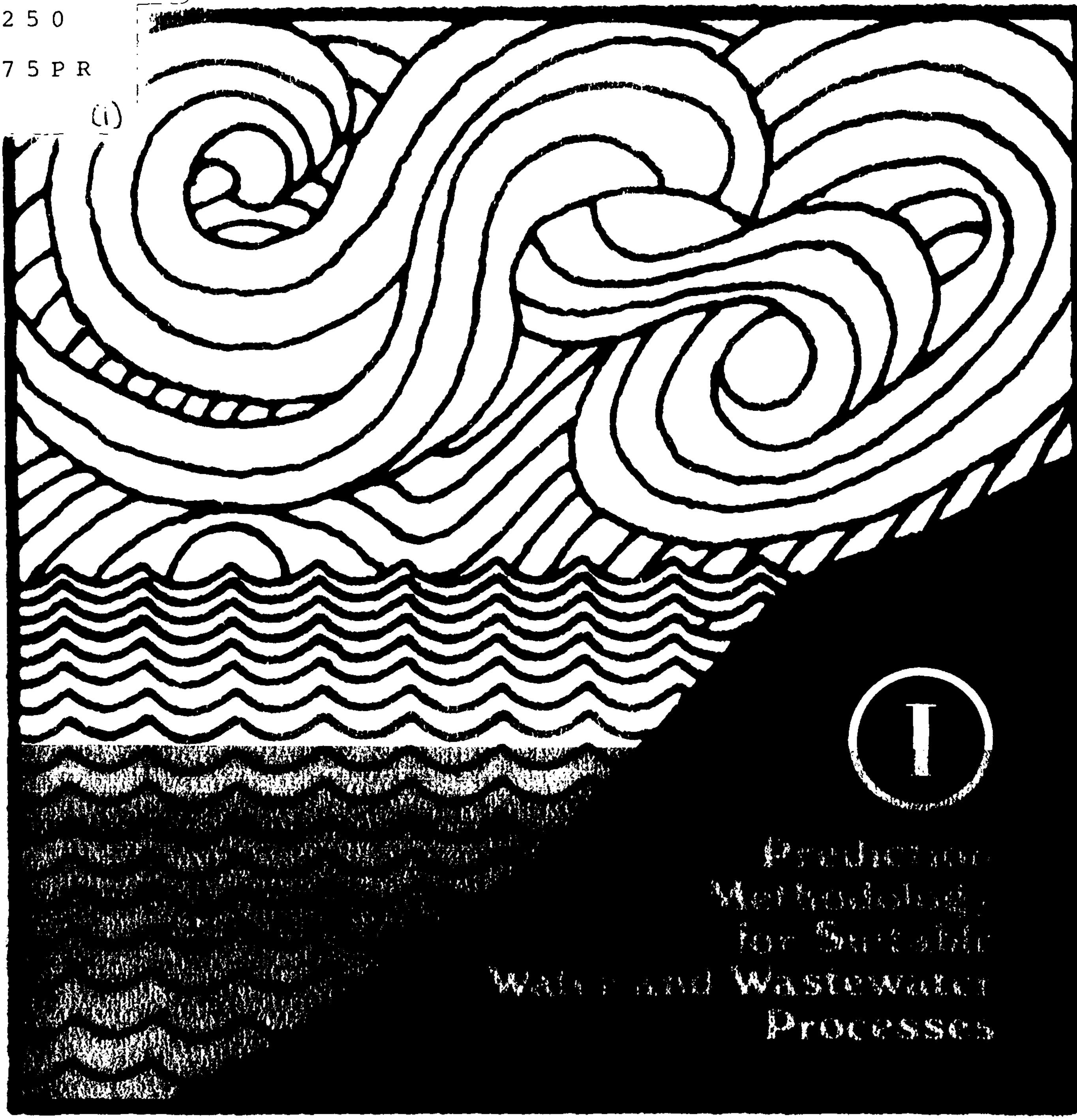

APPROPRIATE METHODS OF TREATING WATER AND WASTEWATER IN DEVELOPING COUNTRIES

THE UNIVERSITY OF OKLAHOMA
BUREAU OF WATER AND ENVIRONMENTAL RESOURCES RESEARCH
Sponsored by: U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHING

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

First of a Series of Reports on this Project

Others:

State of Art Papers - Water and Sewage Treatment in Developing Countries.

Historic Implication of Developed Countries Technology on Developing Countries.

Innovations and Adaptive Technology of Water and Wastewater Treatment.

Catalog of Primative and Emerging Treatments.

PREDICTION METHODOLOGY FOR SUITABLE WATER AND WASTEWATER PROCESSES

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INTRODUCTION

The University of Oklahoma is conducting a project designed to assist in the selection of the most appropriate water and sewage treatment technology for sites in developing countries. The project involves and will produce reports on:

1. A state of the art study.
2. Data collection and reduction formats.
3. Development of a global network of adaptive and innovative technology for water and wastewater treatment process studies that involve unique and adaptive technology.
4. Development of a predictive model to help planners select suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times.

This report, first in the series, covers the predictive model's format, data requirements, detailed flow, selection of appropriate costs, and computerization. It also includes a test of the model using an actual case study.*

The model has the ability to bring together a number of critical inputs relating to the effective installation and use of various water and wastewater treatment methods, processes, and combination of processes. The output of the model is a list of the plausible alternatives for water and/or wastewater treatment in developing country communities. This output allows planners or project engineers to look at all the plausible processes and their related costs, plus the operation, maintenance, and manpower requirements associated with each of the various processes. This technique will eliminate the problem of overlooking good processes for water and wastewater treatment.

The key elements of this approach are:

1. The systematic evaluation of the importance and interrelationships of all relevant aspects of the problem, such as technical, economic, social, political, and cultural factors.

2. The assessment of alternative courses of action.

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*For those interested, there are separate technical manuals for: (1) describing the computer program with instructions for using the program on the IBM/370 computer and (2) the procedure for manually determining the appropriate process. The report is also available in Spanish.

3. An analysis of in-country costs as the basis on which policies can be determined and decisions made.

The emphasis is on obtaining a grasp of the total picture so that international health organizations, lending agencies, and regional institutes will have a viable planning tool.

The model is currently being validated in-house and in the field. The in-house validation includes:

1. Comparison of model outputs with data from existing treatment facilities in developing countries.

2. Identification of user application problems, consultants, planners, bankers, etc.

3. Inclusion of new interpretative/adaptive technology and state-of-the-art information to broaden the available treatment processes and levels of applicability.

The field validation work consists of model runs by users to determine if the appropriate data can be obtained to run the model. The primary objective of this phase of the validation process is to ensure that input data requirements can be met in various developing country situations where substantial national and/or local environmental, economic, and social data are not generally available. In these situations, the test is whether the model outputs still provide the design engineer or planners with useful information on the most acceptable processes.

Although the model is limited from a purely mathematical viewpoint, the output is meaningful in that it allows a rapid examination of the alternatives to planners as well as providing elimination of non-feasible processes on an objective basis. Also, although the model is an important design tool, it does not replace the planner but rather allows him to concentrate his skills and experience on the identified alternatives in the most effective way.

The model has been computerized for a number of reasons. First and probably most important is that a computerized version relieves the planner from the error-prone task of manually evaluating the alternative processes for the selection of the most appropriate treatment method. As indicated earlier, the model is limited from a mathematical point of view; however, the number of steps to execute the model, while not complicated, are numerous and time consuming. The computerized version also can be used by the planner to evaluate several communities in one execution of the program. The second reason for computerization is that, in less developed countries, electronic computers are becoming available for use by those involved in planning water and wastewater treatment. The computerized model enables planners to use the latest technology as an aid to decision making. For those planners who do not have access to a computer capable of executing the model, a manual approach is being developed. This avoids the problem of having to send the data to some central computing center or regional office (if a local computer is not available) to use the model as an operational test for planning. In short, the manual approach gives the model applicability even in the remotest of areas.

Finally, computerization also provides a basis for a uniform analysis of planning water and wastewater treatment on a regional or national basis. Presently, the model is limited to evaluating the plausible treatment methods for a single community. However, it contains the type of information needed for a more aggregate approach of meeting the problem of water and wastewater treatment. It can be easily modified to provide cost information on a regional basis.

Another important point is in-country acceptance of appropriate or suitable technology. The information currently available indicates a strong desire on the part of developing countries to be identified with "high technology" (often termed "going first class"). In effect, the developing countries are expressing a desire to have the latest type of water and/or wastewater treatment facilities now being used in developed countries. Such facilities might be feasible in a few of the developing countries largest cities, but the majority simply do not have the in-country resources to build, maintain, or man these expensive, highly technical plants. In fact, this project stemmed from the all too frequent waste of developing countries resources in attempts to build and operate advanced treatment plants, most of which were complete failures.

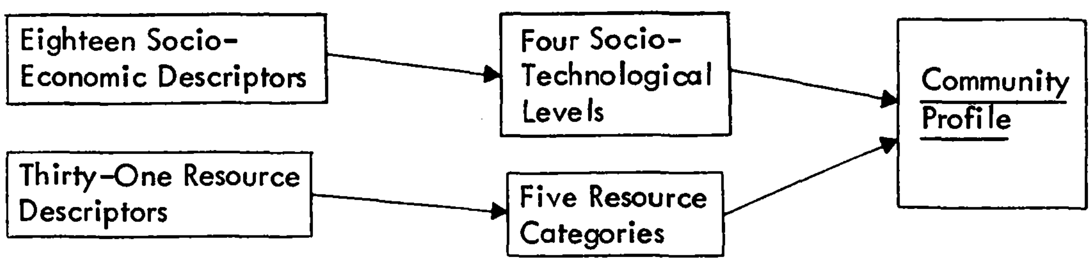
This phenomenon is also prevalent in developed countries. Even U.S. cities and towns often demand the "best" available technology when an older, proven technology would be more appropriate for their environment and available resources.

The selection model developed by this project helps design engineers and planners mitigate the problems created by this desire for high technology. Through the use of this computerized model, a large amount of data/information can be processed quickly, and the resultant output will display the consequences of all the various actions including all relevant cost. Such a display will, in most cases, enhance the design engineer's professional judgment. Also, in his defense of the selection of a lesser technology, the designer can now say that he has a "high technology device" with the mystique of the computer and the systems approach that evaluates quickly the large number of variables associated with the needs and resources of a specific community and the available alternatives. This evaluation will add the prestige of "science" to professional judgment as well as helping formulate that judgment.

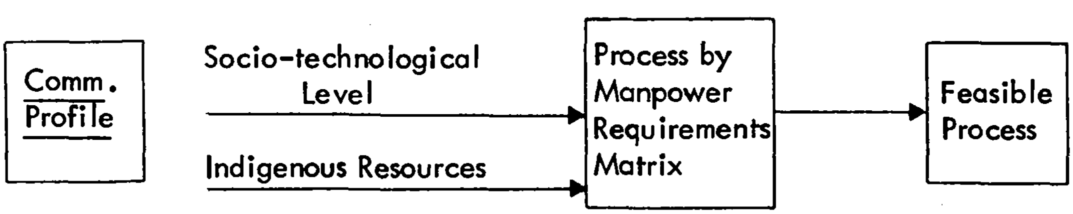
Finally, although the model essentially does the same job done by good designers, it is visible, inclusive, and would be of value as a map for either expert or novice. The model can be run on a computer or operated manually. Both the computer program and manual procedures are provided in technical manuals.

METHODOLOGY

Figure 1 is an overall view of the planning model data flow. This methodology uses 18 inputs that describe socio-economic conditions, 31 inputs that describe the indigenous resources, 2 inputs that describe the demographic profile, and 3 inputs that describe the raw water quality. This constitutes the raw data. The method used to assure the appropriate process selection takes raw data in two categories (socio-economic and indigenous resources) and reduces it through a weighting process to provide a representative community profile. The following sketch illustrates this reduction.



The four socio-technical levels and the five resource categories are used with a matrix of processes, manpower, and material requirements to screen acceptable alternative processes for future considerations as sketched below.



