109
75	85	2825	65	103	118
75	85	3075	69	110	126
75	85	3325	72	116	134
75	85	3575	76	123	142
75	85	3825	79	129	151
110	5	75	28	15	24
110	5	325	32	21	32
110	5	575	35	28	40
110	5	825	39	35	48
110	5	1075	42	41	57
110	5	1325	46	48	65
110	5	1575	50	54	73
110	5	1825	53	61	81
110	5	2075	57	67	90
110	5	2325	60	74	98
110	5	2575	64	81	106
110	5	2825	67	87	114
110	5	3075	71	94	123
110	5	3325	74	100	131
110	5	3575	78	107	139
110	5	3825	82	113	148
110	25	75	28	19	25
110	25	325	32	26	33
110	25	575	35	32	42
110	25	825	39	39	50

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
110	25	1075	42	46	58
110	25	1325	46	52	66
110	25	1575	50	59	75
110	25	1825	53	65	83
110	25	2075	57	72	91
110	25	2325	60	78	99
110	25	2575	64	85	108
110	25	2825	67	92	116
110	25	3075	71	98	124
110	25	3325	74	105	132
110	25	3575	78	111	141
110	25	3825	82	118	149
110	45	75	28	24	26
110	45	325	32	30	35
110	45	575	35	37	43
110	45	825	39	43	51
110	45	1075	42	50	59
110	45	1325	46	57	68
110	45	1575	50	63	76
110	45	1825	53	70	84
110	45	2075	57	76	92
110	45	2325	60	83	101
110	45	2575	64	89	109
110	45	2825	67	96	117
110	45	3075	71	103	125
110	45	3325	74	109	134
110	45	3575	78	116	142
110	45	3825	82	122	150
110	65	75	28	28	28
110	65	325	32	35	36
110	65	575	35	41	44
110	65	825	39	48	53
110	65	1075	42	54	61
110	65	1325	46	61	69
110	65	1575	50	67	77
110	65	1825	53	74	86
110	65	2075	57	81	94
110	65	2325	60	87	102
110	65	2575	64	94	110
110	65	2825	67	100	119
110	65	3075	71	107	127
110	65	3325	74	114	135
110	65	3575	78	120	143
110	65	3825	82	127	152
110	85	75	28	32	29
110	85	325	32	39	37
110	85	575	35	46	46
110	85	825	39	52	54
110	85	1075	42	59	62
110	85	1325	46	65	70
110	85	1575	50	72	79
110	85	1825	53	78	87
110	85	2075	57	85	95
110	85	2325	60	92	103
110	85	2575	64	98	112
110	85	2825	67	105	120
110	85	3075	71	111	128
110	85	3325	74	118	136
110	85	3575	78	124	145
110	85	3825	82	131	153
145	5	75	31	16	26
145	5	325	34	23	34
145	5	575	38	30	42
145	5	825	41	36	51
145	5	1075	45	43	59
145	5	1325	48	49	67

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
145	5	1575	52	56	75
145	5	1825	56	62	84
145	5	2075	59	69	92
145	5	2325	63	76	100
145	5	2575	66	82	108
145	5	2825	70	89	117
145	5	3075	73	95	125
145	5	3325	77	102	133
145	5	3575	80	108	142
145	5	3825	84	115	150
145	25	75	31	21	27
145	25	325	34	27	36
145	25	575	38	34	44
145	25	825	41	41	52
145	25	1075	45	47	60
145	25	1325	48	54	69
145	25	1575	52	60	77
145	25	1825	56	67	85
145	25	2075	59	73	93
145	25	2325	63	80	102
145	25	2575	66	87	110
145	25	2825	70	93	118
145	25	3075	73	100	126
145	25	3325	77	106	135
145	25	3575	80	113	143
145	25	3825	84	119	151
145	45	75	31	25	29
145	45	325	34	32	37
145	45	575	38	38	45
145	45	825	41	45	53
145	45	1075	45	52	62
145	45	1325	48	58	70
145	45	1575	52	65	78
145	45	1825	56	71	86
145	45	2075	59	78	95
145	45	2325	63	84	103
145	45	2575	66	91	111
145	45	2825	70	98	119
145	45	3075	73	104	128
145	45	3325	77	111	136
145	45	3575	80	117	144
145	45	3825	84	124	153
145	65	75	31	30	30
145	65	325	34	36	38
145	65	575	38	43	47
145	65	825	41	49	55
145	65	1075	45	56	63
145	65	1325	48	63	71
145	65	1575	52	69	80
145	65	1825	56	76	88
145	65	2075	59	82	96
145	65	2325	63	89	104
145	65	2575	66	95	113
145	65	2825	70	102	121
145	65	3075	73	109	129
145	65	3325	77	115	137
145	65	3575	80	122	146
145	65	3825	84	128	154
145	85	75	31	34	31
145	85	325	34	41	40
145	85	575	38	47	48
145	85	825	41	54	56
145	85	1075	45	60	64
145	85	1325	48	67	73
145	85	1575	52	74	81

APPENDIX A (Continued)

X_2	X_5	X_6	$D_{w.af}$	$D_{w.as}$	$D_{w.la}$
145	85	1825	56	80	89
145	85	2075	59	87	97
145	85	2325	63	93	106
145	85	2575	66	100	114
145	85	2825	70	106	122
145	85	3075	73	113	130
145	85	3325	77	120	139
145	85	3575	80	126	147
145	85	3825	84	133	155

APPENDIX B

ESTIMATED WASTE WATER DISPOSAL IN GALLONS PER CAPITA PER DAY FOR SELECTED CONDITIONS

D_w	X_{10}	X_{11}	$D_{ww.af}$	$D_{ww.as}$	$D_{ww.la}$
10	5	2	5	6	6
10	5	4	5	6	6
10	5	6	5	6	6
10	5	8	5	6	6
10	5	10	5	6	6
10	5	12	5	6	6
10	5	14	5	6	6
10	20	2	5	6	6
10	20	4	5	6	6
10	20	6	5	6	6
10	20	8	5	6	6
10	20	10	5	6	6
10	20	12	5	6	6
10	20	14	5	6	6
10	35	2	5	6	6
10	35	4	5	6	6
10	35	6	5	6	6
10	35	8	5	6	6
10	35	10	5	6	6
10	35	12	5	6	6
10	35	14	5	6	6
10	50	2	5	6	6
10	50	4	5	6	6
10	50	6	5	6	6
10	50	8	5	6	6
10	50	10	5	6	6
10	50	12	5	6	6
10	50	14	5	6	6
10	65	2	6	6	6
10	65	4	5	6	6
10	65	6	5	6	6
10	65	8	5	6	6
10	65	10	5	6	6
10	65	12	5	6	6
10	65	14	5	6	6
10	80	2	6	6	6
10	80	4	6	6	6
10	80	6	5	6	6
10	80	8	5	6	6
10	80	10	5	6	6
10	80	12	5	6	6
10	80	14	5	6	6
25	5	2	12	13	16
25	5	4	12	13	15
25	5	6	12	13	15
25	5	8	11	13	15
25	5	10	11	13	15
25	5	12	11	13	15
25	5	14	11	13	15
25	20	2	12	13	16
25	20	4	12	13	15
25	20	6	12	13	15
25	20	8	12	13	15
25	20	10	11	13	15
25	20	12	11	13	15
25	20	14	11	13	15
25	35	2	12	13	16
25	35	4	12	13	15
25	35	6	12	13	15
25	35	8	12	13	15
25	35	10	12	13	15
25	35	12	12	13	15
25	35	14	11	13	15
25	50	2	12	13	16

APPENDIX B (Continued)

