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METHODOLOGY FOR THE SELECTION OF APPROPRIATE TECHNOLOGY OF WATER DISTRIBUTION SYSTEMS IN LESS DEVELOPED COUNTRIES

A DISSERTATION

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BY

HOMERO SILVA

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METHODOLOGY FOR THE SELECTION OF APPROPRIATE
TECHNOLOGY OF WATER DISTRIBUTION SYSTEMS
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APPROVED BY THE COLLEGE OF ENGINEERING

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ABSTRACT

METHODOLOGY FOR THE SELECTION OF APPROPRIATE
TECHNOLOGY OF WATER DISTRIBUTION SYSTEMS
IN LESS DEVELOPED COUNTRIES

By: Homero Silva

The objective of this research was to create a planning tool that selects the appropriate technology for water distribution systems for the particular community under study. The selection of appropriate technology is based on manpower capabilities; natural resources, availability of materials and equipment, and the ability to pay of those receiving the service.

At present, 1.2 billion people in the less developed countries do not have access to water. By 1990, this figure is expected to be 2.25 billion. The use of inappropriate technology and design criteria, poverty, and insufficient numbers of manpower are some of the factors that have caused this condition.

Step-wise multiple correlation analysis was used to obtain a water demand model. Interviews were held with people involved with water supply in less-developed countries to obtain information concerning manpower requirements and costs of different technologies. Mail sur-

veys and a statistical analysis were executed to determine the number of employees required for different levels of service.

A methodology that selects appropriate water distribution systems has been developed. This methodology begins by defining the capabilities of the community under study, according to a questionnaire. The capabilities of the community are defined for manpower, level of technology, water resources, and energy. Then each level of service and its requirements for manpower and technology are compared against the resources capability of the community. If a level of service requires manpower of technology that is not available to the community, then this level of service is not utilized.

The methodology ends with an output of capital, operation and maintenance costs, and manpower requirements for those appropriate levels of service.

The output can be used by promoters, designers, planners, and the community to determine in advance the needs for manpower and the water rates that are necessary to be met in order to maintain the water distribution system in working condition. It will also aid the community in deciding what is best for them according to their values.

METHODOLOGY FOR THE SELECTION OF APPROPRIATE TECHNOLOGY FOR WATER DISTRIBUTION SYSTEMS FOR LESS DEVELOPED COUNTRIES

CHAPTER I

Introduction

Access to water is a basic human right. At present, 1.2 billion people in the less developed countries do not have this basic right. This value represents approximately 62 percent of the total population of those countries. By 1990, this figure is expected to be 2.25 billion (1).

By 1963, a World Health Organization study (2) in 75 LDC's indicated that only one-third of the urban population and less than one-tenth of the total population was supplied with piped water in or near their homes. By 1970, another World Health Organization study (3) of the same LDC's showed that of the 2 billion population, about 1.2 billion did not have access to water.

In LDCs, living conditions are crude. Basic sanitation services are needed for the prevention of communicable disease and for the promotion of physical, mental, and social well-being. Although increasing attention is being directed to the baseline problems of safe water supply and disposal of wastewater, public facilities are still not adequate.

Conditions around the world are more or less equal. For example, in some regions of Mozambique and Ethiopia, water must be carried 10 km or more; in Southeast Nigeria permanent water supplies are up to 13 km from villages, and in Eastern Nigeria half of the rural population live more than 5 km away from the perennial streams. Individuals spend up to five hours per day collecting water during the dry season. In East Africa, an average of 46 minutes per day is required. Some of these communities require up to 246 minutes per day. However, in the New Guinea Highlands, an average of 1.6 percent of daytime is spent; in East Africa 12 percent, and in some communities this figure is as high as 27 percent (4).

To understand why this is happening, some of the existing conditions in those countries need to be reviewed. The following paragraphs are intended to aid on this review.

The population of the world was estimated to be four billion in 1975, and it is expected to be between 5.5 and 7.5 billion by the end of the century. The rate of population growth is increasing; in the period from 1750 to 1850 it was 0.5 percent and from 1950 to 1975 it was 1.9 percent (5).

During the last few decades the less developed countries (LDCs) have played an important role in this increase. From 1750 to 1850 they grew at an annual rate of 0.4 percent while the developed countries (DCs) grew at a rate of 0.5 percent; from 1850 to 1950 the rates were 0.6 and 0.9 respectively, and from 1950 to 1975 2.3 for the LDCs and 1.1 for the DCs (6).

The increase in growth rates is the result of improvement in levels of living such as economic organization, agricultural technology, transportation and distribution of facilities. The birth rate, especially in LDCs, has had small variation, but the rate of mortality has decreased as a result of advances in the technology of health and environmental sanitation. The speed with which mortality has been reduced has been much more rapid in the LDCs than in the DCs.

LDCs are in a stage of low mortality and high fertility, being the final stage that of low mortality and low fertility. Forty percent of the total population is under 15 years of age.

The economy rests heavily on subsistence agriculture and other extractive industries. The factors of production, capital, and labor are locally available in quite different proportions than those in DCs. Educated, experienced and skilled managers, engineers and skilled workers are relatively scarce. Domestic markets are small, depriving new industries of economies of scale. The external economies provided by a diverse surrounding industrial system are also absent.

Approximately 8 percent of the people in LDCs have annual per capita incomes of $1,200 or more, but 52 percent have annual per capita income of $100 or less. Moreover, 85 percent do not exceed more than $600 (7). The distribution of incomes is generally more skewed than in DCs. A large proportion of the population is often living in absolute poverty, even in countries where the average income is moderately high. For example, in the Philippines in 1971 the lowest 30 percent of households earned only 8 percent of total income while in Japan the corresponding group accounted for 14 percent. This implies that the tax revenue base of water utility in LDCs is likely to be fairly narrow (8). In this condition, 8 to 10 percent of the national income must be invested to prevent living conditions from deteriorating. All improvements have to come from savings above that level. Such savings are not difficult to obtain in DCs, but they do not come easily from populations so poor that 80 percent of family income goes for food alone. And, even with this percentage of expenditure, people are malnourished.

Works to ameliorate the water supply problem have started since 1960 in the Charter of Punta del Este. At that time goals were set to provide adequate water supply, sewerage and excreta disposal in the next 10 years for at least 70 percent of the urban and 50 percent of the rural population. In 1972, the World Health Assembly set a new target of 25 percent of the rural populations to have water by 1980. To reach that goal, 241 million people were to have been provided with a water supply by 1980.

The United Nations General Assembly has recognized the problem of safe water for the rural areas of LDCs, and it has proclaimed the period from 1981 to 1990 the drinking water sanitation decade. The goal is to provide "clean water and adequate sanitation for all by 1990" (9).

The World Bank estimates that the cost to provide access to water will be around $300 billion, or $30 billion for every year of the decade (10). Experiences in LDCs show that the mere construction of a water supply system does not mean that the goals pursued are met. If records of those water supplies not meeting the goals were included in the statistics of the World Health Organization, one would be surprised how those statistics would worsen.

For example, reliable estimates (11) indicate that 80 percent of the 50,000 wells constructed in drought-prone, hard-rock areas in India, were not producing any water. In Thailand, a survey by students of the Asian Institute of Technology showed that 69 of 79 of the rural water supply systems studied had problems of operation (12).

In Mexico, a city of 2,300,000 people receives water for only 8 hours a day, and in some areas of the city water is available only every three or four days. In the same city in Mexico, at least 200,000 persons are supplied by wells polluted by industrial and domestic discharges. The author had the opportunity to check that situation when he tested the water supply wells on that city.

Reasons for failure in supplying adequate and safe water to the population in LDCs are many and varied. Among those reasons, we name the following:

1. Inappropriate technology
2. Little use of local manpower
3. Indigenous resources not fully utilized
4. Training in developed countries
5. Lack of design criteria
6. Lack of consideration of local cultural conditions
7. Poverty
8. An insufficient number of trained personnel
9. Lack of integration on water programs
10. Slow diffusion of new ideas
11. Resistance to changing professional practices
12. Lack of local involvement during planning

Use of inappropriate technology in water treatment and distribution systems in rural areas in LDCs is very common. Equipment for mechanization and automation that replaces labor is imported. Spare parts and maintenance skills are also imported. In most cases, this technology bears very little relevance to the local situation and cannot be sustained by the local people. There are many communities where a pumping station, a water treatment plant, a distribution system with meters, or other parts of a modern system, cannot be adequately operated and administered.

Some countries have realized the problems of using inappropriate technology. Therefore, filter plants are equipped with manually operated valves instead of using hydraulic cylinders or electric motors. Ditches are dug by hand. Instrumentation and automation are kept to a minimum. In a filter plant a glass tube fastened to the wall in the pipe gallery, where it can be seen from the operating floor, replaces a head-loss gauge.

A facility that can be built and operated with local labor is more appropriate than a facility utilizing the most modern technology. First, because it will employ local labor reducing unemployment; and, second, because it is cheaper. There are some tasks that cannot be performed by manual labor no matter how low cost that labor may be. For example, the pumping of water in large quantities is a mechanical process not easily performed by manual labor.

Little utilization of local manpower during all phases of water supply projects exists. High technology is capital intensive and operated by skilled personnel. Communities in LDCs lack people technically or mechanically experienced. Therefore, this labor has to be imported. The existing conditions in LDCs of unemployment, low wages, and availability of workers make necessary the use of labor-intensive technology. It is cheaper and more reliable to employ men than to install automatic equipment.

Indigenous resources are not fully utilized. Inappropriate technology imposes the importation of equipment and parts that sometimes must travel up to 10,000 miles. This condition leads to the need for large stock of spare parts in order to prevent the system from falling into disrepair. Technology is not adapted to local resources, material or managerial. It is not suited to the low income levels and harsh conditions of LDCs.

Sending professionals to Developed Countries (DCs) to receive their education is a very common mistake of the LDCs. One of the reasons for using inappropriate technology is the engineer. The engineer in less developed countries is more familiar with advanced technology than with appropriate technology. He learns it while attending school in developed countries or in local universities where he studies under professors who themselves studied in developed countries.

Sometimes, teachers and recently graduated professionals are sent to universities in DCs to receive their higher education. These universities do not teach courses in appropriate technology, so almost no benefit is obtained from the high technology learned. For the students sent abroad, it is very pleasant because they will live for some time in a different country than they are used to and, because of this study abroad, they will have a higher status when they return back home. Once a person is more qualified because of education in a DC, he will ask for a better salary to keep pace with his higher status. Unfortunately, salaries in the public water companies in LDC's are not good enough to retain competent personnel. This condition leads the qualified person to look for better employment in private industry or in another city. It would be better to send teachers from DC universities to the universities and schools in the LDCs to teach appropriate technology.

In some LDCs, design criteria utilized for the sizing of distribution systems, pumping stations, storage tanks, etc., come from developed countries. This is one of the consequences of learning technology from DCs. It is common to use figures of 100 gpd for water consumption, and peak factors of 4.0 and design periods of 20 years. This practice leads to the overdesign of the systems, the final result being a higher cost for the project. Developing countries do not have the financial means to do research; therefore, it is easier to use others' design criteria.

Many designers in LDCs use DCs design criteria because they strongly believe they have already been tested so there is not room for failure.

Existing conditions in LDCs are so different from those of DCs that design criteria from DCs cannot be applied. For example, Lauria (13), in working with economies of scale, has concluded that the design period is a function of only the economy of scale factor and the discount rate. He found that in Guatemala and Honduras, economies of scale exist, and that with the discount rate existing in these countries, the optimal design periods are less than 10 years. The design period factor currently utilized in these countries is 20 years. In a similar study developed by the students from the University of El Salvador (14), findings showed that the optimal design period in that country for a water distribution system was 13 years instead of the value of 25 years recommended in the design criteria.

In addition, cultural conditions are little considered during the design. This has played an important role in the failure to obtain the desired goals. It is important to understand the differences of each individual community, and design the system for the community, not the community for the system.

Failure in considering local cultural conditions has brought very bad experiences. In Ethiopia a standpipe was destroyed by people living immediately adjacent to it because they were opposed to noise. In the Ryukyu Island the new water supply failed because a towel was provided on which all of the children of the community wiped their hands, thus spreading trachoma. In some other countries, faucets are ripped off the pipes and the metal used to fashion ornaments (15).

Once the water system is installed people have four choices open to them: (1) they may use the facilities without significant changes in their current behavior, (2) they may change their behavioral habits in order to make use of the new facility, (3) they may misuse the facility, or, (4) they may utterly reject the facility.

It has been found that if the individual cannot easily make the facility work, as in the case of a pump that requires priming, he will let it fall into disrepair. People tend to prefer equipment over which they have an easy and complete control; for example, a bucket and a rope. In other cases, they may use the brass faucet for creating jewelry rather than for water supply because the sense of individual status in possessing jewelry is overriding in these circumstances.

It is important to know what are considered to be the criteria of health, as for example, members of a Filipino community considering that intestinal worms contribute to proper digestion.

There are many supply systems that have been abandoned because not enough revenues were collected for their maintenance and operation costs. People in LDCs are poor and sometimes they are unable to pay water rates. As mentioned earlier, 85 percent of the population earns less than $600 per year. In DCs industrial consumers may account for up to 70 percent of the income of the water utility, so it is possible for them to pay a higher cost for water, to subsidize poor residential consumers. In LDCs, especially in rural areas, industrial consumption is zero. Government's fear of forcing the very poor to use unsafe water sources, if water is charged for, has lead to subsidized water rates. Some persons believe it is necessary that existing systems generate the revenue necessary to service their debt and cover all costs, instead of using funds to subsidize O&M of existing systems, preventing the use of these funds from being used for new construction. They believe that this is a more humanitarian approach than forcing the people without water paying exorbitant amounts for water use delivered by private vendors.

There are some countries that see the water supply as a social service. Tanzania and Zambia are in this category, they do not charge for improved water. People are not always too poor to pay the water rates. Some still regard water like sunlight, as a gift from God and feel that they should not have to pay for it. Some others think they can use their resources to better advantage in building a road or providing an agricultural produce-marketing facility.

An insufficient number of trained personnel is another reason for water system equipment to be lying idle in disrepair soon after construction. LDCs lack adequately trained manpower at the intermediate level. More skilled or semi-skilled technicians who can carry out simple repair and maintenance work are required. Little is done for the training of municipal officials, water utility managers, and the contractors and consultants responsible for technological detail in project design, construction and operation.

Training of personnel is usually part of the contract with the consulting engineer. Usually, local heads of water systems prefer men who have been teachers at the college level but, unfortunately, most professors have never packed a pump or repaired a broken water main.

Training starts during the construction period, so water operators can see the water system being built and will be ready to operate it when construction is completed. In many cases at least one person is retained on the job for the first year of operation to continue the training and to supervise operation of the water systems.

It is very common to find a lack of integration among the governmental and non-governmental organizations active in the field of water supply. It is not rare to find several agencies administering the same program. For example, in Mexico the Water Resources Agency, The Public Health Agency and the Urban Services and Environmental Agency administer the water construction programs. The operation and maintenance is carried out by state and local agencies. This is an obvious waste of resources due to the overlap of functions.

Government agencies do not accept professional advice from private organizations. For an idea to be considered good it must be generated from inside the agency. This situation was encountered by the author while trying to recommend a water saving device to the Water Agency in Monterrey, Mexico. Monterrey has been experiencing a water shortage for five years. The author recommended the use of a device in toilets to reduce by 28 percent the water consumption. The cost of each device was 0.10 U. S. dollars. At this writing, they have not followed this recommendation.

Slow diffusion of new ideas and more appropriate forms of technology exists. A considerable range of choices of intermediate and appropriate forms of technology is available, but is little utilized. This is mainly because it is little known and its availability is limited. Appropriate technology is not taught in universities. Neither the public sector nor private organizations have vigorously promoted the uses of such technologies. There are few international organizations that have promoted workshops in appropriate technology. Results of research on appropriate technology are not made available to the public.

Considerable resistance to changes in professional practice exists in LDCs. Engineers do not like to use simple technology because they equate it with ignorance. To recommend simple, cheap, and effective solutions is not glamorous or likely to attract professional attention, nor does it lead to career and professional rewards.

Appropriate technology is sometimes rejected by leaders and government officials because it is considered "inferior" or "backward"! The LDCs leaders want to be in the vanguard of progress.

Finally, lack of local involvement during planning and design has had a great deal of influence on the failure of water supplies. There are many examples that prove that if the majority of the population of a village does not actively support the installation of a water supply system, the probability of attaining the goals is substantially reduced. Involvement of the community from the beginning of the water supply project is important. Provisions must be made for the users of the water supply system in selecting the different elements in it. These provisions include giving them the opportunity to determine their current preferences, to estimate their current ability to meet their perceived needs, to estimate their capability to adapt to new facilities, and to assess the likelihood of their maintaining the system in the fact of changing preferences over time.

Need of Study and Justification

From what we have seen, there is a need for the use of appropriate technology, use of inexpensive, low-cost technology, more community participation, training, and understanding of local cultures.

Many international agencies are working to solve the problem of appropriate technology in water systems. Hand pump manufacturing has been investigated by the Agency for International Development; Standpipe Design and Construction was investigated by the World Health Organization; Water Distribution Design by the World Bank of Development; Plastic Pipe Manufacturing by AID, and so on. All of these investigations focus on the system components.

It is now necessary to develop a technique that can show the designer the inventory of technologies available and, at the same time, provide means to determine the community capabilities. This technique will need to assure public participation, insure more utilization of local man power and indigenous resources, give an estimate of costs (construction, operation and maintenance), and the number of personnel required for the water system.

The inventory must give an estimate of man power and equipment required to meet the desired level of service. It must include a hierarchy of technologies appropriate to countries with a variety of scarcities and surpluses of different factors. The technologies appropriate for Japan, Taiwan, Hongkong or Singapore--where capital is not seriously scarce, where skills are, if not always plentiful, at least quickly acquired, and where management is competent--are likely to be significantly different from those appropriate to the group of countries of which India, Bangladesh, Pakistan, Sri Lanka, Indonesia are typical, and in which the problems of capital supply are acute, skills, (particularly higher engineering skills) are less plentiful, and managerial skills are somewhat scarce. They will differ again from those appropriate to a group of African countries where the availability of capital varies greatly between Nigeria and Ghana on the one hand and Ruanda, Somalia and Ethiopia on the other where capital for development is scarce. They will differ even more significantly from those appropriate to the OPEC countries, including Saudi Arabia, Kuwait, as well as Iran, where capital availability is not the principal limiting factor.

Professor George W. Reid has developed a methodology that selects suitable water processes for water and waste-water treatment. Socio-technological conditions, indigenous resources available, raw water quality, and population growth are taken into account to select the most suitable treatment in terms of cost and manpower requirements (16).

Charles W. Unsell uses the same approach to develop a methodology that selects appropriate technology for water sources and conveying systems (17).

What is required now is to develop a methodology that selects appropriate technology for levels of service in water distribution systems.

The methodology developed by Reid was field tested by the author in Panama and Indonesia. At that time, people showed concern about the limitations of the methodology in considering location of water sources, conduction works and the distribution systems. They recommended that in order to not eliminate the power of this methodology those aspects must be included.

This research will aim to relieve that limitation by using the same approach to select the most suitable level of service for water distribution systems, according to the socio-technological conditions, indigenous resources available, hydrological and energy resources, and population growth.

This research has the following objectives:

1. To obtain a methodology that selects the most suitable water distribution system (level of service) for a particular site and a particular time, based upon the material, natural resources and manpower resource capabilities available;

2. To enhance the predictive methodology for selection of suitable water processes with the addition of distribution system costs;

3. To provide planners concerned with future water treatment and water distribution systems, the ability to assess the general level of service, amounts of water and costs of water distribution systems required, prior to detailed engineering determination;

4. To provide financial guidance in making preliminary decisions concerning water distribution systems in developing countries;

5. To assist in establishing cost, level of service and resource interrelationships;

6. To assist the consulting engineers in using a system approach and in identifying the major alternatives;

7. To assist developing countries in achieving self-

sufficiency in the selection or production of appropriate technology;

8. To have a simple way to see the different levels of service, in order that more community involvement can exist.

Scope of the Research

This research deals with the water distribution system (Figure 1). It goes from the effluent of the water treatment to the house service connection.

It is limited to organized communities or nucleated villages that range in population from 500 to 100,000 inhabitants. The logic in setting these limits was as follows: In sparsely populated areas (population less than 500), water quantity and quality is normally so marginal that any type of general planning model is inadequate and specific studies must be made. Conversely, in high population concentration areas, the more developed communities have largely been able to develop adequate systems without the need for a planning model.

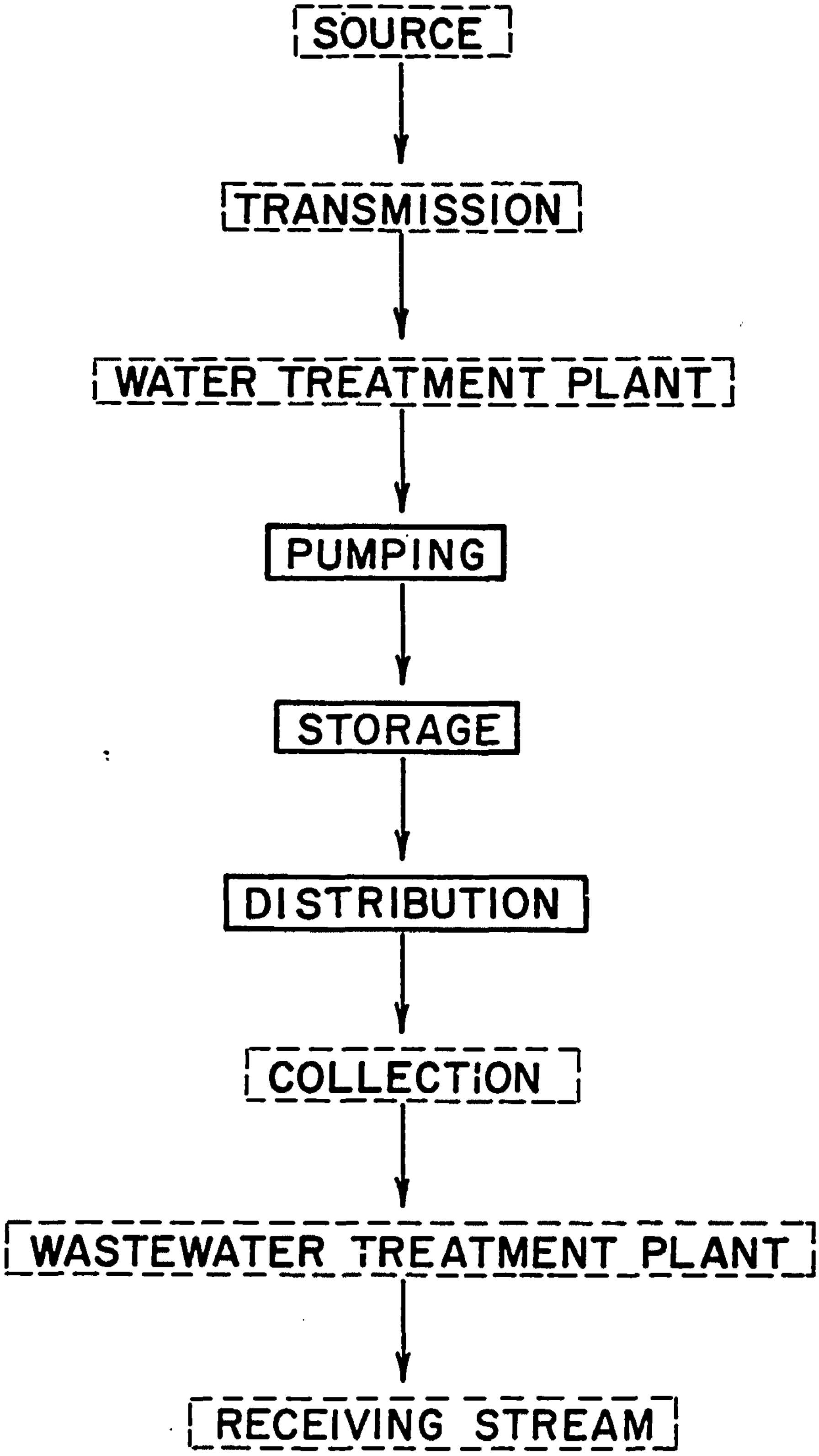


FIGURE I. SCOPE OF WORK

CHAPTER II

REVIEW OF RELATED LITERATURE

Appropriate Technology

Reid and Discenza (18) have developed a prediction methodology for suitable water and wastewater problems. It selects the suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times.

Figure 2 is an overall view of this methodology. There are 18 inputs that describe socio-economic conditions, 31 inputs in five main categories that describe the indigenous resources, two inputs that describe demographic profile, and three inputs that describe the raw water quality. This constitutes the raw data. The method used to assure the appropriate process selection takes two categories of raw data (socio-economic and indigenous resources) and reduces them through a weighting process to four socio-technological, levels and five resources capability categories which are used with a matrix of process constraints (in terms of manpower and material requirements) in order to screen for acceptable alternative processes for future considerations (Table 1). The model identifies basic individual treatment processes. The individual processes determined acceptable by the model are

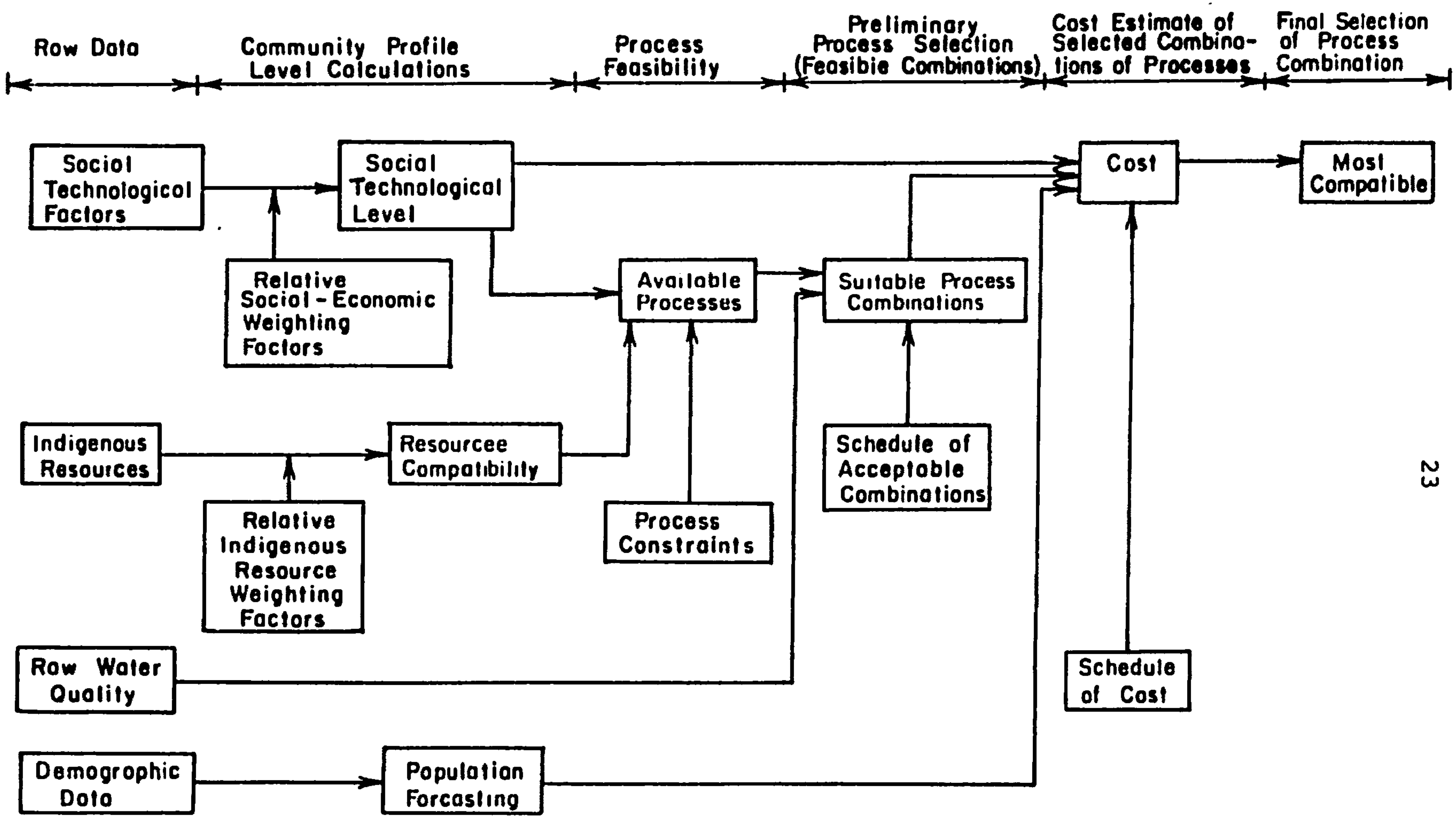


FIGURE 2. COMPLETE INFORMATION FLOW FOR THE MODEL TO SELECT A COMBINATION OF WATER AND WASTEWATER TREATMENT PROCESSES.