The model identifies the basic treatment processes, PW_j and PS_j. In practice, however, many of the basic treatment processes are infrequently utilized separately. Consequently, these processes are used in combination depending on the conditions of raw water to be treated or on the condition of the received waste streams. Since water, theoretically, has 11 processes, there could be $(2^{11} - 1)$ combinations of the water processes to provide treatment. Realistically, about 12 water treatment processes are likely combinations. For wastewater treatment, about 9 sewage treatment processes are candidates. The logic of this screening process is sketched below.

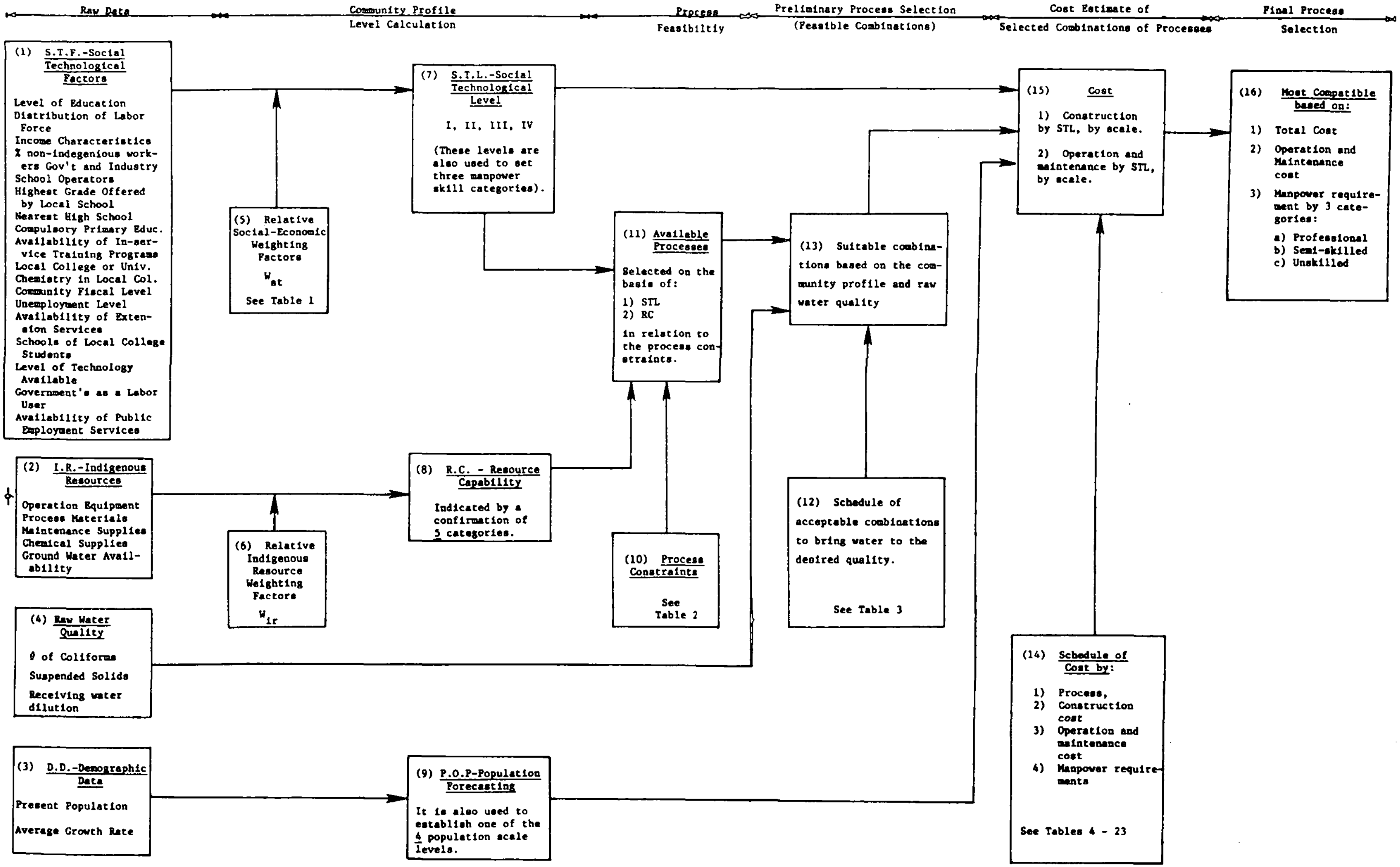
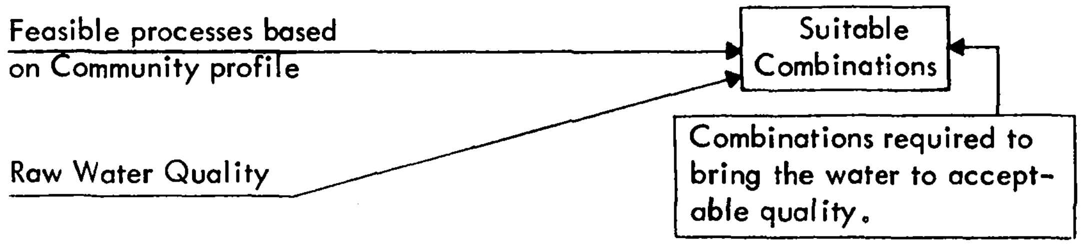
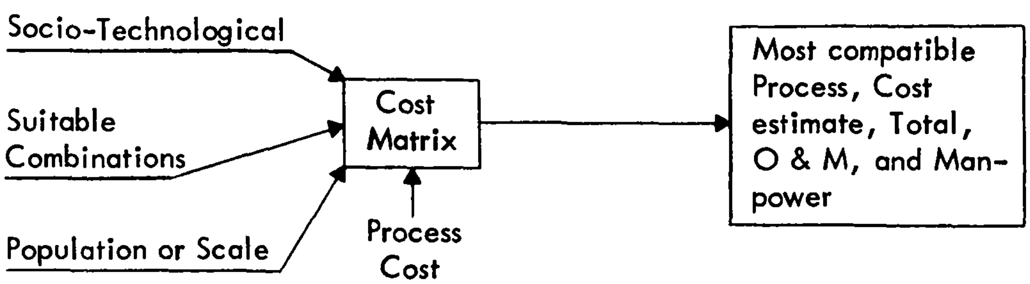


Figure 1. The Complete Information Flow for the Water & Waste Water Treatment Process Selection Model



The model next selects the feasible treatment processes by manpower availability and indigenous resources. Only the feasible processes will be used to set up combinations of processes. The limitation on combinations, in the case of water, relate to initial raw water quality and/or groundwater or a supervised catchment. The screened combinations are designed to provide acceptable groups or sequence of treatments depending on bringing a raw water level to a potable level. For wastewater, the combination of sewage treatment methods are based on effluent dilution available, which is expressed as a ratio of receiving water volume to waste volume or as CFS/PE dilution water* (i.e., cubic feet per second of receiving water flow rate/population equivalent).

Next, the available processes are located in terms of size (population groups or scale) and socio-technological levels, and a matrix of capital, operation, and maintenance costs is constructed. This cost matrix is developed by empirical analysis, regression analysis of developing countries data, or real entries. The empirical analysis technique is used in this report. The development of this technique is shown in Appendix C and is sketched below.



Finally, the alternative costs are presented as totals for operation and maintenance and manpower. The model, in short, will screen acceptable combinations of processes for treatment made up of basic treatment processes which are considered feasible in terms of the manpower and indigenous resources at the community level. The final step will provide the least cost alternative. The raw data requirements for the computerized model are shown in Appendix B.

*These constraints are also subject to alternations; that is, various countries may elect various levels of quality criteria. This is based on the current international levels.

As indicated earlier, Figure 1 outlines the full characterization of the decision variables and the steps performed by the model to determine the most compatible processes for a community. The stepwise, block-by-block process follows. The blocks are noted in Figure 1.

Block One

STF - Social-Technological Factors
Level of Education
Distribution of Labor Force
Income Characteristics
Percent non-indigenous workers in Gov't and Industry
School Operators
Highest Grade Offered by Local School
Nearest High School
Compulsory Primary Education
Availability of in-service Training Programs
Local College or University
Chemistry in Local College
Community Fiscal Level
Unemployment Level
Availability of Extension Services
Schools of Local College Students
Level of Technology Available
Governments as Labor Users
Availability of Public Employment Services

Under the socio-technological levels (STL's) input, four levels of development have been established so that any community could be classified into one of these levels. Each level represents a different stage of development for a community. For example, level I represents a low level of development, such as a subsistence type of environment. Conversely, level IV represents a high level of development, which includes high per-capita income and general availability of manufactured goods and related services. This environment is found in many large communities of Western Europe and the United States. Levels II and III represent differing degrees of the low- and high-development levels.

The term " development" is a comparative one and refers to the performance record of a community's economy. Thus, an " economically underdeveloped" community may be highly developed in art, social organization, religion, philosophy, or another non-economic field. In economic terms, however, " underdevelopment" means that a community is one which affords its people a comparatively poor end product of consumption and material well-being, and that this relatively poor economic performance could be improved by means which are known, understood, and have already been applied by the " developed" countries.

A number of objective measurements of economic performance have been devised over the years which, when applied, demonstrate the above definition fairly well. In fact, despite the economic measure used (death-rates, infant mortality, consumption indexes, per-capita incomes, etc.), the results are about the same. The " developed" communities tend to cluster at the favorable end of the scale. Thus, communities can be roughly differentiated into those which provide their people with a relatively good end product of consumption and material well-being and those which do not.

This stage of development is defined as the sum of socio-cultural and socio-economic factors that are essential parts of any community or group of people. The variables were selected on the basis of their availability at the local level and how they reflect the level of development at the community level. Eighteen socio-economic and socio-cultural variables are used; their characteristics are briefly described below:

1. The level of education is a broad measurement designed to provide a rough estimate of the level of education of the people in a community. Five broad levels are specified: none, primary, high school, technical institute, and college. The high-level communities generally have higher levels of educational attainment.

2. Distribution of the labor force is expressed in terms of the percentage of professional, skilled, and unskilled workers in the employed labor force. The employed labor force means those persons who are in some way connected with the market economy. In a subsistence economy, only a very small portion of the total population is engaged in market activies. At

the advanced level of development, a large percentage of the total population is active in the market, and these workers have expertise levels equivalent to the professional and skilled categories.

3. Income characteristics generally reflect the level of development. A larger per-capita income generally denotes high levels of development.

4. The percentage of non-indigenous workers in government and in industry is also used as an indicator of development. Low levels generally require that the majority of skilled and professional jobs are held by non-indigenous workers.

5-8. These variables relate to the investment that a community has in the education of its youth. When schools are operated by voluntary agencies or missionary organizations, the level of development tends to be at a low level. Increases in the standard of living tend to bring compulsory education to at least the primary level. The general accessibility of schools to a community indicates the level of development. Generally, the higher the grade offered, the higher the level of development.

9. The availability of in-service training programs reflects the level of development. These programs are not generally available in less developed areas. These programs often become more available as the need for higher skills and more expertise in technical areas is required in the community. These in-service programs may be offered through agricultural extension and community development programs.

10-11. These variables relate to the more sophisticated educational opportunities within the community itself. The availability of a college chemistry department gives some indication of the technical expertise available in the community. It also provides a potential place for the testing of water quality characteristics. In short, the availability of higher education indicates a high level of development.

12. The community fiscal level relates to the ability of a community to meet the needs of improved water and sewage treatment by providing for some, if not all, of the funds required for these improvements.

13. Rampant unemployment is characteristic of communities at a low level of development. The bulk of those unemployed in an area of low development are unskilled workers. Generally, the unemployment problem decreases as the level of development increases.

14. Agricultural extension services tend to improve as the level of development increases. At low levels of development, agricultural extension services and demonstration projects are scarce. In addition, there is a tremendous need for advisory services to farmers and other programs to upgrade the skills and enlist the participation of the rural masses. The main hurdle at low levels is that the appropriate organizational and institutional structures lack the means to implement and administer extension services.

15. The universities or colleges that local students attend give an indication of the level of development. If most or all of the college students receive their higher (third) education in neighboring communities or abroad, then the community is at a low level of development.