D_w	X_{10}	X_{11}	$D_{ww.af}$	$D_{ww.as}$	$D_{ww.la}$
25	50	4	12	13	15
25	50	6	12	13	15
25	50	8	12	13	15
25	50	10	12	13	15
25	50	12	12	13	15
25	50	14	12	13	15
25	65	2	12	13	16
25	65	4	12	13	15
25	65	6	12	13	15
25	65	8	12	13	15
25	65	10	12	13	15
25	65	12	12	13	15
25	65	14	12	13	15
25	80	2	12	13	16
25	80	4	12	13	15
25	80	6	12	13	15
25	80	8	12	13	15
25	80	10	12	13	15
25	80	12	12	13	15
25	80	14	12	13	15
40	5	2	18	19	25
40	5	4	18	19	25
40	5	6	18	19	25
40	5	8	18	19	25
40	5	10	18	19	24
40	5	12	18	19	24
40	5	14	18	19	24
40	20	2	18	20	25
40	20	4	18	20	25
40	20	6	18	20	25
40	20	8	18	20	25
40	20	10	18	20	24
40	20	12	18	20	24
40	20	14	18	20	24
40	35	2	19	20	25
40	35	4	18	20	25
40	35	6	18	20	25
40	35	8	18	20	25
40	35	10	18	20	24
40	35	12	18	20	24
40	35	14	18	20	24
40	50	2	19	20	25
40	50	4	19	20	25
40	50	6	18	20	25
40	50	8	18	20	25
40	50	10	18	20	24
40	50	12	18	20	24
40	50	14	18	20	24
40	65	2	19	20	25
40	65	4	19	20	25
40	65	6	19	20	25
40	65	8	19	20	25
40	65	10	18	20	24
40	65	12	18	20	24
40	65	14	18	20	24
40	80	2	19	20	25
40	80	4	19	20	25
40	80	6	19	20	25
40	80	8	19	20	25
40	80	10	19	20	24
40	80	12	19	20	24
40	80	14	18	20	24
55	5	2	25	26	34
55	5	4	25	26	34
55	5	6	25	26	34
55	5	8	25	26	34

APPENDIX B (Continued)

D_w	X_{10}	X_{11}	$D_{ww.af}$	$D_{ww.as}$	$D_{ww.la}$
55	5	10	25	26	34
55	5	12	25	26	34
55	5	14	24	26	34
55	20	2	25	26	34
55	20	4	25	26	34
55	20	6	25	26	34
55	20	8	25	26	34
55	20	10	25	26	34
55	20	12	25	26	34
55	20	14	25	26	34
55	35	2	25	27	34
55	35	4	25	27	34
55	35	6	25	27	34
55	35	8	25	27	34
55	35	10	25	27	34
55	35	12	25	27	34
55	35	14	25	27	34
55	50	2	25	27	34
55	50	4	25	27	34
55	50	6	25	27	34
55	50	8	25	27	34
55	50	10	25	27	34
55	50	12	25	27	34
55	50	14	25	27	34
55	65	2	25	27	34
55	65	4	25	27	34
55	65	6	25	27	34
55	65	8	25	27	34
55	65	10	25	27	34
55	65	12	25	27	34
55	65	14	25	27	34
55	80	2	25	27	34
55	80	4	25	27	34
55	80	6	25	27	34
55	80	8	25	27	34
55	80	10	25	27	34
55	80	12	25	27	34
55	80	14	25	27	34
70	5	2	32	33	43
70	5	4	31	33	43
70	5	6	31	33	43
70	5	8	31	33	43
70	5	10	31	33	43
70	5	12	31	33	43
70	5	14	31	33	43
70	20	2	32	33	43
70	20	4	32	33	43
70	20	6	31	33	43
70	20	8	31	33	43
70	20	10	31	33	43
70	20	12	31	33	43
70	20	14	31	33	43
70	35	2	32	33	43
70	35	4	32	33	43
70	35	6	32	33	43
70	35	8	32	33	43
70	35	10	31	33	43
70	35	12	31	33	43
70	35	14	31	33	43
70	50	2	32	34	43
70	50	4	32	34	43
70	50	6	32	34	43
70	50	8	32	34	43
70	50	10	32	34	43
70	50	12	32	34	43

APPENDIX B (Continued)

D_w	X_{10}	X_{11}	$D_{ww.af}$	$D_{ww.as}$	$D_{ww.la}$
70	50	14	31	34	43
70	65	2	32	34	43
70	65	4	32	34	43
70	65	6	32	34	43
70	65	8	32	34	43
70	65	10	32	34	43
70	65	12	32	34	43
70	65	14	32	34	43
70	80	2	32	34	43
70	80	4	32	34	43
70	80	6	32	34	43
70	80	8	32	34	43
70	80	10	32	34	43
70	80	12	32	34	43
70	80	14	32	34	43
85	5	2	38	40	53
85	5	4	38	40	52
85	5	6	38	40	52
85	5	8	38	40	52
85	5	10	38	40	52
85	5	12	38	40	52
85	5	14	38	40	52
85	20	2	38	40	53
85	20	4	38	40	52
85	20	6	38	40	52
85	20	8	38	40	52
85	20	10	38	40	52
85	20	12	38	40	52
85	20	14	38	40	52
85	35	2	38	40	53
85	35	4	38	40	52
85	35	6	38	40	52
85	35	8	38	40	52
85	35	10	38	40	52
85	35	12	38	40	52
85	35	14	38	40	52
85	50	2	38	40	53
85	50	4	38	40	52
85	50	6	38	40	52
85	50	8	38.	40	52
85	50	10	38	40	52
85	50	12	38	40	52
85	50	14	38	40	52
85	65	2	39	41	53
85	65	4	39	41	52
85	65	6	38	41	52
85	65	8	38	41	52
85	65	10	38	41	52
85	65	12	38	41	52
85	65	14	38	41	52
85	80	2	39	41	53
85	80	4	39	41	52
85	80	6	39	41	52
85	80	8	39	41	52
85	80	10	38	41	52
85	80	12	38	41	52
85	80	14	38	41	52
100	5	2	45	47	62
100	5	4	45	47	62
100	5	6	45	47	62
100	5	8	45	47	62
100	5	10	44	47	61
100	5	12	44	47	61
100	5	14	44	47	61
100	20	2	45	47	62
100	20	4	45	47	62

APPENDIX B (Continued)

D_w	X_{10}	X_{11}	$D_{ww.af}$	$D_{ww.as}$	$D_{ww.la}$
100	20	6	45	47	62
100	20	8	45	47	62
100	20	10	45	47	61
100	20	12	45	47	61
100	20	14	44	47	61
100	35	2	45	47	62
100	35	4	45	47	62
100	35	6	45	47	62
100	35	8	45	47	62
100	35	10	45	47	61
100	35	12	45	47	61
100	35	14	45	47	61
100	50	2	45	47	62
100	50	4	45	47	62
100	50	6	45	47	62
100	50	8	45	47	62
100	50	10	45	47	61
100	50	12	45	47	61
100	50	14	45	47	61
100	65	2	45	47	62
100	65	4	45	47	62
100	65	6	45	47	62
100	65	8	45	47	62
100	65	10	45	47	61
100	65	12	45	47	61
100	65	14	45	47	61
100	80	2	45	48	62
100	80	4	45	48	62
100	80	6	45	48	62
100	80	8	45	48	62
100	80	10	45	48	61
100	80	12	45	48	61
100	80	14	45	48	61
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APPENDIX C

ESTIMATED COST OF WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (SLOW SAND FILTER) IN 1000 U.S. DOLLARS

D_w	X_{13}	X_{14}	X_{15}	$\overline{C''}_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
5	3	5	0.25	26	12	43	15	39	13
5	3	5	2.50	26	3	34	5	39	3
5	3	5	4.75	26	2	31	4	39	2
5	3	5	7.00	26	2	30	3	39	2
5	3	5	9.25	26	1	29	3	39	1
5	3	5	11.50	26	1	29	2	39	1
5	3	35	0.25	20	12	43	13	34	13
5	3	35	2.50	20	3	34	4	34	3
5	3	35	4.75	20	2	31	3	34	2
5	3	35	7.00	20	2	30	2	34	2
5	3	35	9.25	20	1	29	2	34	1
5	3	35	11.50	20	1	29	2	34	1
5	3	65	0.25	18	12	43	12	32	13
5	3	65	2.50	18	3	34	4	32	3
5	3	65	4.75	18	2	31	3	32	2
5	3	65	7.00	18	2	30	2	32	2
5	3	65	9.25	18	1	29	2	32	1
5	3	65	11.50	18	1	29	2	32	1
5	7	5	0.25	26	12	43	15	39	13
5	7	5	2.50	26	3	34	5	39	3
5	7	5	4.75	26	2	32	4	39	2
5	7	5	7.00	26	2	30	3	39	2
5	7	5	9.25	26	1	30	3	39	1
5	7	5	11.50	26	1	29	2	39	1
5	7	35	0.25	20	12	43	13	34	13
5	7	35	2.50	20	3	34	4	34	3
5	7	35	4.75	20	2	32	3	34	2
5	7	35	7.00	20	2	30	2	34	2
5	7	35	9.25	20	1	30	2	34	1
5	7	35	11.50	20	1	29	2	34	1
5	7	65	0.25	18	12	43	12	32	13
5	7	65	2.50	18	3	34	4	32	3
5	7	65	4.75	18	2	32	3	32	2
5	7	65	7.00	18	2	30	2	32	2
5	7	65	9.25	18	1	30	2	32	1
5	7	65	11.50	18	1	29	2	32	1
5	11	5	0.25	26	12	44	15	39	13
5	11	5	2.50	26	3	34	5	39	3
5	11	5	4.75	26	2	32	4	39	2
5	11	5	7.00	26	2	31	3	39	2
5	11	5	9.25	26	1	30	3	39	1
5	11	5	11.50	26	1	29	2	39	1
5	11	35	0.25	20	12	44	13	34	13
5	11	35	2.50	20	3	34	4	34	3
5	11	35	4.75	20	2	32	3	34	2
5	11	35	7.00	20	2	31	2	34	2
5	11	35	9.25	20	1	30	2	34	1
5	11	35	11.50	20	1	29	2	34	1
5	11	65	0.25	18	12	44	12	32	13
5	11	65	2.50	18	3	34	4	32	3
5	11	65	4.75	18	2	32	3	32	2
5	11	65	7.00	18	2	31	2	32	2
5	11	65	9.25	18	1	30	2	32	1
5	11	65	11.50	18	1	29	2	32	1
25	3	5	0.25	26	12	43	15	39	13
25	3	5	2.50	26	3	34	5	39	3
25	3	5	4.75	26	2	31	4	39	2
25	3	5	7.00	26	2	30	3	39	2
25	3	5	9.25	26	1	29	3	39	1
25	3	5	11.50	26	1	29	2	39	1
25	3	35	0.25	20	12	43	13	34	13
25	3	35	2.50	20	3	34	4	34	3

