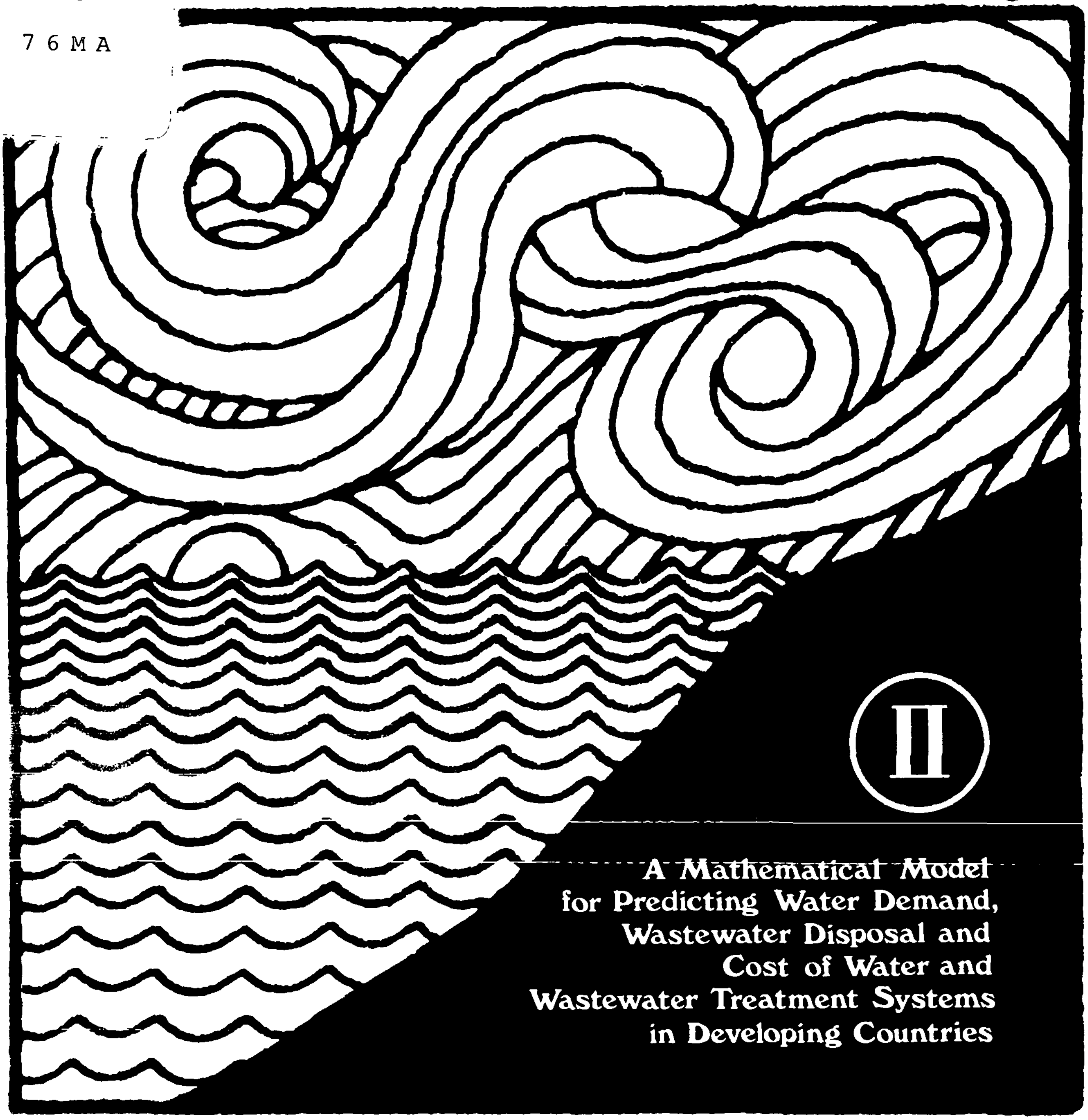


# APPROPRIATE METHODS OF TREATING WATER AND WASTEWATER IN DEVELOPING COUNTRIES

**Low Cost Methods of Treating Water and Wastewater in Developing Countries - Final Reports**

**AID Contract No. AID/CM-ta-C-73-13**

Office of Health
Agency for International Development
Department of State
Washington, D.C. 70523