16. The level of technology available is a generalized data variable that calls on the experience of the planner. It simply asks what level of development is available as signified by four general categories of technology: hand tools, mechanical tools (e.g., gasoline-powered equipment), chemical products (e.g., use of fertilizers and/or chlorine), and electronic technology.

17. The government's role in the labor market also gives an indication of the level of development. At low levels of development, the local

government tends to be the major employer. As development increases, employment in private or non-governmental-related activites tends to increase.

18. The availability of public employment services indicates the level of development. These services are generally only available at high levels of development. Public employment services in less developed countries tend to be service blue-collar workers rather than professionals.

Block Two

RC - Indigenous Resources
Operation Equipment Process Materials Maintenance Supplies Chemical Supplies Groundwater Availability

The second group of raw data inputs is concerned with the indigenous resources available (RC) within the community. Data about the local resources and the present technology available for a community is based on the variables shown below. The list is made up of chemical supplies and mechanical materials needed for the operation of a wide variety of water and wastewater treatment systems. The availability of these items is matched, within the model, against the requirements of the various processes. Those processes which require materials or resources not locally available are eliminated from the plausible treatment alternatives suggested by the model. The data input variables related to these local resources and materials include:

1. Operation Equipment:
   a. Water meters.
   b. Soldering equipment.
   c. Acetylene torches.
   d. Recording devices (e.g., thermostats).
   e. Laboratory equipment (e.g., test tubes).

f. Portable power plants (e.g., portable gasoline-powered electric generators).
g. Motors (e.g., 1-3 horsepower electric motors).
h. Water pumps.

2. Process Materials:
   a. Pipe (clay, steel, cement, plastic, copper, etc.).
   b. Pipe fittings.
   c. Paint.
   d. Valves.
   e. Tanks.
   f. Vacuum gauges.
   g. Heat exchangers.

3. Maintenance Supplies:
   a. Silica sand.
   b. Graded gravel.
   c. Clean water.
   d. Gasoline.

4. Chemical Supplies:
   a. $Al_2(SO_4)_3$ (Aluminum sulphate).
   b. $FeCl_2$ (Ferric chloride).
   c. Char (Activated charcoal).
   d. CaO (Lime).
   e. $NaCO_3$ (Soda ash).
   f. Cl_2 (Chlorine).
   g. O_3 (Ozone).
   h. Laboratory chemicals (e.g., litmus paper).

5. Water Source:
   a. River or stream.
   b. Lake or impoundment.
   c. Wells (is groundwater available?).
   d. Sea or brackish source.

Block Three

DD - Demographic Data
Present population Annual growth rate

The third group of raw data used as input into the model consists of demographic inputs. These inputs to the model are designed to be those most readily available. These inputs include: present population and annual population growth rate.

Block Four

Raw Water Quality
Number of Coliforms
Suspended solids receiving water dilution

The fourth and final group of inputs consists of the results on tests performed on the raw water. This block contains three different measurements:

1. The number of the coliform groups of bacteria as an indicator of pollution in terms of parts per million (ppm).
2. The degree of suspended solids in the water in terms of ppm.
3. The receiving water dilutions as specified by the Biochemical Oxygen Demand (BOD -5 day, 20°) content of the wastewater, or sewage.

The above inputs provide the raw data needed to use the model for the selection of a water and/or wastewater treatment method for a community in a developing country. Hopefully, these data are currently available for the site; if not, then national, regional, or similar data may be substituted.

Block Five

Relative Social-Economic Weighting Factors - W_{st}
See Table 1

Table 1. Data Sheet Weighting Factors for Technology Level Determination for Communities in Less Developed Countries.

Variable Description	Data Sheet Part III Question No.'s 1-19	Possible Choices	Weighting Factor
Level of Educ.	1	1	0
		2	5
		3	10
		4	15
Distribution of Labor force	2	1	0
		2	5
		3	10
		4	15
Income Characteristics	3	1	0
		2	4
		3	8
		4	12
		5	15
% non-idigenous workers in Gov't and industry	4	1	4
		2	3
		3	2
		4	1
		5	0
School operators	5	1	0
		2	5
Highest grade offered by local	6	0	0
		1-6	2
		7-10	4
		11-12	7
		12+	10
Distance to nearest high school	7	1	3
		2	2
		3	1
		4	0
Availability of technical & vocational training	8	1	5
		2	0
Compulsory Primary Education	9	1	10
		2	0
Availability of inservice training programs	10	1	5
		2	0
Local College or University	11	1	10
		2	0
Chemistry in local college	12	1	3
		2	0
Unemployment level	14	1	0
		2	5
Availability of extension services	15	1	3
		2	0
Schools of local college students	16	1	0
		2	3
Level of technology available	17	1	0
		2	5
		3	10
		4	15
Gov't as a labor user	18	1	0
		2	5
Availability of public employment services	19	1	5
		2	0

The next phase of the planning technique is to examine the socio-economic variable to help establish the community profile. The data inputs identified in Block One are weighted as to relative importance (see Table 1).

The weights were designed so that they are basically derived from the descriptions of the socio-technical levels (STL's) described in Appendix A of this manual. That is, the data form (Appendix B) was developed from the scenario described in Appendix A. Hence, by its nature the weighting process coincides with the levels in the Appendix. However, the weights are somewhat arbitrary because more emphasis has been placed on these indicators, which have proven to be reliable indicators of a community's level of development. For example, educational attainment is a good indicator of development and has been given greater weight than the distance to the nearest high school. In the case of the location of the nearest high school, the distance may not be important if the community has a good transportation system. Again, the weighting process is flexible and can be modified to satisfy the requirements of local conditions. The overall objective of the level determination is to classify communities into a usable level of development. Most communities of interest fall into levels two and three. Fine tuning of the level measurement is not required for successful use of the model, especially when local or regional cost data is available.

The weights are totaled, and a socio-technological level is assigned according to the following weight schedule:

Socio-Technical Level (STL)	Total Weighted Factors
1	1-23
2	24-51
3	51-93
4	93-133

Block Six

Relative Indigenous Resource Weighting Factors - W_{ir}

Block Six depicts the grouping process designed to determine if a group of related indigenous resources is available (see Block Two). The purpose is to group these resources into five general categories:

1. Operation equipment.
2. Process materials.
3. Maintenance supplies.
4. Chemical supplies.
5. Groundwater availability.

The basic assumption underlying this grouping is that the items listed in the data sheet are only representive. If the majority of these items were designated as available, then the group (e.g., chemicals) would be considered generally available in the community under consideration. (The majority, herein, is selected as 70 percent.) This judgment value can be altered.

Block Seven

STL - Social-Technological Level

I, II, III, IV

(These levels are also used to set three manpower skill categories.)

Block Seven determines the manpower availability based on the socio-technological level for the community. Decision rules have been developed so that the treatment method selected can be maintained with workers selected from the local manpower supply.* The purpose of the decision rules is to avoid the manpower problems of many previous projects; that is, the installation of processes without regard to supply of local manpower to repair and maintain the treatment operation. These rules, translated into constraints, are:

*This is as opposed to instruction or special training of personnel, which of course is an alternative.

1. In Level I communities, only unskilled manpower is available (Category C only).

2. Level II communities have only unskilled and semiskilled labor available (Categories C and B only).

3. Level III communities have only unskilled and semiskilled labor available in populations under 50,000. In populations over 50,000, Level III and Level IV communities have all categories of manpower available.

These constraints, based on the levels of development presented earlier, help a planner determine the relative availability of various types of manpower needed to operate a plant. The main emphasis of the scheme is operating personnel, as opposed to construction personnel. Investigation to this point has indicated that failure of a project almost always occurs during operation and maintenance rather than during construction. Therefore, skilled workers required in the construction stage are not included. The occupations required on water and sewage treatment programs in the post-construction stage fall into the following categories:

1. Professional (Category A).
2. Skilled and craftsmen (Category B).
3. Unskilled-semiskilled (Category C).

Category A and B occupations required a substantial amount of special formal training. Hence, the sources, volume, and timing of their supply is relatively easy to identify. In category C, by contrast, most individuals can master the required skills by relatively nonformal means on the job and do not undergo formal courses or pass through formal in-plant training schemes. This is true even in those craft occupations that for generations have been termed "apprenticeable." It is even more true in most of the new "industrial" skilled manual occupations, which have emerged since the industrial revolution. The skills cannot normally be gained away from or outside the employing institution because of the nature of the operation or the special machinery and equipment involved or the working environment itself.

The main personnel supply for category B occupations, which require a secondary school education plus two to three years of vocational training, is produced by the training schools and schools maintained by ministries of the government which operate them to meet their own specialized requirements. In many developing countries these facilities are generally well-established.

Block Eight

RC - Resource Capability
Indicated by a confirmation of five categories.

Block Eight represents the indigenous resource capability of the local community. Any number or all five of the resource groups can be available to a community as combinations of the five categories.

The demographic inputs serve as inputs to the population forecasting model (Block Nine).

Block Nine

POP - Population Forecasting
This is also used to establish one of the four population scale levels.

The first portion of the population submodel makes forecasts for the total population of the community under study for each five-year planning interval. The routine is in a loop so that it is used repeatedly. The model that determines the population is very simple; the inputs used are the present population and the annual population growth rate. Although this simple model does not take into account other factors that have an effect on the population of a community, it should give a close approximation of the population if the change is at a fairly constant rate. Population changes are highly contingent on the rates of change in the industrial and commerical institutions of a community. If the average growth rate is not expected to vary appreciably during the time period being forecasted, the method should give a good approximation of the so-called "norm" of the community. This "norm" will be what the area would look like if "nobody tinkered with the works."

The community profile is represented by the data shown in Blocks Seven-Nine.

Blocks Ten and Eleven

Available Processes
Selected on the basis of STL and RC in relation to the process constraints.

Process Constraints
See Table 2

The next step carried out by the model is the selection or screening of feasible processes. The process feasibility is based on the STL and the RC of the community. The third input to the process feasibility is individual process constraints. The model matches the constraints of the processes as shown in Block Eleven. Table 2 shows the specific constraints. These constraints are matched against the capabilities of the community. Processes are screened at this point, and processes that are too sophisticated or those requiring resources not available within the community are eliminated from further consideration for the community.

Block Twelve

Schedule of Acceptable Combinations to Bring the Raw Water to the Desired Quality
See Table 3

Table 3 shows the various combinations of basic processes that are frequently used in combination depending on the conditions of raw water to be treated or on the conditions of the received wastewater. Each combination is associated with one or more of the basic processes, which can be used

Table 2. Water & Sewage Treatment Processes With Essential Components for Operation.

Treatment Methods \ Process Requirements		Process Number	Manpower Operation			Resources Required				
			Unskilled	Skilled	Professional	Operation Equipment	Process Materials	Maintenance Supplies	Chemical Supplies	Groundwater Availability
WATER PROCESSES	No Treatment	PW1	●				●			●
	Pre-Treatment	PW2	●					●		
	Slow Sand Filtration	PW3	●					●		
	Rapid Sand Filter-Conv.	PW4		●	●	●	●	●	●	
	Rapid Sand Filter-Adv.	PW5		●	●	●	●	●	●	
	Softening	PW6		●	●	●	●	●	●	
	Disinfection	PW7		●		●	●	●	●	
	Taste-Odor - Fe, Mn	PW8		●		●	●	●	●	
	Desalting-Salt	PW9		●	●	●	●	●	●	
	Desalting-Brackish	PW10		●	●	●	●	●	●	
	Containment Filter	PW11	●					●		
WASTE PROCESSES	Primary-Conventional	PS1	●							
	Primary-Stab. Pond	PS2	●							
	Sludge-Conventional	PS3	●	●			●	●	●	
	Sludge-Advanced	PS4	●	●		●	●	●	●	
	Sludge-Combined (Imhoff)	PS5	●			●		●		
	Secondary - Standard Filter	PS6	●	●		●		●		
	Secondary - High Rate Filter	PS7	●	●	●	●	●	●	●	
	Secondary - Activated Sludge	PS8	●	●	●	●	●	●		
	Secondary - Extended Aeration	PS9	●	●		●		●		
	Disinfection	PS10		●		●	●			
	Aqua Culture	PS11	●							
	Dilution	PS12	●							
	Individual	PS13	●							●
	Individual (adv)	PS14		●		●		●		●

T[redacted]3. [redacted]tab[redacted]bin[redacted] of [redacted]ment[redacted]
Processes for Potable Water.