APPENDIX C (continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
25	3	35	4.75	20	2	31	3	34	2
25	3	35	7.00	20	2	30	2	34	2
25	3	35	9.25	20	1	29	2	34	1
25	3	35	11.50	20	1	29	2	34	1
25	3	65	0.25	19	12	43	12	32	13
25	3	65	2.50	19	3	34	4	32	3
25	3	65	4.75	19	2	31	3	32	2
25	3	65	7.00	19	2	30	2	32	2
25	3	65	9.25	19	1	29	2	32	1
25	3	65	11.50	19	1	29	2	32	1
25	7	5	0.25	26	12	43	15	39	13
25	7	5	2.50	26	3	34	5	39	3
25	7	5	4.75	26	2	32	4	39	2
25	7	5	7.00	26	2	30	3	39	2
25	7	5	9.25	26	1	30	3	39	1
25	7	5	11.50	26	1	29	2	39	1
25	7	35	0.25	20	12	43	13	34	13
25	7	35	2.50	20	3	34	4	34	3
25	7	35	4.75	20	2	32	3	34	2
25	7	35	7.00	20	2	30	2	34	2
25	7	35	9.25	20	1	30	2	34	1
25	7	35	11.50	20	1	29	2	34	1
25	7	65	0.25	19	12	43	12	32	13
25	7	65	2.50	19	3	34	4	32	3
25	7	65	4.75	19	2	32	3	32	2
25	7	65	7.00	19	2	30	2	32	2
25	7	65	9.25	19	1	30	2	32	1
25	7	65	11.50	19	1	29	2	32	1
25	11	5	0.25	26	12	44	15	39	13
25	11	5	2.50	26	3	34	5	39	3
25	11	5	4.75	26	2	32	4	39	2
25	11	5	7.00	26	2	31	3	39	2
25	11	5	9.25	26	1	30	3	39	1
25	11	5	11.50	26	1	29	2	39	1
25	11	35	0.25	20	12	44	13	34	13
25	11	35	2.50	20	3	34	4	34	3
25	11	35	4.75	20	2	32	3	34	2
25	11	35	7.00	20	2	31	2	34	2
25	11	35	9.25	20	1	30	2	34	1
25	11	35	11.50	20	1	29	2	34	1
25	11	65	0.25	19	12	44	12	32	13
25	11	65	2.50	19	3	34	4	32	3
25	11	65	4.75	19	2	32	3	32	2
25	11	65	7.00	19	2	31	2	32	2
25	11	65	9.25	19	1	30	2	32	1
25	11	65	11.50	19	1	29	2	32	1
45	3	5	0.25	26	12	43	15	39	13
45	3	5	2.50	26	3	34	5	39	3
45	3	5	4.75	26	2	31	4	39	2
45	3	5	7.00	26	2	30	3	39	2
45	3	5	9.25	26	1	29	3	39	1
45	3	5	11.50	26	1	29	2	39	1
45	3	35	0.25	20	12	43	13	34	13
45	3	35	2.50	20	3	34	4	34	3
45	3	35	4.75	20	2	31	3	34	2
45	3	35	7.00	20	2	30	2	34	2
45	3	35	9.25	20	1	29	2	34	1
45	3	35	11.50	20	1	29	2	34	1
45	3	65	0.25	19	12	43	12	32	13
45	3	65	2.50	19	3	34	4	32	3
45	3	65	4.75	19	2	31	3	32	2
45	3	65	7.00	19	2	30	2	32	2
45	3	65	9.25	19	1	29	2	32	1
45	3	65	11.50	19	1	29	2	32	1
45	7	5	0.25	26	12	43	15	39	13

APPENDIX C (Continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
45	7	5	2.50	26	3	34	5	39	3
45	7	5	4.75	26	2	32	4	39	2
45	7	5	7.00	26	2	30	3	39	2
45	7	5	9.25	26	1	30	3	39	1
45	7	5	11.50	26	1	29	2	39	1
45	7	35	0.25	20	12	43	13	34	13
45	7	35	2.50	20	3	34	4	34	3
45	7	35	4.75	20	2	32	3	34	2
45	7	35	7.00	20	2	30	2	34	2
45	7	35	9.25	20	1	30	2	34	1
45	7	35	11.50	20	1	29	2	34	1
45	7	65	0.25	19	12	43	12	32	13
45	7	65	2.50	19	3	34	4	32	3
45	7	65	4.75	19	2	32	3	32	2
45	7	65	7.00	19	2	30	2	32	2
45	7	65	9.25	19	1	30	2	32	1
45	7	65	11.50	19	1	29	2	32	1
45	11	5	0.25	26	12	44	15	39	13
45	11	5	2.50	26	3	34	5	39	3
45	11	5	4.75	26	2	32	4	39	2
45	11	5	7.00	26	2	31	3	39	2
45	11	5	9.25	26	1	30	3	39	1
45	11	5	11.50	26	1	29	2	39	1
45	11	35	0.25	20	12	44	13	34	13
45	11	35	2.50	20	3	34	4	34	3
45	11	35	4.75	20	2	32	3	34	2
45	11	35	7.00	20	2	31	2	34	2
45	11	35	9.25	20	1	30	2	34	1
45	11	35	11.50	20	1	29	2	34	1
45	11	65	0.25	19	12	44	12	32	13
45	11	65	2.50	19	3	34	4	32	3
45	11	65	4.75	19	2	32	3	32	2
45	11	65	7.00	19	2	31	2	32	2
45	11	65	9.25	19	1	30	2	32	1
45	11	65	11.50	19	1	29	2	32	1
65	3	5	0.25	27	12	43	15	39	13
65	3	5	2.50	27	3	34	5	39	3
65	3	5	4.75	27	2	31	4	39	2
65	3	5	7.00	27	2	30	3	39	2
65	3	5	9.25	27	1	29	3	39	1
65	3	5	11.50	27	1	29	2	39	1
65	3	35	0.25	21	12	43	13	34	13
65	3	35	2.50	21	3	34	4	34	3
65	3	35	4.75	21	2	31	3	34	2
65	3	35	7.00	21	2	30	2	34	2
65	3	35	9.25	21	1	29	2	34	1
65	3	35	11.50	21	1	29	2	34	1
65	3	65	0.25	19	12	43	12	32	13
65	3	65	2.50	19	3	34	4	32	3
65	3	65	4.75	19	2	31	3	32	2
65	3	65	7.00	19	2	30	2	32	2
65	3	65	9.25	19	1	29	2	32	1
65	3	65	11.50	19	1	29	2	32	1
65	7	5	0.25	27	12	43	15	39	13
65	7	5	2.50	27	3	34	5	39	3
65	7	5	4.75	27	2	32	4	39	2
65	7	5	7.00	27	2	30	3	39	2
65	7	5	9.25	27	1	30	3	39	1
65	7	5	11.50	27	1	29	2	39	1
65	7	35	0.25	21	12	43	13	34	13
65	7	35	2.50	21	3	34	4	34	3
65	7	35	4.75	21	2	32	3	34	2
65	7	35	7.00	21	2	30	2	34	2
65	7	35	9.25	21	1	30	2	34	1