TABLE 1

Process Constraints--
Water and Sewage Treatment Processes With
Essential Manpower and Resources Required for Operation

	Process Requirements / Treatment Methods	Process Number	Manpower			Resources Required				
			Unskilled	Skilled	Professional	Operation Equipment	Process Materials	Maintenance Supplies	Chemical Supplies	Water Source (Groundwater Availability)
Water Processes	No Treatment	PW1	X				X			X
	Pre-Treatment	PW2	X					X		
	Slow Sand Filtration	PW3	X					X		
	Rapid Sand Filter--Conventional	PW4		X	X	X	X	X	X	
	Rapid Sand Filter--Advanced	PW5		X	X	X	X	X	X	
	Softening	PW6		X	X	X	X	X	X	
	Disinfection	PW7		X		X	X	X	X	
	Taste, Odor--Fe, Mn	PW8		X		X	X	X	X	
	Desalting--Salt	PW9		X	X	X	X	X	X	
	Desalting--Brackish	PW10		X	X	X	X	X	X	
	Containment Filter	PW11	X					X		
Waste Processes	Primary--Conventional	PS1	X							
	Primary--Stabilization Pond	PS2	X							
	Sludge--Conventional	PS3	X	X			X	X	X	
	Sludge-Advanced	PS4	X	X		X	X	X	X	
	Sludge-Combined (Imhoff)	PS5	X			X		X		

TABLE 1 (continued)

Process Constraints--
Water and Sewage Treatment Processes With
Essential Manpower and Resources Required for Operation

	Process Requirements / Treatment Methods	Process Number	Manpower			Resources Required				
			Unskilled	Skilled	Professional	Operation Equipment	Process Materials	Maintenance Supplies	Chemical Supplies	Water Source (Groundwater Availability)
Waste Processes	Secondary--Standard Filter	PS6	X	X		X		X		
	Secondary--High Rate Filter	PS7	X	X	X	X	X	X	X	
	Secondary--Activated Sludge	PS8	X	X	X	X	X	X		
	Secondary--Extended Aeration	PS9	X	X		X		X		
	Disinfection	PS10		X		X	X			
	Aqua Culture	PS11[a]	X							
	Dilution	PS12[a]	X							
	Individual	PS13[a]	X							X
	Individual (Advanced)	PS14[a]		X		X		X		X

[a]PW11 and PS11, 12, 13, and 14 are listed for completeness here and elsewhere in this publication. These processes could easily be incorporated in the model, although they were not so included for this study.

thus used to set up combinations of processes (Table 2). In the case of water, the limitation on combinations relates to initial raw water quality, and the screened combinations are designed to provide acceptable groups or sequences of treatments which will bring a raw water to a potable level. For wastewater, the limitation on the combinations relates to effluent dilution available, which is expressed either as a ratio of receiving water volume to waste volume, or alternatively as a ratio of CFS/1000 PE (i.e., cubic feet per second of receiving water flow/waste load equivalent to that produced by 1000 people in one day).

Next, the processes involved in the suitable combinations are located in terms of size of population groups to be served, and in terms of socio-technological levels. Then a matrix of capital costs, operation and maintenance costs, and manpower requirements is applied. The final step in the model provides the least cost process combination, in terms of total cost and/or in terms of maintenance costs, as desired.

Reid and Unsell (19) developed a methodology that selects the most appropriate technology for water source, intakes and aqueducts. The selection model for water source, intakes and aqueducts is compatible with the model developed by Reid. A geographic screen optimizes the location of the water treatment site, which provides a logical

TABLE 2

ACCEPTABLE COMBINATIONS OF TREATMENT PROCESSES, ACCORDING TO RAW WATER QUALITY OR DEGREE OF DILUTION AVAILABLE TO WASTE FLOWS

	Code for Process Combinations	Process Combinations	Criteria Levels			
			Raw Water Concentration			Receiving Water Volume (7-day Low Flow Level)/ Waste Volume
			Coliform Bacteria (MPN/100 ml)	Solids: Turbidity (JTU)	Solids: Other (mg/l)	
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 and Mn	
	W12	PW7 + PW9			> 3000 TDS[a]	
	W13	PW7 + PW10			> 2000 TDS[a]	
SEWAGE TREATMENT	S1	PS1 + PS5				20 (or 3 - 4 CFS/1000 PE[b])
	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				2 (or 0.3 - 0.4 ")
	S10	PS3 (without water carriage)				not applicable
	S11	PS11				10 (or 1.5 - 2 ")
	S12	PS12				40 (or 6 - 8 ")
	S13	PS2 + PS12				8 (or 1.2 - 1.6 ")

[a]TDS means total dissolved solids.

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

tie for distribution from water source to treatment.

McJunkin (20) studied hand pumps. Information was gathered on hand pumps being produced in both developing and industrialized countries. Revision of simple pumps suitable for manufacture by village artisans using locally procurable materials, field trials, and drafting of guidelines and recommendations on design, manufacture, and maintenance of hand pumps was done.

The Agency for International Development (AID) worked on the design of hand pumps. They contracted Battelle Memorial Institute to design and laboratory test a reciprocating shallow-and deep-well hand pump for LDC manufacture and use. The idea was to design a long-lasting low-cost, easily repaired, locally manufactured hand pump. The Georgia Institute of Technology (21) evaluated the performance and acceptability of the AID pump in comparison with other pumps used in developing countries and the feasibility of local manufacture of the AID pumps. The cost of production of pumps in Costa Rica and Nicaragua was also studied.

A spring-loaded faucet called fordilla has been studied and is utilized in some LDC countries. This device could be considered as a water saving device. This spring-loaded faucet cannot be held or tied open. It only discharges approximately 1 liter at a time (22).

The fordilla was tested, (1) to evaluate the mechanical functioning of the device; (2) to ascertain public acceptance, because in low-income areas resistance to innovation is strong; and (3) to determine the design and operating aspects of the distribution system servicing the device.

Public acceptance of the fordilla was enthusiastic and genuine. Consumers agreed that the principal changes the system had brought into the home were a saving of time and labor in obtaining water, and increased water use and a growth of consciousness of water quality. Major operating difficulties did not develop. Only minor problems arose, all of which were overcome quickly and easily.

When fordillas are used instead of normal faucets, the size of the pipe and the volume of storage tanks are reduced, thereby reducing the cost of the distribution system.

In a report by AID (23), the role of plastic pipe in community water supplies in developing countries is discussed. The basic idea of this report is to enable all the persons connected to the water supply field in developing countries to review the role of plastic pipe in community water supply and further to provide a resource document to support further technical or administrative action. Some of the most important conclusions were: Plastic pipe has a lower cost, it can be manufactured domestically, and raw materials are easily obtained.

WHO (24) has studied water dispensing devices and methods for public water supply in developing countries. Ways and means for the dispensing of water at public watering points which avoid the wastage of water and which can be considered for use on or adaptation of systems, both urban and rural, in the developing countries were studied.

Water Demand Studies

Reid and Muiga (25) developed a model that predicts, for planning purposes, the municipal, agricultural and industrial water requirements for developing countries. The general format of the model is shown in Figure 3. Socio-economic inputs were used to identify four socio-technological levels. Levels representative of socio-economic development were in turn used to identify municipal, agricultural and industrial water requirements. The equations obtained to forecast municipal water demand are as follows:

$$Dw.AF. = 19.72 + 0.063X_2 + 0.0142X_2$$

$$Dw.AS. = 6.81 + 0.46X_2 + 0.225X_5 + 0.027X_6$$

$$Dw.LA. = 13.74 + 0.065X_2 + 0.075X_5 + 0.93X_6$$

Where:

Dw.AF. = Water Demand for Africa (GPD).

Dw.AS. = Water Demand for Asia (GPD).

Dw.LA. = Water Demand for Latin America (GPD).

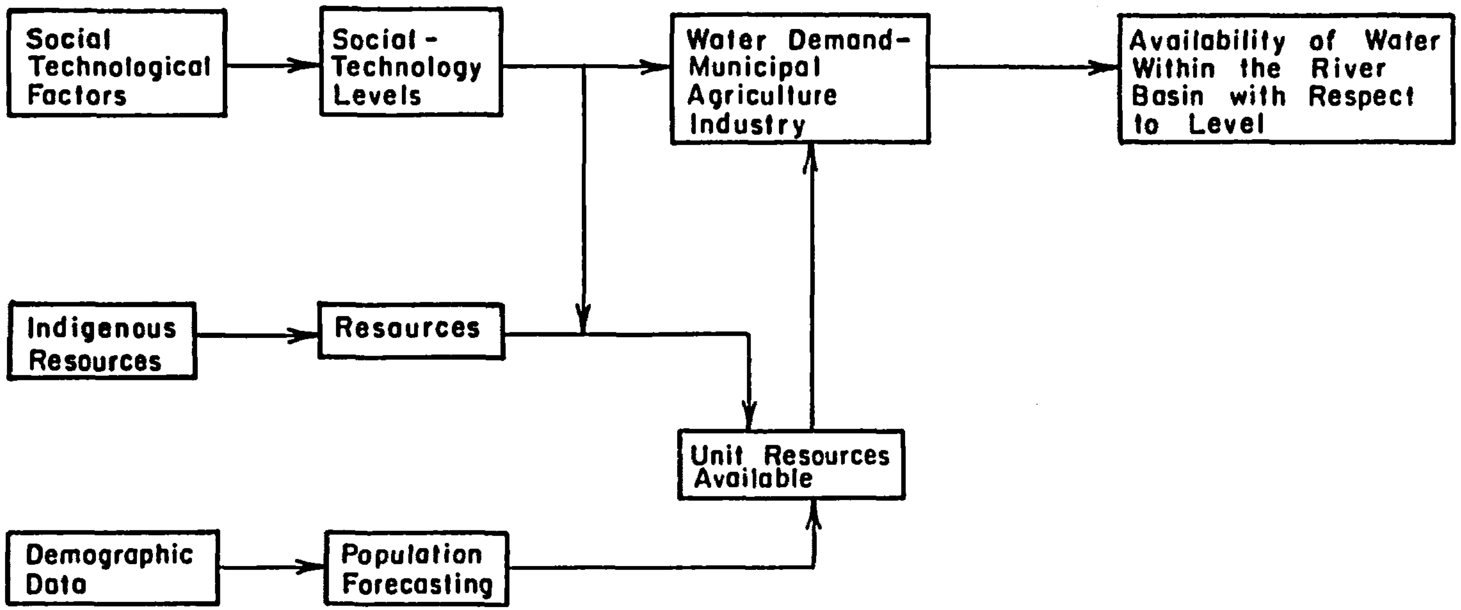


FIGURE 3. GENERAL FORMAT OF WATER DEMAND MODEL DEVELOPED BY REID AND MUIGA (25).

White, Bradley, and White (26), carried out a field examination of domestic water use in East Africa (Kenya, Tanzania and Uganda). The study attempted to relate per capita consumption to income, educational levels, family size, source of available water, cost culture and natural environment. Daily per capita use was found to range from a minimum of 1.4 liters in a farming household to a maximum of 660 liters in an upper income suburb of Moshi, Tanzania. The mean per capita use for piped supplies showed a low of 30 liters per capita daily and a high of 254 liters, while for unpiped supplies, the mean per capita use shown is a high of 21 liters and a low of 4 liters. In general, this study found that per capita use, where water is not piped into the household, is in large measure a function of the income level, the urban versus the rural situation, and the number of children within tne household. Where water is piped into the household a major consumption in water occurs; the amount above that minimum is a function in considerable measure of cost, income level, family size and education. Finally, the study found that even where domestic water demand in the urban areas is relatively price-inelastic, price is of measurable significance. No predictive equations are given.

The Gabon Energy Society (27), made a study in water consumption at the public standpipe (p.s.). They related

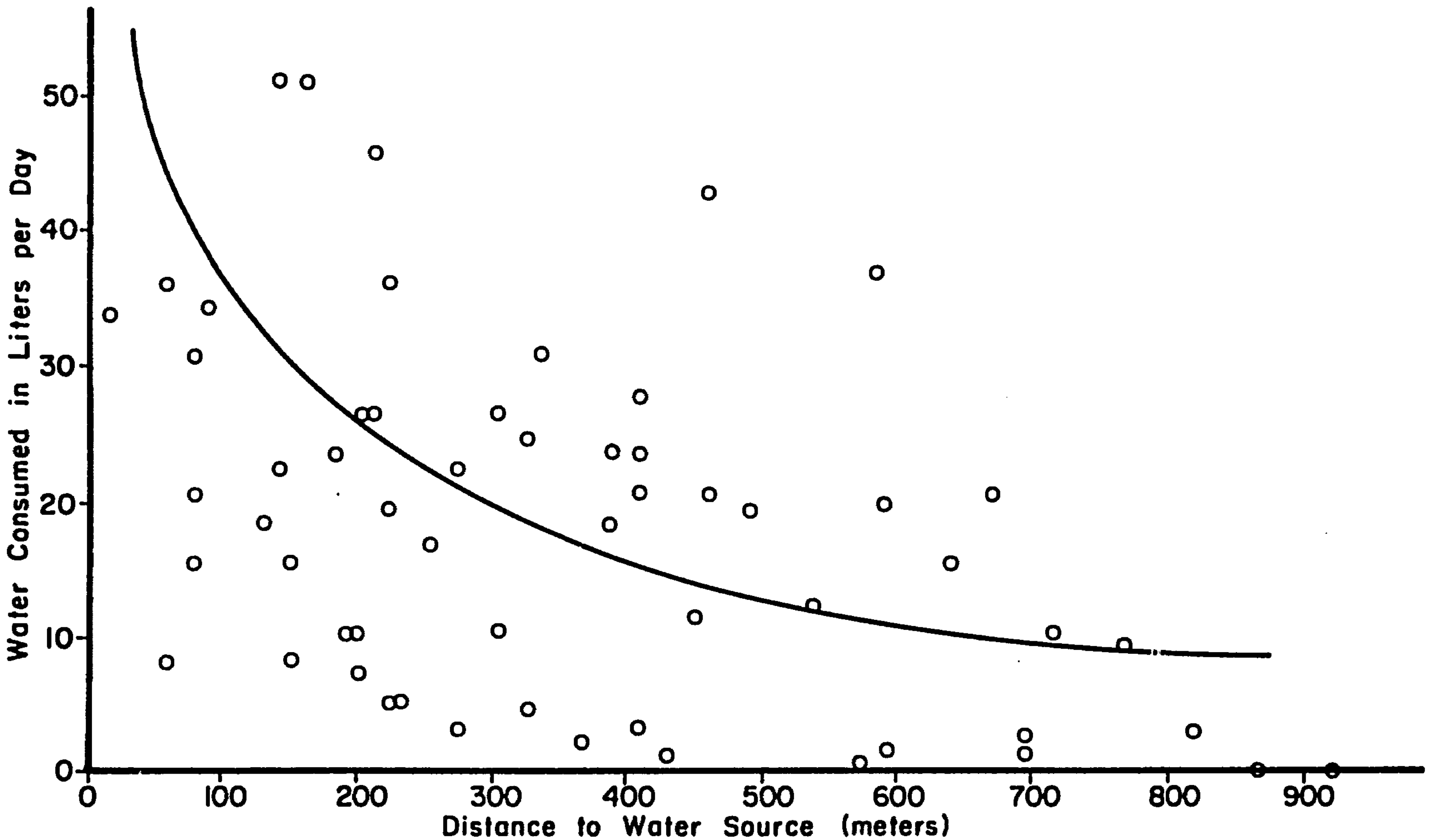


Figure 4. Water Consumption at the public stand pipe

Source: The Gabon Energy Society, Project D' Amenagement et D' Entretien Des Barnes Fontaines Dans Lens Quartiers, Non Urbanises De Libre Ville. Gabon: Societe D' Energie Et D' Eav Du Gabon (1972).

water consumption with distance to the water source (Figure 4).

In 1969, Lee (28) selected 13 sites in Calcutta and New Delhi in an attempt to measure and define the relationship between economic development and the provision or need for public water supply systems through the examination of domestic water consumption. He concluded without giving any predictive equations, that the demand for domestic water supply is a function of accessibility to water, housing conditions, level of income and water using habits.

Some others have developed water demand models that meet local requirements. Huisman (29) proposes the next equations.

<u>Unpiped Supplies</u>

Minimum $Q = 10 + N(5)$
Adequate $Q = 30 + N(7)$

<u>Piped Supplies with Standpipes</u>

$$Q = 50 + N(10)$$

<u>Household with Piped Connections</u>

Small Village $Q = 100 + N(20)$
Large Village $Q = 125 + N(25)$

Where: N = Number of Family Members.

Water Distribution Costs

Lauria (30) worked in intermediate service levels in water distributions for developing countries. Based on field studies in the Middle East and Africa, mathematical equations were developed for predicting the length and mean diameter of network piping for given values of system variables. When coupled with local cost data, these equations enable prediction of system costs for a variety of design conditions, and hence provide a basis for decisions on design variables such as the spacing of public standposts, minimum network pressure and per capita flow.

He used a linear programming approach described by Robinson and Austin (31) to obtain optimal designs for branched standpost systems. For networks of courtyard connections, he used a computer program developed by EPP and Fowler (32), which produced near-optimal designs. Regression analysis was used to obtain piping costs. The piping costs include furnishing and installing water lines. The equations obtained were as follows:

$$\overline{D} = 4.5\ (P/N)^{0.21} Q^{0.39}$$

$$L = 82N^{0.55} A^{0.49} \quad \text{(Branched Networks)}$$

$$L = 105N^{0.32} A^{0.63} \quad \text{(Looped Systems)}$$

$$Cp = 0.0093D^{1,58}$$

where:

D = Mean pipe diameter in mm

P = Population served

N = Number of standposts

Q = Per capita flow (lpc)

L = Length of pipe (m)

A = Area served (has)

Cp = Cost of pipe, furnishing and installing (1976 U.S. dollars).

The World Health Organization (33) gives some cost estimates for different types of standposts. Costs are those from Western Africa (Upper Volta, Ghana, Senegal, Cameron, Gabun and Mauritius). It has been supposed that the installation always consists of a minimum necessary basic unit which is composed of: 1) a concrete (hardened) floor which is sufficiently large with a drainage for wastage, 2) A place on which to put buckets, etc., while drawing water, 3) A solid support on which conduit and tap are well attached, 4) A solid support above, or at least higher than the tap on which to put buckets etc., so as to be able to take them along (e.g. on the head). Typical costs of construction are shown in Table 3.

AID (34) working on hand pumps in Costa Rica and Nicaragua, found that manufacturing costs of the AID pump, for shallow wells are in a range of 68 to 225 (U. S. dollars). Table 4 shows some costs for hand pumps. Figures 5 and 6 show the costs by quantity for Costa Rica and Nicaragua, respectively.

The World Health Organization Chronicle (35) gives the cost of construction and operation of water supply villages of 2,000 - 10,000 and water demand of 68 litres per capita per day. Installation costs (without water treatment) range from 70 cents per person to 45 cents for a driven

TABLE 3

Public Standposts Costs on Western Africa
(1974 U. S. Dollars)

	Mechanism Only (Dollars)	Including Basic Unit (Dollars)
1. Ordinary taps	1-3	100-1000
2. Spring loaded taps (Neptune)	200	500
3. Self closing valves		
Tylor	5-7	500-700
Fordilla	10-12	500-700
Tropicale	250	600
4. Float Mechanisms		
Siphoide	1500	2000
Bedouine		
Special types (Bayard)	300	600

Source: World Health Organization, water dispensing devices and methods for public water supply in developing countries, Interim Report, International Centre for Community Water Supply (I.R.C.), the Hague, Netherlands. (No date).

TABLE 4

Hand Pumps Production Costs, For Some Selected Countries

Country	Shallow Well Dollars	Deep Well Dollars	Pattern Dollars
Costa Rica	98	128	498
Nicaragua	69-225	75-250	1000
Dominican Republic	160-261	200-298	
Ghana	500	500	
AID	87-116	105-135	
Indonesia	50		

Source: Final report on the utilization/evaluation of an AID hand-operated water pump. Office of International Programs Engineering Experiment Station, Georgia Institute of Technology Atlanta, Georgia, 1979.

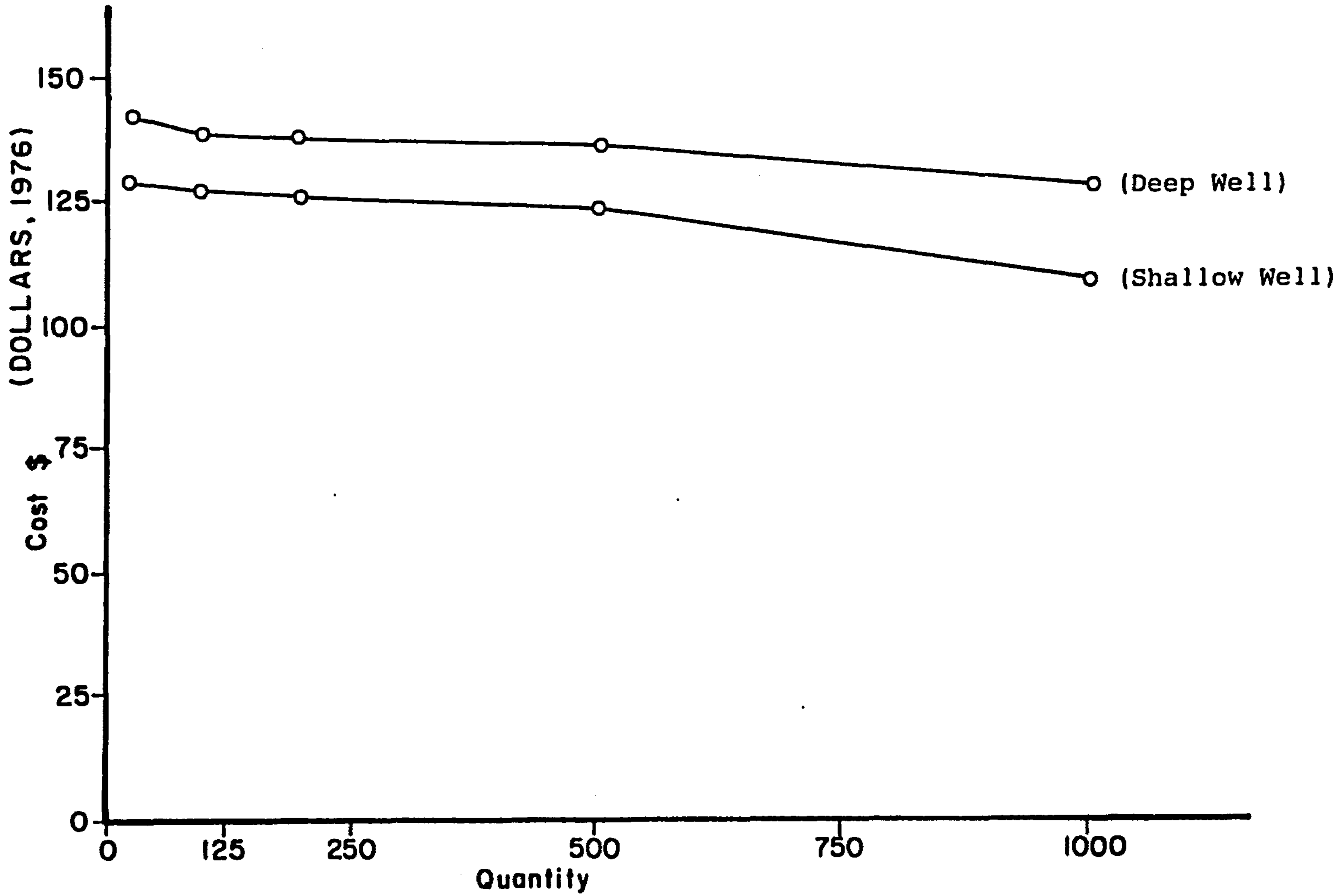
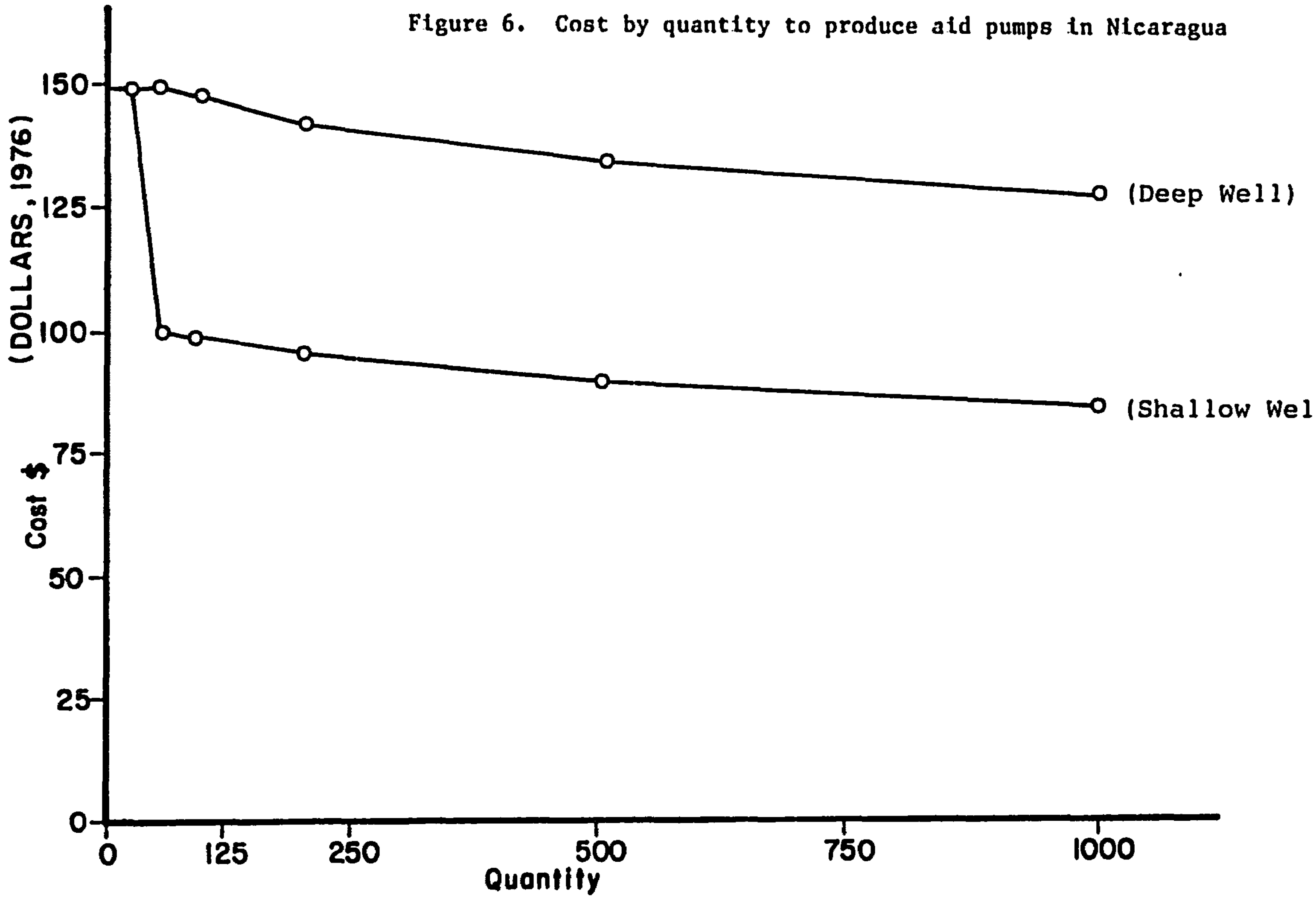


Figure 5. Cost by Quantity to produce aid pumps in Costa Rica

Source: Final Report on the utilization/evaluation of an aid hand-operated water pump. Office of International Programs Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia, 1979.