	Combination CODE	PROCESS COMBINATIONS	CRITERIA LEVEL			
			Raw Water Concentration			Receiving Water
			Coli MPN/100 ml	Solids mg/l		Receiving Water Volume (7-day Low Flow Level)/Waste Volume
				Turb	Other	
WATER TREATMENT	W1	PW1	1 - 2	10		
	W2	PW1 + PW7	100	10		
	W3	PW3	100	100		
	W4	PW2 + PW3	300	800		
	W5	PW11	300	800		
	W6	PW4 + PW7	2,000	100		
	W7	PW2 + PW4 + PW7	3,000	1,000		
	W8	PW5 + PW7	2,000	100		
	W9	PW2 + PW5 + PW7	3,000	1,000		
	W10	(any one of W1 to W8) + PW6			300 Hardness	
	W11	(any one of W1 to W8) + PW8			1-3 Fe & Mn	
	W12	PW7 + PW9			>3000 TDS	
	W13	PW7 + PW10			>2000 TDS	
SEWAGE TREATMENT	S1	PS1 + PS5				20 (or 3-4 CFS/1000 PE*)
	S2	PS1 + PS3				20 (")
	S3	PS2				10 (or 1.5-2 ")
	S4	S1 + PS6				6 (or 0.9-1.2 ")
	S5	PS1 + PS9				3 (or 0.45-0.6")
	S6	S2 + PS6				6 (or 0.9-1.2 ")
	S7	S2 + PS7				5 (or 0.75-1 ")
	S8	S2 + PS8				4 (or 0.6-0.8 ")
	S9	(any one of S1 to S7) + PS10	250			2 (or 0.3-o.4 ")
	S10	PS3 (Without water carriage)				- NA
	S11	PS11				10 (or 1.5-2 ")
	S12	PS12				40 (or 6-8 ")
	S13	PS2 + PS12				8 (or 1.2-1.6 ")

* The unit is defined as cubic feet per second of receiving water flow rate/1000 populaiton equivalent. A population equivalent is a waste equivalent to one person per day, normally taken as 0.17 lb BOD/day.

in combination depending on the criteria level of the incoming water. Block 12 serves as an input into Block 13.

Block Thirteen

Suitable Combinations Based on the Community Profile and Raw Water Quality

This block represents a critical decision point in the model. At this point, the array of process combinations presented in Block Twelve are matched or screened against the individual processes that have been selected as feasible according to the socio-technical level and the indigenous resource capability of the community under study. The results of this decision analysis give a list of one or more combinations of processes that can be considered plausible for the community. Only the feasible processes are used to set up combinations of processes. The screened combinations provide a sequence of treatments for raw water that bring it to a potable level. For wastewater, the sequence of sewage treatment methods are based on effluent dilution which is expressed as a ratio. The details on how to obtain the raw water data are discussed in Appendix A.

Block Fourteen

Schedule of Cost by

1. Process.
2. Construction cost.
3. Operation and Maintenance cost.
4. Manpower requirements.

See Appendix C

Since U.S. Data are readily available, empirical methods used in calculating costs of treatment facilities in developing countries is based on U.S. cost. This was accomplished by breaking down operation and maintenance costs and construction costs into basic components (i.e., labor, material, etc.) for each category of scale (population) and each technology level. Coefficients for a cost transfer equation are produced from socio-economic data collected for the site under study. The equation, when multiplied by U.S. cost, produces total operation and maintenance and capital costs for each treatment process for an individual site based on local conditions. The end result is shown in Appendix D. The details of how these costs were determined is presented in Appendix C.

Block Fifteen

Cost
1. Construction by STL, by scale.
2. Operation and maintenance by STL, by scale.

In communities with limited resources and at low socio-technological levels, the number of treatment processes included in Table 2 will be reduced substantially. Block Fifteen represents the step in the model where the costs of the remaining combinations of processes are determined. Three approaches have been chosen to determine the costs associated with the treatment processes. They are listed below in order of preference and inversely with availability:

1. In-country or local data.
2. Regional or national multiple regression.
3. Empirical formulas.

Because approaches 1 and 2 are still in the formulation stages, approach 3 is currently being used.

Block Sixteen

Most Compatible based on:
1. Total Cost. 2. Operation and Maintenance Cost. 3. Manpower requirement by 3 categories: a. professional. b. semiskilled. c. unskilled.

The final component of the model, represented by Block Sixteen, is the output of the model. The output of the model provides compatible water supply and sewerage treatment alternatives for a specified community in five-year increments for 20 years. The details provided include:

1. Total cost over a 20-year period which includes both the capital or construction cost and the maintenance cost.

2. Manpower needed for the effective maintenance and operation of the plant or plants.

3. The output of both treated water and/or the amount of sewage influent that the suggested methods are capable of handling.

4. The population served under the proposed system.

One further subcharacterization of the combinations of processes as specified by the model can be made. The basic classifications of PW_i and PS_i may still require significant variations within the categories or combinations selected by the model. In short, once the final combination of processes has been selected, a final sort is possible manually on the subcategory of PW_i's and PS_i's. For example, with slow sand filtration (PW3), the following variations are possible: conventional, manually cleaned; upflow; crossflow (dynamic); and dual media. These subprocesses, along with their individual process contraints, are shown in Table 4 and are assumed compatible within their categories and community level constraints.

Table 4. Water and Wastewater Treatment Process Subcharacterization.

WATER

Processes	Constraints
PW1 No-Treatment	
a. Groundwater (not construction, etc.)	Usually limited by size to less than Level IV.
b. Catchment Control	
PW2 Pre-Treatment	
a. Turbidity/Sand - Plain Sedimentation	Level I
b. Algal Control - Thermocline Control**	Level IV
c. Copper Sulfate ($CuSO_4$)**	Level III
d. Microscreen**	Level IV
PW3 Slow Sand Filtration	
a. Conventional, manually cleaned	Usually limited by size to less than Level IV.
b. Upflow**	
c. Crossflow (dynamic)**	
d. Dual media**	
PW4 Rapid Sand Filter-Conventional*	
a. Conventional	Level III
b. Surface Aggitation (air, water, mechanical)	Level III
c. Dual media (sand and artificial)	Level III
d. Upflow	Level IV
PW5 Rapid Sand Filter - Advanced	
a. Multi-media (sand, garnet, coal)	Level IV
b. Plate or tube settling	Level III
c. Polelectrolytes (ionic and anionic)	Level IV
d. Biflow**	
e. Dynamic **	
f. Valve-less**	
PW6 Softening	
a. Lime soda	Level III
b. Zeolite	Level IV
PW7 Disinfection	
a. Disinfection-chlorine	Level III
b. Iodine	Level IV

*Includes Fe, CaO, and/or Al for coagulation, mixing, and settling.

**Requires more field evaluation at present.

Table 4 (Continued)

Processes	Constraints
c. Ozone	Level IV
d. Ultra violite	Level IV
e. Lime, $CuSO_4$	Level I
f. Energy** (Pasteurization)	Level II
PW8 Taste Odor - Fe, Mn	
a. Aeration	Level II
b. Zeolite	Level IV
c. Chlorine	Level III
d. Adsorbent - Char.	Level III
PW9 Desalting - Salt	Level IV
a. Multiple effect	
b. Freezing out	
c. Pressure	
PW10 Desalting-Brackish	Level IV
a. Electrodialysis (ED)	
b. Reverse Osmosis (RO)	
c. Chemical	
PW11 Containment Filters	
a. Dunbar **	
b. Coconut fiber/charred rice**	
c. Asbestos/charred pine needle**	
WASTEWATER	
PS1 Primary - Conventional	Level I
a. Separate	
b. Combined	
PS2 Primary Stabilization Pond	Level I
a. Single Cell	
b. Multiple Cell	
PS3 Sludge - Conventional	
a. Conventional	Level III
b. Heated	Level III
c. Thickened	Level IV
d. Staged, including mixing	Level IV

Table 4 (Continued)

Processes		Constraints
PS 4	Sludge - Advanced a. Zimpro-Pyrolysis b. Incineration c. Fertilizer	Level IV
PS5	Sludge Combined - Imhoff	Level I
PS6	Secondary - Standard Filter	Level II
PS7	Secondary - High Rate Filter a. Bio-filter b. Accelo-filter c. Aero-filter d. Biosorption-filter	Level III
PS8	Secondary - Activated Sludge a. Min. solids b. Conventional	 Level IV Level III
PS9	Secondary Extended Aeration (Oxidation Pond) a. Dutch ditch b. INKA c. Aerated lagoon	Level III
PS10	Disinfection - Chlorine	Level II
PS11	Aqua - Culture a. Fish, culture-milkfish, tilapia, bass b. Vascular plants - Hyacinth, Kang Kung c. Ecological d. Irrigation	Level I
PS12	Dilution a. Coarse screens b. Fine screens c. Chemical Precipitation, Guggenheim	Level III
PS13	Individual a. Septic tank b. Clivus multrum c. Sanitary pit privy	Level I

Table 4 (Continued)

Processes		Constraints
PS14	Individual (Advanced) a. Chemical b. Thermal	Level III

Finally, there has been a basic assumption that all the processes (PW_i and PS_i) require some sort of public or private infrastructure to oversee the construction and operation of the individual treatment installizations. However, there is not necessarily a multi-unit physical system associated with every treatment operation. For example, individual PS13's can be built, supplied, and maintained by an organization, but they are physically limited to a single family unit. A further assumption is that the individual systems (family units) are reasonable competitive with the other processes or combinations which are subject to the constraints specified in Table 4.

A TEST OF THE MODEL

A test was conducted for the community of Nakuru, which is located in the Rife Valley Region of Kenya. The first page of output for the model is contained in Table 5. For each community evaluated, the computer program generates five pages of output. The first output page is generated for the base year, which in the case of Nakuru was 1974. The process combinations listed on the left side of the output sheet are those suitable for Nakuru. On the same line with each of the processes are the initial construction costs of the project, the yearly maintenance cost, the total cost over the life of the project, and the manpower required by three categories of skill level. From the processes listed, the program determines the one with the lowest total cost, and this process is printed again with a heading indicating that this is the lowest total cost process. This output line also contains the population of the community and the approximate plant scale. The plant scale which is determined by the STL level of the community, is the approximate daily capacity in U.S. gallons for the proposed treatment plant.

The output for Nakuru contains most of the possible process combinations. In other situations, the number of feasible combinations may be much smaller because the process requirements could not be met by low resources and manpower. Basic processes may be eliminated by the lack of such resources as silica sand, values, chemicals, or laboratory equipment. In the case where all the processes have been eliminated and there are no feasible process combinations, a message will be printed to indicate this.

The wastewater treatment processes are treated in essentially the same manner as the water treatment processes. Feasible process combinations are listed along with their costs and manpower. The lowest total cost process is printed again with the costs and manpower, plus the projected or present population and the approximate plant scale in gallons per day. For the base year, the default population is the same as that used for the water treatment. Different population parameters can be specified in the input data.

If the low maintenance option is desired, it can be specified by selecting alternative 2 in No. III-13 of Appendix B. When this choice is selected, the lowest maintenance cost process is selected by the model and is printed below the list of acceptable processes with a heading to indicate that

Table 5. The Planning Model Output for the Base Year Showing the Selected Processes and the Related Costs and Manpower.