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

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January, 1976

# 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*

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*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

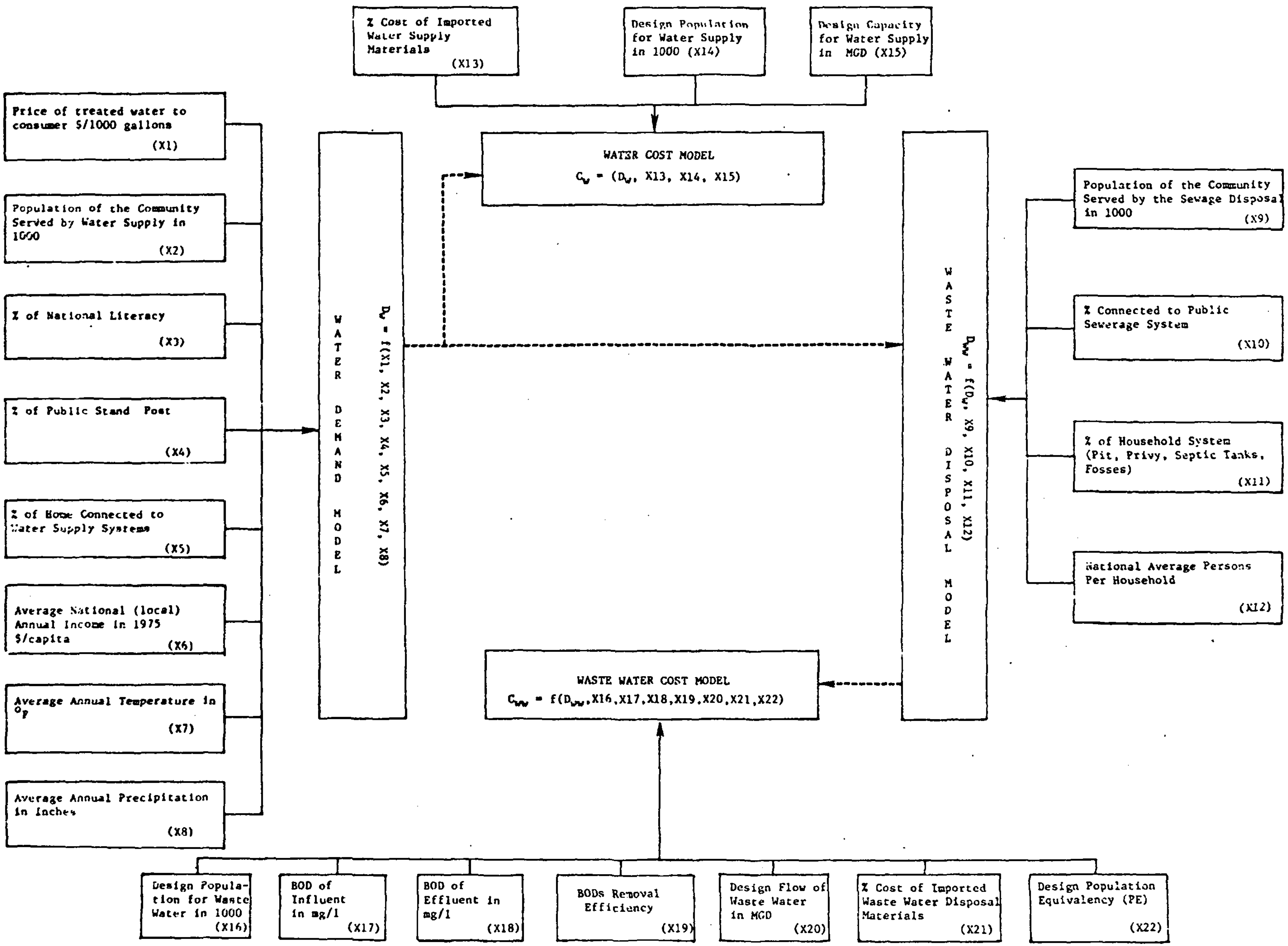

TABLE II

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 | Percent of Total Flow 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:

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

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.