Figure 6. Cost by quantity to produce aid pumps in Nicaragua



Source: Final report on the utilization/evaluation of an AID hand-operated water pump. Office of International Programs Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia, 1979.

well, with maintenance costs of 72 cents per capita per year for any well. Pipe water systems range from 8 - 14 dollars per capita with operation costs of 1.80 dollars per year.

Costs of 68 Central American (36) water systems of the gravity type, which were constructed in the period 1965-1969, were collected. Those systems included piped house services and public fountains. After a least squares analysis was applied, the following equation was obtained:

$$C(z) = 300{,}000\ Z^{0.83}$$

Where:

C(z) = Cost per million gallons per day

Z = Million gallons per day

Gutierrez (37) gives cost estimates for three levels of service: Adequate $85.00/per person (1970 prices), Marginal $60.00, and Submarginal $40.00. The level of service is defined as follows:

Adequate: Sufficient volume available on a 24 hour basis; storage incorporated in system design; treatment and disinfection provided for health protection and taste.

Marginal: Water available intermittently, generally at low pressures (individual home storage tanks prevalent); disinfection probably incorporated but no treatment.

Public Faucets: The minimum level required to improve very needy urban areas. Care in water handling from faucet to drinking containers must be a public health consideration.

Standards

The goal pursued by the World Health Organization of supplying safe water within a reasonable access to people in the world has led to creation of guidelines and criteria for water supply.

There are different approaches to the problem in each country depending on the amount of money available in a particular LDC. Because of that situation, the range of decision variables under consideration in LDCs is broader than in DCs. For example, few engineers in DCs would consider designing a system that works intermitently. He would design it to supply water 24 hours a day, seven days a week and 52 weeks in a year (38).

Per Capita Consumption

The design engineer in DCs may use factors of 75 to 125 gallons per capita per day and in terms of fire flow he may use a design figure of several hundred gallons per hour (39). In LDCs figures are lower and fire flow is not considered. A fire flow of five hundred gallons per minute at 60 PSI would knock down the walls of most of the houses in tropical areas where construction is not necessarily strong

(40). In the U.S., they use standards of Ameen for rural systems (41). That is 15 GPM for an individual residence. The FHA requires 14 GPM. The average daily demand will vary 280-500 GPD per residence.

A revision of design figures used in LDCs shows that the per capita volume of water required may vary from 20 liters in systems based on standpost service to up to 100 liters where the proportion of house or plot connections is very high. Tables 5 through 9 show design values from Guatemala, Peru, Panama, Dominican Republic, El Salvador, Thailand, Bangladesh, Indonesia, Nepal, Sri Lanka, and India. In the Philippines for Level 3A, a figure of 57 liters per capita per day is utilized. A typical water consumption pattern is shown in Table 10.

In Mexico, different design values are used according to climate and size of population, by lot size and population density. Only in very special cases are systems designed for fire flow purposes. Tables 11, 12, and 13 show those design values (42). The Agency for International Development collected data on design standards in some LDCs (43). They are shown in Table 14.

<u>Peak Factor Design</u>

Table 15 shows some typical values used in the design of water distribution systems. The first value usually is the peak day factor. The second one is the peak hour

TABLE 5

Typical Per Capita Consumption Figures

Peru[8]	Dominican Republic	Guatemala[13]
1. Communities up to 500 inhabitants = 60 liters/cap/day	Public fountains = 24-48 liters/cap/day (average 36)	60-130 liters/cap/day (average 100)
2. Communities of 500 to 1,000 inhabitants = 60-80 liters/cap/day	Patio connections = 72-120 liters/cap/day (average 96)	Note: (1) Average increased of demand= 3 lpcd per year.
3. Communities of 1,000 to 2,000 inhabitants = 80-100 liters/cap/day		(2) Rate of connection to system: By the end of the first year about 25% of the population is connected, and additional connections are made at a rate of about 8% a year.
4. Public fountain - 20 liters/cap/day		
Note: (1) Consumption should be raised by 20% for communities located in jungle or desert area.		
(2) Quota should be increased to include an amount for watering stock and gardens when area does not have irrigation.		
(3) Water consumption increase at ± 3%/year as more "connections" are added.		

Source: Progress in the rural water programs of Latin America. (1961-71). David Donaldson, advisor Pan American Health Organization. Regional Office of the WHO. January 1973.

TABLE 6

Per Capita Consumption for Panama

Population	Panama GPD
2000 - 5000	50
5000 - 10000	55
10000 - 20000	60 -
20000 - 30000	70
30000 - 50000	80
50000 - 100000	90
100000 - 400000	100
Greater than 400000	100
Rural 500 - 2000	30
Turismoy Veraneo	80

Source: (1) Normas Tecnicas de Caracter General Para El Disenoy Construccion De Los Sistemas de Agua Potable y Alcantarillado, Vol. I, IDAAN, Panama (1973).

TABLE 7

Per Capita Consumption for El Salvador

Population	% of houses connected	WD lcd	Increase in WD for c/10% of increase in houses connected lcd
Less than 500	20	50	4
500 - 999	30	50 - 75	4 - 6
999 - 1999	40	75 - 100	6 - 7

Source: Donaldson, David. "Progress in the Rural Water Programs of Latin America," PAHO Bulletin. Vol. VIII, No. 1 (1974): 37-53.

TABLE 8

Per Capita Consumption in South Asia

Thailand lcd	Bangladesh lcd	Indonesia lcd	Nepal lcd	Sri Lanka GCD
1. Urban	1. House Connection		1. House Connection	1. House Connection
120-300	150-190	132		40-45
2. Rural	2. Standposts		2. Standposts	2. Standposts
50-80	8-19		40-45	10
			Hand pumps supplies to serve 150/200 each.	

Source: "Community Water Supply and Excreta Disposal in South-East Asia." WHO Regional Publications South-East Asia, Series No. 4.

TABLE 9

Per Capita Consumption in India

Population	Consumption (LCD)
less than 10,000	57 - 76
10,000 - 50,000	76 - 95
more than 50,000	95 - 170
Standposts	19 - 38

Source: "Community Water Supply and Excreta Disposal in South-East Asia." WHO Regional Publications South-East Asia, Series No. 4.

TABLE 10

Typical Water Consumption Pattern in Philippines

Time	Household Activity	Consumption in Liters
5:00 a.m.	Showers	38
6:00 a.m.	Cooking and Cleanup	38
7:00 a.m.	Laundry	38
8:00 - Mid-morning	Miscellaneous gardening cleaning piggery	56
Noon	Cooking and Cleanup	38
Mid-afternoon	Miscellaneous	38
5:00 p.m.	Showers	38
6:00 p.m.	Cooking and Cleanup	38
8:00 p.m.	Showers	56
9:00 p.m.	Miscellaneous	38
	TOTAL	416

Source: Lowry, F. Emmett. "Breaking the Cost Barrier to Household Water Service," Journal of the American Water Works, AWWA, Vol. 72, No. 12 (December 1980): 672-677.

TABLE 11

Water Consumption Figures According to Climate and Size of Population Recommended

Zone	Climate	WD lcd
Rural	Moderate or Humid Cold	100 to 200
	Moderate or Dry Cold	150 to 250
	Humid Hot	150 to 250
	Dry Hot	200 to 300
Urban	Moderate or Humid Cold	150 to 250
	Moderate or Dry Cold	250 to 350
	Humid Hot	250 to 400
	Dry Hot	300 to 600

Source: Secretaria De Recursos Hidraulicos, _Especificaciones y Normas Generales De Diseño De Sistemas De Agua Potable y Alcantarillado_, (Mexico, D. F., Mexico:1962)

TABLE 12

Water Consumption by Lot Size and Population Density, for House Connection, In Mexico

Level	Population Density People/H A.	Size of Lot M^2	WD lcd
1	60-150	1000-2000	600-2000
2	150-250	200- 600	300- 600
3	250-400	100- 250	150- 350

Source: Secretaria De Recursos Hidraulicos, Especificaniones y Normas Generales De Diseño De Sistemas De Agua Potable y Alcantarillado (Mexico D. F., Mexico: 1962)

TABLE 13

Fire Flow Figures Utilized in Mexico

Population Size (1000)	No. Hydrants and Flow L.P.S.	Location of Hydrant
20- 50	2 of 12.6	One in the Business Area and other in the farthest point.
50-200	1 of 31.5	One in the Business Area or in the farthest point.
More than 200	2 of 31.5	Same as 1

Source: Same as Above.

TABLE 14

Design Standards Most Frequently Used By Engineers in the Developing Countries

Item	Range of Values	Most Frequent Values
Design Period	10-25 years or 100% growth whichever is greater	20 years or 100% growth whichever is greater
Domestic Consumption (liters per capita per day)		
Small systems	50-100	115-150
Larger urban systems	150-300	180-250
Public taps	5- 40	10- 15
Maximum Daily Use (times average)	1.2-1.5	1.2-1.5
Maximum Hourly Use (times average)	1.5-4.0	1.5-2.5
Distribution Storage (% daily consumption)		
Large systems	30- 70	40- 50
Small systems	100	100
Fire flow provided for only in large communities having fire departments:		
Hours of Operation	12- 24	12-24
Minimum Static Pressure in meters of water height	7- 23	10
Maximum Static Pressure in meters of water height	46- 50	50
Maximum Dynamic Pressure in meters of water height	100	-

Source: Agency for International Development, Guidelines and Criteria for Community Water Supplies in the Developing Countries. U. S. Department of Health, Education and Welfare, 1966.

TABLE 15

Peak Demand Factor Used for Rural Communities

Country	Peak Demand/Average
Bangladesh	1.2 - 2.0
India	2.0 - 3.0
Sri Lanka	1.25- 2.0
Thailand	1.5 - 4.0
Salvador	1.2 - 2.0
Guatemala	1.0 - 2.0

Sources: "Community Water Supply and Excreta Disposal in South-East Asia." Who Regional Publications South-East Asia, Series No. 4.

Donaldson, David. "Progress in the Rural Water Programs of Latin America" PAHO Bulletin, Vol. VIII, No. 1 (1974): 37-53.

factor. Fair (44) recommends values of 1.2 to 2.0 for maximum day and 2.0 to 3.0 for peak hour.

In Guatemala, in rural areas, the peak factor varies between 1.2 to 1.5. The range of factors found by AID is shown in Table 14.

Storage

For service storage, recommendations are: India up to 3 times average demand, Nepal about 1/2 day demand, Sri Lanka 1/3 to 1/2 maximum day demand, Thailand 70 percent of average supply. For elevated storage, it is 20 percent of the average supply.

In the U. S., 60 percent of the peak demand is recommended. Lauria (45) recommends six to eight hours of storage of the peak day demand. The FHDA recommends in rural communities, storage tanks of capacity equal to two days' average use (46). Also, if the source of supply of water is inadequate in quantity to satisfy the maximum needs of the community, then the water supply source should be complemented with a ground storage reservoir. In the Philippines at a level of service 3A, it is recommended to use a storage tank of 95L, which provides for about 23 percent of the daily consumption.

Design Values

Between 20 and 50 persons per tap are recommended. In Taiwan, every effort is made to limit the distance watercarrying to 100 m. In Nigeria, a figure of 500 persons per well is utilized. The World Health Organization recommends a maximum population of 200 per well or tap. In Bangladesh, 150 to 200 users per tube well is recommended. In Nepal, the same figure is recommended. In Thailand, recommendations are 150 persons per hand pump (47).

In Guatemala public taps are built to supply water to a maximum of 100 persons (48). Wagner (49) has recommended that a well or tap should be provided for each 200 persons in rural areas and that at least one tap be in each dwelling within a city or urban area.

<u>Size of Pipes</u>

As before, the size of the pipe varies according to the country. In Guatemala the minimum diameter utilized is 1 inch. 1-1/4 inch pipe would adequately provide water for five to ten families; 1-1/2 inch pipe is to 18 families; 2 inch, 25 to 30; 3 inch pipe, 60 to 70; 4 inch pipe, 100 to 120; and 6 inch pipe, 250 to 300 families.

A 1/2 inch domestic service line is the accepted standard in many countries. The use of the fordilla has received wide acceptance and is effective against water waste. With this device, as many as 30 houses may be supplied from a one inch street main.

In the U. S., the minimum size accepted is a six inch in gridirons, but the smallest branching pipes are 8 inch and the smallest pipes on principal streets in central districts are 12 inch.

Pressure

Design pressure requirements are frequently expressed in meters of head and range from 3-15 m (4.3-21.5 psi) for small district systems. Wagner (50) has recommended that where fire hydrants are installed a minimum pressure of 25m (35 psi) be provided. Twenty pounds of static pressure is considered adequate.

In the Philippines, the required minimum pressure is 6m for level of service 3a. In Dacca, the system is designed for a minimum pressure of 20 pounds. In the U.S. for normal drafts, the pressure at the street line is at least 20 psig (46 feet of water) but 40 psig is a more desirable pressure. Business blocks are supplied at pressures of 60 to 75 psig. For fire protection 250 GPM must be delivered through a 1-1/8 inch nozzle at a pressure of 45 psig. Table 16 shows some recommended residual pressures in Mexico.

Valves

Guidelines for the location of valves were not available in the literature reviewed on the LDCs. In the U. S., it is customary to provide valves as follows: three at

TABLE 16

Recommended Residual Pressures for Mexico

		Meters
1.	Standposts	8 to 14
2.	One Story Home Areas	14 to 20
3.	Two Story Home Areas	18 to 25
4.	Three Story Home Areas	25 to 30
5.	More than Ten Story Areas	40 to 50
6.	Industrial Areas	14 to 60
7.	Minimum Pressure Urban	15
8.	Maximum Pressure	50
9.	Minimum Pressure Rural	10

Source: Secretaria De Recursos Hidraulicos, Especificaciones y normas generales de Diseño De Sistemas De Agua Potable y Alcantarillado (Mexico D.F., Mexico: 1962).

crosses, two at tees, and one on the single-hydrant branches. In a scheme suggested by Ballou (51), valves are installed as follows: one on each main at intervals of two blocks, one at the junction of the service header with its main, and one on each of two branches to the hydrants.

The spacing recommended is 800 feet for long branches and 500 feet in high-value districts.

Period of Design

For Nepal, it varies from 10 to 25 years, Sri Lanka is 10 years, Thailand, ten years for both rural and urban communities, El Salvador is 20 years, and Guatemala, 20 years.

Fair (52) recommends using 20-25 when pipes are more than 12 inches in diameter; for lateral and secondary mains, less than 12 inches in diameter, until full development. Also he recommends choosing the design period keeping the following factors in mind.

1. Useful life of structure and equipment.
2. Ease, or difficulty, of extending or adding to existing system.
3. Anticipated rate of population grwoth.
4. Rate of interest on bonded indebtedness.
5. Performance of the works in early years.

Methodologies

The shortage of engineers in LDCs to design every single community has led to the creation of methodologies that design water distributing systems in a "Mass Approach" basis.

In the Philippines (53), a formulated approach to system design for rural communities has been developed. It leads the designer step by step through each community problem. A two-day training program is required to familiarize engineers in groups of 25 with the methodology. Thereafter, a design can be worked up for an average community with one day of field work and four hours of office application. No formal drawings are required; sketches are adequate. The methodology does not extend to source determination other than the comparison of alternatives. Design criteria are used to determine the size and location of storage, selects pipeline sizes, pressure materials complete with cost estimate, ready for procurement.

Feachem (54) proposes a methodology that selects the water supply improvements according to established goals. According to him a water supply has various levels or goals from the immediate and short-term goals. (Table 17 sets out a scheme of possible goals). Under "immediate aims" are listed the improvements to water which, in some combination, will form the basis of the design. A combination of improvements is appropriate to a particular case; it is necessary to examine the potential benefits from a water supply and to assess the degree to which different

TABLE 17

Aims and Potential Benefits of Water Supply Improvements

Immediate aims (1)	Stage I benefits (2)	Stage II benefits (3)	Stage III benefits (4)
Improve water quality quantity	Save time Save energy Improve health	Labor release Crop innovation Crop improvement	Higher cash incomes Increased and more reliable sus-sistance
Availability		Animal husbandry innovation	Improved health
Reliability		Animal husbandry improvement	Increased leisure

Source: Feachem, G. Richard "Water Supplies for Low-Income Communities in Developing Countries," Journal of the Environmental Division, ASCE, Vol. 101, No. EES, (October 1975): 687-702.

improvements will realize different levels of benefits. In this way, the improvements with the most impact on a given cost can be determined and the anticipated cost-effectiveness of alternative schemes can be compared. To reach Stage I through III benefits, external or complementary development inputs and initiatives are necessary. (Table 18 lists the basic complementary inputs necessary to achieve the immediate aims and the two stages of benefits. In using this methodology, three things are possible. First, the design (in other words, the combination of different improvements to water quality, quantity, availability, and reliability) can be selected with the specific goals in mind. Secondly, the cost-effectiveness of a design can be assessed and compared with that of rural designs, by weighing the cost against the savings associated with the chosen design benefits. Thirdly, water schemes can be retrospectively appraised by comparing the costs with the values of the benefits that were actually achieved and so provide guidance for entire projects.

David Donaldson (55) developed an approach for the Latin American countries. The program is broken down into its component parts -- community promotion, technical design, program financing, etc. -- and each is studied for its effect upon the others. A program model is then developed which coordinates these elements into the lowest cost solution that will best focus the program element

TABLE 18

Complementary Inputs Necessary for Achievement of Various Aims and Benefits Set Out in Table 17

Aim or benefit (See Table 1) (1)	Complementary input or prerequisite condition (2)
Immediate aims	Active community participation and support; competent design; adequate facilities for operation and maintenance; and appropriate technology utilized.
Stage I benefits	New supply used in preference to old; new supply closer to dwellings than old; water use pattern changed to utilize improved supply; other environmental health measures taken; and supply must not create new health hazards (e.g., mosquito breeding sites).
Stage II benefits	Good advice and extension services must be provided by government personnel concerned with agriculture, animal husbandry, cooperatives, marketing, education, credit, etc.
Stage III benefits	Water supply development must be just a single component of an integrated rural development program that has the active support of the local community.

Source: Same as Table 17.

(human, financial, technical, and management) on the desired goal (i.e., a large-scale program that will result in building of the greatest number of systems in the shortest time, as well as their long-term operation). Projects are designed as follows: using existing maps or aerial photographs, standard design criteria, pre-designed elements and standardized equipment lists. Once the design has been reviewed by a professional, the materials would be assembled in a central yard and sent to the community as a package, along with all the necessary tools and items not readily available locally.

Benefits

The construction of a water supply system brings different benefits in the short and long run. Some of the benefits frequently cited to justify water programs are: health improvement, energy saving, time saving, community organization, redistribution of income, quality of life improvement, economic output improvement, population migration slowing, etc. Of these, the most immediate benefits are redistribution of income, energy and time saving (especially if the new supply is closer to the customer).

The other benefits need additional inputs to be achieved, as will be seen later. In a study performed in Africa (56) after the implementation of a water supply program, the following benefits were observed: Improved health, increased productivity, Ujamar socialism, self-reliance, modernization, and education. An overall total of 87 benefit occurrences were identified and accepted in the measurement of 30 hypothetical benefits. Sixty-one benefits occurred in villages with improved water supplies. The health category had the largest proportion of benefit occurrences among the tested hypotheses (31 percent), followed by self-reliance (23 percent), Ujamar socialism (22 percent), education (20 percent, productivity (13 percent) and modernization (9 percent).

Ujamar socialism benefits refer to the combination of attitudes, actions and physical factors representing the political and economic orientation of the community.

Self-reliance benefits refers to the material and social resources of the community. In a Tanzanian context, material self-reliance includes home ownership, the use of local resources on water projects, and the dependability of the water supply. Social self-reliance, on the other hand, consists of both community involvement in development projects and community awareness of the benefits of such involvement.

Modernization benefits refer to the state of mind and the physical level of development. Individual attitudes toward the nation-state and towards technology represent the psychological side, while the rate of material improvement in the community represents the physical side.

Education benefits refer to the acquisition of new skills by workers employed on water projects. Indirect benefits include participation in adult education activities and enrollment at the local primary school.

The most obvious and immediate impact of a water supply scheme is to change the nature of the water collection journey. Savings of time and energy are important. Some investigators have placed a monetary value on the water collection journey by cost-analyzing the amount of staple food required to produce the number of calories that are needed to collect water. There is little evidence that in the short run a rural water supply program, by itself, will have any effect on migration. A potable water supply for residents of an area may be a necessary condition for significant economic development, but clearly is not sufficient - even as a catalyst - to achieve this objective. If the system is designed to include the provision that livestock can be watered and small gardens can be irrigated, the probability that the system will have a significant economic impact is increased substantially.

The benefit in improvement in health depends also on the level health in the first place, cultural habits, educational level, and the general physical environment including adequate means of waste disposal and income level.

The relationship between the quantity and the quality of water consumed and the level of various water-associated diseases provides some evidence that more and better water and better sanitary facilities are associated with better health.

A rural water supply program which is designed solely to improve the health of the labor force may increase the extent to which there is an oversupply of labor but have very little impact on economic output and earnings.

Bradley (57) has classified the water-related diseases into categories that relate diseases directly to water. (See Table 19) He gives the following definitions of the water related diseases:

> Waterborne Diseases: Those transmitted when the pathogen is in water that is then drunk by an animal or human which may then become infected. Examples are cholera, typhoid, hepatitis, and bacillary dysentery.
>
> Water-Washed Diseases: are those, the prevalence of which will fall following increases in the volume of water used for hygienic purposes, irrespective of the quality of that water. There are two main types: First, there are the infections of the intestinal tract, such as diarrhea diseases; the second type are the skin and eye infections, such as bacterial skin sepsis, scabies, and cutaneous fungal infections, and trachoma.

TABLE 19

Four Mechanisms of Water-Related Disease Transmission and Preventive Strategies Appropriate to Each Mechanism

Transmission mechanism (1)	Preventive strategy (2)
Waterborne	Improve water quality; and prevent casual use of other unimproved sources.
Water-washed	Improve water quantity; improve water accessibility; and improve hygiene.
Water-based	Decrease need for water contact; control snail population and improve quality.
Water-related insect vector	Improve surface water management; destroy breeding site of insects; and decrease need to visit breeding sites.

Source: Bradley, D. J. "Water Supplies: The Consequences of Change," Human Rights on Health, CIBA Foundation Symposium 23 (New Series), (Amsterdam; Netherlands, 1974): 81-88.

Water-Based Diseases: Here the pathogen spends a part of its life cycle in an intermediate aquatic host or hosts. All these diseases are due to infection by parasitic worms that depend on aquatic intermediate hosts to complete their life cycles. Schistosomiases (Bilharxia) and Guinea worm (Dracunculus Medinensis) are in this category.

Water-Related Insect Vectors: Here insects that either breed in water or bite near the water, spread the disease. Malaria, yellow fever, dengue, onchoceriasis and trypanosomiasis are some of those diseases.

Feachem (58), reclassifies Bradley's categorization, since Bradley's leads to the problem of having all the faecal-oral diseases assigned to both the waterborne and the water-washed categories and so the categories cease to be mutually exclusive. Feachem's classification is shown in Table 20. Also, a list of the major water-related infections and how they are classified in Table 21, and the linking with their pathogenic agent is shown in Table 21. Finally, by consulting Table 20, an unfamiliar disease may be linked to its pathogenic agent and may be further identified by consulting the appropriate section of Table 22.

Levels of Service

Economic limitations have created quite different

TABLE 20

Classification of Water-Related Diseases

Category (1)	Example (1)
1. Faecal-oral (waterborne or water-washed)	
(a) low-infective dose	Cholera
(b) high-infective dose	Bacillary dysentery
2. Water-washed	
(a) skin and eye infections	Trachoma, scabies
(b) other	Louseborne fever
3. Water-based	
(a) penetrating skin	Schistosomiasis
(b) ingested	Guinea worm
4. Water-related insect vectors	
(a) biting near water	Sleeping sickness
(b) breeding in water	Malaria

Source: Same as Table 17.

TABLE 21

Water-Related Diseases with their Water Associations and Pathogenic Agents

Water related disease (1)	Category from Table 4 (2)	Pathogenic agent (see Table 6) (3)
Amoebic dysentery	1b	c
Ascariasis	1b	d
Bacillary dysentery	1b	a
Balantidiasis	1b	c
Cholera	1a	a
Diarrhoeal disease	1b	g
Enteroviruses (some	1b	b
Gastroenteritis	1b	g
Giardiasis	1b	c
Hepatitis (infectious)	1b	b
Leptospirosis	1a	e
Paratyphoid	1b	a
Tularaemia	1b	a
Typhoid	1a	a
Conjunctivitis	2a	g
Leprosy	2a	a
Louseborne fevers	2b	e
Scabies	2a	g
Skin sepsis and ulcers	2a	g
Tinea	2a	f
Trachoma	2a	g
Yaws	2a	e
Clonorchiasis	3b	d
Diphyllobothriasis	3b	d
Fasciolopsiasis	3b	d
Guinea worm	3b	d
Paragonimiasis	3b	d
Schistosomiasis	3a	d
Arboviral infections (some)	4b	b
Dengue	4b	b
Filariases	4b	d
Malaria	4b	c
Onchocerciasis	4b	d
Trypanosomiasis	4a	c
Yellow Fever	4b	b

Source: Same as Table 17.

TABLE 22

NOTES ON SOME WATER-RELATED INFECTIONS

Disease (1)	Pathogen (2)	Vector and transmission (3)	Water association (4)	Severity (5)	Chronicity (6)	Notes (7)
			(a) Bacteria			
Bacillary dysentery	*Shigella* Spp.	Transmitted by faecal-oral route	Water-washed or waterborne	+++		
Bacterial enteritis	*Salmonella* spp.	Transmitted by faecal-oral route	Water-washed or waterborne	++		
	Other bacteria	Man ⟶ man or animal⟶ man				
Cholera	*Vibrio Cholerae*	Transmitted by faecal-oral	Water-washed or waterborne	+++		Not established in Australia, New Zealand, Pacific Islands, or the Americas.
Leprosy	*Mycobacterium leprae*	Skin to skin contact	Water-washed	++	++	Epidemiology still uncertain-10,000 new cases reported annually in Americas.
Tularaemia	*Brucella tularensis*	Focus of infection is among rodents.Transmitted to man by ingesting water contaminated by rodent faeces or corpses, or by eating infected rodents or by bites from ticks, flies, or mosquitoes. Also common in rabbits.	Waterborne and sometimes spread by water-breeding mosquitoes	++		Mainly in North America, Europe, USSR, and Japan.
Typhoid, paratyphoid	*Salmonella* Spp.	Transmitted by faecal-oral route	Water-washed or waterborne	+++		
			(b) Viral			
Dengue	Dengue virus	Transmitted by the mosquito *Aedes aegypti*	*Aedes aegypti* breeds in water.	+++		
Yellow fever	Yellow fever virus	Transmitted by mosquitoes, *Aedes* spp., Haemagogu spp.Man ⟶ mosquito⟶ man or monkey⟶ mosquito ⟶ man.	Mosquitoes breed in water	+++		Not reported from Asia or Australia
Other arboviral diseases	Arboviruses causing various haemorrhagic and encephalitic	Transmitted by mosquitoes of many species from many birds and animals to man or, in some cases (e.g. o'nyong nyong) from man to man.	Mosquitoes breed in water	+++		
Infectious hepatitis	Hepatitis virus	Virus trasmitted by faecal-oral route	Water-washed or waterborne	++	+	Epidemiology in doubt

TABLE 22 (Continued)

Disease (1)	Pathogen (2)	Vector and transmission (3)	Water association (4)	Severity (5)	Chronicity (6)	Notes (7)
			(c) Protozoal			
Amoebiasis or Amoebic dysentery	*Entamoeba hisolytica*	Cysts transmitted by faecal-oral route. Found in rats, monkeys, dogs, and pigs but infection is mainly man → man.	Water-washed and possibly waterborne. Cysts can live in salt water for 12 days. Killed by heating to 50°C. for 5 min.	++	++	Does not occur epidemically
Balantidiasis	*Balantidium coli*	Cysts transmit- by faecal-oral route. Found in rats, monkeys and pigs. Often pig → man.	Water-washed and waterborne	+ often asymptomatic		Epidemics reported in Brazil, Georgia, and USSR
Giardiasis	*Giardia intestinalis*	Cysts transmitted by faecal-oral route.	Water-washed and waterborne	+	+	Epidemic from water supply reported in Colorado.
Malaria	*Plasmodium* spp.	Anopheles mosquito. Man → mosquito → man. Occasionally in Africa, chimpanzee → mosquito → man.	*Anopheles* breed in water	+++	+++	514,000 people living in malarious areas that do not yet have eradication program.
Trypanosomiasis	Gambian sleeping sickness due to T. gambiense	*Glossina* spp. the riverine tsetse fly. Man → fly man or also in Congo, domestic pig → fly → man.	Flies live and bite near water	+++	+	In West and Central Africa
	Rhodesian sleeping sickness due to T. rhodesiense	*Glossina* spp. the game tsetse fly. Game → fly → man. In Kenya has come adapted to riverine tsetse fly.	If spread by game tsetse fly, has no water association. If spread by riverine tsetse fly, see preceding association.	+++	+	In East Africa

TABLE 22 (Continued)

Disease (1)	Pathogen (2)	Vector and transmission (3)	Water association (4)	Severity (5)	Chronicity (6)	Notes (7)
(d) Helminths						
Ascariasis	Nematode *Ascaris lumbricoides*	Ova transmitted by faecal-oral route. *Ascaris suum* may be transmitted from pigs to man.	Water-washed and possibly waterborne	+	+	
Clonorchiasis	Trematode *Clonorchis sinensis*	Parasite of bile duct of man, dog, cat, and other animals. Man → aquatic snail → fish → man. Man infected by eating infected fish.	Parasite depends on two aquatic hosts to complete its life cycle.	++	++	19,000,000 people infected in China, Japan, Indochina, Taiwan, and Korea. Promoted by raw fish eating and fish culture in ponds.
Diphyllobothriasis	Cestode *Diphyllobothrium latum*	Man → aquatic crustacean → fish → man. Man infected by eating infected fish.	Parasite depends on two aquatic hosts to complete its life cycle.	often asymptomatic		Common in many parts of Europe. Also found in North America, USSR, Japan, Australia, and parts of Africa and South America.
Fasciolopsiasis	Trematode *Fasciolopsis buski*	Pig → aquatic snail → water plant → pig. Man infected by eating contaminated water plant.	Parasite depends on an aquatic snail and an aquatic plant to complete life cycle.	+	+	10,000,000 people infected in Southeast Asia and China.
Filariases	Infection by certain nematodes *(filariae)*	Transmission from man to man by many different mosquitoes and flies.	Spread by water-breeding mosquitoes and flies	+++	++	Filariasis occur in some form throughout the tropics 200,000,000 infected by fileriae *Wuchereria bancrofti and Brugia malayi*. Urban varieties trasmitted by *Culex fatigans* are increasing due to poor sanitation in growing tropical cities providing more breeding sites.