APPENDIX C (Continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
65	7	65	2.50	19	3	34	4	32	3
65	7	65	4.75	19	2	32	3	32	2
65	7	65	7.00	19	2	30	2	32	2
65	7	65	9.25	19	1	30	2	32	1
65	7	65	11.50	19	1	29	2	32	1
65	11	5	0.25	27	12	44	15	39	13
65	11	5	2.50	27	3	34	5	39	3
65	11	5	4.75	27	2	32	4	39	2
65	11	5	7.00	27	2	31	3	39	2
65	11	5	9.25	27	1	30	3	39	1
65	11	5	11.50	27	1	29	2	39	1
65	11	35	0.25	21	12	44	13	34	13
65	11	35	2.50	21	3	34	4	34	3
65	11	35	4.75	21	2	32	3	34	2
65	11	35	7.00	21	2	31	2	34	2
65	11	35	9.25	21	1	30	2	34	1
65	11	35	11.50	21	1	29	2	34	1
65	11	65	0.25	19	12	44	12	32	13
65	11	65	2.50	19	3	34	4	32	3
65	11	65	4.75	19	2	32	3	32	2
65	11	65	7.00	19	2	31	2	32	2
65	11	65	9.25	19	1	30	2	32	1
65	11	65	11.50	19	1	29	2	32	1

APPENDIX D

ESTIMATED MEAN COST OF WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (RAPID SAND FILTER) IN 1000 U.S. DOLLARS

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
5	4	5	0.25	357	127	564	183	478	137
5	4	5	4.00	357	114	564	157	448	118
5	4	5	7.75	357	112	564	151	441	114
5	4	5	11.50	357	110	564	148	437	112
5	4	45	0.25	341	127	518	183	478	137
5	4	45	4.00	341	114	518	157	448	118
5	4	45	7.75	341	112	518	151	441	114
5	4	45	11.50	341	110	518	148	437	112
5	4	85	0.25	336	127	506	183	478	137
5	4	85	4.00	336	114	506	157	448	118
5	4	85	7.75	336	112	506	151	441	114
5	4	85	11.50	336	110	506	148	437	112
5	24	5	0.25	363	132	570	191	480	148
5	24	5	4.00	363	119	570	164	450	128
5	24	5	7.75	363	116	570	158	443	124
5	24	5	11.50	363	115	570	155	439	121
5	24	45	0.25	347	132	524	191	480	148
5	24	45	4.00	347	119	524	164	450	128
5	24	45	7.75	347	116	524	158	443	124
5	24	45	11.50	347	115	524	155	439	121
5	24	85	0.25	342	132	512	191	480	148
5	24	85	4.00	342	119	512	164	450	128
5	24	85	7.75	342	116	512	158	443	124
5	24	85	11.50	342	115	512	155	439	121
5	44	5	0.25	365	134	572	194	481	152
5	44	5	4.00	365	121	572	167	450	131
5	44	5	7.75	365	118	572	161	443	127
5	44	5	11.50	365	116	572	157	439	124
5	44	45	0.25	349	134	527	194	481	152
5	44	45	4.00	349	121	527	167	450	131
5	44	45	7.75	349	118	527	161	443	127
5	44	45	11.50	349	116	527	157	439	124
5	44	85	0.25	344	134	514	194	481	152
5	44	85	4.00	344	121	514	167	450	131
5	44	85	7.75	344	118	514	161	443	127
5	44	85	11.50	344	116	514	157	439	124
5	64	5	0.25	367	135	574	196	481	155
5	64	5	4.00	367	122	574	168	451	134
5	64	5	7.75	367	119	574	162	444	129
5	64	5	11.50	367	117	574	159	440	126
5	64	45	0.25	350	135	528	196	481	155
5	64	45	4.00	350	122	528	168	451	134
5	64	45	7.75	350	119	528	162	444	129
5	64	45	11.50	350	117	528	159	440	126
5	64	85	0.25	345	135	515	196	481	155
5	64	85	4.00	345	122	515	168	451	134
5	64	85	7.75	345	119	515	162	444	129
5	64	85	11.50	345	117	515	159	440	126
45	4	5	0.25	357	127	564	183	478	137
45	4	5	4.00	357	114	564	157	448	118
45	4	5	7.75	357	112	564	151	441	114
45	4	5	11.50	357	110	564	148	437	112
45	4	45	0.25	341	127	518	183	478	137
45	4	45	4.00	341	114	518	157	448	118
45	4	45	7.75	341	112	518	151	441	114
45	4	45	11.50	341	110	518	148	437	112
45	4	85	0.25	336	127	506	183	478	137
45	4	85	4.00	336	114	506	157	448	118
45	4	85	7.75	336	112	506	151	441	114
45	4	85	11.50	336	110	506	148	437	112
45	24	5	0.25	363	132	570	191	480	148
45	24	5	4.00	363	119	570	164	450	128
45	24	5	7.75	363	116	570	158	443	124

APPENDIX D (Continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
45	24	5	11.50	363	115	570	155	439	121
45	24	45	0.25	347	132	524	191	480	148
45	24	45	4.00	347	119	524	164	450	128
45	24	45	7.75	347	116	524	158	443	124
45	24	45	11.50	347	115	524	155	439	121
45	24	85	0.25	342	132	512	191	480	148
45	24	85	4.00	342	119	512	164	450	128
45	24	85	7.75	342	116	512	158	443	124
45	24	85	11.50	342	115	512	155	439	121
45	44	5	0.25	365	134	572	194	481	152
45	44	5	4.00	365	121	572	167	450	131
45	44	5	7.75	365	118	572	161	443	127
45	44	5	11.50	365	116	572	157	439	124
45	44	45	0.25	349	134	527	194	481	152
45	44	45	4.00	349	121	527	167	450	131
45	44	45	7.75	349	118	527	161	443	127
45	44	45	11.50	349	116	527	157	439	124
45	44	85	0.25	344	134	514	194	481	152
45	44	85	4.00	344	121	514	167	450	131
45	44	85	7.75	344	118	514	161	443	127
45	44	85	11.50	344	116	514	157	439	124
45	64	5	0.25	367	135	574	196	481	155
45	64	5	4.00	367	122	574	168	451	134
45	64	5	7.75	367	119	574	162	444	129
45	64	5	11.50	367	117	574	159	440	126
45	64	45	0.25	350	135	528	196	481	155
45	64	45	4.00	350	122	528	168	451	134
45	64	45	7.75	350	119	528	162	444	129
45	64	45	11.50	350	117	528	159	440	126
45	64	85	0.25	345	135	515	196	481	155
45	64	85	4.00	345	122	515	168	451	134
45	64	85	7.75	345	119	515	162	444	129
45	64	85	11.50	345	117	515	159	440	126
85	4	5	0.25	357	127	564	183	478	137
85	4	5	4.00	357	114	564	157	448	118
85	4	5	7.75	357	112	564	151	441	114
85	4	5	11.50	357	110	564	148	437	112
85	4	45	0.25	341	127	518	183	478	137
85	4	45	4.00	341	114	518	157	448	118
85	4	45	7.75	341	112	518	151	441	114
85	4	45	11.50	341	110	518	148	437	112
85	4	85	0.25	336	127	506	183	478	137
85	4	85	4.00	336	114	506	157	448	118
85	4	85	7.75	336	112	506	151	441	114
85	4	85	11.50	336	110	506	148	437	112
85	24	5	0.25	363	132	570	191	480	148
85	24	5	4.00	363	119	570	164	450	128
85	24	5	7.75	363	116	570	158	443	124
85	24	5	11.50	363	115	570	155	439	121
85	24	45	0.25	347	132	524	191	480	148
85	24	45	4.00	347	119	524	164	450	128
85	24	45	7.75	347	116	524	158	443	124
85	24	45	11.50	347	115	524	155	439	121
85	24	85	0.25	342	132	512	191	480	148
85	24	85	4.00	342	119	512	164	450	128
85	24	85	7.75	342	116	512	158	443	124
85	24	85	11.50	342	115	512	155	439	121
85	44	5	0.25	365	134	572	194	481	152
85	44	5	4.00	365	121	572	167	450	131
85	44	5	7.75	365	118	572	161	443	127
85	44	5	11.50	365	116	572	157	439	124
85	44	45	0.25	349	134	527	194	481	152
85	44	45	4.00	349	121	527	167	450	131
85	44	45	7.75	349	118	527	161	443	127
85	44	45	11.50	349	116	527	157	439	124
85	44	85	0.25	344	134	514	194	481	152
85	44	85	4.00	344	121	514	167	450	131