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

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):

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

where: $E_d$ = demand function

Equation (2.5) can be described by the regression line

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

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:

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

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:

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

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.

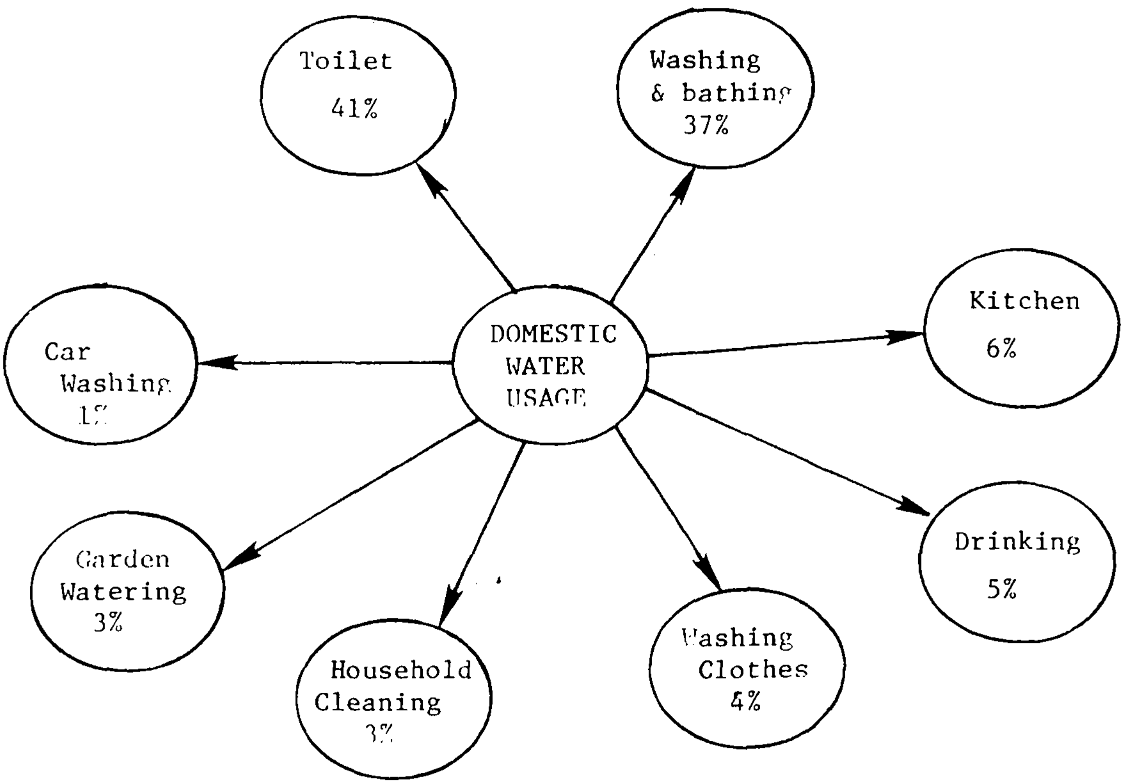


Figure 2: Domestic Water Usage

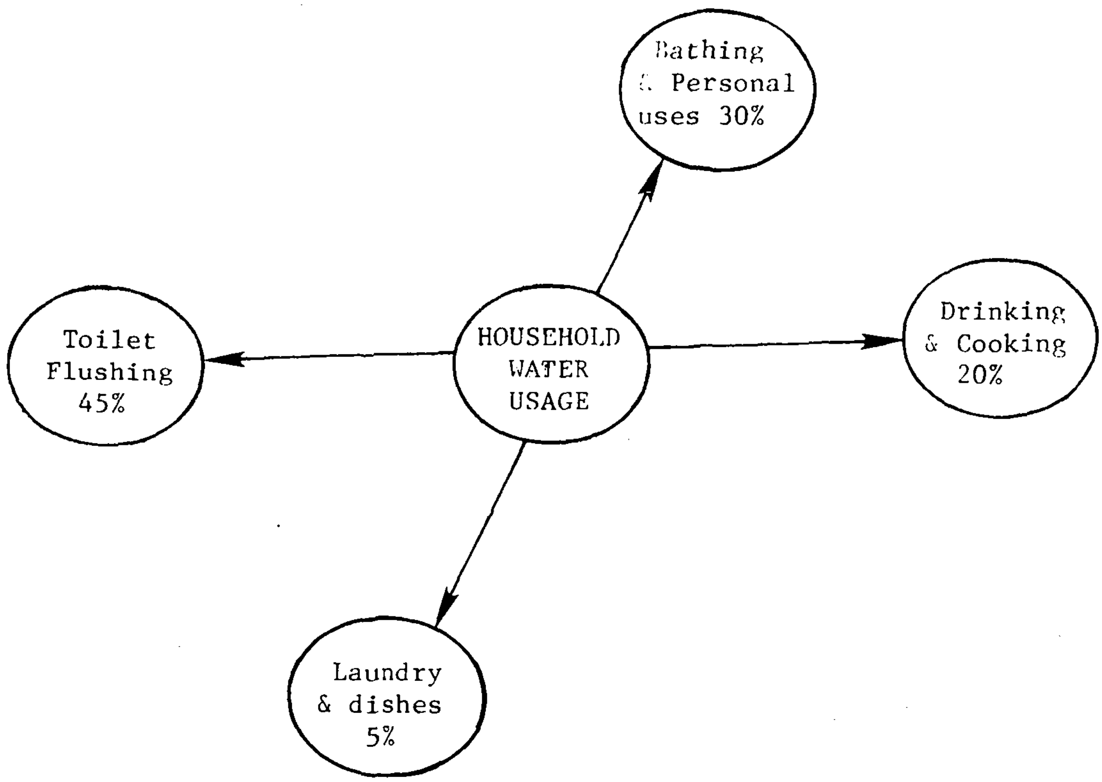


Figure 3: Classification of Household Water Usage

## 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):

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

where: C = investment cost in thousand dollars

K = design capacity in MGD

and ß = coefficients

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

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

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:

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

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:

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

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:

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

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:

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

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:

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

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:

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

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

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

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

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:

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

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:

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

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:

$$C = KP^{n}S^{m} \qquad (2\text{-}24)$$

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 $\leq 10{,}000$

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

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

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

Activated Sludge (factory built)

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

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

Conventional plant operating cost

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

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:

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

## 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:

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

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:

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

The sum of squared residuals, can be written as:

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

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

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

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

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

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

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

$$\cdot$$

$$\cdot$$

$$\cdot$$

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

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

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

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

which is equivalent to:

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

## 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:

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

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

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

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 $n_1$.

$\mu$ and $\sigma^2$ are the mean and variance of the discrete distribution of $\mu$, the number of runs.

The residual mean square of the model has the expected value of the error variance, $\sigma^2$, 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 $\sigma^2$, $S_{pe}^2$ 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:

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

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:

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

and the total degrees of freedom equals

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

The mean square for the variance error is

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

## 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 ($\bar{R}^2$) 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.

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

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:

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

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

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

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 $^{o}$F_________or $^{o}$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 Infflue nt | | | | | | | |
| 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:

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

and for more than one independent variables is given by:

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

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):

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

where: N = total population size

V = desired variance

$V^2$ is defined by the following:

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

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 nu mber 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 | | | | | | ● | |
| Guatamala | | | | | | ● | |
| 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.**

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

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

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

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

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

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

$X_i$ = independent variables like $X_1, X_2 \ldots X_{22}$

$b_i$ = 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.