TABLE 22 (Continued)

Disease (1)	Pathogen (2)	Vector and transmission (3)	Water association (4)	Severity (5)	Chronicity (6)	Notes (7)
Guinea Worm	Nematode *Dracunculus Medinensis*	*Cyclops* spp. intermediary hosts. Man → cyclops → man. Reinfection of of human is oral.	Cyclops lives in water. Cyclops killed by heat or adding potash, perchloron, or barbel fish to in-fected waters.	++	++	Particularly common in parts of West Africa.
Onchocerciasis (River blindness)	Nematode *Onchocerca volvulus*	*Simulium* spp. the black fly. Man → fly → man.	*Simulium* breed in water	++	++	Mainly found in West and Ceneral Africa and Central America—10% of the 10,000,000 inhabitants of the Volta River basin are infected and 7% are "economically blind."
Paragonimiasis	Trematode *Paragonimus* spp.	Pig (or other animal) → aquatic snail → crab or crayfish → pig. Man in- by eating infected crab or crayfish.	Parasite depends on two aquatic hosts to complete life cycle	+	+	East Asia and West Africa.
Schistosomiasis	Trematode *Schistosoma* spp.	Aquatic snails are internediary hosts. Schistosome eggs are passed in urine or faeces.Snails become infected and later humans are infected through the skin.	Infection depends on skin contact with polluted water. Snails die above 39° C. and are eaten by ducks and other snails. Snails killed by molluscicides.	++	++	Perhaps 200,000,000 infected. Between 1970 and 1972 the prevalence of infection in the Kainji Dam area of Nigeria doubled to 69%
(e) Spirochaetes						
Leptospirosis	*Leptospira* spp.	Focus in wild and domestic animals. Leptospires shed in animal urine and infect man through skin, nose, mouth, or eyes.	Leptospires can survive well in nature in warm conditions and neutral pH. Water-washed or water-borne	++		
Louse-borne fever	*Borrelia* spp.	Transmitted by the louse *Pediculus humanus*. Man → louse → man.	Cleanliness of body and clothing prevents infestation. Therefore a water-washed disease.	+++		
Yaws	*Treponema pertenue*	Skin to skin contact	Water-washed	++	++	

TABLE 22 (Continued)

Disease (1)	Pathogen (2)	Vector and transmission (3)	Water association (4)	Severity (5)	Chronicity (6)	Notes (7)
			(f) Fungal			
Tinea or ringworm	*Trichophyton concentricum*	Skin to skin contact	Water-washed	+		Very common in Australasia and Pacific.
			(g) Miscellaneous			
Conjunctivities Trachoma	Infection of the conjuctiva	Common in conditions of poor hygiene, sanitation, and nutrition,	Water-washed	++	++	1/6 of world's population suffer from Trachoma.
Gastroenteritis (Diarrhoeal disease)	Enteric infection by bacterial or viral agent	Common in conditions of poor hygiene, sanitation, and nutrition. Probably faecal-oral transmission.	Water-washed	+++		A major cause death among children in tropics. Poorly understood.
Scabies	Bacterial infection of burrows in skin caused by mite	Mite is *Sarcoptes scabiei*. Mite infestations can pass Man ⟶ man or animal ⟶ man	Water-washed	+	+	
Skin sepsis and ulcer	Infection of minor skin trauma by bacteria or spirochaetes, or both.	Found in conditions of poor hygiene and poor nutrition in tropics.	Water-washed	+	+	

levels of service in different countries. Donaldson (59) considers three levels of service in Latin America.

1. Community well program for dispersed population.
2. Rudimentary adequate program for semi-concentrated populations.
3. Rural adequate program for the concentrated and village population.

In Africa, six levels of service are utilized (60).

Class 1 improvement in individual basis, a single household makes an improvement, such as a private spring or rainwater catchment for its own use.

Class 2 is a group improvement. The group improvement may include a well system, surface reservoirs, or an area wide catchment system.

Class 3 is a rural pipeline, where water is carried to central distribution points.

Class 4 is a municipal standpipe, where the commucan obtain water from the single source.

Class 5 is the single tap to each household.

Class 6 is multiple taps to households.

In the Philippines four levels of service are available (61).

Level 1: Small well and hand pumps are provided to small and sparsely populated communities.

Level 2: Is a piped system with public faucets.

Level 3: Is the conventional household connection system, complete with meters.

Level 3A: Is a variation of Level 3. In this case the maximum-day to peak-hour transition point is relocated closer to the user by the use of individual water storage tanks.

In some other countries three levels of service are utilized:

Adequate: Enough volume available on a 24-hour basis; storage incorporated in system design; treatment and disinfection provided for health protection and taste.

Marginal: Water available intermittently, generally at low pressures (individual home storage tanks prevalent); disinfection probably incorporated but not treatment.

Public Faucets: The minimum level required to improve very needy urban areas. Care in water handling from faucet to drinking containers must be a public health consideration. Hygienc standards are low or marginal.

In Tanzania and Malawi, the government has adopted the policy of not providing any individual connections until the whole population has been provided with a minimum level of service. In Kenya individual service connections are encouraged in high potential areas with the hope of achieving higher economic and health benefits and to facilitate the collection of revenue for the service. In South Korea rural schemes are based on patio connections to all households.

CHAPTER III

DEVELOPMENT OF THE MODEL FOR THE SELECTION OF SUITABLE LEVELS OF SERVICE ON WATER DISTRIBUTION SYSTEMS

Introduction

The major objective of this research is to obtain a model that selects the most suitable level of service of a water distribution system for a given community, in terms of its materials, natural resources and manpower availability and the ability to pay for the service.

Materials availability is utilized here to describe the community's capability of having the material and equipment required for the construction, operation and maintenance of the water distribution system. Natural resources availability describes those resources needed to satisfy water and energy requirements during the operation of the system. Manpower availability defines the community's capability to satisfy the needs for manpower (unskilled, skilled and professional), during the satisfactory operation and maintenance of the system.

Ability to pay is defined as the amount of money people are willing to pay for the water service. This amount of money must be enough to pay for the depreciation, operation and maintenance, taxes, interest, and normal and expansion costs of the water system.

The model must include an inventory of available technologies utilized in water distribution systems; a way to predict capabilities of the community in terms of manpower, materials and energy; a way to forecast water demand requirements; and a way to predict production costs and manpower requirements; an interrelationship between available technologies and levels of service; and an interrelationship between technology available and its requirements for manpower, equipment and materials. A pattern flow for the model is shown in Figure 7.

In order to develop the selection model the following work needs to be done:

1. Select levels of service.
2. Inventory available technologies utilized for those selected levels of service.
3. Develop a model of water demand requirements for different levels of service and different socio-technological levels.
4. Select a technique to define community capabities in terms of manpower availability.
5. Develop a method to predict energy requirements.
6. Relate available technologies with levels of service.

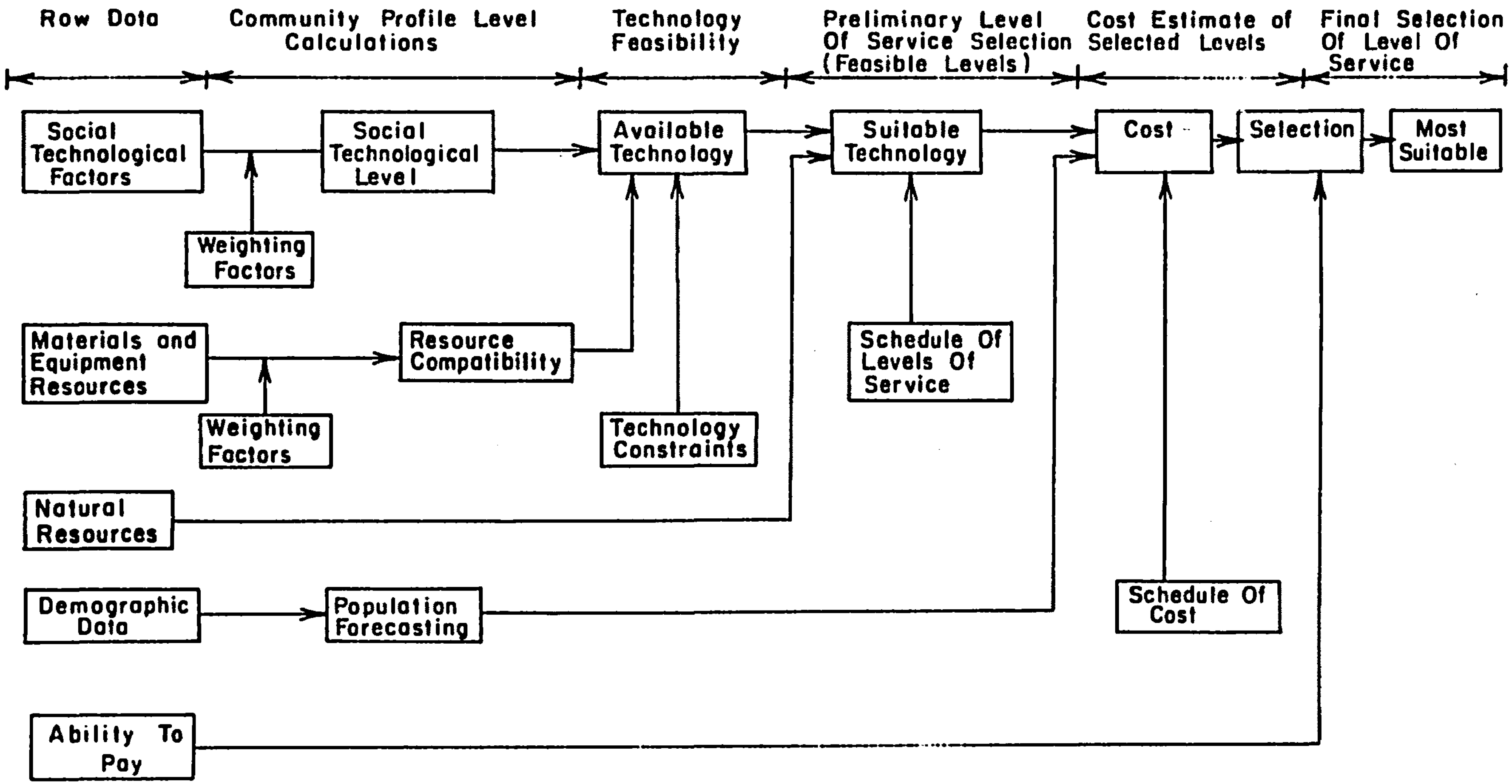


FIGURE 7. PATTERN FLOW FOR THE MODEL TO SELECT A SUITABLE LEVEL OF SERVICE FOR WATER DISTRIBUTION SYSTEMS IN LESS DEVELOPED COUNTRIES.

7. Define requirements on manpower, equipment and materials for each technology on the inventory.
8. Create a matrix of levels of service and technology.
9. Develop cost equations for different components in a water distribution system.

Level of Service

The level of service suitable for a community depend on different factors (Figure 8). Until now the levels of service available to a given community are defined in terms of distance to the water source, i.e., standposts, patio connections, and inside building connections. In this methodology new levels of service are created. Levels of service for time and reliability are added.

There are two levels of service according to time, continuous and intermittent. The intermittent level of service is that where the distribution system is designed to meet either the peak day or average demand but not the peak demand. This level of service will permit saving some money when reducing the diameter of the pipe. The continuous level of service is the one that is designed to meet the peak hour demand. There are many water distribution systems in the LDCs that work intermittently. They were not designed to work like that, but again, inability

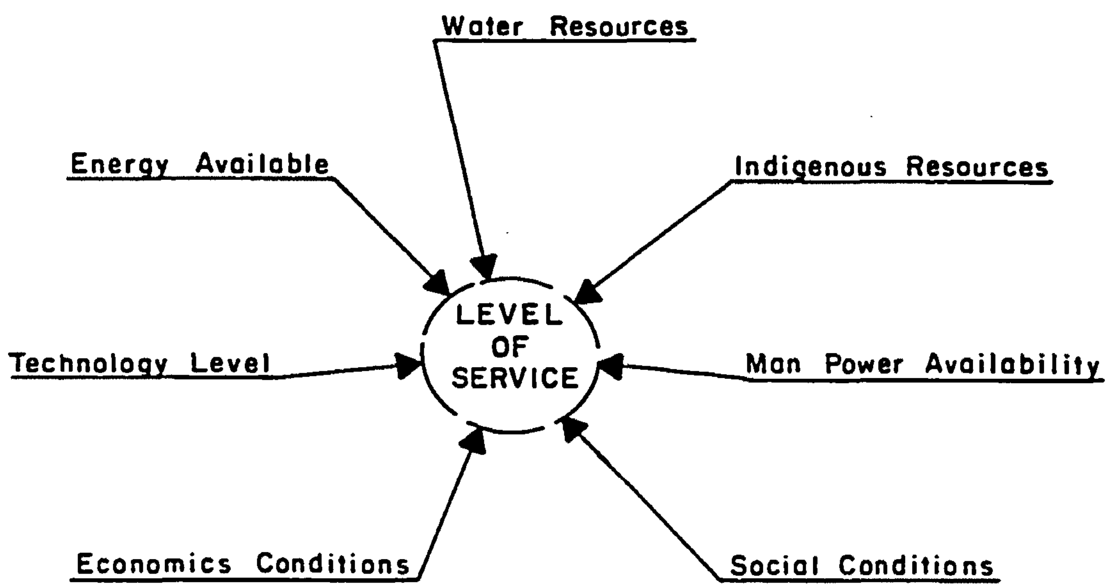


FIGURE 8. FACTORS AFFECTING WATER DISTRIBUTION SYSTEM LEVELS OF SERVICE

of people to pay water rates led to this situation.

Many people oppose the use of water distribution systems that work intermittently because they say those are a threat to health. In this situation of economic poverty in LDCs, what _is_ more humanitarian or healthy -- to have all the people with some water, or to have only a small portion of the population with good water? Leaving the "have-nots" without water would push them to water vendors and other sources of very poor quality water.

It is understood that this design criteria would not be acceptable in developed countries where economic conditions are quite different from those in LDCs. In DCs, the design asks for sufficient amount of water of excellent quality 24 hours a day, 7 days a week, and 52 weeks a year.

The level of service according to reliability is defined as the length of piping to be out of service in case of a broken line. This level of service depends on the type of distribution system (branched or looped) and the location of valves.

With all of this in mind, levels of service selected to be used in this model are listed on the following pages, and explained on the next paragraphs. A description of each level of service follows:

One source. In this case one source of water is provided. It could be located in every house or in a central distribution point. It could be a private spring, a rainwater catchment, a dug well, a hand pump, or a rural pipeline, where water is carried to a central distribution point. In any case, piping is not required to distribute water.

Standposts. Consist of a piped system with public faucets.

Patio Connections. It is a piped system with a single tap to each household.

Vendors. In this case a person distributes potable water in a tank truck.

House Connections. It is a piped system where water is delivered to each household in a point inside the building.

Intermittent. In this level of service, the system is designed to meet water demands for a certain period of the day.

Peak Day. The system is designed to supply water for the peak day; the size of the system will not be enough to meet the peak hour demand.

Average Day. The system is designed to supply water for the average day; there would be water shortages during peak day and peak hour demand.

Continuous. The system is designed to meet the peak hour demand. No water shortages will occur due to the lack of capacity of the distribution system.

Reliability. This level relates to the amount of people that are out of service in case of repairment. Looped systems will create less problems than branched systems.

Levels of Service Considered in this Model

Level of Service

1. By Distance
    - 1.1 One source (unpiped system)
        - 1.1.1 Private Spring (DW1)
        - 1.1.2 Rainwater Catchment (DW2)
        - 1.1.3 Dug Well (DW3)
        - 1.1.4 Individual Well (DW4)
        - 1.1.5 Rural Pipeline (DW5)
        - 1.1.6 Vendors (DW6)
    - 1.2 Standpost (DW7)
    - 1.3 Patio (DW8)
    - 1.4 House (DW9)
2. By Time
    - 2.1 Intermittent
        - 2.1.1 Average Day (T1)
        - 2.1.2 Maximum Day (T2)
    - 2.2 Continuous (Peak Hour) (T3)
3. By reliability
    - 3.1 Branched (R1)
    - 3.2 Looped (R2)

Inventory Technology

The technology available in water distribution systems can be divided according to the system components. The system components are distribution, reservoirs, pumps, controls, meters, prime movers, energy sources, water dispensing devices. Each system component can be divided in different sub-components. Those sub-components are shown next. A description of each one is shown in Appendix C.

Inventory of Technology

1. Distribution
   - 1.1 Wells
     - 1.1.1 Driven Wells
     - 1.1.2 Hand-Drilled Wells
     - 1.1.3 Mechanically Drilled Wells
   - 1.2 Pipes
     - 1.2.1 Cast Iron
     - 1.2.2 Asbestos-Cement
     - 1.2.3 Plastic
     - 1.2.4 Steel
     - 1.2.5 Concrete
     - 1.2.6 Bamboo
   - 1.3 Valves
     - 1.3.1 Diaphragm
     - 1.3.2 Globe

1.3.3 Rotary

1.3.4 Slide

1.3.5 Automatic Control

1.4 Fittings

1.4.1 Clamps

1.4.2 Sleeves

1.4.3 Couplings

2. Reservoirs

2.1 Cut and Fill

2.2 Ground

2.2.1 Standard Concrete

2.2.2 Prestressed Reinforced Concrete

2.2.3 Steel

2.3 Elevated

(Same as Above)

2.4 Standpipe

2.5 Wooden Tanks

2.6 Hydropneumatic

2.7 Individual

2.7.1 Asbestos-Cement

2.7.2 Plastic

3. Meters

3.1 Piston

3.2 Nutating

3.3 Turbine

3.4 Propeller

3.5 Multi-Jet

3.6 Compound

3.7 Proportional

3.8 Venturi

3.9 Orifice

3.10 Pitot

3.11 Rotometers

3.12 Magnetic

3.13 Sonic

4. Pumps

4.1 Centrifugal

4.1.1 Volute Design

4.1.2 Diffuser Type

4.1.3 Multistage

4.1.4 Turbine

4.1.5 Mixed-Flow

4.1.6 Submersible

4.2 Positive Displacement

4.2.1 Piston

4.2.2 Plunger

4.2.3 Diaphragm

4.2.4 Rotary

4.3 Jet

4.4 Air Lift

4.5 Hydraulic Ram

4.6 Hand Pumps

5. Controls

5.1 Sensors or Meters

5.1.1 Magnetic Type Floats

5.1.2 Liquid-Level Electrical

5.1.3 Bubble-Sensors

5.1.4 Liquid Level Sensors

5.1.5 Displacer Type Floats

5.1.6 Pressure Sensors

5.1.7 Flow Sensors

5.2 Controllers

5.2.1 On-Off Switches

5.2.2 Throttling by Valve

5.2.3 By-Pass by Valve

5.3 Actuators and Relays

5.3.1 Transducers

5.3.2 Transmitters

5.3.3 Telemetry Systems

5.4 Alternators

5.5 Data Processing

5.5.1 Digital Data Loggers

5.5.2 Digital Computer Control

6. Prime Movers

6.1 Electrical Motors

6.1.1 Squirrel Cage

6.1.2 Wound-Motor

6.1.3 Synchronous

6.2 Internal Combustion Motors

6.3 Steam Engines

6.4 Turbines

7. Energy Sources

7.1 Electricity

7.2 Gasoline

7.3 Diesel

7.4 Natural Gas

7.5 Solar

7.6 Wind

8. Water Saving Devices

8.1 Toilets

8.1.1 Shallow Trap

8.1.2 Dual Cycle

8.1.3 Sink-Bob

8.1.4 Monterrey

8.1.5 Save it Water Saver

8.1.6 Nibo

8.1.7 Brick in the Tank

8.1.8 Pedamatic

8.1.9 Norway

8.2 Showers

8.2.1 Flow Limiting Shower Head

8.2.2 Thermostatic Mixing Valve

8.3 Lavatory and Kitchen Sinks

8.3.1 Flow Limiting

8.3.2 Faucet Aerator

8.3.3 Fordilla

Water Demand Model

The amount of water required by a certain population is a function of the level of technological development (STL), distance to water source and climatological conditions. Design criteria and water demand models reviewed in the previous chapter do not consider both the STL of a community and the level of service at the same time when selecting water consumption figures. Therefore, the purpose of this research is to develop a water demand model that considers these above factors. The model is then utilized to calculate the water requirements for each level of service, at each level of socio-techological development.

Different people have used stepwise multiple correlation analysis to obtain these types of equations. The equation has the following general form:

$$W_D = A_0 + A_1 f(X_1) + A_2 f(X_2) + \ldots + A_n f(X_n)$$

where

W_D = Water Demand Per Capita

$f(X_1)$, ..., $f(X_n)$ + STL, Distance to Water, etc.

Statistical Analysis

For the purposes of this study the following parameters will be utilized in insuring that the mathematical model obtained be statistically valid:

1) Coefficient of determination (R^2) is a measure of the explained variation over the total variation. R^2 values range from 0 to 1 with a value of 1 representing the situation where all variation has been explained.

2) F-Statistic (F) is a measure of the explained variance over the unexplained variance. At a confidence level of 95%, the value obtained for 6-10 sample size can be considered significant if over 6. For a sample greater than 10, the F-Statistic must have a value of 5 or greater to be considered significant.

3) Standard error of forecast (SEF) defines a confidence interval around forecasts based on the regression line. Normally a 95 percent confidence interval is used and this test will allow a 95 percent certainty that the actual value will be within ± 2 standard errors of forecast around the forecasted value.

Data Utilized

To obtain the equation, data from three Latin-American countries were utilized. The data are part of a study sponsored by the Pan-American Health Organization. Graduating students from the Civil Engineering schools at

Guatemala, San Salvador and Panama collected the data.

They spent a great deal of time taking a census of the population, measuring water in tanks, reviewing monthly meter readings, etc. to calculate water consumptions and peak demand factors.

Two or three students were assigned per town. They presented a final report as the final social work before they received their degree. Part of the data collected are shown in Table 23.

Results

After several runs an equation was obtained. This equation relates water demand with socio technological level, percent of population served by electricity, and distance to water source (level of service). The equation is as follows:

$$W_D = \frac{79.2\, X_1^{0.17} X_2^{0.10}}{X_3^{0.12}}$$

Where

W_D = Water Demand in Liters Per Capita Per Day

X_1 = Socio-Technnological Level

X_2 = Percent of Population Served by Electricity

X_3 = Distance to Water Source

TABLE 23

DATA FROM LATIN AMERICAN COUNTRIES, USED TO PREDICT WATER DEMAND AND PEAK FACTOR EQUATIONS

Case	Population Size	STL (STL)	Distance to Water (Dist.)	% People Electricity (pelec)	Water Demand (WD)	Pk Day Factor (K_1)	Pk Hour Factor (K_2)
			Mts.		lcd		
1	459	1	20	0	16	1.68	1.75
2	1868	1	20	0	54	1.38	1.52
3	1586	3	5	62	116	1.10	2.34
4	3554	1	18	30	103	1.23	2.78
5	640	1	20	0	19	1.25	2.23
6	664	1	20	0	63	1.16	1.84
7	5228	1	19	26	83	1.29	3.63
8	4263	2	2	36	110	1.24	3.58
9	1891	2	11	68	104	1.17	1.82
10	971	3	7	77	122	1.31	3.61
11	1750	1	20	40	72	1.24	2.67
12	3400	1	3	30	145	1.51	1.88
13	2623	3	12	65	134	1.12	1.87
14	6213	1	18	0	105	1.27	3.72
15	865	2	17	48	93	1.08	1.98

TABLE 23 (Continued)

Case	Population Size	STL (STL)	Distance to Water (Dist.)	% People Electricity (pelec)	Water Demand (UD)	Pk Day Factor (K_1)	Pk Hour Factor (K_2)
			Mts.		lcd		
16	855	3	0	93	134	1.32	2.46
17	2421	1	19	55	84	1.15	2.54
18	1010	4	0	100	217		
19	6679	4	13	65	173	1.21	2.27
20	1197	1	20	44	70	1.45	2.43
21	1001	1	20	0	65	1.42	2.40
22	9489	3	0	100	114		
23	67750	3	0	100	136		
24	21840	3	0	100	106		
25	5700	2	0	100	121		
26	2430	2	0	100	1		
27	1536	3	68	62	108		
28	3554	1	80	30	107		
29	4263	2	300	36	59		
30	971	3	37	77	72		
31	1750	1	300	40	34		
32	3400	1	150	30	57		
33	2623	3	126	65	106		
34		1	700	0	26		

The correlation coefficient (R^2) had a value of 0.67 and the F-statistics value was 17.3. In this case, climatological conditions (i.e., temperature and rainfall), didn't have a good correlation with water demand. This is quite understandable because the data utilized were from a region where no great variation of temperature and rainfall exists.

Resource Capabilities of the Community

Resource capabilities of the community under study must be defined. Later, these factors will serve to eliminate those levels of service not appropriate for the community. Resource capabilities are defined in terms of manpower and materials.

Manpower capabilities are defined using an approach developed by Reid (62), in his methodology for the selection of water and waste water. This approach is called the resource capability model. Materials capabilities are defined through the use of a questionnaire in terms of materials and equipment used on construction, operation, maintenance, and service for the different components of the distribution system.

The Resources Capability Model

This model uses eighteen inputs that describe socio-economic conditions. Those data are reduced through a weighting process to four socio-technological levels.