APPENDIX D (Continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
85	44	85	7.75	344	118	514	161	443	127
85	44	85	11.50	344	116	514	157	439	124
85	64	5	0.25	367	135	574	196	481	155
85	64	5	4.00	367	122	574	168	451	134
85	64	5	7.75	367	119	574	162	444	129
85	64	5	11.50	367	117	574	159	440	126
85	64	45	0.25	350	135	528	196	481	155
85	64	45	4.00	350	122	528	168	451	134
85	64	45	7.75	350	119	528	162	444	129
85	64	45	11.50	350	117	528	159	440	126
85	64	85	0.25	345	135	515	196	481	155
85	64	85	4.00	345	122	515	168	451	134
85	64	85	7.75	345	119	515	162	444	129
85	64	85	11.50	345	117	515	159	440	126
125	4	5	0.25	357	127	564	183	478	137
125	4	5	4.00	357	114	564	157	448	118
125	4	5	7.75	357	112	564	151	441	114
125	4	5	11.50	357	110	564	148	437	112
125	4	45	0.25	341	127	518	183	478	137
125	4	45	4.00	341	114	518	157	448	118
125	4	45	7.75	341	112	518	151	441	114
125	4	45	11.50	341	110	518	148	437	112
125	4	85	0.25	336	127	506	183	478	137
125	4	85	4.00	336	114	506	157	448	118
125	4	85	7.75	336	112	506	151	441	114
125	4	85	11.50	336	110	506	148	437	112
125	24	5	0.25	363	132	570	191	480	148
125	24	5	4.00	363	119	570	164	450	128
125	24	5	7.75	363	116	570	158	443	124
125	24	5	11.50	363	115	570	155	439	121
125	24	45	0.25	347	132	524	191	480	148
125	24	45	4.00	347	119	524	164	450	128
125	24	45	7.75	347	116	524	158	443	124
125	24	45	11.50	347	115	524	155	439	121
125	24	85	0.25	342	132	512	191	480	148
125	24	85	4.00	342	119	512	164	450	128
125	24	85	7.75	342	116	512	158	443	124
125	24	85	11.50	342	115	512	155	439	121
125	44	5	0.25	365	134	572	194	481	152
125	44	5	4.00	365	121	572	167	450	131
125	44	5	7.75	365	118	572	161	443	127
125	44	5	11.50	365	116	572	157	439	124
125	44	45	0.25	349	134	527	194	481	152
125	44	45	4.00	349	121	527	167	450	131
125	44	45	7.75	349	118	527	161	443	127
125	44	45	11.50	349	116	527	157	439	124
125	44	85	0.25	344	134	514	194	481	152
125	44	85	4.00	344	121	514	167	450	131
125	44	85	7.75	344	118	514	161	443	127
125	44	85	11.50	344	116	514	157	439	124
125	64	5	0.25	367	135	574	196	481	155
125	64	5	4.00	367	122	574	168	451	134
125	64	5	7.75	367	119	574	162	444	129
125	64	5	11.50	367	117	574	159	440	126
125	64	45	0.25	350	135	528	196	481	155
125	64	45	4.00	350	122	528	168	451	134
125	64	45	7.75	350	119	528	162	444	129
125	64	45	11.50	350	117	528	159	440	126
125	64	85	0.25	345	135	515	196	481	155
125	64	85	4.00	345	122	515	168	451	134
125	64	85	7.75	345	119	515	162	444	129
125	64	85	11.50	345	117	515	159	440	126
165	4	5	0.25	357	127	564	183	478	137
165	4	5	4.00	357	114	564	157	448	118
165	4	5	7.75	357	112	564	151	441	114

APPENDIX D (Continued)

D_w	X_{13}	X_{14}	X_{15}	$C''_{w.af}$	$C''''_{w.af}$	$C''_{w.as}$	$C''''_{w.as}$	$C''_{w.la}$	$C''''_{w.la}$
165	4	5	11.50	357	110	564	148	437	112
165	4	45	0.25	341	127	518	183	478	137
165	4	45	4.00	341	114	518	157	448	118
165	4	45	7.75	341	112	518	151	441	114
165	4	45	11.50	341	110	518	148	437	112
165	4	85	0.25	336	127	506	183	478	137
165	4	85	4.00	336	114	506	157	448	118
165	4	85	7.75	336	112	506	151	441	114
165	4	85	11.50	336	110	506	148	437	112
165	24	5	0.25	363	132	570	191	480	148
165	24	5	4.00	363	119	570	164	450	128
165	24	5	7.75	363	116	570	158	443	124
165	24	5	11.50	363	115	570	155	439	121
165	24	45	0.25	347	132	524	191	480	148
165	24	45	4.00	347	119	524	164	450	128
165	24	45	7.75	347	116	524	158	443	124
165	24	45	11.50	347	115	524	155	439	121
165	24	85	0.25	342	132	512	191	480	148
165	24	85	4.00	342	119	512	164	450	128
165	24	85	7.75	342	116	512	158	443	124
165	24	85	11.50	342	115	512	155	439	121
165	44	5	0.25	365	134	572	194	481	152
165	44	5	4.00	365	121	572	167	450	131
165	44	5	7.75	365	118	572	161	443	127
165	44	5	11.50	365	116	572	157	439	124
165	44	45	0.25	349	134	527	194	481	152
165	44	45	4.00	349	121	527	167	450	131
165	44	45	7.75	349	118	527	161	443	127
165	44	45	11.50	349	116	527	157	439	124
165	44	85	0.25	344	134	514	194	481	152
165	44	85	4.00	344	121	514	167	450	131
165	44	85	7.75	344	118	514	161	443	127
165	44	85	11.50	344	116	514	157	439	124
165	64	5	0.25	367	135	574	196	481	155
165	64	5	4.00	367	122	574	168	451	134
165	64	5	7.75	367	119	574	162	444	129
165	64	5	11.50	367	117	574	159	440	126
165	64	45	0.25	350	135	528	196	481	155
165	64	45	4.00	350	122	528	168	451	134
165	64	45	7.75	350	119	528	162	444	129
165	64	45	11.50	350	117	528	159	440	126
165	64	85	0.25	345	135	515	196	481	155
165	64	85	4.00	345	122	515	168	451	134
165	64	85	7.75	345	119	515	162	444	129
165	64	85	11.50	345	117	515	159	440	126

APPENDIX E

ESTIMATED MEAN COST OF WASTE WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (STABILIZATION LAGOON) IN 1000 U.S. DOLLARS

X_{16}	X_{20}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
5	0.25	55	6	96	9	105	9
5	3.50	55	5	96	9	103	9
5	6.75	55	5	96	9	103	9
5	10.00	55	5	96	9	103	9
20	0.25	52	4	67	9	103	7
20	3.50	52	3	67	9	102	7
20	6.75	52	3	67	9	102	7
20	10.00	52	3	67	9	102	7
35	0.25	50	3	58	9	103	6
35	3.50	50	3	58	9	102	6
35	6.75	50	3	58	9	102	6
35	10.00	50	3	58	9	101	6
50	0.25	50	3	53	9	103	6
50	3.50	50	3	53	9	102	6
50	6.75	50	3	53	9	101	6
50	10.00	50	3	53	9	101	6
65	0.25	49	3	50	9	103	5
65	3.50	49	3	50	9	101	5
65	6.75	49	2	50	9	101	5
65	10.00	49	2	50	9	101	5
80	0.25	49	3	47	9	102	5
80	3.50	49	2	47	9	101	5
80	6.75	49	2	47	9	101	5
80	10.00	49	2	47	9	101	5
95	0.25	48	3	45	9	102	5
95	3.50	48	2	45	9	101	5
95	6.75	48	2	45	9	101	5
95	10.00	48	2	45	9	101	5
110	0.25	48	2	43	9	102	5
110	3.50	48	2	43	9	101	5
110	6.75	48	2	43	9	101	5
110	10.00	48	2	43	9	100	5
125	0.25	48	2	42	9	102	5
125	3.50	48	2	42	9	101	5
125	6.75	48	2	42	9	101	5
125	10.00	48	2	42	9	100	5
140	0.25	47	2	41	9	102	5
140	3.50	47	2	41	9	101	4
140	6.75	47	2	41	9	100	4
140	10.00	47	2	41	9	100	4
155	0.25	47	2	40	9	102	4
155	3.50	47	2	40	9	101	4
155	6.75	47	2	40	9	100	4
155	10.00	47	2	40	9	100	4
170	0.25	47	2	39	9	102	4
170	3.50	47	2	39	9	101	4
170	6.75	47	2	39	9	100	4
170	10.00	47	2	39	9	100	4
185	0.25	47	2	38	9	102	4
185	3.50	47	2	38	9	101	4
185	6.75	47	2	38	9	100	4
185	10.00	47	2	38	9	100	4

APPENDIX E (Continued)