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

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

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

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

---

* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

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

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

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

---

* 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

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

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

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

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

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

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

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

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

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

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

---

* 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:

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

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

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

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

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

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

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

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

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

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

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

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

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

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 criteriasthe following equations were developed.

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

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

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

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

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

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

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

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

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

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

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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:

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

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

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

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

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

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

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

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* Satisfies sequential F-test criteria

** Satisfies corrected coefficient of determination

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

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

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

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

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

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

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

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

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

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

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

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

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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

| WATER DEMAND MODEL | CORRELATION MATRIX $C_{ij}$ | | | | | | DEVIATIONS | | | Resms | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{22}$ | $C_{55}$ | $C_{66}$ | $C_{25}$ | $C_{26}$ | $C_{56}$ | $X_2$ | $X_5$ | $X_6$ | | |
| $D_{w.af}$ | 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:

$$S_{D_{w.af}} = \pm t_{.95,df} \left[ Resms\left(\frac{1}{n} + C_{22}X_2^2 + C_{66}X_6^2 + 2C_{26}X_2X_6\right)\right]^{\frac{1}{2}} \qquad df = N-V-1 = 89-2-1 = 86$$

$$S_{D_{w.as}} = \pm t_{.95,df} \left[ Resms\left(\frac{1}{n} + C_{22}X_2^2 + C_{55}X_5^2 + C_{66}X_6^2 + 2C_{25}X_2X_5 + 2C_{26}X_2X_6 + 2C_{56}X_5X_6\right)\right]^{\frac{1}{2}} \qquad df = 66$$

$$S_{D_{w.la}} = \pm t_{.95,df} \left[ Resms\left(\frac{1}{n} + C_{22}X_2^2 + C_{55}X_5^2 + C_{66}X_6^2 + 2C_{25}X_2X_5 + 2C_{26}X_2X_6 + 2C_{56}X_5X_6\right)\right]^{\frac{1}{2}} \qquad df = 61$$

TABLE XI

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WASTE WATER DISPOSAL

| WASTE WATER DISPOSAL MODEL | CORRELATION MATRIX $C_{ij}$ | | | | | | DEVIATIONS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_{ww}$ | $C_{10\ 10}$ | $C_{11\ 11}$ | $C_{w\ 10}$ | $C_{w\ 11}$ | $C_{10\ 11}$ | $d_w$ | $X_{10}$ | $X_{11}$ | Resms | N |
| $D_{ww.af}$ | 0.0024 | 0.0016 | 0.0000 | -0.000 | 0.000[illegible] | 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 | 0.00502 | 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

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

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

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

TABLE XII

EQUATIONS FOR ESTIMATING STANDARD ERRORS FOR WATER TREATMENT COST MODEL

| | | Correlation Matrix $e_i$: | | | | | | | | | | Deviations | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_{ww}$ | $C_{13\,13}$ | $C_{14\,14}$ | $C_{15\,15}$ | $C_{w\,13}$ | $C_{w\,14}$ | $C_{w\,15}$ | $C_{13\,14}$ | $C_{13\,15}$ | $C_{14\,15}$ | $d_w$ | $x_{13}$ | $x_{14}$ | $x_{15}$ | Resms | N |
| 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