FOR THE COMMUNITY NAKURU

IN THE STATE OR PROVINCE OF RIFT VALLEY REGION

IN THE COUNTRY OF KENYA

FOR THE PLANNING GROUP RIFT WATER CENTER BASE YEAR = 1974

****** SUITABLE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1974******

FEASIBLE PROCESS COMBINATIONS	INITIAL CONSTRUCTION COST (U.S.$)	YEARLY MAINTENANCE COST (U.S.$)	TOTAL COST 20 YEARS	REQUIRED MANPOWER USKIL	SKIL	PROF	POPULATION SERVED	PLANT SCALE U.S. GALLONS
PW1 + PW7	24947	14108	307120	4	0	0		
PW2 + PW3	346687	32930	1005292	5	0	0		
PW4 + PW7	34926	320830	6451526	6	2	2		
PW2 + PW4 + PW7	1922850	211964	6162130	6	2	2		
PW5 + PW7	67150	76459	1596348	2	1	1		
PW2 + PW5 + PW7	1530290	379229	9114872	6	2	2		

THE LOWEST TOTAL COST WATER TREATMENT PROCESS IS THE FOLLOWING

NO TREATMENT + DISINFECTION	$ 24947	$ 14108	$ 307120	4	0	0	60181	4513575

****** SUITABLE WASTE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1974 ******

PS1 + PS5	763087	34744	1457982	2	1	0		
PS1 + PS3	142989	19914	541276	4	0	0		
PS2	9919186	128343	12486062	2	1	0		
PS1 + PS5 + PS6	728736	104725	2823236	2	1	0		
PS1 + PS9	1894573	98743	3869433	2	1	0		
PS1 + PS3 + PS6	12918747	31096	13540667	4	1	1		
PS1 + PS3 + PS7	4158555	14701	4452575	4	1	1		
PS1 + PS3 + PS8	1432547	61890	2670347	4	1	1		

THE LOWEST TOTAL COST WASTE WATER TREATMENT PROCESS IS THE FOLLOWING

PRIMARY-CONVENTIONAL + SLUDGE - CONVENTIONAL	$ 142989	$ 19914	$ 541276	4	0	0	60181	4513575

It is the lowest maintenance process available. In the Nakuru example, an examination of the results shows that the lowest total cost water treatment processes selected are also those which have the lowest yearly maintenance. However, the lowest total cost wastewater treatment processes in this example or in the testing of other examples did not always give this result. In cases where there is not a central wastewater collection system, the model does not investigate for a suitable wastewater treatment process.

Table 6 gives the output of the second page of the Nakuru printed output. At this point, the population was projected for five years to 1979. The water and wastewater treatment costs were again computed for the various processes selected and in each case the lowest total cost treatment method was repeated with the population and plant scale data added. In this particular example, the lowest total cost process for water treatment is no treatment and disinfection (PW1 + PW7). For wastewater treatment, the lowest total cost feasible combination is the primary-conventional and the sludge-conventional processes PS1 + PS3). Table 7 gives the results of simulation for 1984, and these show again that the no treatment plus disinfection and primary-conventional plus sludge-conventional are the lowest total cost processes. The lowest cost processes stay the same for 1989 and 1994.

Table 6. The Planning Model Output for the Base Year + 5 Years Showing the Selected Processes and the Related Costs and Manpower

FOR THE COMMUNITY	NAKURU
IN THE STATE OR PROVINCE OF	RIFT VALLEY REGION
IN THE COUNTRY OF	KENYA
FOR THE PLANNING GROUP	RIFT WATER CENTER

BASE YEAR = 1974

****** SUITABLE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1979******

FEASIBLE PROCESS COMBINATIONS	INITIAL CONSTRUCTION COST (U.S.$)	YEARLY MAINTENANCE COST (U.S.$)	TOTAL COST 20 YEARS	REQUIRED MANPOWER USKIL	SKIL	PROF	POPULATION SERVED	PLANT SCALE U.S.GALLONS
PW1 + PW7	26741	15424	335241	4	0	0		
PW2 + PW3	379032	36002	1099084	5	0	0		
PW4 + PW7	487750	350763	7503010	6	2	2		
PW2 + PW4 + PW7	2268843	231740	6923643	6	2	2		
PW5 + PW7	73415	83593	1745283	2	1	1		
PW2 + PW5 + PW7	1673062	414610	9965269	6	2	2		

THE LOWEST TOTAL COST WATER TREATMENT PROCESS IS THE FOLLOWING

NO TREATMENT + DISINFECTION	$ 26741	$ 15424	$ 335241	4	0	0	65796	4934681

****** SUITABLE WASTE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1979 ******

PS1 + PS5	834281	37986	1594009	2	1	0
PS1 + PS3	156330	21772	591776	4	0	0
PS2	10844623	140318	13650983	2	1	0
PS1 + PS5 + PS6	890022	107295	3035922	2	1	0
PS1 + PS9	2071332	101688	4105092	2	1	0
PS1 + PS3 + PS6	14124037	34930	14822630	4	1	1
PS1 + PS3 + PS7	4546539	15110	4848739	4	1	1
PS1 + PS3 + PS8	1566201	69530	2956801	4	1	1

THE LOWEST TOTAL COST WASTE WATER TREATMENT PROCESS IS THE FOLLOWING

PRIMARY-CONVENTIONAL + SLUDGE - CONVENTIONAL	$ 156330	$ 21772	$ 591776	4	0	0	65796	4934681

Table 7. The Planning Model Output for the Base Year + 10 Years Showing the Selected Processes and the Related Costs and Manpower.

FOR THE COMMUNITY NAKURU

IN THE STATE OR PROVINCE OF RIFT VALLEY REGION

IN THE COUNTRY OF KENYA

FOR THE PLANNING GROUP RIFT WATER CENTER BASE YEAR = 1974

****** SUITABLE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1984******

FEASIBLE PROCESS COMBINATIONS	INITIAL CONSTRUCTION COST (U.S.$)	YEARLY MAINTENANCE COST (U.S.$)	TOTAL COST 20 YEARS	REQUIRED MANPOWER USKIL	SKIL	PROF	POPULATION SERVED	PLANT SCALE U.S.GALLONS
PW1 + PW7	27424	18432	396064	8	0	0		
PW2 + PW3	380992	43616	1253312	8	0	0		
PW4 + PW7	581228	391744	8416108	10	5	2		
PW2 + PW4 + PW7	2382459	246680	7316059	10	5	2		
PW5 + PW7	85280	88336	1852000	4	1	1		
PW2 + PW5 + PW7	3516141	426645	12049041	10	5	2		

THE LOWEST TOTAL COST WATER TREATMENT PROCESS IS THE FOLLOWING

NO TREATMENT + DISINFECTION	$ 27424	$ 18432	$ 396064	8	0	0	71934	5395068

****** SUITABLE WASTE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1984 ******

PS1 + PS5	510799	38232	1675439	4	2	0		
PS1 + PS3	169126	48929	1147706	6	0	0		
PS2	17470290	145953	20389350	4	2	1		
PS1 + PS5 + PS6	1093642	119182	3477282	4	2	1		
PS1 + PS9	2678080	111380	4905680	4	1	1		
PS1 + PS3 + PS6	21286723	37692	22040563	6	2	1		
PS1 + PS3 + PS7	4866692	23381	5334312	6	1	1		
PS1 + PS3 + PS8	1667648	78242	3232497	8	2	2		

THE LOWEST TOTAL COST WASTE WATER TREATMENT PROCESS IS THE FOLLOWING

PRIMARY-CONVENTIONAL + SLUDGE-CONVENTIONAL	$ 169126	$ 48929	$ 1147717	6	0	0	71934	5395068

Table 8. The Planning Model Output for the Base Year + 15 Years Showing the Selected Processes and the Related Costs and Manpower.

FOR THE COMMUNITY NAKURU

IN THE STATE OR PROVINCE OF RIFT VALLEY REGION

IN THE COUNTRY OF KENYA

FOR THE PLANNING GROUP RIFT WATER CENTER BASE YEAR = 1974

****** SUITABLE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1989******

FEASIBLE PROCESS COMBINATIONS	INITIAL CONSTRUCTION COST(U.S.$)	YEARLY MAINTENANCE COST(U.S.$)	TOTAL COST 20 YEARS	REQUIRED MANPOWER USKIL	SKIL	PROF	POPULATION SERVED	PLANT SCALE U.S.GALLONS
PW1 + PW7	29983	19218	414343	8	0	0		
PW2 + PW3	407208	45820	1323608	8	0	0		
PW4 + PW7	635454	409633	8828114	10	5	2		
PW2 + PW4 + PW7	2604733	248499	7574713	10	5	2		
PW5 + PW7	91370	89644	1884250	4	1	1		
PW2 + PW5 + PW7	3844184	447791	12800004	10	5	2		

THE LOWEST TOTAL COST WATER TREATMENT PROCESS IS THE FOLLOWING

NO TREATMENT + DISINFECTION	$ 29983.54	$ 19218	$ 414343	8	0	0	78645	5898407

****** SUITABLE WASTE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1989 ******

PS1 + PS5	977114	39612	1769372	4	2	0		
PS1 + PS3	237676	53494	1307565	6	0	0		
PS2	19100200	146771	22035620	4	2	1		
PS1 + PS5 + PS6	1160983	130301	3767003	4	2	1		
PS1 + PS9	2834639	121771	5270059	4	1	1		
PS1 + PS3 + PS6	31406769	41208	32230929	6	2	1		
PS1 + PS3 + PS7	5040848	25562	5552088	6	1	1		
PS1 + PS3 + PS8	1895245	85542	3606085	8	2	2		

THE LOWEST TOTAL COST WASTE WATER TREATMENT PROCESS IS THE FOLLOWING

PRIMARY-CONVENTIONAL + SLUDGE-CONVENTIONAL	$ 237676	$ 53494	$ 1307565	6	0	0	78645	5898407

Table 9. *The Planning Model Output for the Base Year + 20 Years Showing the Selected Processes and the Related Costs and Manpower.*

FOR THE COMMUNITY NAKURU

IN THE STATE OR PROVINCE OF RIFT VALLEY REGION

IN THE COUNTRY OF KENYA

FOR THE PLANNING GROUP RIFT WATER CENTER BASE YEAR = 1974

FEASIBLE PROCESS COMBINATIONS	INITIAL CONSTRUCTION COST (U.S.$)	YEARLY MAINTENANCE COST (U.S.$)	TOTAL COST 20 YEARS	REQUIRED MANPOWER USKIL	SKIL	PROF	POPULATION SERVED	PLANT SCALE U.S.GALLONS
****** SUITABLE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1994******								
PW1 + PW7	32780	20078	434340	8	0	0		
PW2 + PW3	435870	48229	1400450	8	0	0		
PW4 + PW7	694740	429191	9278560	10	5	2		
PW2 + PW4 + PW7	2847746	251420	7876146	10	5	2		
PW5 + PW7	98029	93635	1970909	4	1	1		
PW2 + PW5 + PW7	4202834	470909	13621014	10	5	2		
THE LOWEST TOTAL COST WATER TREATMENT PROCESS IS THE FOLLOWING								
NO TREATMENT + DISINFECTION	$ 32780	$ 20078	$ 434340	8	0	0	85983	6448710
****** SUITABLE WASTE WATER TREATMENT PROCESSES FOR IMPLEMENTATION IN...1994 ******								
PS1 + PS5	1049617	43308	1915777	4	2	0		
PS1 + PS3	244488	58485	1414188	6	0	0		
PS2	20882190	158599	24054170	4	2	1		
PS1 + PS5 + PS6	2143936	142457	4993076	4	2	1		
PS1 + PS9	2905805	133132	5568445	4	1	1		
PS1 + PS3 + PS6	35380160	45053	36281220	6	2	1		
PS1 + PS3 + PS7	6231252	27947	6790212	6	1	1		
PS1 + PS3 + PS8	1934746	93522	3805186	8	2	2		
THE LOWEST TOTAL COST WASTE WATER TREATMENT PROCESS IS THE FOLLOWING								
PRIMARY-CONVENTIONAL + SLUDGE-CONVENTIONAL	$ 244488	$ 58485	$ 1414188	6	0	0	85983	6448710

SCOPE AND LIMITATIONS OF THE MODEL

Since the perspective of the model is global, a large array of treatment processes are considered potential candidates for the treatment of water and wastewater. The array of processes is open to expansion as new ideas are tested through the global network working on adaptive and innovative technological transfer. However, in certain areas some processes lend themselves to greater probabilities for success than others. For example, the obvious ones for a rural community are:

Water	Wastewater
PW1 No Treatment	PS2 Primary Stabilization Pond
PW2 Pre-Treatment	PS3 Sludge - Conventional
PW11 Containment	PS4 Sludge - Advanced
	PS11 Aqua - Culture
	PS12 Dilution
	PS13 Individual

To account for local variations, the model can be adapted by the addition and elimination of processes as needed.