X_{16}	X_{20}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
200	0.25	47	2	37	9	102	4
200	3.50	47	2	37	9	100	4
200	6.75	47	2	37	9	100	4
200	10.00	47	2	37	9	100	4
215	0.25	47	2	36	9	102	4
215	3.50	47	2	36	9	100	4
215	6.75	47	2	36	9	100	4
215	10.00	47	2	36	9	100	4
230	0.25	46	2	36	9	102	4
230	3.50	46	2	36	9	100	4
230	6.75	46	2	36	9	100	4
230	10.00	46	2	36	9	100	4
245	0.25	46	2	35	9	101	4
245	3.50	46	2	35	9	100	4
245	6.75	46	2	35	9	100	4
245	10.00	46	2	35	9	100	4

APPENDIX F

ESTIMATED MEAN COST OF WASTE WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (AERATED LAGOON) IN 1000 U.S. DOLLARS

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
5	0.25	3	155	65	195	70	284	93
5	0.25	5	155	65	195	71	284	93
5	0.25	7	155	65	195	71	284	93
5	0.25	9	155	65	195	71	284	93
5	0.25	11	155	65	195	71	284	93
5	3.50	3	112	31	112	40	184	35
5	3.50	5	112	31	112	40	184	35
5	3.50	7	112	31	112	40	184	35
5	3.50	9	112	31	112	40	184	35
5	3.50	11	112	31	112	40	184	35
5	6.75	3	104	25	98	34	165	28
5	6.75	5	104	25	98	35	165	28
5	6.75	7	104	25	98	35	165	28
5	6.75	9	104	25	98	35	165	28
5	6.75	11	104	25	98	35	165	28
5	10.00	3	99	23	90	32	155	24
5	10.00	5	99	23	90	32	155	24
5	10.00	7	99	23	90	32	155	24
5	10.00	9	99	23	90	32	155	24
5	10.00	11	99	23	90	32	155	24
20	0.25	3	154	65	183	70	284	93
20	0.25	5	154	65	183	71	284	93
20	0.25	7	154	65	183	71	284	93
20	0.25	9	154	65	183	71	284	93
20	0.25	11	154	65	183	71	284	93
20	3.50	3	112	31	105	40	184	35
20	3.50	5	112	31	105	40	184	35
20	3.50	7	112	31	105	40	184	35
20	3.50	9	112	31	105	40	184	35
20	3.50	11	112	31	105	40	184	35
20	6.75	3	103	25	91	34	165	28
20	6.75	5	103	25	91	35	165	28
20	6.75	7	103	25	91	35	165	28
20	6.75	9	103	25	91	35	165	28
20	6.75	11	103	25	91	35	165	28
20	10.00	3	98	23	84	32	155	24
20	10.00	5	98	23	84	32	155	24
20	10.00	7	98	23	84	32	155	24
20	10.00	9	98	23	84	32	155	24
20	10.00	11	98	23	84	32	155	24
35	0.25	3	154	65	178	70	284	93
35	0.25	5	154	65	178	71	284	93
35	0.25	7	154	65	178	71	284	93
35	0.25	9	154	65	178	71	284	93
35	0.25	11	154	65	178	71	284	93
35	3.50	3	112	31	102	40	184	35
35	3.50	5	112	31	102	40	184	35
35	3.50	7	112	31	102	40	184	35
35	3.50	9	112	31	102	40	184	35
35	3.50	11	112	31	102	40	184	35
35	6.75	3	103	25	89	34	165	28
35	6.75	5	103	25	89	35	165	28
35	6.75	7	103	25	89	35	165	28
35	6.75	9	103	25	89	35	165	28
35	6.75	11	103	25	89	35	165	28
35	10.00	3	98	23	82	32	155	24
35	10.00	5	98	23	82	32	155	24
35	10.00	7	98	23	82	32	155	24

APPENDIX F (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
35	10.00	9	98	23	82	32	155	24
35	10.00	11	98	23	82	32	155	24
50	0.25	3	154	65	175	70	284	93
50	0.25	5	154	65	175	71	284	93
50	0.25	7	154	65	175	71	284	93
50	0.25	9	154	65	175	71	284	93
50	0.25	11	154	65	175	71	284	93
50	3.50	3	112	31	100	40	184	35
50	3.50	5	112	31	100	40	184	35
50	3.50	7	112	31	100	40	184	35
50	3.50	9	112	31	100	40	184	35
50	3.50	11	112	31	100	40	184	35
50	6.75	3	103	25	88	34	165	28
50	6.75	5	103	25	88	35	165	28
50	6.75	7	103	25	88	35	165	28
50	6.75	9	103	25	88	35	165	28
50	6.75	11	103	25	88	35	165	28
50	10.00	3	98	23	81	32	155	24
50	10.00	5	98	23	81	32	155	24
50	10.00	7	98	23	81	32	155	24
50	10.00	9	98	23	81	32	155	24
50	10.00	11	98	23	81	32	155	24
65	0.25	3	154	65	173	70	284	93
65	0.25	5	154	65	173	71	284	93
65	0.25	7	154	65	173	71	284	93
65	0.25	9	154	65	173	71	284	93
65	0.25	11	154	65	173	71	284	93
65	3.50	3	111	31	99	40	184	35
65	3.50	5	111	31	99	40	184	35
65	3.50	7	111	31	99	40	184	35
65	3.50	9	111	31	99	40	184	35
65	3.50	11	111	31	99	40	184	35
65	6.75	3	103	25	86	34	165	28
65	6.75	5	103	25	86	35	165	28
65	6.75	7	103	25	86	35	165	28
65	6.75	9	103	25	86	35	165	28
65	6.75	11	103	25	86	35	165	28
65	10.00	3	98	23	80	32	155	24
65	10.00	5	98	23	80	32	155	24
65	10.00	7	98	23	80	32	155	24
65	10.00	9	98	23	80	32	155	24
65	10.00	11	98	23	80	32	155	24
80	0.25	3	154	65	171	70	284	93
80	0.25	5	154	65	171	71	284	93
80	0.25	7	154	65	171	71	284	93
80	0.25	9	154	65	171	71	284	93
80	0.25	11	154	65	171	71	284	93
80	3.50	3	111	31	98	40	184	35
80	3.50	5	111	31	98	40	184	35
80	3.50	7	111	31	98	40	184	35
80	3.50	9	111	31	98	40	184	35
80	3.50	11	111	31	98	40	184	35
80	6.75	3	103	25	86	34	165	28
80	6.75	5	103	25	86	35	165	28
80	6.75	7	103	25	86	35	165	28
80	6.75	9	103	25	86	35	165	28
80	6.75	11	103	25	86	35	165	28
80	10.00	3	98	23	79	32	155	24
80	10.00	5	98	23	79	32	155	24
80	10.00	7	98	23	79	32	155	24
80	10.00	9	98	23	79	32	155	24
80	10.00	11	98	23	79	32	155	24
95	0.25	3	153	65	170	70	284	93
95	0.25	5	153	65	170	71	284	93
95	0.25	7	153	65	170	71	284	93

APPENDIX F (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
95	0.25	9	153	65	170	71	284	93
95	0.25	11	153	65	170	71	284	93
95	3.50	3	111	31	97	40	184	35
95	3.50	5	111	31	97	40	184	35
95	3.50	7	111	31	97	40	184	35
95	3.50	9	111	31	97	40	184	35
95	3.50	11	111	31	97	40	184	35
95	6.75	3	103	25	85	34	165	28
95	6.75	5	103	25	85	35	165	28
95	6.75	7	103	25	85	35	165	28
95	6.75	9	103	25	85	35	165	28
95	6.75	11	103	25	85	35	165	28
95	10.00	3	98	23	78	32	155	24
95	10.00	5	98	23	78	32	155	24
95	10.00	7	98	23	78	32	155	24
95	10.00	9	98	23	78	32	155	24
95	10.00	11	98	23	78	32	155	24
110	0.25	3	153	65	169	70	284	93
110	0.25	5	153	65	169	71	284	93
110	0.25	7	153	65	169	71	284	93
110	0.25	9	153	65	169	71	284	93
110	0.25	11	153	65	169	71	284	93
110	3.50	3	111	31	97	40	184	35
110	3.50	5	111	31	97	40	184	35
110	3.50	7	111	31	97	40	184	35
110	3.50	9	111	31	97	40	184	35
110	3.50	11	111	31	97	40	184	35
110	6.75	3	103	25	84	34	165	28
110	6.75	5	103	25	84	35	165	28
110	6.75	7	103	25	84	35	165	28
110	6.75	9	103	25	84	35	165	28
110	6.75	11	103	25	84	35	165	28
110	10.00	3	98	23	78	32	155	24
110	10.00	5	98	23	78	32	155	24
110	10.00	7	98	23	78	32	155	24
110	10.00	9	98	23	78	32	155	24
110	10.00	11	98	23	78	32	155	24