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

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 |
| | $C''_{ww.af}$ | 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 |
| | $C'''_{ww.af}$ | 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 |
| | $C''''_{ww.af}$ | 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 |
| | $C''_{ww.as}$ | 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 |
| | $C'''_{ww.as}$ | 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 |
| | $C''''_{ww.as}$ | 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 |
| | $C''_{ww.la}$ | 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 |
| | $C'''_{ww.la}$ | 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 |
| | $C''''_{ww.la}$ | 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 |
| | $C''_{ww.af}$ | 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 |
| | $C'''_{ww.af}$ | 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 |
| | $C''''_{ww.af}$ | 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 |
| | $C''_{ww.as}$ | 0.0203 | 0.0040 | 0.0065 | 0.0006 | 0.0081 | 0.0007 | $\ln X_{16}-(-45)$ | $\ln X_{20}-(-5)$ | $\ln X_{21}-(-6.6)$ | 0.1607 | 41 |
| | $C'''_{ww.as}$ | 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 |
| | $C''''_{ww.as}$ | 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 |
| | $C''_{ww.la}$ | 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 |
| | $C'''_{ww.la}$ | 0.0060 | 0.0016 | 0.0000 | 0.0056 | 0.0040 | 0.0010 | $\ln X_{16}-(-19)$ | $\ln X_{20}-(-3)$ | $\ln X_{21}-(+0.4)$ | 0.2109 | 36 |
| | $C''''_{ww.la}$ | 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

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

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 yr | |
|---|---|---|---|---|---|---|---|
| | | | | 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 | -- | 2.31 | 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 | 1.39 |
| | 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 presented in 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.

<u>Solution</u>

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)

$X_6 = 250$

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

$$= 23.61 \text{ gpcd}$$

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 = <u>13.78 dollars</u>

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 = <u>1.51 dollars</u>

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 $= \dfrac{19.03 \times 5000}{106} = 0.095$ 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

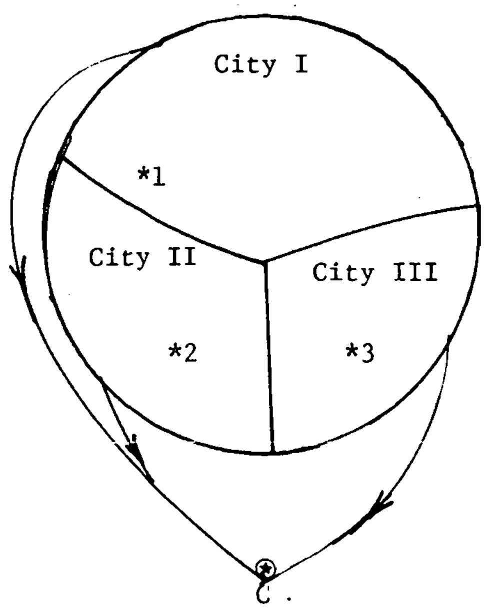
$$\ell_n C''_{ww.as} = -0.3274 - 0.1846 \ \ell_n 100$$

$$= -0.3274 - 0.8501$$

$$= -1.1775$$

Anti log -1.1775 = 0.30 dollars/capita/year

Figure 4: Sample Problem 2




City I, Population = 100,00
City II, Population = 25,000
City III, Population = 75,0

* Location of Stabilization Lagoons

C Location of Activated Sludg

→ Transportation of waste w 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

$$
\begin{aligned}
\ell_n C'''_{w.af} &= 0.4346 + 0.0160\ \ell_n D_w - 0.3628\ \ell_n X_{14} \\
&= 0.4346 + 0.0160\ \ell_n (12.72 + 0.0683\ X_2 + 0.0142\ X_6) \\
&\quad - 0.3628 \ell_n X_{14} \\
&= 0.4346 + 0.0160\ \ell_n (12.72 + 0.0683\ (5) + 0.0142\ (500)\ ) \\
&\quad - 0.3628\ \ell_n (5) \\
&= 0.4346 + 0.0480 - 0.5838 \\
&= -0.1012
\end{aligned}
$$

Anti log -0.1012 = 0.90 dollars/capita/year

$$
\begin{aligned}
\ell_n C'_{w.as} &= 2.7436 + 0.0088\ \ell_n (6.6817 + 0.04597\ (5) + 0.2204\ (65) \\
&\quad + 0.0263\ (1100)\ ) - 0.1065\ \ell_n (5) \\
&= 2.7436 + 0.0344 - 0.1711 \\
&= 2.6069
\end{aligned}
$$