The model initially was limited to organized communities or nucleated villages that range in population from 500 to 100,000 inhabitants. At the lower level, the logic was one of *a minimal system. Individual family systems would be acceptable, if they are collectively* managed, etc. In high population concentration areas, the more developed communities have largely been able to develop adequate systems without the need for a planning model.* That is, they can afford the professional expertise.

The model's data requirements are reasonable. The model is so structured that up to 30 percent of the items may be missing, yet reasonable community identification can still be achieved. In fact, one alternative would be to arrive at the community level by simply consulting the scenarios in Appendix A, thus bypassing the data requirements entirely.

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*D. Donaldson, "Progress in the Rural Water Programs of Latin America," Bulletin of the Pan American Health Organization, VIII 1, 1974, pp. 41-42.

Another limitation of the study concerns the components of the water supply and sewage treatment.* By assuming a single community, the water system may be broken down into four sets or a series of linages: (1) water resources, (2) delivery system, (3) use system, and (4) disposal system. Water resources refers to location, quantity, and quality of available water and other characteristics of the natural environment such as climate and topography. The delivery system refers to the means available for developing the resources and supplying water to the point where it is to be used. This encompasses technology, engineering skills, and hardware from the most primitive to the most sophisticated levels. The use system refers to the purposes for which the water is employed and the quantities and qualities required for each. The disposal system refers to the means available for taking used water and its content of wastes away from the household and returning it to the environment.

The water treatment phase of the study deals only with treatment of the water somewhere between the source and the ultimate user. This technique is bounded on one side by water procurred from reservoirs, wells, and pipelines and on the other side by the distribution system such as a grid or hydrant. Both sides are considered fixed, but procurement and distribution methods do affect treatment costs, to some degree. However, this effect should not be too evident because water quality and system scale are both included in the model. Therefore, each solution is for a particular source by scale and quality.

The same constraint applies to wastewater treatment. The methods of treating waste are concerned with returning the wastewater to the environment so that pollution will be minimized. Transportation of wastewater away from households is not presently considered.

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* The model structure can also be considered as processes, activities, trajectories, and systems. In this view, processes are the smallest technological operations, such as sedimentation, filtration, etc. Combinations of processes to meet specific quality goals, the next level of aggregation of one or more processes, would be activities providing levels of treatment. Trajectories are linked sets of activities within the water system, the waste disposal system, etc. The total system would then concern itself with the world of water, including drainage, irrigation, etc.

APPENDIXES

Appendix A - Description of the STL Categories

Appendix B - The Water and Wastewater Treatment Planning Model Data Sheet

Appendix C - Process Cost Determination

Appendix D - Cost and Manpower Parameters for Selected Water and Wastewater Treatment Processes by Socio-Technical Level and Scale

APPENDIX A

DESCRIPTION OF THE STL CATEGORIES

The approach in this study was to set up four levels of development so that any community would be classified rather easily into one of these levels. The stage of development was defined as the sum of the socio-cultural and socio-economic factors that are such an essential part of any community or group of people. The general characteristics of each level of community is described below.

Level I Communities

Level I communities are those whose economic and social progress is dependent upon continued employment of outside high-level manpower in a wide variety of core positions in major public and private institutions. In this stage the indigenous human resources are insufficient to permit these communities to move forward on their own. Almost without exception they require external aid for progress. Normally the Level I community is essentially an agricultural society, with the majority of the population being rural or nomadic. The bulk of the rural population surrounding the community is engaged in subsistence activities contributing marginally to the market economy. Those engaged in cash crops, such as tea or vegetables, are a small minority.

The bulk of the population is engaged in traditional subsistence activities and has very little contact with the modernizing sectors of the community. There is a critical shortage of all categories of highlevel manpower: professional and subprofessional, administrative and clerical, teachers, supervisors, and senior craftsmen. In many of these communities, the total number of native persons in the population who have a secondary education or equivalent is certainly less than 1 percent, and in some cases, it may be closer to one-tenth of 1 percent.

In many Level I communities, the population is no longer stable, but is beginning to increase as progress is made in the control of diseases with the expansion of health services.

In some areas, overcrowding on the land, the initial thrust of education into these areas, and the building of roads has encouraged the movement of people to large towns and cities. Over-crowding and unemployment are becoming noticeable in the larger urban areas.

The education in Level I communities is underdeveloped at every level. It reaches only a small fraction of the population; its quality is low; and it is incapable of meeting even the minimum needs for local high-level manpower. Many of the schools are operated by "voluntary agencies" or missionary organizations and the variations in curricula are wide. In most of these communities, the bulk of the primary school teachers are "unqualified" which generally means that they have had little more than six or seven years of primary schooling themselves. The characteristic pattern of most Level I communities is that many pupils start in the first grade, then drop out, and then come back again as repeaters and drop out again.

Level II Communities

Level II communities could also be called "relatively advanced" ones. These partially developed communities for the most part are still dependent upon the more advanced communities or central cities for critically needed scientific and engineering manpower. But they are able to produce the greater part of their own non-technical high-level manpower, such as teachers, managers, and supervisors with some assistance from advanced countries or other areas within the country. They are still unable to develop enough strategic high-level manpower (particularly engineers, scientists, and highly qualified teachers) to progress on the road to industrialization completely under their own power. In many areas, a large portion, approximately half of the population, is engaged in subsistence activities outside the market economy. Most of the agricultural population produces at least some commodities which are sold for cash. In some areas there is a nucleus of modern industry and in some communities the industrial sector is sizable. Some communities have textile factories and light metal manufacturing plants while others have large mining or petroleum companies, most of which are partly owned and operated by foreign concerns. Banking and commercial establishments are much more developed than they are in Level I communities, as are the systems of transportation and communication. Thus, the modern sector of the community is larger and a great deal more complex than that in the Level I community, and government employment no longer dominates the labor market.

In nearly all Level II communities, there is widespread consciousness of the need for rapid economic and social development, yet in most cases there is no clear-cut strategy for achieving it. But in comparison with Level I communities, there is more widespread participation of the people in the political life of the community and, consequently, greater pressure for expansion of education and general improvement in the standards of living.

Level III Communities

In terms of human resource development the average Level III community has travelled about half the distance between the partially developed (Level II) and the advanced communities (Level IV). The secondary school enrollment ratio is three times higher, and their primary enrollment is 50 percent higher. The semi-advanced community (Level III) has available practically all of the high level manpower that it needs except for those occupations requiring scientific and technical personnel. Although shortages of scientists and engineers persist, they are not great enough to prevent the community from successfully importing and adapting modern technology without substantial external help. In short, the Level III community is "over the hump" in human resource development. It is on the road to becoming an advance community, and it can travel on that road largely under its own power.

The quantity and quality of high-level manpower in the Level III communities is far below those in the advanced communities. The Level III community is a follower rather than an originator of scientific, engineering, and organizational innovations. Actually, a community in this level has a broad base of primary education with generally well-developed secondary schools and maybe an institution of higher education. It has not been able to develop the research manpower and research institutes which are characteristics of advanced communities. In the area of manpower, institutions though capable of supplying initial minimum needs are often improperly oriented to meet the challenges posed by rapid modernization. In some cases, too many people are being trained in fields for which the prospective demand does not match the supply. Industrialization is well advanced in Level III communities. Most of them are no longer predominantly agricultural oriented. Transport, power, and communication are, on the whole, well-developed. There are, however, bottlenecks in electric production, railroad service, irrigation, etc., partly because of a shortage of the skilled and technical manpower to build and operate them.

Like many of the less developed communities, some of the Level III communities have surplused of unskilled human resources. There is a relative surplus among certain types of university graduates. Unlike the advanced communities, however, the level of economic development is still not high enough to absorb all those finishing higher education, regardless of the field of study. Even among those professionally trained, there are likely to be relative surpluses and shortages.

Generally, the salaries paid to high-talent manpower in science, engineering, and managerical positions in most of the Level III communities are sufficient to attract young people to train for these fields. The prestige of the technically trained man is high, and professional management is more highly regarded as a career than in the lesser developed areas. Government administrative posts also carry high prestige and high salaries, but they are no lower than in other professions requiring equivalent education and skills. Allocation of high-level manpower by other means than the relative salary structure has advanced somewhat in Level III communities. There are public employment services, although these tend to service blue-collar workers rather than professionals. Some attempts have also been made to establish registers of scientific and technical personnel, but generally the employment opportunities for these people are sufficient without the assistance of formal placement procedures.

Level IV Communities

The typical community in the fourth level of human resource development is in an advanced industrial economy. It is capable of making major scientific, technological, and organizational discoveries and innovations. This is because it has a relatively large stock of high-level manpower, particularly scientists, engineers, and managerial and administrative personnel. The community has made a heavy commitment to education, especially to higher education, and to human resource development in general. Since rapid changes in technology affect skills and occupations at all levels in the advanced industrial community, education and training tend to be geared to flexibility rather than to specialization.

Measures of educational development show narrow differentials, but they are still substantial. For example, Level IV communities have over 3 times more students enrolled in first-level (primary) education than do Level I communities and about one-fifth more then Level III communities. Even the percentages enrolled in scientific and technical facilities are higher and those enrolled in humanities, fine arts, and law are smaller in the advanced communities than in the communities of the lower levels of human resource development. Finally, the advanced communities spend nearly one-third more of their income on public education than do Level III communities.

From the general description of the levels of development, a number of variables were selected on the basis of their availability at the local level and how they reflected the level of development at the community level.

APPENDIX B

THE WATER AND WASTEWATER TREATMENT PLANNING MODEL DATA SHEET

I. General Information

1. Location of Community

   City Name ______________________________

   State or Province ______________________

   Country ________________________________

2. Planning Group or Agency ________________________________

II. Demographic - The model requires some basic population data for the purposes of capacity planning. Two inputs are required. If local or site data is not available please use a national estimate and also indicate whether it is national or local source.

Answer either A or B.

A. 1. Present Population - The figure or estimate of the present population should reflect the number of inhabitants that the proposed water or wastewater treatment facility is going to serve.

Actual population ____________________________ or estimate the following:

______ (1) Between 500 and 2,500 people

______ (2) 2,500 - 15,000

______ (3) 15,000 - 50,000

______ (4) 50,000 - 100,000

______ (5) Source __________________

2. Annual population growth rate _____________ or estimate in the following:

______ (1) Less than 1%

______ (2) 1% - 1.5%

APPENDIX D

Cost and Manpower Parameters for Selected Water and Wastewater Treatment Processes by Socio-technological Level and Scale*

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*These data cover processes PW1 through PW10, and PS1 through PS10. PW11 and PS11, 12, 13, and 14 require additional information. All these data are based on modified U.S. experiences. See Appendix C. New data, for the global network and other sources, are under development.

(3) 1.5% - 2.0%

(4) 2.0% - 2.5%

(5) 2.5% - 3.0%

(6) 3.0% - 3.5%

(7) 3.5% - 4.0%

(8) Greater than 4%

(9) Source ______________

B. *Population estimate at last census* ______________________________

Date of Census ____________________ Source of Census ________________

Annual Growth rate at time of last census or present annual growth rate ______

____

III. Socio-Economic Data - The purpose of this section is to gather enough information about the community so that it can be classified into one of the four levels of development. The approach has been to request information that is generally available and can be obtained on a local level. Please include any other information you feel is relevant.