Socio-Technological Factors

These inputs are defined as the sum of socio-cultural and socio-economic factors relevant to the model that are essential parts of any community or group of people. The variables were selected on the basis of the availability of related data at the local level and their ability to reflect the level of development at the community level. The characteristics of the eighteen variables used are briefly described in Appendix A. The questionnaire utilized to define these 18 inputs is shown in Appendix E. The inputs are as follows:

1. Level of Education
2. Labor Force Distribution
3. Income
4. Non-Indigenous Workers
5. Education Investment
6. In-service Training
7. Local College
8. Unemployment
9. Extension Services
10. Schools of Local College Students
11. Level of Technology Available
12. Government as a Labor User

13. Public Employment Services

Social-Economic Weighting Factors

Each social-economic factor is given a certain weight. (See Table 24). So, the level of development of each community is determined by giving a weight to every factor and then totalizing all the factors. For example, educational attainment is a good indicator of development and has been given greater weight than the distance to the nearest high school, since the distance may not be important if the community has a good transportation system. The weighting process is flexible and can be modified to satisy the requirements of local conditions.

Social-Technological Level

The values of the weighting factors are totaled, and a socio-technological level is assigned according to the following weight schedule:

Socio-Technological Level (STL)	Range for Total of Weighting Factors
1	1-23
2	24-51
3	51-93
4	93-133

TABLE 24

WEIGHTING FACTORS FOR SOCIAL-TECHNOLOGICAL LEVEL DETERMINATION FOR COMMUNITIES IN LESS DEVELOPED COUNTRIES

Description of Variable	Data Part III, Questions No. 1-19	Possible Choices	Weighting Factor
Level of Education	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	5
		3	8
		4	12
		5	15
Percent Non-Indigenous Workers in Government 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 School	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

TABLE 24 (CONTINUED)

Description of Variable	Data Part III Questions No. 1-19	Possible Choices	Weighting Factor
Availability of Technical and Vocational Training	8	1 2	5 0
Compulsory Primary Education	9	1 2	10 0
Availability of In-Service Training Programs	10	1 2	5 0
Local College or University	11	1 2	10 0
Chemistry in Local College	12	1 2	3 0
Unemployment Level	14	1 2	0 5
Availability of Extension Services	15	1 2	3 0
Schools of Local College Students	16	1 2	0 3
Level of Technology Available	17	1 2 3 4	0 5 10 15
Government as a Labor User	18	1 2	0 5
Availability of Public Services	19	1 2	5 0

Each STL has different manpower availability. Manpower availability is divided in three skill categories.

A. Professional

B. Skilled and Craftsmen

C. Unskilled and Semiskilled

For professional, is meant those with a university degree, such as engineers, or administrators; skilled and craftsman, those with secondary school plus two to three years of vocational training. Unskilled and semi-skilled are those that master these skills by relatively non-formal means in the plant and on the job and do not undergo formal courses.

The main emphasis of the scheme is on operating personnel, as opposed to construction personnel, since investigation to this point has indicated that failure of a project due to lack of personnel almost always occurs during operation and maintenance rather than during construction. The decision rules developed for the model provide the following manpower constraints for each of the four social-technological levels:

1. In Level I communities, only unskilled or semi-skilled manpower is available (Category C only).
2. In Level II communities and in Level III communities with populations under 50,000, only

unskilled and some skilled labor is available (Categories C and B only).

3. In Level III communities with populations over 50,000 and in Level IV communities, all categories of manpower are available (Categories A, B, and C).

In the event that information obtained is not enough to fill out the questionnaire, an alternative approach exists. This approach describes the characteristics of each of the levels of development that are considered, so the planner can determine the STL of the community under study by looking at the description of each level. A description of each level of development is included in Appendix B.

Material Availability

In this case the model through a questionnaire defines the general availability of equipment and materials in the community. Material availability is defined in terms of material and equipment needed for the construction, operation, control, maintenance and service. Again, this is a general model, and in order to apply it to a particular country it must be tailored to fit the conditions of that country. Perhaps, in some cases there is no need for construction materials because materials will be brought from other places.

The model considers the community under study as if it were isolated. One way to take care of this condition is to set a delivery time or an out of service time. This time may vary for the different components of the system or it may be constant.

In order to determine the availability of materials there are different approaches. This model considers that if more than 30 percent of the materials or equipment is not available then all material is not available.

A list of the materials and equipment that is included in the questionnaire is shown in Table 25. No effort has been made to list the material needed for the management tasks, since it is assumed that this is not a limiting factor. In this case no effort has been made to include all of the materials and equipment, only the most important. None of the materials have been ranked. The list of materials will vary according to the type of technology employed.

TABLE 25

List of Material and Equipment Required in Water Distribution Systems

1. Construction Equipment/Material

   1.1 Transit/Level

TABLE 25 (contd)

1.2 Measuring Tapes

1.3 Shovels

1.4 Backhoes

1.5 Concrete/Cement/Sand/Gravel

1.6 Pipes

1.7 Fittings

1.8 Valves

1.9 Glue/Primer

1.10 Combustible/Lubricants

1.11 Soldering Equipment

2. Operation Equipment/Material

2.1 Pumps

2.2 Power Generators

2.3 Electrical Motor

2.4 Internal Combustion Motor

2.5 Chlorine

2.6 Gasoline

2.7 Electricity

3. Control Equipment

3.1 Pressure Meters

3.2 Flow Meters

3.3 Vacuum Gauges

3.4 Valves

3.5 Float Sensors

3.6 Pressure Control Valves

TABLE 25 (Contd)

	3.7 Flow Control Valves
4.	Maintenance Supplies
	4.1 Chlorine
	4.2 Lubricants
	4.3 Clean Water
	4.4 Ferric Chloride
5.	Repair Materials/Equipment
	5.1 Pipes
	5.2 Soldering Equipment
	5.3 Valves
	5.4 Acetylene Torches
	5.5 Contractor Pumps
	5.6 Jackets
	5.7 Pipe Fittings
	5.8 Clean Water
	5.9 Chlorine

Natural Resources Availability

These raw data are defined in terms of water and energy available. The model takes them as constraints in order to select the most suitable level of service. The water resources are expressed as liter per capita per day. This value is obtained dividing the total production of the water source by the population to be served by the end of the design period.

The head available is expressed in meters, and it is the difference in elevation between the water source and the highest point in the system. In this case the water source is understood as the effluent of the water treatment plant or the discharge point of the pump, or the intake of the aqueduct in a spring.

The availability of water resources for a community depends on the marginal cost of water, so it depends on the willingness to pay for the water service. If willingness of the community to pay (a very high water cost) were unlimited, water resources were unlimited, therefore, any level of service would be available for the community. In the case of developing countries where poverty is high and money is not available, water resources are limited; perhaps not physically but economically, in such a way that the nearest source is considered as the only one available.

The head available could be determined roughly from aerial photographs or maps. Generally, governments have maps available at different scales. The water resources are determined through pump tests, river gauging, or other less accurate methods like the Theis, etc.

In case these data are not available, it is recommended at least to determine the energy available, and assume an infinite amount of water available, let then the model set the constraints through the economic analysis and discussion with the people in the community.

Demographic Data

This is the last set of inputs in the model. Two types of input are needed, present population and average growth rate. This information is the most readily available. The recommended methods to forecast is not limiting other methods. The population forecast method that suits better to the community under study must be used, i.e., geometric, arithmetric, exponential, Reid, etc.

Manpower and Materials Requirements

Every country has its own way to manage the water supply systems. Some countries prefer central management, while others allow locals to take care of the operation and maintenance of the water distribution system. Others do the planning, design and financial management from central offices. Due to this situation, manpower and material requirements will vary widely.

The approach here will be to list all the system components with their needed tasks and analyze them to define their manpower and material requirements. In case of a particular country, the model can be adapted to reflect the local conditions. Table 26 lists most of the tasks performed in a water distribution system.

Before the analysis of the system components, a classification of required tasks was done. Tasks were classified as scheduled, routine and emergency. Also, they were classified as necessary and desirable. (See Table 27). Scheduled tasks are those planned to be executed well ahead of time, they are rarely limiting because required personnel, equipment and material could be brought from other places. Also, it may be the case that these tasks were not performed by water system personnel, and contractors might execute them. Routine tasks are those performed almost every day, i.e., stop and start of the pumps, meter reading, pressure reading, etc. Emergency tasks are those not possible to predict. They may occur from normal operation, because of a bad operation or in disaster events, i.e., pipe breaking due to earthquakes, pump failure due to motor burning, etc.

TABLE 26

Tasks Performed in Water Distribution Systems

Field	
Engineering	Planning, design, project management, construction, supervision, technical studies, maps and records, etc.
Administration	Financial management, billing and collecting, personnel training, contracting and purchasing, general services.
Operation and Maintenance	Storage tanks, pumping stations, transmission lines, well, standposts, handpumps, valves, meters,etc.
Service	Installations, disconnections, meter repairs, plumbing inspections, standposts, hand pumps, etc.

TABLE 27

Manpower, material and equipment requirements for different tasks on water distribution systems and tasks classification

Field	TASK	Manpower Requirements			Materials Requirement					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Engineering	Planning	X	X	X						X		X	X	
	Design	X	X	X						X		X	X	X
	Project Mgt.	X	X	X						X				
	Construction	X	X		X					X			X	
	Specifi-cations	X	X	X						X			X	
	Technical Studies	X	X	X						X			X	
	Maps		X	X						X			X	
	Records	X	X				X				X			X
Administration	Financial Management	X	X	X						X	X			X
	Billing and Collecting	X	X								X		X	
	Personnel Training		X	X						X				X
	Contracting	X	X								X			X
	Purchasing	X	X								X			X
	General Services	X	X								X			X

Table 27 (contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	<u>Pipe</u>													
	Leak Detection	X	X				X			X		X	X	
	Water Tests	X	X			X					X			X
	Corrosion Control	X	X	X				X		X				X
	Record Keeping	X	X				X				X			X
	Painting	X						X		X				X
	Leak Repair	X	X		X				X			X	X	
	In-Line Treatment	X	X	X				X		X		X	X	
	Line Flushings	X				X		X		X		X	X	
	Pigging	X	X		X	X		X	X	X				X
	Pipe Location	X							X	X		X		X
	Pumping A. <u>Centrigugal Positive Displacement</u>													
	Lubrication	X						X			X		X	
	Alingment	X	X				X		X	X		X	X	
	Shaft Replac	X	X					X	X	X		X	X	
	Pressure Reading	X					X				X			X
	Flow Reading	X					X				X			X
	Records	X	X				X				X			X

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	Painting	X						X		X				X
	Replacement	X	X		X				X	X		X	X	
	Operation	X				X					X		X	
	B. <u>Jet and Air lift</u>													
	Lubrication	X						X			X		X	
	Pressure Reading	X					X				X			X
	Flow Reading	X					X				X			X
	Records	X	X				X				X			X
	Painting	X						X		X				X
	Replacement	X	X		X				X	X		X	X	
	Operation	X				X					X		X	
	C. <u>Hydraulic Ram</u>													
	Valve Replacement	X							X	X		X	X	
	Leak Detection	X					X				X			X
	Pressure Reading	X					X				X			X
	Flow Reading	X					X				X			X
	Records	X					X				X			X
	Painting	X						X		X				X
	Replacement	X	X						X	X		X	X	
	Operation	X									X		X	

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	D. **Hand Pumps**													
	Lubrication	X						X			X			X
	Leak Detection	X					X			X		X		X
	Replacement of Cup Seals	X						X		X		X	X	
	Records	X									X			X
	Replacement	X								X		X	X	
	Operation	X									X		X	
	Valves													
	Location	X							X	X		X		X
	Operation													
	Manual	X									X		X	
	Mechanical	X									X		X	
	Electrical	X				X					X		X	
	Replacement	X	X						X	X		X	X	
	Repair													
	Manual	X							X			X	X	
	Mechanical	X	X						X	X		X	X	
	Electrical	X	X						X	X		X	X	
	Maintenance													
	Manual	X								X				X
	Mechanical	X						X		X				X
	Electrical	X	X					X		X				X
	Testing	X	X				X			X				X
	Meters													
	Reading	X									X			X

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	Record Keeping	X	X				X				X			X
	Replacement	X			X				X	X		X	X	
	<u>Repair</u>													
	Mechanical	X	X					X	X	X				X
	Electrical	X	X					X	X	X				X
	Electronic	X	X	X				X	X	X	X			X
	Testing	X	X				X			X				X
	<u>Reservoirs</u>													
	A. <u>Cut and Fill</u>													
	Operation	X									X		X	
	Leak Detection	X	X				X			X		X	X	
	Leak Repair	X	X				X		X	X		X	X	
	Disinfection	X	X					X		X		X		X
	Algae Control	X	X	X				X		X		X	X	
	B. <u>Ground, Elevated, and Standpipe</u>													
	Operation	X									X		X	
	Leak Detection	X	X				X			X		X	X	
	Leak Repair	X	X		X	X		X	X	X		X	X	
	Corrosion Control	X	X	X				X		X				X
	Painting	X						X		X				X
	Disinfection	X	X					X		X		X		X
	Algae Control	X	X	X				X		X		X	X	

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	C. Wooden													
	Operation	X									X		X	
	Leak Detection	X	X				X			X		X	X	
	Leak Repair	X	X			X		X	X	X		X	X	
	Wood Decomposition Control	X	X					X		X				X
	Painting	X						X		X				X
	Disinfection	X	X					X		X		X		X
	Algae Control	X	X	X				X		X		X	X	
	D. Pneumatic													
	Operation	X				X					X		X	
	Leak Detection	X					X			X		X		X
	Leak Repair	X	X			X			X	X		X	X	
	Corrosion Control	X	X					X		X				X
	Painting	X						X		X				X
	Disinfection	X	X					X		X		X		X
	E. Individual	X												
	Prime Movers Electrical													
	Operation	X				X	X	X			X		X	
	Minor Maint.	X	X					X			X		X	
	Repair	X	X						X			X	X	
	Testing	X	X				X			X				X
	Replacement	X	X		X		X		X	X		X	X	

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	<u>Internal Combustion</u>													
	Operation	X				X	X	X			X		X	
	Minor Maintenance	X						X			X		X	
	Repair	X							X			X	X	
	Testing	X					X			X				X
	Replacement	X	X		X				X	X		X	X	
	<u>Steam Engines</u>													
	Operation	X					X	X			X		X	
	Minor Maintenance	X						X			X		X	
	Repair	X							X			X	X	
	Testing	X					X			X				X
	Replacement	X	X		X				X	X		X	X	
	<u>Turbines</u>													
	Operation	X	X			X	X	X			X		X	
	Minor Maintenance	X	X					X			X		X	
	Repair	X	X	X			X		X		X	X		
	Testing	X	X				X			X				X
	Replacement	X	X	X	X				X	X		X	X	
	<u>Energy Sources</u>													
	A. <u>Electrcity</u>					X					X			X
	B. <u>Gasoline</u>					X					X			X
	C. <u>Diesel</u>					X					X			X
	D. <u>Natural Gas</u>					X					X			X

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	E. Solar													
	Operation	X									X		X	
	Minor Maintenance	X						X			X		X	
	Repair	X	X	X			X		X			X	X	
	Testing	X	X				X			X		X		X
	Replacement	X	X	X	X		X		X	X		X	X	
	F. Wind													
	Operation	X									X		X	
	Minor Maintenance	X						X			X		X	
	Repair	X						X	X			X	X	
	Testing	X					X			X		X		X
	Replacement	X	X		X				X	X		X	X	
	Controls													
	A. Manual													
	Operation	X									X		X	
	Minor Maintenance	X						X			X			X
	Repair	X							X	X		X		X
	Testing	X	X				X			X				X
	Replacement	X			X			X	X	X		X		X
	B. Mechanical													
	Operation	X				X					X		X	
	Minor Maintenance	X						X			X			X

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
Operation and Maintenance	Repair	X	X						X	X		X		X
	Testing	X	X				X			X				X
	Replacement	X	X		X			X	X	X		X		X
	C. Electrical													
	Operation	X				X					X		X	
	Minor Maintenance	X	X					X			X			X
	Repair	X	X						X	X		X		X
	Testing	X	X				X			X				X
	Replacement	X	X		X			X	X	X		X		X
	D. Electronic													
	Operation	X	X			X	X				X		X	
	Minor Maintenance	X	X				X	X			X			X
	Repair	X	X	X			X		X	X		X		X
	Testing	X	X			X			X					X
	Replacement	X	X	X	X			X	X	X		X		X
	Water Saving													
	Operation	X									X		X	
	Installation	X							X	X		X	X	
	Replacement	X							X			X	X	
	Reparation	X							X			X	X	

Table 27 (Contd)

Field	TASK	Manpower Requirements			Materials Requirements					Classification				
		Unskilled	Skilled	Professional	Construction Equipment	Operation Equipment	Control Equipment	Maintenance Supplies	Repair Equipment	S	R	E	N	D
	Wells													
	Operation	X									X		X	
	Disinfection	X	X						X	X	X	X		X
	Development	X							X	X		X		X

S = Schedule

R = Routine

E = Emergency

N = Necessary

D = Desirable

O = In some cases necessary

Necessary tasks are those needed to keep the water system running; for example, the operation of a pump. Desirable tasks are the ones that even if not performed, the system still runs. They add quality or control of the distribution system, for example the replacement of a pressure gauge.

The quality of service that a water distribution provides depends on the degree the system is prepared to do the necessary tasks. The best water system will be the one that has all the personnel required to perform all the tasks. Here it is possible to see that, for some communities, it would not be economically feasible to have all the required personnel.

First, every system component was analyzed for its requirements of manpower. Manpower was divided as unskilled, skilled and professional. Requirements for equipment and materials were divided as follows: construction, operation, control, maintenance and repair. Table 27 shows the results of the analysis.

The model does not consider availability of stock parts. Perhaps this is a shortcoming of the model, since in a real situation there is always a tendency to stock parts and materials. Some people consider that conditions in LDCs are so limited that a stock of parts cannot be afforded.

<u>Matrix of Levels of Service</u>

Levels of service can be given using different technologies and system components. The idea here was to define for every level of service, its requirements for system components.

To create the matrix, the system components were classified as necessary and desirable. The necessary components are those that are necessary for the level of service to work. These components are piping, pumping, valves, etc. The desirable components are those that increase the quality of level of service; if they are not available, the system still works (i.e., meters, reservoirs, controls, etc.). There are some desirable components that are essential in certain levels of service and those are noted in the matrix. Table 28 shows the matrix of system components obtained.

Energy Requirements

The amount of energy required is different for every level of service, size of population and STL.

Energy requirements depend on the total head curve of the distribution system, which can be expressed as:

$$TDH = H + hf_i + P\ min$$

where

TDH = total head curve

H = the difference in altitude from the source of water to the controlling point i.

Ehf_1 = Head loss in distribution system from the source

TABLE 26

Matrix of System Components and
Levels of Service

		PUMPS						VALVES			METERS				STORAGE							PRIME MOVERS					ENERGY SOURCES						CONTROLS							
	Piping	Centrifugal	Pos. Disp.	Jet	Air Lift	Hyd. Ram	Hand Pumps	Manual	Mechanical	Electrical	Parshall	Mechanical	Electrical	Electronic	Water Saving	Cut and Fill	Ground	Elevated	Stand Pipe	Wooden	Pneumatic.	Individual	Electrical	Internal Comb.	Steam Eng.	Turbines	Wind Mill	Electricity	Gasoline	Diesel	Natural Gas	Solar	Wind	Manual	Mechanical	Electric	Electronic	Wells	Ground Water	Sewerage	Precipitation
A. GRAVITY																																									
1. One Source																																									
Private Spring								0														0																	X		
Roof Catchment								X														X																			X
Dug Well																																									
Private Well							X															0																X	X		
Public Well							X										0																					X	X		
Rural Pipeline	X							X								0	0	0	0	0																					
Vendors																																									
2. Standposts	X							X	0	0	0	0	0	0		0	0	0	0	0														X							
3. Patio Connections	X							X	0	0	0	0	0	0	0	0	0	0	0	0																				0	
4. House Connections																																									
Normal	X							X	0	0	0	0	0	0	0	0	0	0	0	0		0												X	0	0	0			X	
Saving	X							X	0	0	0	0	0	0	X	0	0	0	0	0		0												X	0	0	0			X	
Storage	X							X	0	0	0	0	0	0	0							X												X	0	0	0			X	
B. PUMPING																																									
1. One Source																																									
Public Well		X	X	X	X			X									0	0	0	0	0		X	X	X	X	X	X	X	X	X	X	X	X	0	0	0	X	X		
Rural Pipeline	X	X	X	X	X	X		X	0	0	0	0	0	0		0	0	0	0	0	0		X	X	X	X	X	X	X	X	X	X	X	X	0	0	0				
2. Standposts	X	X	X	X	X			X	0	0	0	0	0	0		0	0	0	0	0	0		X	X	X	X	X	X	X	X	X	X	X	X	0	0	0				
3. Patio Connections	X	X	X	X	X			X	0	0	0	0	0	0	0	0	0	0	0	0	0		X	X	X	X	X	X	X	X	X	X	X	X	0	0	0				
4. House Connections																																									
Normal	X	X	X	X	X			X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	X	X	X	X		X	X	X	X	X	X	X	0	0	0				
Saving	X	X	X	X	X			X	0	0	0	0	0	0	X	0	0	0	0	0	0	0	X	X	X	X		X	X	X	X	X	X	X	0	0	0				
Storage	X	X	X	X	X			X	0	0	0	0	0	0	0	0					X	X	X	X	X	X		X	X	X	X	X	X	X	0	0	0				

*Those are not system components but they will be necessary for some levels of service.

**That means either necessary if the component is classified as desirable or desirable if component is classified as necessary.

of water to the controlling point.

P Min = Minimum Pressure recommended.

The head loss is calculated using the Hazen-Williams equation. From that equation it can be seen that head loss is a function of flow, diameter of the pipe, and roughness coefficient of the pipe material.

$$Q = 0.28\ CD^{2.63}\ S^{0.54}$$

$$hf = \left(\frac{3.59Q}{C\ D^{2.63}} \right)^{1.85} x\ L$$

where

hf = head loss in meters

Q = flow in cubic meters per second

C = Hazen Williams factor

D = diameter of the pipe (meters)

L = length (meters)

In the case where flow Q, C factor, and L are constant, the head loss will increase if the diameter of the pipe is decreased. Now if the diameter is reduced, more energy (larger pump) will be required.

From the above discussion, it is possible to see that an optimum hydraulic gradient can be calculated. The value of the optimum hydraulic gradient is determined using costs of pipes, pumps and energy. Obviously, an economic analysis to determine the optimum hydraulic gradient must be done in each country, since these costs vary widely from country to country. For example, in Tanzania, gasoline costs $5.70/Gal., in Mexico it costs $0.63/Gal. From this, it is easily seen that in Mexico utilization of smaller pipes but larger pumps is possible.

Besides the cost of pipes, pumps and energy, maximum velocity allowed in pipes is the other constraint taken into account in the selection of pipe sizes. There are some countries where energy is provided free for the water supply systems, so the economic analysis depends only on the cost of pipes or maximum velocity allowed.

There are different methods to calculate the head losses through the distribution system (system head curves); among them are the Hardy-cross, the method of sections, etc. They use the Darcy-Weisbach equation or the Hazen-Williams. In any event the system head curve of a community depends on the physical distribution of the system, water demand (level of service), density, location of storage tanks, and water sources.

In this model, calculation of the optimum hydraulic gradient is not intended because this ia a general model. Rather a very simple approach will be utilized to calculate head losses. It is assumed that an optimum hydraulic gradient value has already been obtained. It is also assumed that the hydraulic gradient is constant in all pipes and the population density is also constant. The head loss is calculated multiplying the hydraulic gradient by the length of the distribution. Now the length of the distribution system is obtained measuring the distance from the source of water to the controlling point.

Figure 9 shows a series of curves that were calculated to obtain the length of pipe for different areas of town (population/density) and different L/W arrangements. L/W is the relation of length/width of the town. The head loss is added to the value of minimum pressure recommended in the system. This value is called "energy required." Once the amount of energy required is calculated, then this value is compared with the one obtained in the section of availability of energy. In the event that energy required be smaller than the value of available energy, then pumping is not necessary, in the opposite case, gravity systems can not be used.

Water Demand

The water demand of a certain population can be calculated using local design criteria or water demand models. In this model the amount of water required will be calculated utilizing the previous water demand model for the Latin American countries.

The following assumptions were made in the calculation of the water demand for different levels of service. For the level of service called "one source" where roof catchments are considered, the amount of water required will be to fulfill the needs for cooking, drinking and household

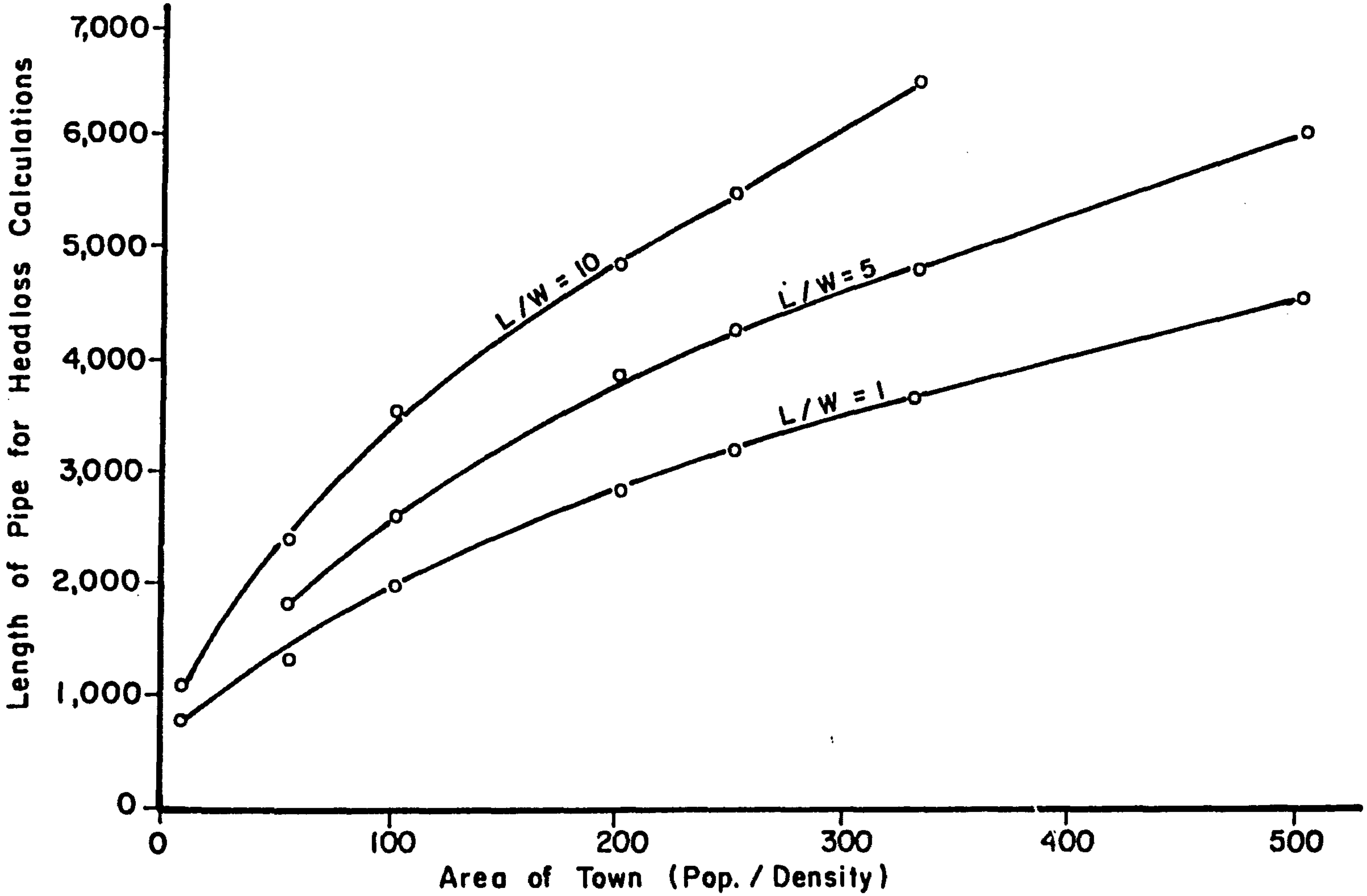


Figure 9. Graph to Calculate Length of Pipe with Different Area of Town and Physical Configuration

cleaning. This amount will be 18% of the water demand for patio connections (See Table 29). In the case of hand pumps and dug wells the water demand will be similar to that of patio connections. For public wells the amount demanded is similar to that of standposts, and for central distribution points the water demand will be equal to that demanded for stand posts spaced 500 meters apart.