Anti log 2.6069 = 13.55 dollars/capita

$$
\begin{aligned}
\ell_n C'''_{w.as} &= 0.5017 - 0.0751\ \ell_n (5) \\
&= 0.3809
\end{aligned}
$$

Anti log 0.3809 = 1.46 dollars/capita/year

$$
\begin{aligned}
\ell_n C'_{w.la} &= 2.5461 + 0.0096\ \ell_n (5) \\
&= 2.5292
\end{aligned}
$$

Anti log 2.5292 = 12.54 dollars/capita

$$
\begin{aligned}
\ell_n C'''_{w.la} &= 0.3559 - 0.1511\ \ell_n (5) \\
&= 0.1127
\end{aligned}
$$

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)

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

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

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

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

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

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

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

$$= \pm 2.021 (0.05796)$$

$$=\pm 0.11713$$

Anti log 0.11713 = $\pm$ 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 = $\pm$ 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

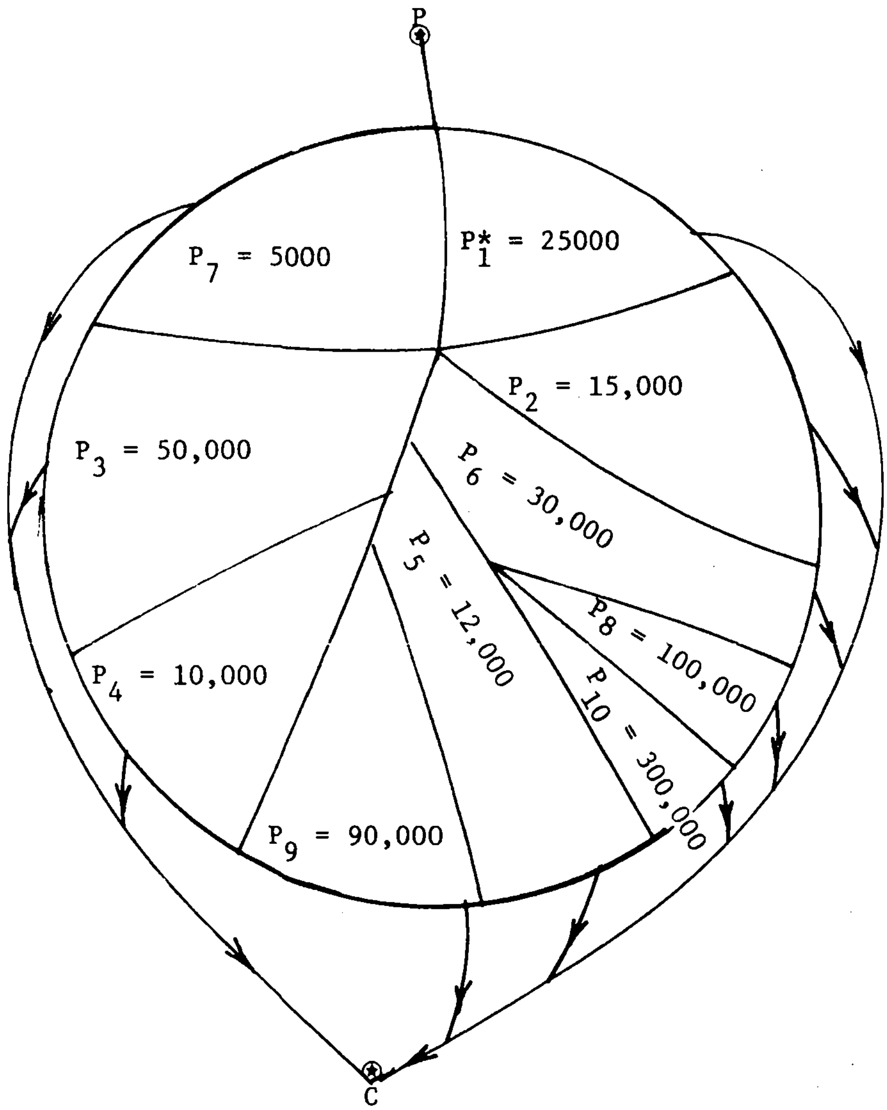
Maximum Total Construction Cost = (4.31 + 2.57) (637,000) + (4.31 + 2.57)