CHECK THE MOST APPROPRIATE CATEGORY FOR THE FOLLOWING QUESTIONS

1. Average level of education obtained by inhibitants living in the community.

	Level	None	Primary	High School	Technical Institute	College
______	(1)	95%	4%	1%	0%	0%
______	(2)	70%	19%	7%	3%	1%
______	(3)	55%	22%	14%	6%	3%
______	(4)	9%	34%	42%	8%	7%
______	(5)	Other				

2. Average distribution of labor force in the community.

Level	Unskilled	Semi-Skilled	Professional
______ (1)	97%	2%	1%
______ (2)	80%	16%	4%
______ (3)	61%	27%	12%
______ (4)	45%	30%	25%

3. Annual average income per family in your country's currency.

______________________ amount

______________________ unit

If available, also check the approximate U.S. dollars equivalency of this amount shown in the following.

______ (1) Less than $100

______ (2) $100 - $500

______ (3) $500 - $1,000

______ (4) $1,000 - $3,000

______ (5) Greater than $3,000

4. Among the highly skilled and technical workers (for example, engineer, chemist, etc.) what percentage of these is non-local or non-native people.

______ (1) Less than 10%

______ (2) 10% - 25%

______ (3) 25% - 50%

______ (4) 50% - 75%

______ (5) 75% - 100%

5. Are there any primary and secondary schools operated by voluntary or missionary organizations rather than the government itself?

__________ (1) Yes __________ (2) No

6. What is the highest grade offered by local schools on a regular basis? (Circle one)

1 2 3 4 5 6 7 8 9 10 11 12 12+

7. If the number selected in #6 above is less than 12, how far away is the nearest high school offering the 12th grade?

_____ (1) Less than 10 miles (or less than 16 kilometers)

_____ (2) 10 - 30 miles (or 16 - 48 kilometers)

_____ (3) 30 - 50 miles (or 48 - 80 kilometers)

_____ (4) Greater than 50 miles. (Greater than 80 kilometers.)

_____ (5) Other (specify) ____________________

8. Are there any technical or vocational schools in the community?

_____ (1) Yes _____ (2) No

9. Has the community achieved compulsory primary education of at least six years?

_____ (1) Yes _____ (2) No

10. Are there any formal in-service training programs by either the government or local industry for their employees?

_____ (1) Yes _____ (2) No

11. Is there a college or universityin the local community?

_____ (1) Yes _____ (2) No

12. Does the university have a chemistry department or laboratory?

_____ (1) Yes _____ (2) No

13. How do you rate the ability of the community to finance a water and sewage treatment project?

_____ (1) Unable to repay; the project is a gift because the beneficiaries are poor.

_____ (2) Limited ability to repay; however, the benefits exceed the costs.

______ (3) Repayment prospects are good; the beneficiaries have relatively high incomes.

14. Is unemployment widespread?

______ (1) Yes ______ (2) No

15. Are advisory services widely available to farmers for community development or for other programs designed to upgrade the skills and enlist the participation of the inhibitants?

______ (1) Yes ______ (2) No

16. Do most college or university students of the community receive their education in neighboring communities, neighboring countries, or other foreign countries?

______ (1) Yes ______ (2) No

17. The level of technology available can generally be classified as

______ (1) Hand tools only

______ (2) Mechanical tools (i.e., gasoline powered equipment)

______ (3) Chemical products (fertilizers, chlorine)

______ (4) Electronic technology

18. Does the government dominate the labor market?

______ (1) Yes ______ (2) No

19. Are public employment services readily available?

______ (1) Yes ______ (2) No

Questions 20-23 relate to the availability of materials and equipment. Check those items that are never available in the community.

20. Operation equipment. Which of the following are never available in the local community?

______ (1) Water meters

______ (2) Soldering equipment

______ (3) Acetylene torches

______ (4) Recording devices - such as thermostats

______ (5) Laboratory equipment i.e. test tubes

______ (6) Portable power plants i.e. gasoline powered electric generators

______ (7) Motors i.e. 1-3 horsepower electric motors

______ (8) Water pumps

21. Process materials. Which of the following are never available in the local community?

______ (1) Pipe (clay, steel, cement, plastic, copper, etc.)

______ (2) Pipe fittings

______ (3) Paint

______ (4) Valves

______ (5) Tanks

______ (6) Vacuum gauges

______ (7) Heat exchangers

22. Operation and Maintenance supplies: Which of the following are never available in the local community?

______ (1) Silca sand

______ (2) Graded gravel

______ (3) Clean water

______ (4) Gasoline

23. Chemicals supplies: Which of the following are never available in the local community?

______ (1) $Al_2(SO_4)_3$ (aluminum sulfate)

______ (2) $FeCl_3$ (ferric chloride)

______ (3) Activated charcoal

______ (4) CaO (lime)

_____ (5) $NaCo_3$ (Soda ash)

_____ (6) Cl_2 (Chlorine)

_____ (7) O_3 (Ozone)

_____ (8) Laboratory chemicals

24. Major Water Source (check appropriate category)

_____ (1) River or stream

_____ (2) Lake or impoundment

_____ (3) Wells

_____ (4) Sea or brackish

25. Approximate per capita water demand (daily)

(1) Current demands _______________ in _______________ (units)

(2) 10 year projection: ____________________________________

26. Is ground water available?

_____ (1) Yes _____ (2) No

27. Are wells already drilled? Current Capacity? _______________ mgd

_____ (1) Yes _____ (2) No

28. Is a central wastewater collection system in existence?

_____ (1) Yes _____ (2) No

29. Is the following wastewater data available? Please fill in the percentage of people in the community that are:

(1) Currently connected to the system _______________ %

(2) To be connected within 5 years of the start of the project ____________________________ %

(3) To be connected within 10 years _______________ %

30. Are industrial and commercial concerns using the wastewater system and if so, in what quantity (in thousands of gallons)?

(1) Currently ______________

(2) Within 5 years ______________

(3) Within 10 years ______________

IV. A. Raw Water Quality - The purpose of this section is to provide as input to the model the results of tests that have been carried out on the input or raw water. Presently, the results of seven tests are requested; however, only two are required, turbidity and coliform.

(1) *Number of coliforms ______________ (MPN/100 ml)

(2) *Turbidity ______________ (mg/l or JTU)

(3) BOD ______________ (mg/l)

(4) pH ______________ (0 ⟶ 14)

(5) Dissolved oxygen ______________ (mg/l)

(6) Temperature ______________ (°C)

(7) Chlorine ______________ (mg/l)

B. WasteWater Quality:

(1) *Hardness ______________ (mg/l)

(2) *Total dissolved solid ______________ (mg/l)

(3) *Dilution ______________ (CFS/1000 PE)

(4) *Fe and Mu ______________ (mg/l)

*Data needed for the predictive model

APPENDIX C

PROCESS COST DETERMINATION

The procedure is as follows:

Step 1. Determine for each treatment process the percentage of the total cost involving labor and materials. As an example suppose construction of a secondary standard filter installation cost analysis showed 50% material. Operational costs might break down as 80% labor and 20% material.

Step 2. Labor costs are further divided into skilled and unskilled. Materials are divided into the percent that can be purchased in-country and the percent that must be imported.

Steps 1 and 2 are shown as follows with typical percentages for the secondary standard filter process. These values differ with population size and from country to country, depending on technology level:

An Example of the Percentage Labor and Material for the Construction and the Operation and Maintenance of the Secondary Standard Filter Process

A. Construction Cost

Process No.	Process	Percent Labor	Unskilled	Skilled	Percent Material	In-country	Imported
PS6	Secondary Standard Filter	50%	30%	20%	50%	40%	10%

B. Operation and Maintenance Yearly Costs

Process No.	Process	Percent Labor	Unskilled	Skilled	Percent Material	In-country	Imported
PS6	Secondary Standard Filter	80%	60%	20%	20%	5%	15%

To determine costs of construction or operation and maintenance for less developed countries by using U.S. costs, the following formula is used:

$$C_{LDC} = C_{U.S.}\left[(L_{unskilled} \times \frac{LDC}{U.S.}) + (L_{skilled} \times \frac{LDC}{U.S.}) + (M_{in-country} \times \frac{LDC}{U.S.}) + (M_{imported} \times \frac{LDC}{U.S.})\right]$$

where:

- C = cost
- L = labor percent of cost
- M = materials percent of cost
- LDC = less developed countries
- U.S. = United States

The *actual* values for cost of labor and materials were collected for the resource matrix described earlier. From this data the cost transfer coefficients will be calculated, and total per capita cost for construction and operation and maintenance will be available for evaluation in the selection of the most appropriate (least cost) treatment process.

The determination of the total cost for the water and sewage treatment process is as follows:

(construction)

$$C_2 = C_1(P)[(X_{11})\left(\frac{X_{21}}{X_{22}}\right) + (X_{12})\left(\frac{X_{31}}{X_{32}}\right) + (X_{41})(X_{51}) + (X_{42})(X_{52})]$$

(maintenance)

$$C_3 = C_5(P)[(X_{11})\left(\frac{X_{21}}{X_{22}}\right) + (X_{12})\left(\frac{X_{31}}{X_{32}}\right) + (X_{41})(X_{51}) + (X_{42})(X_{52})]$$

Consequently the total cost over a twenty year period is:

$$C_4 = C_2 + C_3 \quad (20)$$

Where:

C_1 = Total construction cost per capita in U.S.,

C_2 = Total construction cost for the process,

C_3 = Total maintenance cost for the process for one year,

C_4 = Total cost for the process for 20 years,

C_5 = Total maintenance cost per capita in U.S.,

P = Population served,

X_{11} = Percent Unskilled Labor--LDC,

X_{12} = Percent Skilled Labor--LDC,

X_{21} = Hourly Wage Unskilled Labor--LDC,

X_{22} = Hourly Wage Unskilled Labor--DC,

X_{31} = Hourly Wage Skilled Labor--LDC,

X_{32} = Hourly Wage Skilled Labor--DC,

X_{41} = Percent on-site materials manufactured,

X_{42} = Percent off-site materials manufactured,

X_{51} = Cost on-site materials manufactured--LDC/DC, and

X_{52} = Cost off-site materials manufactured--LDC/DC.

The above variables will differ depending on the technological or development level of the community under consideration. *Variations will also occur because of the size of* the population served. For example, larger populations generally have a lower per capita cost for water and sewage treatment. For the purposes of figuring the costs on a per capita basis, communities were broken down into four population groups:

1. 500 - 2,499
2. 2,500 - 14,999
3. 15,000 - 49,999
4. 50,000 - 100,000

APPENDIX D

Cost and Manpower Parameters for Selected Water and Wastewater Treatment Processes by Socio-technological Level and Scale*

*These data cover processes PW1 through PW10, and PS1 through PS10. PW11 and PS11, 12, 13, and 14 require additional information. All these data are based on modified U.S. experiences. See Appendix C. New data, for the global network and other sources, are under development.

TABLE D-1 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: No Treatment (PW1)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	8.65	6.45	5.50	6.00			
	Operation & Maintenance	0.50	0.90	1.02	2.00	1		
2 (2,500-14999)	Construction	2.16	1.61	1.48	1.50			
	Operation & Maintenance	0.31	0.56	0.64	1.25	2		
3 (15000-49999)	Construction	1.08	0.80	0.66	0.75			
	Operation & Maintenance	0.12	0.25	0.31	0.50	4		
4 (50000-100000)	Construction	0.72	0.53	0.51	0.50			
	Operation & Maintenance	0.06	0.13	0.16	0.25	8		

* For a complete description of these levels see Appendix A.

TABLE D-2 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Pre-Treatment (PW2)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	8.87	10.76	12.51	14.59			
(500-2,499)	Operation & Maintenance	3.27	2.95	2.19	4.00	1	1	
2	Construction	7.29	8.85	10.56	12.00			
(2,500-14999)	Operation & Maintenance	1.63	1.35	1.10	2.00	1	1	
3	Construction	4.86	6.96	7.59	8.00			
(15000-49999)	Operation & Maintenance	0.82	0.73	0.62	1.00	3	2	1
4	Construction	1.22	1.49	2.03	2.00			
(50000-100000)	Operation & Maintenance	0.41	0.37	0.31	0.50	5	4	1

* For a complete description of these levels see Appendix A.