In the case where level of service with water saving devices is utilized, there should be savings of 50% of the water demanded. Therefore, the amount of water demanded will be 50% of the water for the house connection.

Where individual tanks are used, the amount of water required is the same as that for house connections.

Figures 10, 11, 12, and 13 were completed to calculate the amount of water required for different levels of service, STL and percentage of people with electrical service. In order to calculate the amount of water required one must select the proper figure for the STL calculated, then enter with the value of percentage of people with electricity and select the value of W for the different levels of service. These values of W are compared with the value obtained in the section of water resources capabilities. The feasible levels of service will be those where the volume of water demanded is equal or less than the volume of water resources available.

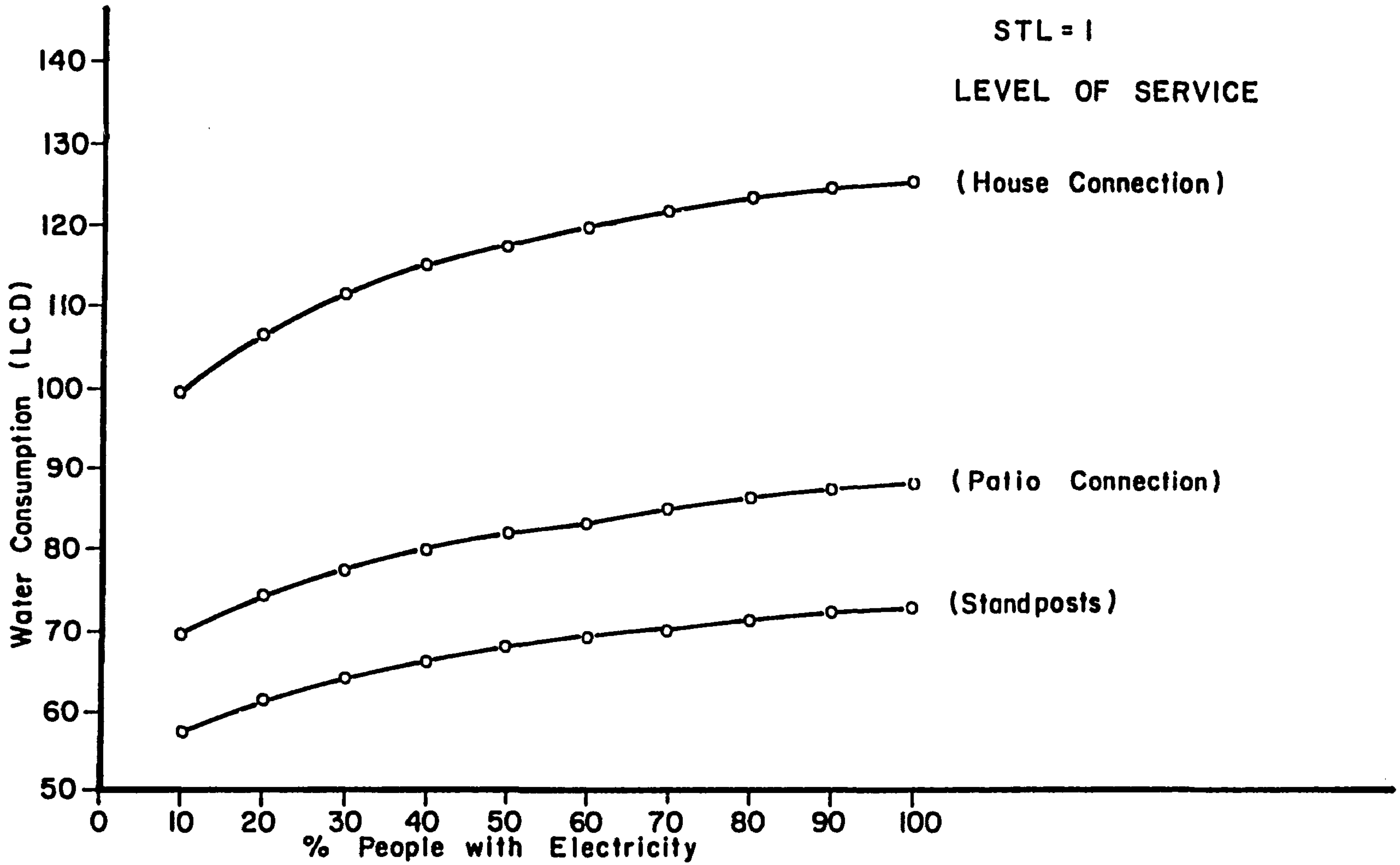


FIGURE 10. WATER CONSUMPTION FOR STL 1

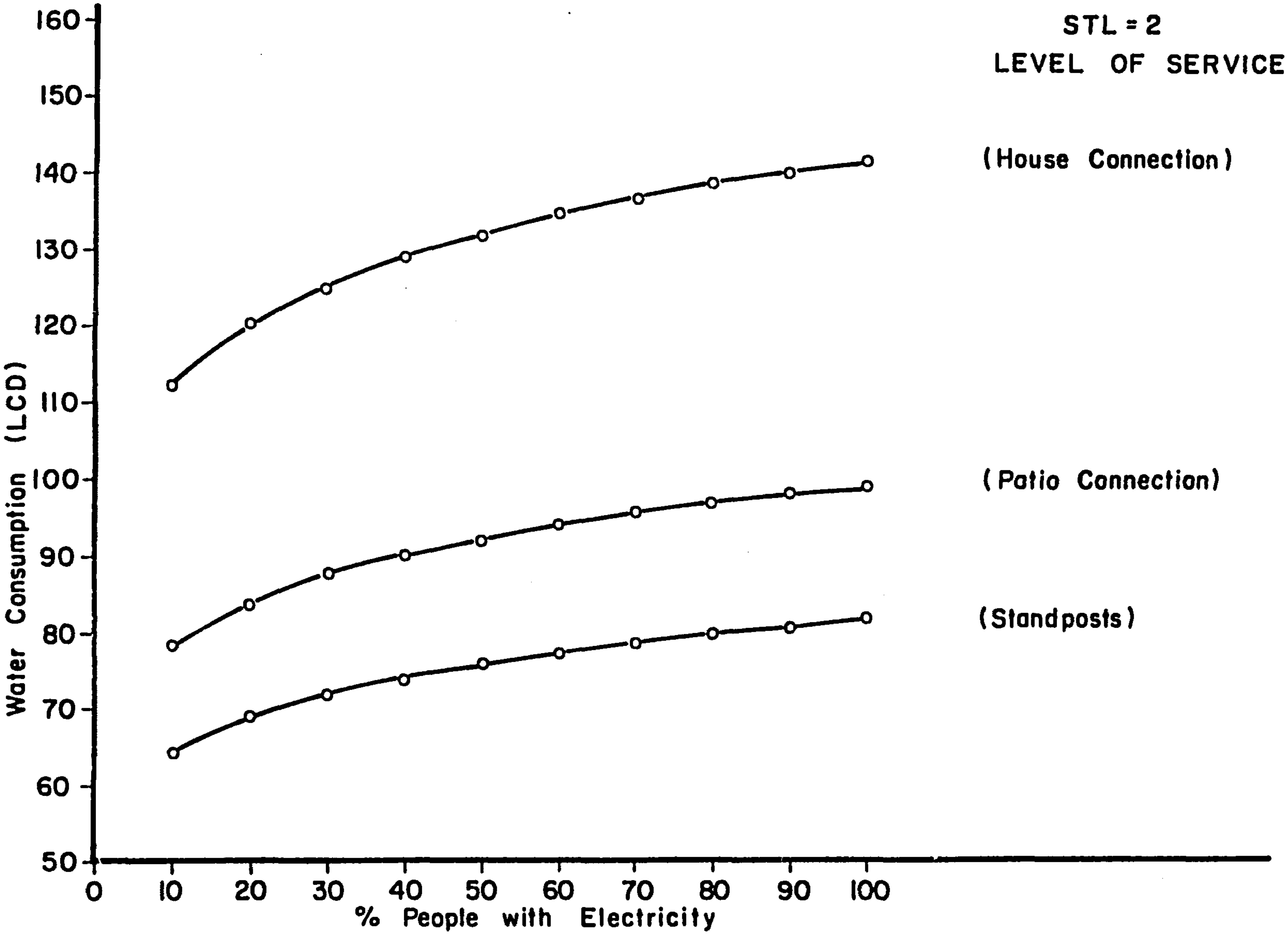


FIGURE 11. WATER CONSUMPTION FOR STL 2

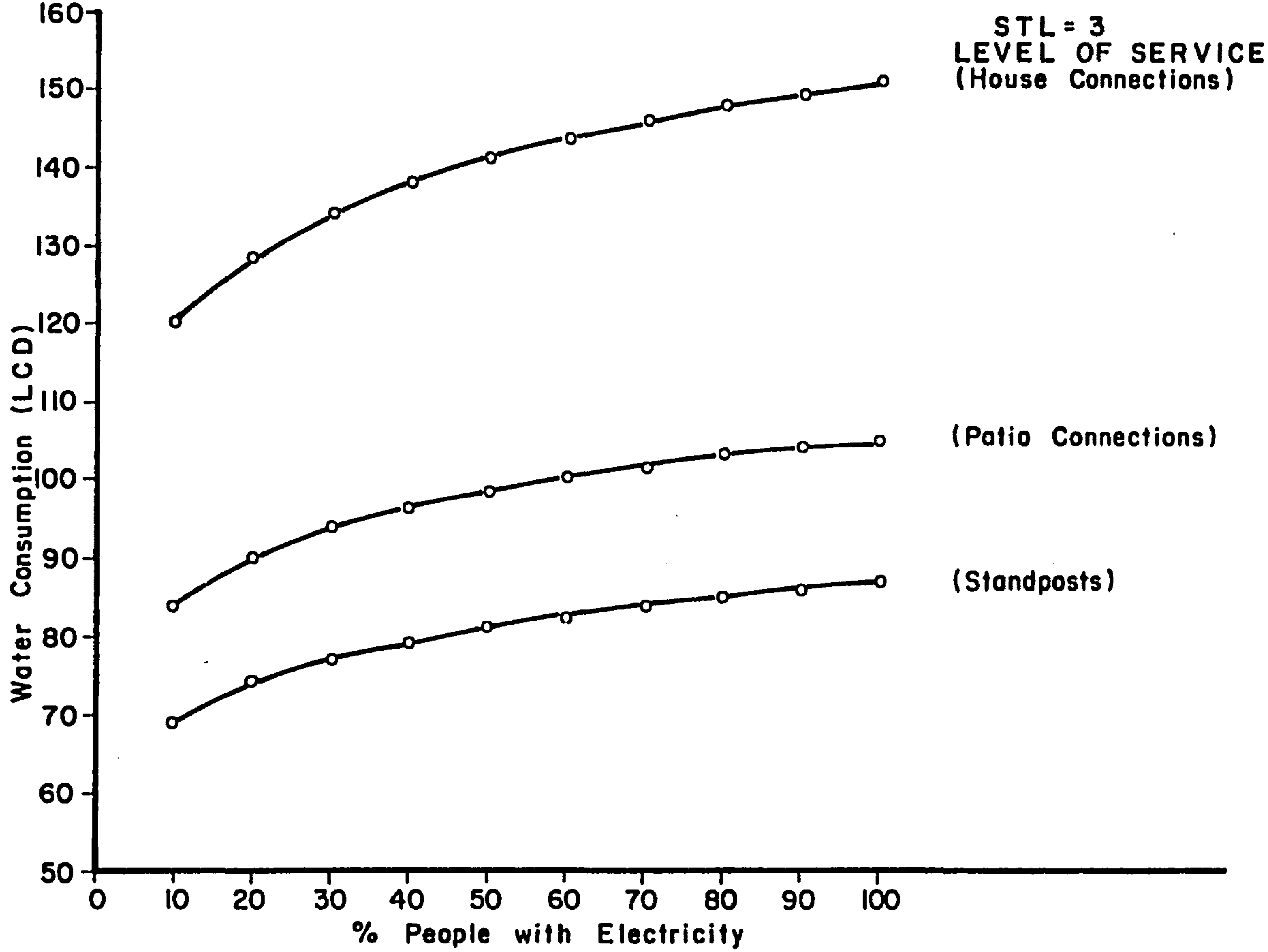


FIGURE 12. WATER CONSUMPTION FOR STL 3

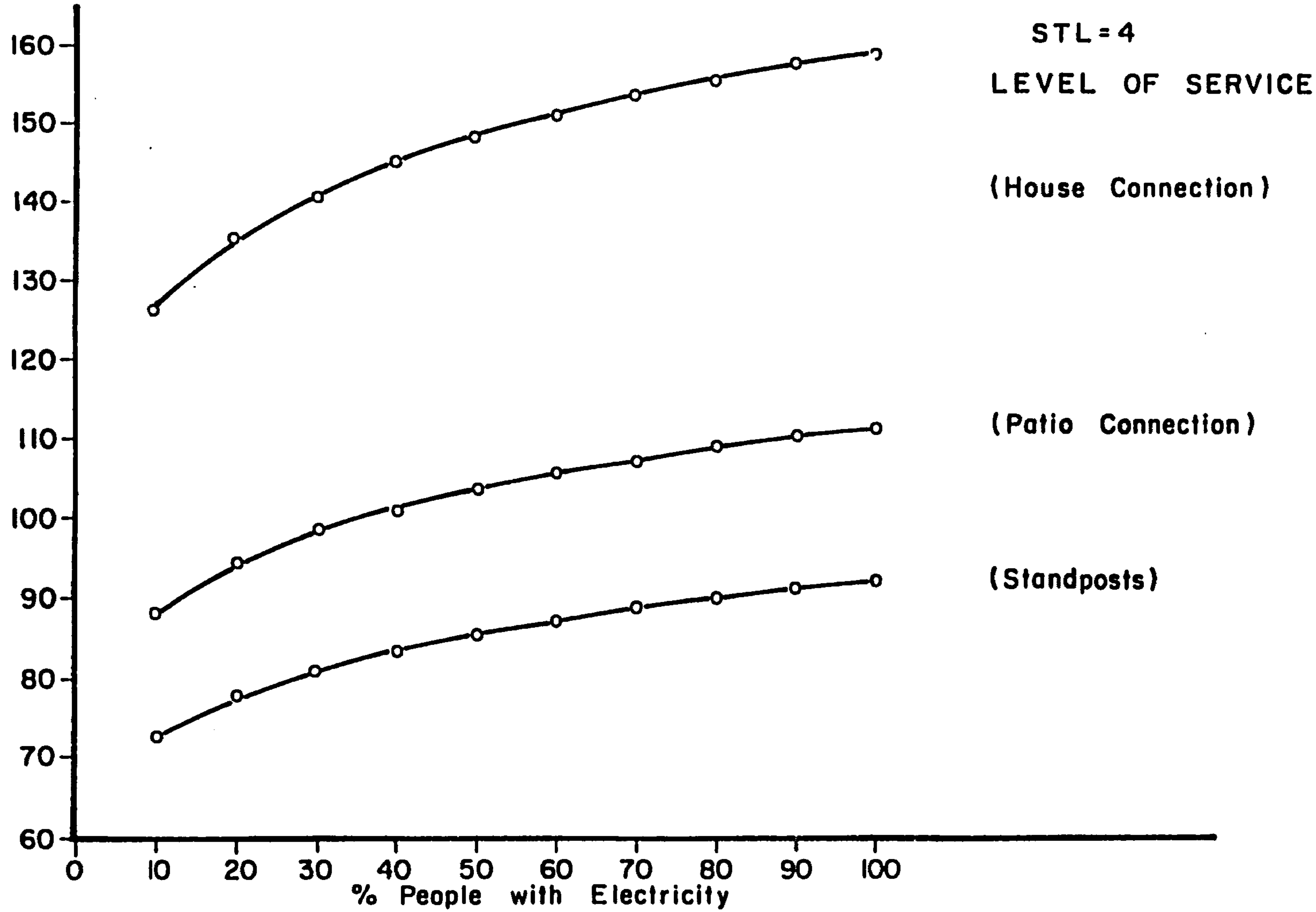


FIGURE 13. WATER CONSUMPTION FOR STL 4

In the event the system is designed to meet the maximum day or the maximum hour demand, the above value must be corrected by multiplying it by the respective value factor of maximum day.

Once the water demand for every level of service is calculated, those values are compared with the amount of water available. Now, those values that exceed the amount of water available are not suitable to be included, therefore, they are deleted in the matrix of system components (Table 28).

TABLE 29

Typical Water Use in Monterrey, Mexico

Use	lcd	%
Toilet	80	40
Shower and Lavatory	60	30
Kitchen	12	6
Drinking	10	5
Clothes Washing	20	10
House Cleaning	10	5
Garden	4	2
Car Washing	4	2
	200	100

Source: Monterrey Water Agency

Number of Employees per Level of Service

An attempt to predict the number of employees required on different levels of service was done in the model. Again, the amount of people required will depend on the tasks (engineering, administration, operation and maintenance, and service), done by the people at the utility. It also depends on the size of the town and the level of service. The size of the town can be defined by the length of the distribution system. The level of service depends on the number of pumping stations, storage tanks, length of service (8 hours, 12 hours, or 24), the method of billing (metered and unmetered), use of guards at standposts, etc.

Access to some studies developed on some water systems in Central America provided information on the number of employees required according to the size of the town. Table 30 shows this information. Unfortunately, this information does not include details about the length of the system and the level of service provided. No attempt was done to develop a predictive equation with this information.

It was felt that more inputs were needed. Therefore it was decided to conduct a mail survey on some towns in Northern Mexico. A questionnaire was formulated, requiring information about water source, water demand, cost of water, type and number of manpower, operation and maintenance activities, etc. Approximately 20 questionnaires were sent naires were sent to different cities. The population varied from 500 to 100,000 inhabitants.

TABLE 30

Manpower Available in some Distribution Systems, in Central America

Population	Power Input	Manpower Administration	Manpower System
5788	P	2	1
3663	G	2	1
3350	G	2	1
1960	G	2	1
1773	G	2	1
1306	P	1	1
1198	G	1	1
1096	G	1	1
827	G	1	1

Less than 50 percent of the questionnaires were returned. Information was analyzed and it was concluded that it could not be utilized for our purposes since the number of people accounted for, not only included that from the water distribution system, but also personnel involved system. Although information obtained was not bad at all since at least an indication on the type and number of manpower for different sizes of population was obtained.

Table 31 shows some of the information obtained during the mail survey.

TABLE 31

Results of Mail Survey for some Communities in the state of Tamaulipas, Mexico

Population	Source of Water	Power Input	Water Demand (lcd)	Cost of Water (US/M)	Manpower U	S	P
63,000	Canal	Pumping	260	0.30	30	4	1
24,000	Canal	Pumping	300	0.16	22	0	0
12,000	Canal	Pumping	432	0.11	2	3	0
7,000	Reservoir	Pumping	220	0.20	10	0	0
5,500	Canal	Pumping	300	Fixed	4	0	0
2,200	River	Pumping	200	0.13	12	0	0
4,290	Reservoir	Pumping	180	0.13	7	0	0

Since the mail survey didn't give the desired results, information obtained from different distribution systems around the United States was utilized. Mayne (63) gathered this information. Data about distribution system lengths and total number of employees, for different water sources were available. Information utilized was that from towns where the source of supply was wells. It was believed that in this way personnel working on the treatment plant was not considered. Data utilized are shown in Table 32. An equation was obtained using the least-square method.

TABLE 32

Data Utilized to Develop an Equation for Number of

Employees vs. Length of Distribution System

Town	Total Employees	Operators	Taps	Length Dist. Lines	M G D	Population
Memphis	481.2	6.0	180,000	2,000	100.0	623,530
Lynnbrook	135.0	10.0	70,287	695	26.4	260,100
Salem	56.4	2.0	21,248	342	16.5	90,000
Vancouver	33.8	2.0	27,671	340	--	80,000
Merced	11.0	--	8,998	122	8.7	31,500
Edmond	14.5	4.0	6,020	125	6.0	23,200
Americus	14.7	7.0	5,000	--	1.8	17,500
Conway	7.3	--	3,438	--	1.2	8,750
Weatherford	13.5	3.0	2,479	85	1.3	8,050
Rogersville	7.6	2.0	2,485	6.5	0.65	6,100
Purcell	4.6	2.0	1,725	--	2.0	5,425
Cordell	7.4	1.0	--	--	--	3,185
Bronwood	1.4	1.0	250	--	0.1050	500

Source: Mayne`Tony "A Systems Approach to Manpower Planning for the Water Treatment Industry," Doctoral Dissertation, Norman, Oklahoma, 1976.

in the system to the length of the distribution system. The equation is as follows:

$$y = 0.52\ x^{0.737} \qquad R = 0.88$$

where

y = Total number of employees

x = Length of distribution system (KMS)

In order to use the above equation in the model, a way to consider the level of service must be included in the equation. Lauria (64) working in distribution systems in LDCs developed an equation that predicts length of distribution systems for different levels of service. This equation is as follows:

$$x = 2267\ A\ R^{-0.8}$$

where

x = Length of distribution system (mts)

A = area of town (has)

R = Level of service (distance between standposts) (mts)

Combining the two equations above, a new one is obtained:

$$y = 0.155\ A^{0.737}\ R^{-0.59}$$

This equation can be utilized to calculate manpower required if the surface area of town and level of service is known. The surface area of a town can be obtained from aerial photographs. Figure 14 shows the number of employees according to the area of town and different levels of

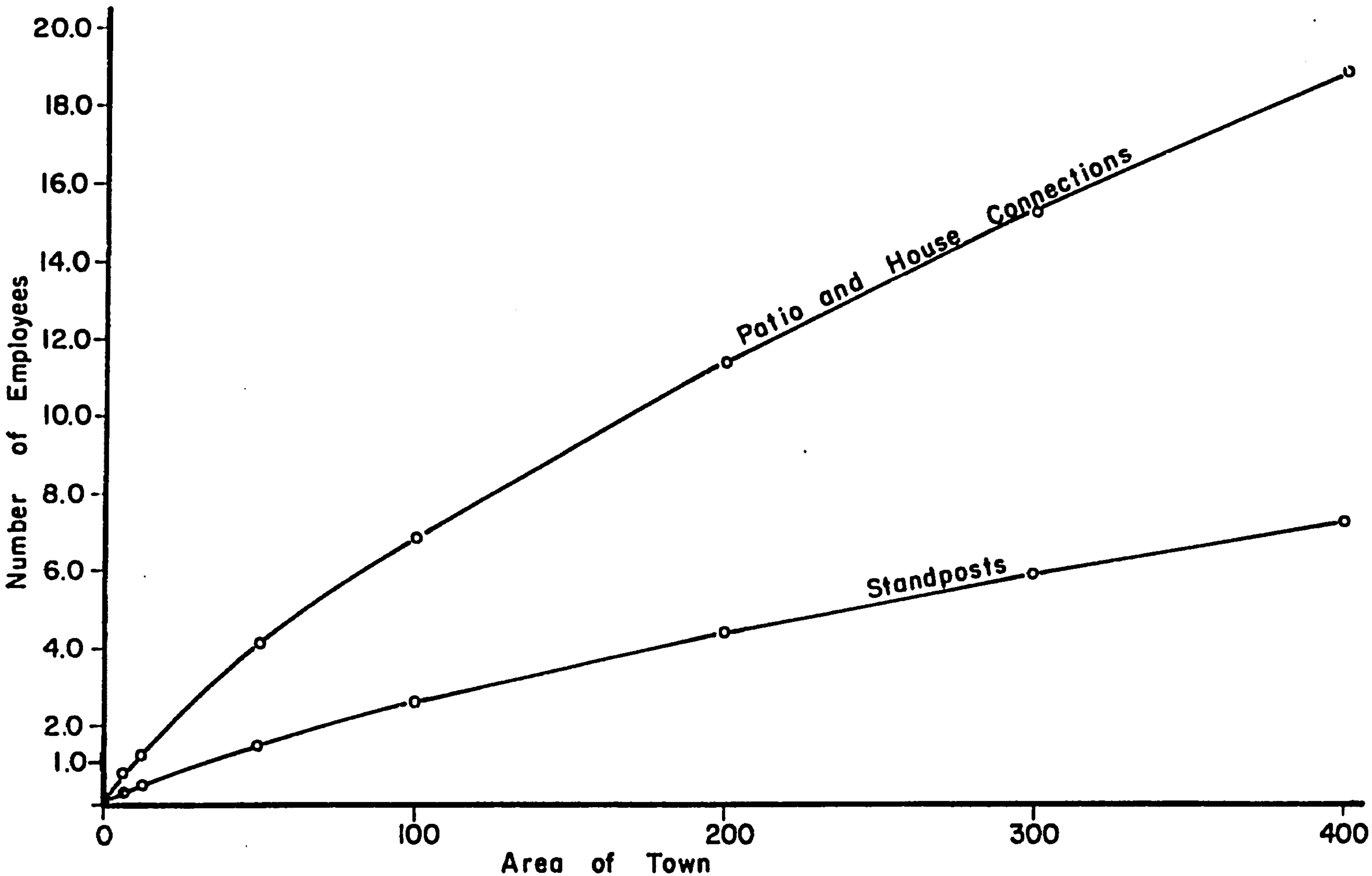


FIGURE 14. NUMBER OF EMPLOYEES BY LEVEL OF SERVICE

service. The levels of service considered are for standposts, patio and house connections. No attempt was made to consider individual sources of supply, because in this case the O & M is done by the household.

It must be realized that the developed equation is applicable for water distribution systems that will work 24 hours a day, 7 days a week, 52 weeks a year. In the event that intermittent service is considered, necessary corrections must be made to the equation.

In case of standposts, some local water authorities would like to have a guard to collect water revenues and operate and maintain the standpost. In other instances, service will be for 8 hours or 12 hours, instead of 24 hours. The prediction equation does not take into account those particular cases. It must be remembered that this is a general approach and care must be taken when using the model. An adaptation for local norms and situations must be done before it is utilized.

Costs

One of the objectives of the model is to give cost estimates on construction, operation and maintenance. It is necessary to have an estimate of how much people need to pay for different levels of service available to them in order for them to decide for which level of service they are willing to pay. Appropriate technology is being developed in different countries around the world. Some technologies are still not developed or practiced in some countries. Therefore local data on costs are not always available. Costs from other countries may not be utilized because of the difference in salaries and cost of materials. Construction, operation and maintenance costs vary from one region to another in a country, reflecting the scarcities and surpluses of materials and manpower. The relative amount of money needed for materials and manpower in relation to the total cost of the project varies according to the technology utilized for construction, operation and maintenance.

In order to solve that difference, a method called cost transfer, developed by Reid (65) may be utilized to calculate costs in one country, using costs from a second country. The cost transfer method is explained in Appendix D.

In any instance, if the model is going to be utilized in a specific country, local costs can be employed. In the event that local costs for a specific technology were not available, costs from another country may be used if they are modified to reflect the conditions of the first country.

Calculation of Costs Equations

In our case, construction, operation and maintenance costs were available for some of the components utilized in water distribution systems. Some of the costs were from the United States, others from developing countries. Therefore, the cost transfer method was utilized to normalize all the costs for the year 1970. Data utilized and calculations are shown in Appendix D. The equations obtained are shown in Table 33.

TABLE 33

Equations Obtained
Costs (1970 Dollars)

System Component	Capital	O & M
Pumping	$1909\ V^{0.49}$	$32.7\ V^{0.78}$
Distribution	$205\ V^{1.08}/P_D^{0.46}$	$1.29\ V^{1.08}/P_D^{0.46}$
Storage		
Elevated	$241\ V_1^{0.84}$	$6.73\ V_1^{0.62}$
Ground	$17000 + 10\ V_1$	$-4388 + 755 \ln V_1$
Private	$5.9 + 31\ V_2$	0
Hand Pumps[a]	$88.0 - 5.18\ P_1$	0[b]
Stand Posts	350.00/unit	120.00/unit
Roof Catchment[a]	$67 + 3.87\ V_3$	0
Dug Wells[a]	230.00	0
Drilled Wells[a]	165.00	0
Saving Devices[a]	15.00	0

V = Design Volume (M^3/day)

P_D = Population Density (People/Hectare)

V_1 = 60% of Design Volume

V_2 = 60% of House Consumption (M^3)

V_3 = 18% of House Consumption times number of days of dry season (M^3)

P_1 = Thousand of pumps

a = Cost per unit

b = In the case of Public Hand Pumps, operation cost is $120.00/year

APPLICATION OF THE MODEL FOR THE SELECTION OF WATER LEVELS OF SERVICE IN A CENTRAL AMERICAN COUNTRY

CHAPTER IV

INTRODUCTION

The model developed was applied to a country in Central America. This country is planning to enhance some already constructed water distribution systems in some towns and build new systems in some others. For our purposes a province was selected for the application of the model. In that province, only four communities were selected. Two communities formerly had a water distribution system, but they were destroyed by an earthquake. Therefore a new system will be constructed in each of them. The region has grown at an annual rate of 2.3 percent from 1950 to 1980. Approximately eight percent of the people have an annual per capita income of $1,200 or more, 85 percent do not exceed more than $600 and 52 percent have an income of $100 or less.