(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 |

| $X_2$ | $X_5$ | $X_6$ | $D_{w.af}$ | $D_{w.as}$ | $D_{w.la}$ |
|---|---|---|---|---|---|
| 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 |

| $D_w$ | $X_{10}$ | $X_{11}$ | $D_{ww.af}$ | $D_{ww.as}$ | $D_{ww.la}$ |
|---|---|---|---|---|---|
| 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 |

| $D_w$ | $X_{10}$ | $X_{11}$ | $D_{ww.af}$ | $D_{ww.as}$ | $D_{ww.la}$ |
|---|---|---|---|---|---|
| 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 |
| 115 | | | | | |

## APPENDIX C

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

| $D_w$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $C''_{w.af}$ | $C''''_{w.af}$ | $C''_{w.as}$ | $C''''_{w.as}$ | $C''_{w.la}$ | $C''''_{w.la}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

| $\bar{D}_w$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $\overline{C''}_{w.af}$ | $C''''_{w.af}$ | $C''_{w.as}$ | $C''''_{w.as}$ | $C''_{w.la}$ | $C''''_{w.la}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

| $\bar{D}_w$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $C''_{w.af}$ | $C''''_{w.af}$ | $C''_{w.as}$ | $C''''_{w.as}$ | $C''_{w.la}$ | $C''''_{w.la}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

| $D_w$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $C''_{w.af}$ | $C''''_{w.af}$ | $C''_{w.as}$ | $C''''_{w.as}$ | $C''_{w.la}$ | $C''''_{w.la}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

| $D_w$ | $X_{13}$ | $X_{14}$ | $X_{15}$ | $C''_{w.af}$ | $C''''_{w.af}$ | $C''_{w.as}$ | $C''''_{w.as}$ | $C''_{w.la}$ | $C''''_{w.la}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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 |

| $X_{16}$ | $X_{20}$ | $C''_{ww.af}$ | $C''''_{ww.af}$ | $C''_{ww.as}$ | $C''''_{ww.as}$ | $C''_{ww.la}$ | $C''''_{ww.la}$ |
|---|---|---|---|---|---|---|---|
| 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 |

| $X_{16}$ | $X_{20}$ | $X_{21}$ | $C''_{ww.af}$ | $C''''_{ww.af}$ | $C''_{ww.as}$ | $C''''_{ww.as}$ | $C''_{ww.la}$ | $C''''_{ww.la}$ |
|---|---|---|---|---|---|---|---|---|
| 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 |

| $X_{16}$ | $X_{20}$ | $X_{21}$ | $C''_{ww.af}$ | $C''''_{ww.af}$ | $C''_{ww.as}$ | $C''''_{ww.as}$ | $C''_{ww.la}$ | $C''''_{ww.la}$ |
|---|---|---|---|---|---|---|---|---|
| 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 |

| $X_{16}$ | $X_{20}$ | $X_{21}$ | $C''_{ww.af}$ | $C''''_{ww.af}$ | $C''_{ww.as}$ | $C''''_{ww.as}$ | $C''_{ww.la}$ | $C''''_{ww.la}$ |
|---|---|---|---|---|---|---|---|---|
| 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 |

| $X_{16}$ | $X_{20}$ | $X_{21}$ | $C''_{ww.af}$ | $C''''_{ww.af}$ | $C''_{ww.as}$ | $C''''_{ww.as}$ | $C''_{ww.la}$ | $C''''_{ww.la}$ |
|---|---|---|---|---|---|---|---|---|
| 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 |