APPENDIX G

ESTIMATED MEAN COST OF WASTE WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (ACTIVATED SLUDGE) IN 1000 U.S. DOLLARS

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
5	0.25	3	1110	268	277	88	2358	463
5	0.25	5	1111	268	317	88	2358	463
5	0.25	7	1111	268	347	89	2358	463
5	0.25	9	1112	268	370	89	2358	463
5	0.25	11	1113	268	391	89	2358	463
5	3.50	3	500	110	277	88	918	165
5	3.50	5	501	110	317	88	918	165
5	3.50	7	501	110	347	89	918	165
5	3.50	9	501	110	370	89	918	165
5	3.50	11	501	110	391	89	918	165
5	6.75	3	410	89	277	88	726	128
5	6.75	5	411	89	317	88	726	128
5	6.75	7	411	89	347	89	726	128
5	6.75	9	411	89	370	89	726	128
5	6.75	11	411	89	391	89	726	128
5	10.00	3	364	78	277	88	631	110
5	10.00	5	365	78	317	88	631	110
5	10.00	7	365	78	347	89	631	110
5	10.00	9	365	78	370	89	631	110
5	10.00	11	365	78	391	89	631	110
20	0.25	3	1110	268	192	60	2346	458
20	0.25	5	1111	268	220	60	2346	458
20	0.25	7	1111	268	240	60	2346	458
20	0.25	9	1112	268	257	60	2346	458
20	0.25	11	1113	268	271	60	2346	458
20	3.50	3	500	110	192	60	913	163
20	3.50	5	501	110	220	60	913	163
20	3.50	7	501	110	240	60	913	163
20	3.50	9	501	110	257	60	913	163
20	3.50	11	501	110	271	60	913	163
20	6.75	3	410	89	192	60	722	127
20	6.75	5	411	89	220	60	722	127
20	6.75	7	411	89	240	60	722	127
20	6.75	9	411	89	257	60	722	127
20	6.75	11	411	89	271	60	722	127
20	10.00	3	364	78	192	60	627	109
20	10.00	5	365	78	220	60	627	109
20	10.00	7	365	78	240	60	627	109
20	10.00	9	365	78	257	60	627	109
20	10.00	11	365	78	271	60	627	109
35	0.25	3	1110	268	166	52	2342	456
35	0.25	5	1111	268	190	52	2342	456
35	0.25	7	1111	268	207	52	2342	456
35	0.25	9	1112	268	221	52	2342	456
35	0.25	11	1113	268	233	52	2342	456
35	3.50	3	500	110	166	52	912	163
35	3.50	5	501	110	190	52	912	163
35	3.50	7	501	110	207	52	912	163
35	3.50	9	501	110	221	52	912	163
35	3.50	11	501	110	233	52	912	163
35	6.75	3	410	89	166	52	721	126
35	6.75	5	411	89	190	52	721	126
35	6.75	7	411	89	207	52	721	126
35	6.75	9	411	89	221	52	721	126
35	6.75	11	411	89	233	52	721	126
35	10.00	3	364	78	166	52	626	108
35	10.00	5	365	78	190	52	626	108
35	10.00	7	365	78	207	52	626	108
35	10.00	9	365	78	221	52	626	108
35	10.00	11	365	78	233	52	626	108
50	0.25	3	1110	268	151	47	2339	455

APPENDIX G (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
50	0.25	5	1111	268	172	47	2339	455
50	0.25	7	1111	268	189	47	2339	455
50	0.25	9	1112	268	201	47	2339	455
50	0.25	11	1113	268	212	47	2339	455
50	3.50	3	500	110	151	47	910	162
50	3.50	5	501	110	172	47	910	162
50	3.50	7	501	110	189	47	910	162
50	3.50	9	501	110	201	47	910	162
50	3.50	11	501	110	212	47	910	162
50	6.75	3	410	89	151	47	720	126
50	6.75	5	411	89	172	47	720	126
50	6.75	7	411	89	189	47	720	126
50	6.75	9	411	89	201	47	720	126
50	6.75	11	411	89	212	47	720	126
50	10.00	3	364	78	151	47	625	108
50	10.00	5	365	78	172	47	625	108
50	10.00	7	365	78	189	47	625	108
50	10.00	9	365	78	201	47	625	108
50	10.00	11	365	78	212	47	625	108
65	0.25	3	1110	268	141	44	2336	454
65	0.25	5	1111	268	161	44	2336	454
65	0.25	7	1111	268	176	44	2336	454
65	0.25	9	1112	268	188	44	2336	454
65	0.25	11	1113	268	198	44	2336	454
65	3.50	3	500	110	141	44	910	162
65	3.50	5	501	110	161	44	910	162
65	3.50	7	501	110	176	44	910	162
65	3.50	9	501	110	188	44	910	162
65	3.50	11	501	110	198	44	910	162
65	6.75	3	410	89	141	44	719	125
65	6.75	5	411	89	161	44	719	125
65	6.75	7	411	89	176	44	719	125
65	6.75	9	411	89	188	44	719	125
65	6.75	11	411	89	198	44	719	125
65	10.00	3	364	78	141	44	625	108
65	10.00	5	365	78	161	44	625	108
65	10.00	7	365	78	176	44	625	108
65	10.00	9	365	78	188	44	625	108
65	10.00	11	365	78	198	44	625	108
80	0.25	3	1110	268	133	41	2335	453
80	0.25	5	1111	268	152	41	2335	453
80	0.25	7	1111	268	166	41	2335	453
80	0.25	9	1112	268	178	41	2335	453
80	0.25	11	1113	268	188	41	2335	453
80	3.50	3	500	110	133	41	909	162
80	3.50	5	501	110	152	41	909	162
80	3.50	7	501	110	166	41	909	162
80	3.50	9	501	110	178	41	909	162
80	3.50	11	501	110	188	41	909	162
80	6.75	3	410	89	133	41	719	125
80	6.75	5	411	89	152	41	719	125
80	6.75	7	411	89	166	41	719	125
80	6.75	9	411	89	178	41	719	125
80	6.75	11	411	89	188	41	719	125
80	10.00	3	364	78	133	41	624	107
80	10.00	5	365	78	152	41	624	107
80	10.00	7	365	78	166	41	624	107
80	10.00	9	365	78	178	41	624	107
80	10.00	11	365	78	188	41	624	107
95	0.25	3	1110	268	127	39	2333	453
95	0.25	5	1111	268	146	39	2333	453
95	0.25	7	1111	268	159	39	2333	453
95	0.25	9	1112	268	170	39	2333	453
95	0.25	11	1113	268	179	39	2333	453
95	3.50	3	500	110	127	39	908	162
95	3.50	5	501	110	146	39	908	162

APPENDIX G (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
95	3.50	7	501	110	159	39	908	162
95	3.50	9	501	110	170	39	908	162
95	3.50	11	501	110	179	39	908	162
95	6.75	3	410	89	127	39	718	125
95	6.75	5	411	89	146	39	718	125
95	6.75	7	411	89	159	39	718	125
95	6.75	9	411	89	170	39	718	125
95	6.75	11	411	89	179	39	718	125
95	10.00	3	364	78	127	39	624	107
95	10.00	5	365	78	146	39	624	107
95	10.00	7	365	78	159	39	624	107
95	10.00	9	365	78	170	39	624	107
95	10.00	11	365	78	179	39	624	107
110	0.25	3	1110	268	122	38	2332	452
110	0.25	5	1111	268	140	38	2332	452
110	0.25	7	1111	268	153	38	2332	452
110	0.25	9	1112	268	164	38	2332	452
110	0.25	11	1113	268	172	38	2332	452
110	3.50	3	500	110	122	38	908	161
110	3.50	5	501	110	140	38	908	161
110	3.50	7	501	110	153	38	908	161
110	3.50	9	501	110	164	38	908	161
110	3.50	11	501	110	172	38	908	161
110	6.75	3	410	89	122	38	718	125
110	6.75	5	411	89	140	38	718	125
110	6.75	7	411	89	153	38	718	125
110	6.75	9	411	89	164	38	718	125
110	6.75	11	411	89	172	38	718	125
110	10.00	3	364	78	122	38	624	107
110	10.00	5	365	78	140	38	624	107
110	10.00	7	365	78	153	38	624	107
110	10.00	9	365	78	164	38	624	107
110	10.00	11	365	78	172	38	624	107