A study has been conducted to determine costs of water distribution components. Information about construction and operation and maintenance costs is already available. A water demand model for the Central American countries will be used to forecast water needs. Water sources have already been determined, so water resources available are known. Energy available will be determined from aerial photographs.

A questionnaire (See Appendix E) is going to be used to determine the socio-technological levels of the four communities. The questions are constructed so that a minimum amount of effort is required by the respondent, and the user of the model can easily fit the data into the various screening mechanisms.

Description of the Communities under Study

Real names of communities are not used. They will be called Community A, B, C, and D.

City A

The actual population is 7200 people. It has an annual population growth rate of 3.2. They are willing to pay 5 percent of their salary for water rates. The water supply comes from deep wells. A well has been drilled and has a potential of 65.7 liters per second. People have agreed that one level of service must be provided to the population. The actual level of service provided to the population is a public well. Only 50 percent of the community is receiving the benefit from the water system.

City B

The actual population is 70,000 people. The annual population growth rate is 4.7 percent. They are willing to pay five percent of their salary for water rates. The water supply source is a river that passes nearby. A treatment plant has been constructed, with a capacity of 500 l/s. People have agreed to receive different levels of service, according to the capacity to pay for it.

City C

The actual population is 2,700 people. The annual population growth rate is 0.84 percent. They are willing to pay five percent of their mean salary for water rates. The water supply source will be a lake near the community. The lake has an unlimited capacity. It is planned to construct a water treatment plant. Its capacity will be predicted later with the use of the water demand model. People have agreed to receive only one level of service. At present, they don't have a water supply system. It is planned to give water to 100 percent of the population. Vendors are being used to supply the water needs of the community.

City D

The actual population is 5,130 people. The annual population growth rate is 3.0 percent. They are willing to pay 2.5 percent of their mean salary for water rates. The water supply source will be groundwater from artesian wells. The wells have a capacity of 30 lps. No other water source is around at this time. People have agreed to receive different water levels of service. Currently they don't have a water supply system. Dug wells and vendors provide the water to the community. It is planned to give water to 100 percent of the population.

Application of the Model

The model is going to be applied to these four communities. It is understood that a fixed amount of money is available to every province, and that money resources are limited in such a way that money invested in one community is depriving the other community of its use. Also, water resources are supposed to be unlimited; then no water competition exists between communities.

Results of the questionnaire applied are shown in Table 34.

Level of Socio Technological Development

The weighting factors shown in Table 24 are applied to the answers on the questionnaire. Total scores are as follows:

Community	Score
A	70
B	89
C	45
D	51

TABLE 34

Answers to Questionnaire for Selecting Socio-Technological Level

Question	Answers City A	City B	City C	City D
1	2	3	2	2
2	1	2	1	1
3	3	3	3	3
4	4	3	5	4
5	2	2	2	2
6	12+	12+	12	12
7	NA	NA	NA	NA
8	1	1	2	2
9	1	1	1	1
10	2	1	2	1
11	1	1	2	2
12	1	1	2	2
13	2	1	2	2
14	1	1	2	2
15	1	2	1	1
16	1	2	1	1
17	2	2	2	2
18	2	2	2	2

Using the total score obtained and comparing it with the required score for different levels of services, we know that the communities under study have the next STL.

Community	STL
A	3
B	4
C	2
D	2

Manpower Capabilities

As explained before, the decision rules developed for the model have provided the following manpower constraints for each of the four socio-technological levels:

1. In Level 1 communities, only unskilled or semiskilled manpower is available (Category C only).
2. In Level II communities and in Level III communities with populations under 50,000, only unskilled and some skilled labor is available (Categories C and B only).
3. In Level III communities with populations over 50,000 and in Level IV communities, all categories of manpower are available (Categories A, B, and C).

Based on these guidelines, the communities under study have the following capabilities:

City	Manpower Capabilities
A	Unskilled, skilled
B	Unskilled, skilled, professional
C	Unskilled, skilled
D	Unskilled, skilled

<u>Material Capabilities</u>

To determine material capabilities, information about equipment and material for construction, operation, control, maintenance, and repair was obtained on each community. This was made possible by using the list of materials shown in Table 25. A delivery time of 24 hours was considered. It was assumed that material was not available if more than 30 percent of its subcomponents were not available. A summary of the availability of materials is shown below:

Material	Availability			
	City A	City B	City C	City D
Construction	Yes	Yes	Yes	Yes
Operation	Yes	Yes	Yes	Yes
Control	No	Yes	No	No
Maintenance	Yes	Yes	No	No
Repair	Yes	Yes	Yes	Yes
Groundwater	Yes	No	No	Yes
Sewerage	No	Yes	No	No

Natural Resources Available

Energy Available

Maps obtained from aerial photographs were used to locate water sources and differences of elevations. Results obtained are as follows:

City	Distance to Source	Energy Available (Mts)
A	4 kms	50
B	0 kms	0
C	1 km	1
D	1 km	30

Water Available

Information about water availability was gathered.

City	Source	Amount (M3/day)
A	Ground Water	5,700
B	River	43,200
C	Lake	Infinite
D	Artesian	26,000

Levels of Service Available

Information about manpower and materials capabilities for each town was utilized to select the suitable levels of service of each community.

Results of this screening were as follows:

System Component	City A	City B	City C	City D
		Availability		
Engineering	No	Yes	No	No
Administration	No	Yes	No	No
Pipes	No	Yes	No	No
Pumps	No	Yes	No	No
Valves	No	Yes	No	No
Meters	No	Yes	No	No
Reservoir	No	Yes	No	No
Prime Movers	No	Yes	No	No
Energy Sources				
Solar	No	Yes	No	No
Wind	Yes	Yes	No	No
Controls	No	Yes	No	No
Standposts	No	Yes	No	No
Roof Catchment	Yes	Yes	No	No
Individual Wells	Yes	Yes	No	No

These results were obtained considering all tasks as necessary. In the event that only the routine and necessary tasks are considered to determine availability of materials, then all system components will be available for communities A and B. Communities C and D will have available all systems components except pumping, controls, and prime movers.

The levels of service available for each community were as follows:

City A: Roof catchment, dug wells, individual wells, hand pumps.

City B: All levels available.

City C: Same as A.

City D: Same as A.

Water Demand

Water demand was calculated by first calculating per capita demand and then multiplying it by the design population. The per capita demand was calculated using the water demand model. The design population was obtained using the logarithmic method and the growth rate factors from the socio-technological questionnaires. Results are as follows:

Population Forecast

City	Actual Pop.	Growth Rate	Design Pop.
A	7,200	3.20	9,866
B	70,000	4.70	110,800
C	2,700	0.84	2,935
D	5,130	3.00	6,894

Per capita demand

City A (50% electricity, STL = 2)

Level of Service	Wd	Wt
	lcd	M3/day
Roof catchment	ls	N.A.

Dug Well	82	810
Public well	75	740

City B (90% electricity, STL = 4)

Level of service	WD	WT
	lcd	M3/day
Roof catchment	20	--
Dug well	110	9504
Individual well	110	9504
Rural pipeline	75	6480
Vendors	75	6480
Standposts	91	7870
Patio Connections		
Ave	110	9504
pk day	220	19000
pk hour	330	28500
House connections		
Normal (avg. day)	157	13600
Saving (avg. day)	79	6800
Storage (avg. day)	157	13600
Normal (pk. day)	314	27000
Saving (pk. day)	157	13600
Storage (pk. day)	314	27000
Normal (pk. day)	314	27000
Saving (pk. day)	157	13600
Storage (pk. day)	314	27000

City C (90% electricity, STL = 2)

Level of Service	wd	wt
	lcd	M3/day
Dug Wells	97	8380
Roof Catchment	25	--
Private Well	97	8380
Public Well	80	6900

City D (80% electricity, STL = 2)

Level of service	wd	wr
	lcd	M3/day
Roof Catchment	25	--
Dug wells	96	8300
Private well	96	8300
Public well	79	6800

<u>Energy Requirements</u>

To calculate energy requirements, method explained in Chapter III will be utilized. First, the side length of the system will be calculated using the aerial map, then it will be multiplied by the optimal slope. Optimal slope in this Central American country has been found to be 0.002. The minimum pressure required is 10 meters (14.2 psi), at the critical point. In this case, the critical point was assumed to be at the farthest point of the water distribution system. Also it was assumed that the optimal slope does not vary with the diameter.

City	Length (Mts)	hf	Min. Pressure	Head Required
A	2000	4	20	24
B	7000	14	20	34
C	1800	3.6	20	23.6
D	2000	4.0	20	24

From here we can see that cities B and C need to use a pumping system, or one source system.

Manpower Requirements

They are going to be calculated using the equation developed in Chapter III or using Figure 14, also in Chapter III. The equation developed in Chapter III is as follows:

$$y = 0.95\ A \qquad R$$

Where

y = Total number of Employees

A = Area of Town (HAS)

R = Level of service (distance between standposts)

Next results were obtained:

City	Level of Service	Area	#Employees
A	Roof catchment	100	0
	Dug wells	100	0
	Private wells	100	0
	Public wells	100	3
	Vendors	100	2
B	Roof catchment	1200	0

	Dug well	1200	0
	Private wells	1200	0
	Public wells	1200	17
	Vendors	1200	20
	Standposts	1200	17
	Patio Connections	1200	29
	House Connections	1200	29
C	Roof catchment	10	0
	Dug wells	10	0
	Private wells	10	0
	Public wells	10	1
	Vendors	10	1
D	Roof catchment	66	0
	Dug wells	66	0
	Private wells	66	0
	Public wells	66	2
	Vendors	66	2

<u>Cost Calculations</u>

Once levels of service suitable for each community were obtained, then the cost for each system was calculated.

<u>City A</u>

System	Cost (1000 dollars) Capital	O&M	$/Month
Private well	407	0	3.54
Roof catchment	198	0	1.72
Public well	13	35	0.11

Dug wells	378	0	3.30
Vendors	--	--	--

<u>City B</u> Cost Calculations

Level of Service	Costs (1000 dollars) Capital	O&M	Total	$/Month
Roof catchment	2329	0	2329	1.80
Standposts				
Pumping	625	649	1274	0.99
Pumping & Storage	703	713	1416	1.10
Patio Connection				
Pumping	506	304	810	0.63
Pumping & Storage	597	368	965	0.75
House Connection				
Normal				
(Ave. day)				
Pumping	692	404	1096	0.85
Pumping & Storage	814	470	1284	0.99
(Pk. day)				
Pumping	1302	700	2002	1.55
Pumping & Storage	1528	770	2298	1.78
Saving				
(Ave. day)				
Pumping	659	233	892	0.69
Pumping & Storage	728	296	1024	0.79
(Pk. day)				
Pumping	969	404	1373	1.06
Pumping & Storage	1091	470	1561	1.21
Private				
Pk. day	1125	404	1529	1.18
Pk. hour	1734	700	2434	1.89

City C

Level of Service	Capital	O&M	$/Month
Roof catchment	58	0	1.69
Vendors	--	--	--

City D

Private well	284	0	3.53
Roof catchment	137	0	1.71
Public well	9	25	0.11
Dug wells	264	0	3.29
Vendors	--	--	

Screening for People's Capability to Pay

Using economic data from the region and supposing that people will pay two percent of their salary, we have the following figures:

Annual Income (dollars)	% People	Capability to pay (dollars)
- 1200	8	5.00
1200 - 600	12	3.75
600 - 100	33	0.73
100	52	0.40

Comparing these figures with costs of the different levels of services, we have the following suitable levels.

City A 20 percent of the people can afford a private well in their home. The rest of them will have to live with public wells with hand pumps. Dug wells and roof catchment are too expensive for them.

City B 20 percent of the town can afford any level of service. Thirty-three percent can afford to have public wells, standposts, patio connections with average demand and private storage tanks, house connections with ground storage tanks and average daily demand, house connections with elevated storage and water saving devices.

City C Water vendors are the only service that can be provided. Twenty percent of the population will have no problem paying for the water rate. Thirty percent of the population will pay six percent of their income, and 52 percent will need to pay eleven percent of their income.

City D Private wells are available for 20 percent of the people. The 80 percent remaining can afford only public wells.

CHAPTER V

Conclusions and Recommendations

A methodology that selects the most suitable level of service of a water distribution system for a given community has been obtained. Material, natural resources, manpower availability, and ability to pay are considered in determining the most suitable level of service.

Different levels of service were selected and new levels (for time and reliability) were created. All the available technologies for water distribution systems were inventoried. A water demand model was obtained using data from Central American countries. A method to predict energy requirements was developed, then available technologies were related to the different levels of service. Requirements of manpower, equipment, and materials were defined for every technology in the inventory. A matrix of levels of service and technology was created. Finally, cost equations for different components in a water distribution system were developed.

This methodology can be added to the predictive methodology for the selection of suitable water and wastewater processes, and to the predictive methodology for the selection of water sources and conveying systems, to create a methodology that selects water supply and wastewater systems. This methodology can provide to planners the ability to assess the general level of service, the amounts of water, the costs of water distribution systems, and the manpower required, prior to detailed engineering determination. Also, it can provide financial guidance in making preliminary decisions concerning water distribution systems. It will assist in relating cost, level of service and resources. Further, it will aid the consulting engineers of developing countries in using a system approach and in identifying the major alternatives. Finally, this methodology aids in creating a simple approach to seeing the different levels of service, in order to promote greater community involvement. A more detailed discussion of the conclusions obtained follows:

Water Demand Model

A water demand model has been obtained for the Central American countries. This model shows that water demand is directly proportional to the socio-technological level of development and to the economic conditions of the community considered, but it is inversely related to the level of service.

The model shows that the level of service (distance to water) is the single factor with the most impact on water consumption. Consumption on standposts is 42 percent smaller than average consumption in house connections.

Consumption in patio connections is 21 percent smaller than house connections. The water consumption in STL 1 communities is 21 percent smaller than consumption in STL 4 communities.

Temperature and rainfall were not taken as variables in the model. These values are very similar in each of the studied communities.

Manpower

A statistical analysis of the tasks performed in a water distribution system during the operation and maintenance phase shows that professionals are required in only 9 percent of them, skilled personnel 49 percent, and unskilled 100 percent. During the engineering phase, professionals are required in 75 percent of the tasks, and skilled personnel 100 percent. During the administration phase the percentages are 33 percent professionals and 100 percent skilled labor.

All tasks were divided as routine, scheduled, or emergency. They were further subdivided as necessary and desirable. If only the routine and emergency tasks (both necessary and desirable) are considered, 9.2 percent of those tasks need professionals and 48 percent need skilled labor. For those necessary tasks, both routine and emergency, 10.5 percent need a professional and only 47 percent need a technician.

From this it can be shown that sending professionals to obtain their higher education (Masters and Ph.D.s) in the sanitary/environmental field is a waste of money. For example, in the case of Mexico, the money invested in a student sent abroad for five years can be better utilized to educate 75 sanitary technicians for an entire year, or to run a rural school for five years.

From these results it can be concluded that in water distribution systems and in populations ranging from 500 to 100,000, professionals are required only during the engineering phase and not in the operation and maintenance. Therefore, the inavailability of professionals is not a limiting factor in the selection of a level of service.

Material Requirements

A statistical analysis also was performed on materials requirements. Equipment and materials for repair, maintenance, and control are the most frequently utilized in the tasks analyzed. Equipment and material for control is required in 36 percent of the tasks. Equipment and material for maintenance is required in 44 percent of the tasks. In 39 percent of them, repair equipment and material is required.

In the tasks analyzed, 56 percent of them can be scheduled, 40 percent are routine operations, and 44 percent can be classified as emergency. Moreover, 50 percent of the tasks are necessary and 50 percent are desirable. Routine and emergency tasks cover 84 percent of all of the tasks. Of these, 50 percent are considered necessary for the system.

Technology

From the tasks analyzed, it can be seen that technology is available for all levels of development. That is, technology is varied to perform all of the required works. The most advanced technology is utilized in the control of the system, but alternate, less complicated technology is available. The availability of spare parts may be due to economic problems not to the unavailability of them. Technology is not limiting, as in the case of water and wastewater treatment.

Cost Equations

A great deal of effort was made to obtain data on costs for different water distribution systems. Costs equations were obtained when enough data were available. The method of minimum squares was utilized to obtain the equations, the coefficient of determination was calculated to monitor the statistical validity of the equation.

From the obtained equations, it is possible to see that capital costs of pumping stations are higher than capital costs of distribution systems in communities with water consumption smaller than 3700 cubic meters (64,000 people for STL 1 and standposts to 8,000 people for STL 4, and house connections with PK demand). In communities where water consumption is above that value the cost of the distribution system is higher. In communities of 100,000 people the cost of the distribution system is 63 percent of the total cost, while the cost of the pumping system is only 10.6 percent.

The operation and maintenance cost of the pumping station is very high when compared with the operation and maintenance costs of the other systems components (distribution, storage tanks, etc.). For example, in a community of 100,000 people, this cost is 80 percent of the total cost while the distribution system accounts for only 9 percent and the storage tank 11 percent. Fifty percent of the operation and maintenance cost is due to energy spent in pumping. This is the reason for investigating alternate sources of energy (solar and wind) in LDCs, especially in those countries along the equator. Capital costs for elevated tanks are higher than capital costs of distribution systems in communities with water consumption of 4,450 M^3 (76,000 people for STL 1 and standpost service to 9,400 people for STL 4 and house connection with peak demand).

Manpower Equation

An equation that predicts manpower requirements has been developed. The equation gives an estimate of number of employees required using data on area of town and level of service. The number of employees is proportional to the area of the community and inverse to the level of service. The original equation obtained was only proportional to the length of the distribution system. The equation obtained was tested against the data obtained from the mail survey carried in Mexico, the calculated values are 50 percent smaller than the values obtained on the survey. For example for a city of 63,000 and density of 200, the equation gives 17 persons while the information obtained shows 35. This big difference is due to the fact that in the mail survey, personnel involved in the O & M of the treatment plant and the sewerage system was taken in account. The equation performs better in populations below 10,000 people. Another reason for this difference may be that in Mexico some distribution systems employ more people than necessary because of the approach that the government takes to solve the problem of unemployment. The last reason is that data utilized to develop these equations came from United States systems where the degree of automation is high. In any instance, this model is developed to be utilized for planning purposes, therefore, accurate results are not needed.

Ability to Pay

In order to determine the ability to pay we need to take in account the salaries people earned in LDCs. Approximated 8 percent of the people have an annual per capita income of $1,200 or more, 52 percent have an annual per capita income of $100 or less, and 85 percent do not exceed more than $600. Assuming they are able to pay 5 percent of their income, then 52 percent can pay $5.00 a year for water rates. That means they can receive only 12.5 liters per capita per day (less than the amount required for cooking and drinking). This means that with the present cost of water, we are not able to give an adequate water service to 52 percent of the people, as proposed by the World Health Organization and the United Nations. To achieve that, water systems must be subsidized or a better distribution of income must be obtained (socialistic approach).

Water Saving Devices

There are some interesting conclusions that can be made, the most important being that we have taken the wrong approach in supplying water to the LDCs. That is, the approach utilized has not been the optimum one. We have employed the standpost level of service to reduce the cost of supplying water. In so doing we have taken the water away from the consumer instead of bringing it closer to him.

With the latest discoveries in water saving devices, this approach is obsolete. This conclusion is based on the results obtained from the water demand model and costs equations developed in this research. By using savings devices, water consumption savings of up to 50 percent are obtainable. To obtain the equivalent reduction in water consumption using the standpost system, it is necessary to locate the standpost an average of 330 meters away from the consumer. The immediate benefits of using water saving devices are those of time saved and energy saved in getting water, since water will be available inside the home. Water saving devices is a technology that can be more easily accepted and utilized by local people. Neither professional nor high technology need to be used.

Among the recommendations that can be made out of this study are the following:

1. A water demand model that considers climatological conditions must be obtained to be used around the world.

2. The results obtained must be shown to the people related to the water industry in less developed countries to make them aware of some of the findings.

3. More detailed studies of water saving devices and their uses in less developed countries must be made.

4. An integration of this model with the other methods previously developed must be done.

5. A computer program for different technological

levels (hand programmable calculators, home computers, and computers) must be obtained.

6. A catalog of all the technologies utilized in water distribution systems must be created. This catalog must include the costs and efficiencies of these technologies.

7. More consideration must be given to the use of solar and wind energy to substitute for fuel engines, especially in those countries where gasoline must be imported.

8. Ways to reduce costs of water must be obtained to eliminate water subsidies and allow money to be invested in other facilities.

9. Stop sending professionals to developed countries to get their higher education.

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APPENDIX A

Socio Technological Factors

These inputs are defined as the sum of socio-cultural and socio economic factors relevant to the model that are essential parts of any community or group of people. The variables were selected on the basis of the availability of related data at the local level and their ability to reflect the level of development at the community level. The characteristics of the eighteen variables used are briefly described below:

Level of Education

Five broad levels of education are specified: none, primary, high school, technical institute, and college. The economically more developed communities generally provide opportunities for higher levels of educational attainment.

Labor Force Distribution

Distribution of the labor force is expressed in terms of the percentage of professional, skilled, and unskilled workers 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 activities. 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.

Income

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

Non-Indigenous Workers

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

Education Investment

In this case, it relates to school operators, highest grade offered by local school, distance to nearest high school, availability of technical and vocational training, and compulsory primary education. 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 of the community 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 is an indicator of the level of development, and generally, the higher the grade offered, the higher the level of development.

In-Service Training

In-service training programs are generally not 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.

Local College

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. The availability of a college or university education indicates a high level of development.

Ability to Pay

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. The response to this question is not used in computing the STL. If response (2) is indicated then a lowest maintenance cost alternative will be sought by the model.

Unemployment

Rampant unemployment is characteristic of communities at a low level of development, and the bulk of those unemloyed will be unskilled workers. Generally, the unemployment problem descreases as the level of development increases.

Extension Services

Agricultural extension services tend to improve as the level of development increases. The main hurdle at lower levels of development is that the appropriate organizational and institutional structures lack the means to implement and administer extension services.

Schools of Local College Students

If most or all of the college students receive their higher (third level) education in neighboring communities aboard, this indicates that the community is at a lower level of development.

Level of Technology Available

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.

Government as a Labor User

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 activities tend to increase.

Public Employment Services

Public employment services are generally only available at high levels of development.

APPENDIX B

Description of Socio-Technological Level Communities

In the event that information obtained not be enough to fill out the questionnaire, an alternative approach exists. This approach describes the characteristics of each of the levels of development that are considered so the planner can determine the STL of the community under study by looking at the description of each level.

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 the main public and private institutions. At this stage the indigenous human resources are insufficient and almost without exception external aid is required. Normally, the Level I community is essentially an agricultural society with the majority of the population of the area being rural or nomadic and engaged in subsistence activities contributing marginally to a market economy.

There is a critical shortage of all categories of high-level 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 the equivalent is certainly less than one percent, and in some cases, it may be closer to one-tenth of one 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.

The education in Level I communities 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, for the most part, are 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 unable to develop enough strategic high-level manpower (particularly engineers, scientists, and highly qualified teachers). 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

The secondary school enrollment ratio is three times higher than in Level II communities and the primary enrollment is fifty percent higher. There is available practically all of the high-level manpower needed 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.

The quantity and quality of high-level manpower in the Level III communities is far less than those in Level IV communities. The Level III community is a follower rather than an originator of scientific, engineering, and organizational innovations. 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 Level IV communities. In the area of manpower, though capable of supplying initial minimum needs, institutions 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 there is insufficient prospective demand. Industrialization is well advanced in Level III communities. Most of them are no longer predominantly agriculturally oriented. Transport, power, and communication are, on the whole, well-developed. There are, however, bottlenecks in such areas as electric production, railroad service, and irrigation, partly because of a shortage of the skilled and technical manpower to build and operate them.

Like many of the Level I or II communities, some of the Level III communities have surpluses of unskilled human resources. Generally, the salaries paid to high-talent manpower in science, engineering, and managerial positions in most of the Level III communities are sufficient to attract young people to train for these fields. Government administrative posts also carry high prestige and high salaries. 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 has 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 more than three times the number of students enrolled in first-level (primary) education than do Level I communities, and about one-fifth more than Level III communities. The percentages of those enrolled in scientific and technical facilities are higher, and of those enrolled in humanities, fine arts, and law, lower in

Level IV communities than in the other communities. Finally, Level IV communities spend more of their income on public education than do Level III communities.

APPENDIX C

Inventory Technology

The next paragraphs are intended to describe the technology available on every system component of a water distribution system.

Distribution

Catchment Roofs

The use of rain catchment as a source of drinking water is practiced extensively in various areas of the world. Rainwater catchment are a form of renewable energy technology, using solar energy, which evaporates surface water, both purifying and elevating it. There are two main types of rainwater catchment systems. The catchment can be the ground itself, which has been made impervious by either natural or artificial means. These types of systems are usually located in rural farm areas where the water is used for irrigation, and drinking water for farm animals and humans. The other type of system uses the roofs of houses as the catchment area and is usually used for domestic consumption within the house. The components of the catchment roofs are simple: a catchment system, a conduit system and a storage tank. A sediment trap or other means of disposing of dirty water may be added; and if the storage tank is below the ground surface, a pump will be required to extract the water. Finally, a device may be needed to purify the water.

Wells

Individual wells are commonly utilized in developed developed countries. Among them are the ones that follows:

Driven Wells

They are the simplest and least expensive of all well types. They are constructed by driving into the ground a drive-well point which is fitted to the end of a series of pipe sections. The drive point is of forged or cast iron. Drive points are usually 1 1/4 or 2 inches in diameter. The well is driven with the aid of a maul or a special drive weight.

Hand-Drilled Wells

They are drilled by using a 10 inches auger turned by two labourers. When the hole has reached the required depth, it is lined with slotted 6 inches diameter PVC pipe casing and gravel-filter packing is applied. This method is the cheapest one for drilling wells for hand pumps, but it is only applicable in sand and soft materials where it is not difficult to drill with such an auger.

Mechanically Drilled Wells

A percusion rig is used where the aquifer is deeper or the material is harder and cannot be penetrated by hand drills. The borehole is cased with slotted 6 inches diamter PVC pipe with gravel packing. One foreman, four rig-crew members, and three labourers can produce one well per week. This method is the only one practical in cases where many wells must be produced in a short period of time. Its main disadvantage, however, is that it does not involve the community nor leave any drilling expertise in the community.

Pipes

Water is distributed through pipes. Pipes must have sufficient strength to resist a variety of forces. Pipe placed into service is usually covered by a layer of dirt or gravel. If laid in a street it must be able to withstand the load of passing vehicles. The pipe must also be able to resist damage from impact.

The types of piping used in distribution systems are:

1. Cast Iron Pipe
2. Asbestos - Cement
3. Plastic
4. Steel
5. Concrete
6. Bamboo

Valves

Valves can be classified by use, by design and by material from which the valve is made. The four most common types of valves encountered in a water distribution system are: Diaphragm, Globe, Rotary and Slide.

Classification According to Use

According to its use, valves can be classified as: air and vacuum relief valves, blowoff and drain valves, sectionalizing valves, backflow prevention or cross connection control, altitude valve, and automatic control valves (pressure reducing, pressure sustaining, pump control, rate of flow controller, solenoid).

Air and Vacuum Relief Valves are utilized when air or vacuum exists in pipelines. Air in water lines collects at peaks and at high spots. Vacuum conditions can occur in pipelines during drawing of the line, which can cause the collapse of some pipelines.

Blowoff and Drain Valves are usually placed at low spots in water lines. These on-off valves are used to dewater lines for repairs or to blowoff any sediment that accumulates at low points.