TABLE D-3 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Slow Sand Filter (PW3)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	12.65	16.50	16.00	20.00			
(500-2,499)	Operation & Maintenance	1.33	2.00	2.33	5.00	1		
2	Construction	9.03	11.72	11.85	14.28			
(2,500-14999)	Operation & Maintenance	0.60	0.90	1.05	2.25	2		
3	Construction	6.33	7.18	7.68	10.01			
(15000-49999)	Operation & Maintenance	0.33	0.58	0.73	1.25	5		
4	Construction	3.95	6.98	5.21	6.25			
(50000-100000)	Operation & Maintenance	0.20	0.35	0.44	0.75	8		

* For a complete description of these levels see Appendix A.

TABLE D-4 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Rapid Sand Filter-Conv. (FW4)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	9.51	9.24	14.56	11.20			
(500-2,499)	Operation & Maintenance	1.80	2.20	2.17	4.00	1	1	
2	Construction	7.47	7.26	11.51	8.80			
(2,500-14999)	Operation & Maintenance	0.90	1.10	1.08	2.00	1	1	1
3	Construction	4.24	5.58	5.25	5.00			
(15000-49999)	Operation & Maintenance	0.79	1.05	1.12	1.75	8	2	1
4	Construction	2.25	2.96	2.83	2.65			
(50000-100000)	Operation & Maintenance	0.67	0.90	0.89	1.50	10	3	1

* For a complete description of these levels see Appendix A.

TABLE D-5 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Rapid Sand Filter-Adv. (PW5)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	323.61	280.21	272.35	209.50			
	Operation & Maintenance	19.77	15.77	14.19	17.77	1	1	1
2 (2,500-14999)	Construction	72.75	63.00	61.61	47.10			
	Operation & Maintenance	13.37	10.67	9.60	12.02	1	1	1
3 (15000-49999)	Construction	32.44	26.59	22.04	21.00			
	Operation & Maintenance	9.90	7.86	7.11	8.90	6	2	2
4 (50000-100000)	Construction	15.60	12.84	10.77	10.10			
	Operation & Maintenance	4.95	3.93	3.55	4.45	10	5	2

* For a complete description of these levels see Appendix A.

TABLE D-6 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: *Softening* (PW6)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	255.95	221.62	215.41	165.70			
	Operation & Maintenance	14.93	11.91	10.72	13.42	1	1	1
2 (2,500-14999)	Construction	172.69	149.53	146.23	111.80			
	Operation & Maintenance	8.83	7.05	6.37	7.94	1	1	1
3 (15000-49999)	Construction	127.90	104.82	86.91	82.80			
	Operation & Maintenance	6.54	5.19	4.70	5.88	6	2	2
4 (50000-100000)	Construction	63.95	52.41	44.16	41.40			
	Operation & Maintenance	3.27	2.60	2.35	2.94	10	5	2

* For a complete description of these levels see Appendix A.

TABLE D-7 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements

Process: Disinfection (PW7)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	5.26	5.30	5.43	4.00			
	Operation & Maintenance	9.29	6.37	5.01	5.00	1		
2 (2,500-14999)	Construction	3.05	1.06	1.09	0.80			
	Operation & Maintenance	4.27	2.93	2.30	2.30	1	1	
3 (15000-49999)	Construction	1.97	2.04	1.49	1.50			
	Operation & Maintenance	3.25	2.16	1.69	1.75	2	1	1
4 (50000-100000)	Construction	1.58	1.63	1.21	1.20			
	Operation & Maintenance	2.79	1.85	1.45	1.50	4	1	1

* For a complete description of these levels see Appendix A.

TABLE D-8 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Taste-Cdor - Fe, Mn (PW8)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	200.65	173.74	168.87	129.90			
(500-2,499)	Operation & Maintenance	23.41	12.61	16.80	21.04	1	1	1
2	Construction	135.47	117.30	114.71	87.70			
(2,500-14999)	Operation & Maintenance	15.81	12.61	11.35	14.21	1	1	1
3	Construction	49.89	40.89	33.90	32.30			
(15000-49999)	Operation & Maintenance	11.70	9.29	8.40	10.52	6	2	2
4	Construction	94.38	77.35	65.17	61.10			
(50000-100000)	Operation & Maintenance	5.85	4.64	4.20	5.26	10	5	2

* For a complete description of these levels see Appendix A.

TABLE D-9 . Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Desalting - Salt (PW9)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	326.85	283.01	275.08	211.60			
(500-2,499)	Operation & Maintenance	8.23	6.57	5.91	7.40	1	1	1
2	Construction	233.55	202.23	197.77	151.20			
(2,500-14999)	Operation & Maintenance	7.68	6.12	5.51	6.90	1	1	1
3	Construction	167.44	137.23	113.78	108.40			
(15000 - 49999)	Operation & Maintenance	5.12	4.06	3.67	4.60	6	2	2
4	Construction	83.26	68.24	57.49	53.90			
(50000 - 100000)	Operation & Maintenance	2.56	2.03	1.84	2.30	10	5	2

* For a complete description of these levels see Appendix A.

TABLE D-10. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Desalting - Brackish (PW10)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	236.95	205.17	199.42	153.40			
(500-2,499)	Operation & Maintenance	15.66	12.50	11.25	14.08	1	1	1
2	Construction	160.03	138.56	135.51	103.60			
(2,500-14999)	Operation & Maintenance	11.74	9.36	8.43	10.55	1	1	1
3	Construction	118.48	97.10	80.51	76.70			
(15000-49999)	Operation & Maintenance	7.82	6.21	5.61	7.03	6	2	2
4	Construction	59.32	48.61	40.96	38.40			
(50000-100000)	Operation & Maintenance	3.97	3.15	2.85	3.57	10	5	2

* For a complete description of these levels see Appendix A.

TABLE D-11. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Primary-Conventional (PS1)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	70.34	80.30	88.00	88.00			
	Operation & Maintenance	1.65	0.99	1.17	2.56	1		
2 (2,500-14999)	Construction	19.18	21.90	24.41	24.00			
	Operation & Maintenance	1.25	0.75	0.89	1.94	1		
3 (15000-49999)	Construction	15.59	16.05	16.91	19.50			
	Operation & Maintenance	1.10	0.78	0.77	1.71	2	1	
4 (50000-100000)	Construction	12.39	14.35	13.17	15.50			
	Operation & Maintenance	0.98	0.69	0.67	1.51	4	2	

* For a complete description of these levels see Appendix A.

TABLE D-12. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Primary-Stabilization Pond (PS2)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	28.46	43.55	55.27	67.00			
(500-2,499)	Operation & Maintenance	0.16	0.45	0.60	1.70	1		
2	Construction	2.55	3.90	5.05	6.00			
(2,500-14999)	Operation & Maintenance	0.13	0.35	0.47	1.34	2		
3	Construction	1.70	2.73	3.17	4.00			
(15000-49999)	Operation & Maintenance	0.12	0.44	0.44	1.26	4		
4	Construction	1.64	1.82	3.59	2.70			
(50000-100000)	Operation & Maintenance	0.10	0.35	0.45	0.65	6		

* For a complete description of these levels see Appendix A.

TABLE D-13. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Sludge-Conventional (PS3)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	162.49	136.13	99.40	103.72			
(500-2,499)	Operation & Maintenance	8.04	6.69	6.83	12.45	1	1	
2	Construction	95.80	80.26	61.54	61.15			
(2,500-14999)	Operation & Maintenance	4.74	3.95	4.03	7.34	1	1	
3	Construction	70.94	62.50	49.76	45.28			
(15000-49999)	Operation & Maintenance	3.51	3.21	2.84	5.43	2	1	
4	Construction	56.37	49.66	32.38	35.98			
(50000-100000)	Operation & Maintenance	2.78	2.55	2.15	4.31	4	2	1

* For a complete description of these levels see Appendix A.

TABLE D-14. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Sludge-Advanced (PS4)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	201.74	169.01	123.40	128.77			
	Operation & Maintenance	16.43	18.30	18.48	25.45	1	1	
2 (2,500-14999)	Construction	103.87	87.02	66.72	66.30			
	Operation & Maintenance	5.14	4.28	4.37	7.96	1	1	
3 (15000-49999)	Construction	74.42	65.57	38.30	47.50			
	Operation & Maintenance	3.68	3.37	2.98	5.70	2	1	
4 (50000-100000)	Construction	57.87	50.99	33.25	36.94			
	Operation & Maintenance	2.86	2.62	2.21	4.43	4	2	1

* For a complete description of these levels see Appendix A.

TABLE D-15. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Sludge-Combined Imhoff (PS5)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	197.16	138.47	151.58	136.76			
	Operation & Maintenance	10.60	8.82	9.00	16.41	1	1	
2 (2,500-14999)	Construction	112.23	78.82	88.15	77.85			
	Operation & Maintenance	6.03	5.02	5.12	9.34	1	1	
3 (15000-49999)	Construction	70.58	51.72	41.98	48.96			
	Operation & Maintenance	3.79	3.47	3.07	3.87	2	1	
4 (50000-100000)	Construction	49.82	36.51	31.10	34.56			
	Operation & Maintenance	2.67	2.45	2.06	4.14	4	1	

* For a complete description of these levels see Appendix A.

TABLE D-16. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Secondary-Standard Filter (PS6)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	112.89	121.59	141.57	137.00			
(500-2,499)	Operation & Maintenance	1.40	1.81	2.06	3.92	1		
2	Construction	33.37	35.94	43.23	40.50			
(2,500-14999)	Operation & Maintenance	0.81	1.05	1.19	2.27	1	1	
3	Construction	27.19	30.83	31.22	33.00			
(15000-49999)	Operation & Maintenance	0.64	0.94	0.91	1.79	4	1	1
4	Construction	21.84	24.76	23.85	26.50			
(50000-100000)	Operation & Maintenance	0.51	0.75	0.70	1.42	6	2	1

* For a complete description of these levels see Appendix A.

TABLE D-18. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Secondary-Activated Sludge (PS8)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	197.05	162.47	186.48	134.00			
(500-2,499)	Operation & Maintenance	2.86	3.12	3.34	5.20	1	1	
2	Construction	58.82	48.74	54.67	40.00			
(2,500-14999)	Operation & Maintenance	1.94	2.11	2.26	3.52	2	1	
3	Construction	47.06	38.94	31.74	32.00			
(15000-49999)	Operation & Maintenance	1.64	1.94	1.81	2.98	4	1	1
4	Construction	38.23	31.64	25.33	26.00			
(50000-100000)	Operation & Maintenance	1.39	1.64	1.45	2.52	8	2	2

* For a complete description of these levels see Appendix A.

TABLE D-19. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Secondary-Extended A Aeration (PS9)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1 (500-2,499)	Construction	154.00	158.81	255.37	165.00			
	Operation & Maintenance	33.21	52.82	38.86	73.14	1	1	
2 (2,500-14999)	Construction	102.78	105.99	106.34	110.12			
	Operation & Maintenance	3.38	5.31	3.96	7.45	2	1	
3 (15000-49999)	Construction	88.67	93.26	81.45	95.00			
	Operation & Maintenance	1.26	2.08	1.55	2.78	4	1	1
4 (50000-100000)	Construction	23.33	24.54	21.25	25.00			
	Operation & Maintenance	0.24	0.39	0.28	0.52	6	2	1

* *For a complete description of these levels see Appendix A.*

TABLE D-20. Per Capita Cost Parameters in U.S. Dollars & Operation & Maintenance Manpower Requirements
Process: Disinfection (PS10)

Population Scale		Socio-Technological Levels*				MANPOWER (# of workers)		
Level	Type of Cost	I	II	III	IV	Unskilled	Skilled	Professional
1	Construction	32.01	48.72	54.13	24.32			
(500-2,499)	Operation & Maintenance	2.12	4.20	4.23	7.50	1		
2	Construction	42.93	36.41	35.60	17.42			
(2,500-14999)	Operation & Maintenance	2.42	2.71	2.73	1.50	2		
3	Construction	20.55	27.86	27.25	15.61			
(15000-49999)	Operation & Maintenance	1.21	2.46	2.17	0.75	4	1	1
4	Construction	14.10	20.18	19.07	10.71			
(50000-100000)	Operation & Maintenance	0.58	1.79	1.49	0.36	6	1	1

* For a complete description of these levels see Appendix A.