APPENDIX H

ESTIMATED MEAN COST OF WASTE WATER TREATMENT PER MGD FOR SELECTED CONDITIONS (TRICKLING FILTER) IN 1000 U.S. DOLLARS

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
5	0.25	3	2990	268	2532	128	1706	593
5	0.25	5	2990	269	2532	130	1706	593
5	0.25	7	2990	269	2532	131	1706	593
5	0.25	9	2990	269	2532	131	1706	593
5	0.25	11	2990	269	2532	132	1706	593
5	3.50	3	700	111	561	128	715	272
5	3.50	5	700	111	561	130	715	272
5	3.50	7	700	111	561	131	715	272
5	3.50	9	700	111	561	131	715	272
5	3.50	11	700	111	561	132	715	272
5	6.75	3	487	89	386	128	576	224
5	6.75	5	487	89	386	130	576	224
5	6.75	7	487	89	386	131	576	224
5	6.75	9	487	89	386	131	576	224
5	6.75	11	487	89	386	132	576	224
5	10.00	3	393	78	308	128	506	199
5	10.00	5	393	78	308	130	506	199
5	10.00	7	393	78	308	131	506	199
5	10.00	9	393	78	308	131	506	199
5	10.00	11	393	78	308	132	506	199
20	0.25	3	2990	268	2532	89	1706	593
20	0.25	5	2990	269	2532	90	1706	593
20	0.25	7	2990	269	2532	90	1706	593
20	0.25	9	2990	269	2532	91	1706	593
20	0.25	11	2990	269	2532	91	1706	593
20	3.50	3	700	111	561	89	715	272
20	3.50	5	700	111	561	90	715	272
20	3.50	7	700	111	561	90	715	272
20	3.50	9	700	111	561	91	715	272
20	3.50	11	700	111	561	91	715	272
20	6.75	3	487	89	386	89	576	224
20	6.75	5	487	89	386	90	576	224
20	6.75	7	487	89	386	90	576	224
20	6.75	9	487	89	386	91	576	224
20	6.75	11	487	89	386	91	576	224
20	10.00	3	393	78	308	89	506	199
20	10.00	5	393	78	308	90	506	199
20	10.00	7	393	78	308	90	506	199
20	10.00	9	393	78	308	91	506	199
20	10.00	11	393	78	308	91	506	199
35	0.25	3	2990	268	2532	76	1706	593
35	0.25	5	2990	269	2532	77	1706	593
35	0.25	7	2990	269	2532	78	1706	593
35	0.25	9	2990	269	2532	78	1706	593
35	0.25	11	2990	269	2532	79	1706	593
35	3.50	3	700	111	561	76	715	272
35	3.50	5	700	111	561	77	715	272
35	3.50	7	700	111	561	78	715	272
35	3.50	9	700	111	561	78	715	272
35	3.50	11	700	111	561	79	715	272
35	6.75	3	487	89	386	76	576	224
35	6.75	5	487	89	386	77	576	224
35	6.75	7	487	89	386	78	576	224
35	6.75	9	487	89	386	78	576	224
35	6.75	11	487	89	386	79	576	224
35	10.00	3	393	78	308	76	506	199
35	10.00	5	393	78	308	77	506	199
35	10.00	7	393	78	308	78	506	199
35	10.00	9	393	78	308	78	506	199

APPENDIX H (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
35	10.00	11	393	78	308	79	506	199
50	0.25	3	2990	268	2532	70	1706	593
50	0.25	5	2990	269	2532	70	1706	593
50	0.25	7	2990	269	2532	71	1706	593
50	0.25	9	2990	269	2532	71	1706	593
50	0.25	11	2990	269	2532	72	1706	593
50	3.50	3	700	111	561	70	715	272
50	3.50	5	700	111	561	70	715	272
50	3.50	7	700	111	561	71	715	272
50	3.50	9	700	111	561	71	715	272
50	3.50	11	700	111	561	72	715	272
50	6.75	3	487	89	386	70	576	224
50	6.75	5	487	89	386	70	576	224
50	6.75	7	487	89	386	71	576	224
50	6.75	9	487	89	386	71	576	224
50	6.75	11	487	89	386	72	576	224
50	10.00	3	393	78	308	70	506	199
50	10.00	5	393	78	308	70	506	199
50	10.00	7	393	78	308	71	506	199
50	10.00	9	393	78	308	71	506	199
50	10.00	11	393	78	308	72	506	199
65	0.25	3	2990	268	2532	65	1706	593
65	0.25	5	2990	269	2532	66	1706	593
65	0.25	7	2990	269	2532	66	1706	593
65	0.25	9	2990	269	2532	66	1706	593
65	0.25	11	2990	269	2532	67	1706	593
65	3.50	3	700	111	561	65	715	272
65	3.50	5	700	111	561	66	715	272
65	3.50	7	700	111	561	66	715	272
65	3.50	9	700	111	561	66	715	272
65	3.50	11	700	111	561	67	715	272
65	6.75	3	487	89	386	65	576	224
65	6.75	5	487	89	386	66	576	224
65	6.75	7	487	89	386	66	576	224
65	6.75	9	487	89	386	66	576	224
65	6.75	11	487	89	386	67	576	224
65	10.00	3	393	78	308	65	506	199
65	10.00	5	393	78	308	66	506	199
65	10.00	7	393	78	308	66	506	199
65	10.00	9	393	78	308	66	506	199
65	10.00	11	393	78	308	67	506	199
80	0.25	3	2990	268	2532	61	1706	593
80	0.25	5	2990	269	2532	62	1706	593
80	0.25	7	2990	269	2532	63	1706	593
80	0.25	9	2990	269	2532	63	1706	593
80	0.25	11	2990	269	2532	63	1706	593
80	3.50	3	700	111	561	61	715	272
80	3.50	5	700	111	561	62	715	272
80	3.50	7	700	111	561	63	715	272
80	3.50	9	700	111	561	63	715	272
80	3.50	11	700	111	561	63	715	272
80	6.75	3	487	89	386	61	576	224
80	6.75	5	487	89	386	62	576	224
80	6.75	7	487	89	386	63	576	224
80	6.75	9	487	89	386	63	576	224
80	6.75	11	487	89	386	63	576	224
80	10.00	3	393	78	308	61	506	199
80	10.00	5	393	78	308	62	506	199
80	10.00	7	393	78	308	63	506	199
80	10.00	9	393	78	308	63	506	199
80	10.00	11	393	78	308	63	506	199
95	0.25	3	2990	268	2532	59	1706	593
95	0.25	5	2990	269	2532	59	1706	593
95	0.25	7	2990	269	2532	60	1706	593
95	0.25	9	2990	269	2532	60	1706	593

APPENDIX H (Continued)

X_{16}	X_{20}	X_{21}	$C''_{ww.af}$	$C''''_{ww.af}$	$C''_{ww.as}$	$C''''_{ww.as}$	$C''_{ww.la}$	$C''''_{ww.la}$
95	0.25	11	2990	269	2532	60	1706	593
95	3.50	3	700	111	561	59	715	272
95	3.50	5	700	111	561	59	715	272
95	3.50	7	700	111	561	60	715	272
95	3.50	9	700	111	561	60	715	272
95	3.50	11	700	111	561	60	715	272
95	6.75	3	487	89	386	59	576	224
95	6.75	5	487	89	386	59	576	224
95	6.75	7	487	89	386	60	576	224
95	6.75	9	487	89	386	60	576	224
95	6.75	11	487	89	386	60	576	224
95	10.00	3	393	78	308	59	506	199
95	10.00	5	393	78	308	59	506	199
95	10.00	7	393	78	308	60	506	199
95	10.00	9	393	78	308	60	506	199
95	10.00	11	393	78	308	60	506	199
110	0.25	3	2990	268	2532	56	1706	593
110	0.25	5	2990	269	2532	57	1706	593
110	0.25	7	2990	269	2532	57	1706	593
110	0.25	9	2990	269	2532	58	1706	593
110	0.25	11	2990	269	2532	58	1706	593
110	3.50	3	700	111	561	56	715	272
110	3.50	5	700	111	561	57	715	272
110	3.50	7	700	111	561	57	715	272
110	3.50	9	700	111	561	58	715	272
110	3.50	11	700	111	561	58	715	272
110	6.75	3	487	89	386	56	576	224
110	6.75	5	487	89	386	57	576	224
110	6.75	7	487	89	386	57	576	224
110	6.75	9	487	89	386	58	576	224
110	6.75	11	487	89	386	58	576	224
110	10.00	3	393	78	308	56	506	199
110	10.00	5	393	78	308	57	506	199
110	10.00	7	393	78	308	57	506	199
110	10.00	9	393	78	308	58	506	199
110	10.00	11	393	78	308	58	506	199