Sectionalizing Valves are gate valves that are installed at various points in the distribution grid. They permit the isolation of arms under repair or areas of contamination.

Back-flow Prevention or Cross-Connection Control units provide for normal flow, but when pressure levels drop or back-flow occurs these valves close off the flow of water. Globe or swing designs are normally used for this purpose. A double check-valve arrangement is generally used in backflow prevention.

Check Valve is a type of valve designed to permit flow in only one direction.

Altitude Valve is utilized to maintain the water level in a reservoir at a certain elevation. This type of valve is generally operated by the water pressure or a float and is usally a globe valve.

Automatic Control Valves are globe or diaphragm valves. They can be operated by hand, pressure, with a solenoid, by a difference in two pressures and by a float. They could be throttling or non-throttling. In non-throttling operation a simple control either opens the valve wide or closes it tightly. In throttling operation the main valve modulates to any degree of opening in response to changes in the throttling control. A description of the most used control valves follows:

Pressure Reducing Valve: Maintains a constant delivery pressure. Also functions a non-slam check valve when pump stops.

Pressure Sustaining Valve: Prevents excess demands in the lower zone from drawing down the pressure in the upper zone below a certain set point. Also it is used to prevent over-pumping and pump cavitation due to excessive downstream demands by holding a constant back pressure on the pump discharge.

Pump Control Valve: It is a pilot-operated valve designed for installation on the discharge of booster pumps to eliminate pipeline surges caused by the starting and stopping of the pump.

Backflow Preventer Valve: It protects potable water lines against contamination. This device combines maximum protection against backflow with exceptionally low head loss characteristics.

Rate of Flow Controller Valve: Maintains a constant flow rate regardless of changing line pressure.

Solenoid Valve: A solenoid valve is a combination of two basic functional units: (1) a solenoid (electromagnet) with its plunger (or core), and (2) a valve containing an orifice in which a disc or plug is positioned to stop or allow flow. The valve is opened or closed by movement of the magnetic plunger (or core) which is drawn into the solenoid when the coil is energized.

Fittings

Fittings have a variety of uses for a water utility. They can connect similar pipe, connect two different sizes of pipe, change the direction of flow, and stop the flow.

Fittings are available in most materials and sizes. Some are designed for the connection of two dissimilar piping materials. Fittings are also available for connecting pipes with different types of ends.

Fittings that are used to connect pipe include clamps, sleeves, couplings, adapters, and expansion joints. Fittings that reduce the size of pipe are called reducers and include reducing flanges, tees, Y-laterals, and crosses. Elbows, tees, and bends are used to change direction of flow. For stopping flow there are caps, plugs, and blind flanges (a flange with no opening). Fittings for tapping pipe include tapping sleeves, tapping crosses and tapping clamps.

Fittings that connect two pipes are called joints. Five types of joints exist: bell and spigot, flanged, ball and socket, mechanical and push-on.

1. The bell and spigot is the oldest joint. It is not used in new installations. It requires caulking material such as lead or lead substitutes which should be sterilized before use to prevent bacterial growth.

2. Flanged joints are used only for aboveground installations.

3. Ball-and-socket joints allow for considerable deflection and are used in special situations--usually water crossings.

4. The mechanical joint is still in use. Bolts through a retaining ring compress the gasket between the bell and spigot end of the pipe. Joint deflection of a few degrees is possible.

5. The push-on joint is the most widely used and the newest form of jointing. It requires less skilled labor to install, provides a non-leak joint, permits joint deflection of several degrees and has an overall lower cost.

Reservoirs

Reservoirs are a necessary part of any distribution system if the water utility is to meet peak demands and do so at minimum cost. They "float" on the water system. This means that the flow into a reservoir, whether by pumps or some other means, is set at about the average demand for water. During times of the day when demand is low, the reservior will be filling. During periods of peak or above-average demand, the reservoir will be emptying. Reservoirs, primarily, therefore average or equalize the demand on supply facilities.

Reservoirs allow pumps to be used at a uniform rate. This results in savings for the utility, which can operate with fewer pumps, and smaller water utilities also can contract for power during reduced demand periods when power rates are low. With treated-water-reservoir reserve it is also possible to have one- or two-shifts operations rather than 24-hour-duty personnel. Without adequate reservoir capacity to handle periods of peak demand, pumping is required to maintain capacity and positive pressure throughout the system.

Water may be held in distribution reservoirs in order to provide an extended detention time for effective chlorination. The reservoir may also serve as a sand trap to allow the settling out of suspended solids in the water.

Reservoirs may be very useful if a utility is obtaining its water from wells. Waters from different wells can be mixed in a reservior to provide water that will be of a consistent quality. Also, pumps may be automatically controlled to maintain the level in the reservoir, allowing for the use of low-capacity wells only during periods of sustained peak flow. This should result in a longer useful life for the low capacity wells.

Distribution reservoirs are often located in the outlying or low-pressure problem areas to provide the necessary pressure for the area during peak demand periods. They provide the necessary pressure by being either elevated, ground-storage located at the highest area, or ground storage with a booster station (whereby pumps provide the necessary pressure).

Reservoirs may be of several different types. Often a water utility will have more than one type of reservoir. The types more frequently used are: Cut and fill, ground reservoirs (standard or prestressed reinforced concrete and steel), elevated reservoirs, standpipe, wooden tanks, hydropneumatic, and individual tanks.

Meters

The most common use of water meters is for settling costs according to use. Meters serve in many other ways. Main-line meters are used to measure water flow into different areas and thereby provide for system control. Meters measure the flow in and out of reservoirs and the influent to and effluent from treatment plants; they also provide information for production. Meters allow for the accurate blending of waters of different quality. Meters also allow a water utility to determine how efficiently it is operating. If large amounts of water are unaccounted for, then the utility can begin a survey to determine where the water loss is occurring.

There are different types of meters, among those are the following:

Piston

Nutating Disc

Turbine

Propeller

Multi-jet

Compound

Proportional

Venturi

Orifice

Pilot

Rotometers

Magnetic

Sonic

Pumps

Pumps are often classified by their service application, classifications include: low-lift, high-lift, well service, booster pumps, standby pumps.

Low-Lift usually involves pumping of raw untreated water from the source of supply to a treatment plant.

High-Lift is the pumping of treated water into the distribution system under pressure.

Well Service is the pumping of water from a well. Pumps on wells may be located throughout the system. They may either pump to a central point, such as a reservoir or treatment plant, or they may pump directly into the distribution system.

Booster Pumps are used for increasing the pressure in the distribution system or for supplying an elevated storage tank. They are commonly used in outlying areas of the distribution system to avoid low-pressure areas or to serve high elevations. Booster pumps are normally horizontal but may be vertical as well.

Standby Pumps, frequently called fire pumps, are pumps that are available during periods of high water demand or when pumping units are out of service for repair or maintenance. (This demand may or may not be during a fire.)

Usually in water distribution systems only the high-lift, well service, booster and standby are utilized.

The different types of pumps used are:

1. Centrifugal
2. Positive-Displacement
3. Jet
4. Air Lift
5. Hydraulic Rams
6. Hand Pumps

Centrifugal Pumps

Centrifugal pumps have a rotating impeller within the pump case. Water enters at the center of the impeller. When the impeller is rotated, water in the pump is forced radially out of the pump because of centrifugal force. This causes a vacuum condition at the eye or center, which provides the necessary condition to lift or move the water. There are different types of centrifugal pumps: Volute Design, Diffuser Type, Multistage, Turbine, Mixed-Flow, Submersible.

Positive-Displacement Pumps

Positive-Displacement pumps were at one time the most commonly used pumps in the water-utility field. This type of pump is now used primarily for special situations because it must produce a pulsating flow rather than a steady one. Also the volume produced is ordinarily too small. Uses include the "mud sucker" diaphragm pump used to dewater excavations, metering pumps, priming pumps, and special-purpose pumps requiring high pressure with low volume. These pumps include: Piston Pumps, Plunger Pumps, Diaphragm Pump, Rotary-type.

Jet Pumps

This type of pump consists of a nozzle that discharges air, steam, or water into a constricted throat much like a venturi. This throat leads from a suction pipe. This arrangement permits the energy of a high-pressure fluid (air, steam, or water) to be converted into that of a high-velocity fluid. With an ejector pump mounted on the top of the well, it is possible to lift water 400 feet because 35-50 percent of the discharge goes back to the nozzle. This type of pump is not the most efficient but it is frequently used in small wells for lifts greater than 25 feet and for net discharge of 50 GPM or more.

Air-Lift Pumps

Air-lift pumps use a submerged air diffuser to lift water. As fine bubbles are introduced into water confined in a well casing, the water in the casing becomes lighter than the water outside. The heavier water on the outside forces the lighter water-air mixture up and out of the well casing. Although the air-lift pump is sometimes used to lift water from deep wells, it is not generally favored because it will not move the water horizontally through the distribution system. Also, because of the increased oxygen in the water, this method leads to a more corrosive water.

Hydraulic Ram

Hydraulic rams use the energy of falling water to raise a smaller quantity of water to heights greater than that of the falling water. This pump operates by taking advantage of the same forces that create water hammer in a system. Because of this, the hydraulic ram is often called an impulse pump. To operate correctly, this pump must have a constant supply of water available of the correct pressure. This is normally accomplished by having a reservoir feeding the ram. The quantity of water discharged by a hydraulic ram depends upon the working fall, the quantity of water flowing to the ram, and the total head or pressure against the ram. As a general rule, approximately one seventh of the volume of water flowing into the ram can be raised to about five times the height of the working fall.

Hand Pumps

This kind of pump is very old, it was known by the Romans, was frequently used during medieval Europe, and was mass produced in the late 1800's.

There are many different designs around the world. The Mark Series, Shinyanga, Kangaroo, Consallen, Mono, Boswell, EWRA/IDRC, etc. A brief discussion of some of them follows:

Mark Series Pumps

They use a casing of PVC and a plunger of polyethylene. They are bicycle-type pumps. They have high plungers without seals (cup leathers or piston rings). Badly worn plungers still function satisfactorily when operated at high pumping rates. The advantages in using this type of pump are no corrosion, lower investment costs, and a smoother surface.

NDOWA Pump

It is a hand pump suitable for use with heads of up to 10 meters. It is a bicycle pump type, which does not require lever. The pump stand is made of 2 inches galvanized pipe and fittings, and the pump pipe is a 50 MM class 10 PVC pipe. The outlet tee, which is situated above the slab, is welded to a 2.5 inches pipe end. A 2.5 inches socket is cast into the slab and the pump stand is screwed into this pocket. A 2 inches pump pipe is screwed into the galvanized tee of the pump stand by means of a reducing adaptor bushing. The cost of materials for a 6 meter long pump is approximate U. S. $60.00.

Shinyanga Pump

It is an improvement of the United Nations Children's Fund and Uganda pumps consists of four main parts: pump stand, wooden upright and handle, rising main and pump rod, and pump cylinder and piston. With the exception of the cylinder and piston, the rest of the pump is fabricated in a Shinyanga workshop. The workshop has the capacity to manufacture 35 pumps per month. Since June 1978 about 200 pumps have been sold to other regions in Tanzania.

Kangaroo Pump

This pump was designed to try to minimize maintenance by avoiding the use of hinge points requiring periodic lubrication. The head of the pump incorporates a spring which is compressed by pushing on a foot plate. As the spring recoils it produces the energy for the pumping stroke. Water can be pumped from a depth of 6 meters with a 4 inches cylinder, 10 meters with a 3 inches cyclinder, and 20 meters with a 2 inches cylinder. Because there are no hinges and wear on the pipes is minimal, a maintenance-free period of 10 years has been estimated.

Consallen

They have a 2, 2.5, or 3 inches piston and cylinder (depending upon the depth of the well); a 1.25 inches riser PVC pipe; steel pump rod; and steel pump stand with lever.

The piston has rings and is running in a stainless steel cylinder. The foot valve consists of a steel body. Unless foreign particles are introduced, the sealer is quite effective. These pumps have an approximate cost of $432 U.S. dollars.

MONO

This is a rotary positive-displacement pump. The piston is a solid steel helix running in a matching rubber cylinder. There may or may not be a foot valve because the fit of the piston and cylinder is very tight. The transmission shaft is steel and is guided by rubber bearings in the riser pipe. Pumping is accomplished by rotating the arms that are on opposite sides of the pump stand. A bevel-gear pair transmits the torque to the pump rod, which has the piston attached to its other end. This pump is normally regarded as the best type as far as reliability and ease of pumping are concerned. The only maintenance problem is oil loss at the seal of the gearbox bearings. The greatest problem with this type of pump is its cost, which is around $1200 U. S. Dollars.

Boswell

This pump is basically a piston pump, with a distinctive, above-ground structure. The piston and foot valve both possess leather cup seals to minimize leakage. The cylinder is brass-lined, galvanized steel pipe. The foot valve can be withdrawn without taking up the 2 inches (S CM) galvanized steel riser pipe by screwing the lower end of the piston into the foot valve. The pump rod is galvanized steel. The pump rod, piston, cylinder, and foot valve are still being imported at a cost of $100 U. S. dollars per pump. The pump stand is being made for $178 U.S. dollars.

Controls

Controls are utilized in water distribution systems in the next areas:

1. Pumps
   - 1.1 Flow metering at each station
   - 1.2 Alarms (activated in case of malfunction) for power failure, pump failure, and other malfunctions
2. Reservoirs
   - 2.1 Elevation or amount in storage
   - 2.2 Water flow in and out
3. Distribution System
   - 3.1 Pressure at critical locations
   - 3.2 Pressure regulations

Controls in the broadest sense give the user (1) the flow rate, pressure or liquid level that he desires (2) Protection on his water distribution system, and (3) Administrative freedom in decisions on operation and maintenance.

Controls can be accomplished either manually, semiautomatically or automatically. In manual control, the operator performs individual control functions either by turning valves, closing switches or pressing buttons. In semiautomatic control, the operator manually adjusts the controller, which then automatically performs the programmed control sequence. In automatic control, the controller is actuated automatically by a signal from the process.

All control systems have:

1. A sensing or measuring element
2. A means of comparing the measured value with a desired value
3. A final control element (a valve) to produce the needed change in the measured variable of the liquid
4. An actuator to move the final control element to its desired position
5. Relaying or force-building means to enable a weak sensing signal to release enough force to power the actuator

Sensing and Measuring Elements

These elements detect values of and changes in liquid level, pressure, and flow rate. The signal emitted by the element often needs amplification or conversion into another medium, which is done in a transducer.

Magnetic Type Floats

In this case an armature is attached to the top of the float rod sliding in a tube. Outside the non magnetic tube is mounted the control switch with a permannent magnet attached to it and set close to the tube. When the level rises, the armature passes the permanent magnet and attracts it so that the switch is actuated. A spring retracts the magnet when the level falls enough and the switch is reactuated.

Liquid-Level Electrical Sensors

In this case no floats are used. If the liquid is at all conductive, probes can be used. The electrods probes are fixed, usually mounted in the same holder, and extend down into the tank. Two or three electrodes are most common. In a tank filled by a pump, a drop in level the lower electrode breaks the circuit to allow a relay to start a pump or open a valve. When the liquid rises to the high-level electrode, the direct electric circuit between electrodes is established, and a relay stops the pump or closes the valve.

Bubble-Sensors

Bubble sensors measure liquid level by determining the air pressure required to force a small stream of air bubbles through the lower end of a tube extending to the bottom of an open tank.

The sensors most commonly used are classified in liquid-level sensors, pressure level sensors, and flow sensors.

Liquid-level Sensor

The simplest of several types of sensors is the float in the main tank, or in a separate float chamber connected at top and bottom to the tank or drum. Floats on vertical rods can actuate switches outside and above the float chamber. Depths can vary from less than 1 to over 50 feet with rod guides often necessary at the greater depths.

Displacer Type Floats

In this case a ceramic displacer is suspended from one end of a stainless steel tape that passes over a pulley and down again to counterweight. The extended pulley shaft drives through a reducing gear to a shaft which carries mercury switches controlling as many as four circuits.

In other displacers, porcelain bodies on a cable are suspended from the armature of a magnetic head control. In one form a spring partly supports the weight of the displacers, as liquid rises to the displacers in succession, their apparent weight decreases, and the spring can move the cable and armature upward to actuate snap-action switches.

Pressure Sensors

Pressure controllers of the simple on-off variety may have a single-pole double-throw mercury switch actuated by a bourdon tube. In other types of pressure sensors, one sensor is provided for pump start and one for pump stop. Adjustable time delay prevents surging or water hammer from giving a spurious start or stop signal. Increasing liquid pressure transmitted through tubing to an air chamber acts on a bellows and, overcoming adjustable spring tension, trips a mercury switch.

Flow Sensors

In this case flow meters are utilized. The different type of meters have already been discussed.

Comparing Measured Value

Comparison of a measured value with a desired value can be done manually or automatically. For example, comparison of flow or pressure with a desired value could be done by reading a meter or a pressure gauge. Means, liquid level reading can be done automatically with the sensors explained before.

Controllers

Once the sensor determines that the value is not desirable for proper operation of the system, there are four controllers to obtain the desired output parameter:

1. On-off
2. Throttling by valve
3. By pass by valve
4. Submergence

On-Off Method

The simplest mechanism for on-off control of constant-speed pumps is the push button switch and starter for across-the-line start of small pumps. For large pumps, reduced - voltage starting is customary. Number of starts per hour is restricted in all cases to prevent overheating. The electric impulse to cause start or stop of the motor can originate in any of the sensors or switches described above.

Throttling by Valve

It is very common and can provide refined control under difficult conditions where rapid response and outstanding dynamic stability are sought. Positive-displacement pumps cannot use this method.

Bypass by Valve

It is an occasional variation of valve control based on bleedoff of discharge liquid to reduce flow rate at a downstream point or to allow a cooling flow to pass through a constant-speed pump when its discharge has been blocked. The method can serve both centrifugal and positive-displacement pumps.

Submergence Control

For centrifugal pumps, relies on temporary decrease in available NPSH to reduce pump flow rate to the valve at which is entering the sump.

Actuators and Relays

Transducers and Transmitters

The variable that is most convenient or advantageous to measure is rarely the one best suited for direct use in the control system or for actuation of the final control element. A small differential pressure in a liquid-level or flow-control system can scarcely open a large valve. Conversion of measured-variable values into another signal medium is therefore necessary and is the task of transducers and transmitters. The terms are used interchangeably to some extent, although the transducer usually converts a signal into an electric current, and the output of the transmitter is usually an air pressure.

A pressure-to-voltage transducer is especially useful in a pump control.

A transmitter is a device which can sense pressure, temperature, flow, liquid level or differential pressure and convert the signal into a pneumatic pressure for transmission to receiving instruments several hundred feet distant.

Telemetry Systems

When pump control must be exercised over distances greater than the few hundred feet capability of most pneumatic control equipment, telemetry systems find application.

Telemeters are long-distance transmitters and include both the old electric and the new electronic type. Most telemetering systems in water control today are essentially monitoring systems. However, automatic or semiautomatic control elements are available for converting a monitoring system into a remotely controlled system. All quantities that normally can be controlled directly can be placed under remote control; e.g., motors, circuit breakers, valves, compressors, etc. All significant quantities can be monitored; e.g., pressure, valve position, reservoir-level readiness, motor on or off, flow readings. In some of these, the sensor's output is converted to a proportionally variable 3 to 15 v DC voltage at the transmitter input. The transmitter then converts the DC voltage into a square-wave pulse with duration varying in proportion to the input signal. The resultant pulse-width-modulation (PWM) signal is sent directly over transmission lines or via tone carrier in microwave, VHF, or UHF systems. The receiver converts the pulse signal back to a variable 3 to 15 v DC signal identical to the transmitter input signal and capable of use for indication or control.

If transmission is not received for a certain time period, an alarm can be actuated and the pumps started or stopped.

Alternators

An alternator may be installed to achieve regular use and equal wear of each pump in multipump installations. The simplest versions serve on two-pump systems, but more advanced designs can rotate starting sequence of as many as twelve pumps.

Control Loops

Two types of control loops are used in automatic control: open and closed loops.

Open Loops

The simplest mode of automatic control is open-loop control, in which the pump-speed (or displacement in some pump types) or the control-valve setting is adjusted to and held at a desired valve calculated or calibrated to produce the required output of flow, level, or pressure. In operation, only the deviation of the input variable from its desired value is measured, and the control system adjusts the input variable to eliminate the deviation. Because the output variable is not measured, a change in the conditions on which calculation or calibration were based will introduce output errors. Change of input variable can be done manually or by another control system.

Closed-Loop Control

A closed-loop control system eliminates much of the error of the open-loop system. In the basic closed-loop, or feedback system, the output variable is measured and the valve compared with an arbitrary desired or set value. If the comparison reveals an error, the pump-speed or control-value setting is changed to correct the error.

Data Processing

Data processing involves the monitoring, recording, computing, logging, and evaluating of variables in order to obtain improved operation, protection of the equipment, and saving in time. The computations range from simple scaling to operating guides. In computerized systems, the computer may be applied to closed-loop control of the process.

In continuous monitoring, as discussed previously, all points are observed continuously. Each variable being monitored must have its own instrumentation and detection equipment. Scanning systems are programmed to observe or sample sequentially a large number of points, whereas the recording and indicating equipment is time-shared, thereby reducing costs.

The objectives of data processing are: (1) to provide alarms in case of process or equipment malfunctioning, (2) to supply accurate records for accounting, (3) to provide records for process analysis, (4) to compute operating guides, (5) to accomplish automatic control, and (6) to provide for automatic adjustment of mathematical models.

Digital Data Loggers

Digital data loggers contain all the functions of the monitoring and recording system and can also provide some analog computation and digital records such as typewriter printout.

The logger is programmed to print out all variables at specified intervals (e.g., hourly). Between logging cycles, all variables are scanned for off-limit values and printed out in red when detected. Another printout is made when the variable returns to normal.

Digital Computer Control

The use of a digital computer affords completely automatic control. Specifically designed digital computers are available and are being used in automated water systems. The advantages of computer control have been reported as follows: (1) decreased operating cost, (2) increased system efficiency, (3) increased safety of operation, (4) rapid logging and summarizing of operating data, (5) ability to perform special tasks such as preventive-maintenance scheduling and plant-inventory control, and (6) ease of expansion to provide for additional plant capacity.

Prime Movers

Electric, Steam, Gasoline, Diesel, and Natural-gas engines are used as sources of power for operation of reciprocating and centrifugal pumps.

Electrical Motors

The electric motor has been the favored source of power to drive the pumps. This is largely due to the relatively low cost of electricity, reliability of electric motors, ease of automation, and generally quieter operation. Three types of electric motors are chiefly used: The squirrel cage, the wound-rotor (or slip-ring), and the synchronous.

Squirrel Cage Motor

It is the least expensive, simplest, and most reliable type of motor. It is used for constant-speed service.

Wound-Rotor Motor

This motor may be brought up to speed gradually, or the speed may be changed. Because of this, it is used to change the capacity of a pump by changing the pump's speed.

Synchronous Motor

This motor is normally used for large applications, requiring more than 105 hp. This motor is more efficient than the squirrel cage motor and uses less power.

Internal Combustion Motors

Because of the popularity of electric motors, internal-combustion engines are seldom used as the main power unit. However, they are frequently used as backup or reserve units or with portable pumps. As such they are much like the engine used in automobiles. Internal combustion engines are powered by diesel fuel, natural gas, or gasoline. Except for natural gas, these types of motors are not desirable for continuous use because of the high cost of maintenance upkeep and need for continuous fuel supply and upkeep. Natural-gas engines are often used because of lower fuel costs.

Steam Engines and Others

Steam and hydraulic turbines are still occasionally used as a power source. These units are reliable and efficient. However, because of the high cost of both the turbines and the accompanying boiler plant, they are seldom used today for any but older pumping plants.

Energy Sources

Electricity, Gasoline, Diesel and Natural-Gas are the most common sources of energy to operate pumps. Solar and wind energy have been used in the past, but unfortunately these sources of energy did not survive competition with cheap fossil fuels. Nowadays, the situation of cheap fossil fuels have changed. For example, there are some

African countries where periods last several weeks when gasoline is unavailable. In Tanzania one cannot buy gasoline from Wednesday evening until Monday morning and, when available, it is rationed and costs about $5.70 per gallon. Because of that it is considered important to look in more detail to solar and wind resources.

<u>Solar</u>

Use of solar energy to produce steam which is used as source of power started last century. At an exhibition in Paris in 1878, sunlight was focused onto a steam boiler that operated a small steam engine and ran a printing press. In 1907 and 1911 near Philadelphia, F. Shuman developed solar steam engines of several horsepower which pumped water. In 1913 near Cairo, Egypt, F. Shuman and C.V. Boys built a large solar engine, of over 50 Hp with long parabolic cylinders that focused the solar radiation onto a central pipe with a concentration ratio of 4.5 to 1. It pumped irrigation water from the Nile River. J. A. Harrington in New Mexico, focused sunlight onto a boiler and ran a steam engine that pumped water up 20 feet into a 5,000 gallon tank from which it ran down through a water turbine operating a dynamo and small electric lamps that lighted a small mine day and night.

Solar energy also is utilized to produce electricity, to run electric motors. At present, the two most promising technological approaches are photovoltaic conversion with electrical storage, and solar-thermal conversion with heat storage for night-time operation.

The two main approaches to solar-thermal power generation are the solar furnace approach, in which sunlight reflected from many different locations is concentrated on a single heat exchanger, and the solar farm, with large numbers of linear reflectors focusing solar radiation on long pipes which collect the heat.

Solar cells offer a potentially attractive means for the direct conversion of sunlight into electricity with high reliability and low maintenance, as compared with solar-thermal systems. The present disadvantages are the high cost and the difficulty of storing large amounts of electricity for later use as compared with the relative ease of storing heat for later use.

A 250 watt electric power plant in the Soviet Union uses a concentrator consisting of 26 plane mirror facets forming an approximate parabolic cylinder. These plants were developed to provide power for water pumps in the grazing areas of the southern regions of the U.S.S.R. One of them was installed at the Bakharden State Livestock-Breeding Farm situated in the Kara-Kum Dessert, Turkmenia. Its output equals about 400 watts, enough to lift from a depth of 20 meters a sufficient amount of water to water 2,000 sheep.

Windmills

Water pumping windmills are used in many parts of the world, not only for pumping water for farm and rural household. These types of machines commonly have metal fan-blades, 12 to 16 feet in diameter, mounted on a horizontal shaft, with a tail-vane to keep the rotor facing into the wind. The shaft is usually connected to a set of gears and a cam that move a connecting rod up and down. This rod, in turn, operates a pump at the bottom of the tower. A 12-foot diameter rotor of this type develops about 2/3 Hp in a 15 mph wind and can pump about 10 gallons of water per minute to a height of about 100 feet.

The Agricultural Research Service at Manhattan, Kansas has installed a 20 foot diameter, 30 foot high darrieus rotor and windturbine, coupled to a shallow-well irrigation pump, for gravity distribution. The Agricultural Research Service at Bushland, Texas is operating a 37 foot diameter, 55 foot high rotor of the same type, in parallel with a 40 Hp electric motor to drive a deep well pump for irrigation applications. Other applications include the pumping of water for aqueduct systems. Here, large-scale wind-driven units can provide power for the pumping of water from the main reservoir to auxiliary reservoirs in other parts of the aqueduct system. This can be done either by the direct mechanical pumping of the water or through the generation of electricity by the wind units, and the subsequent use of this energy to operate electrical water pumps incorporated in the aqueduct system.

Water Saving Devices

The main purpose in using these devices is to reduce the water consumption and hence the capital cost of the water distribution systems. Water saving devices may account for a reduction of water consumption of up to 50 percent of the total.

Water saving devices exist for:

1. Toilets
2. Showers
3. Lavatory and kitchen sinks

Toilets

There are many different designs in toilets, some of them are described in the next paragraphs:

Shallow Trap

This device is designed to use approximately one-third less water than ordinary toilets. It is similar in appearance and cost to the standard model except for a noticeable small tank.

Dual Cycle Water Closet

It is designed to save water while maintaining the advantages of flushing toilets. The cistern releases either one or two gallons of water according to requirements. One gallon is flushed if the cistern handle is released immediately after processing down, two gallons if the handle is held down until the flush is completed.

Sink-Bob

This device consists of a polystyrene float and lead sinker connected to the float stem by a split brass ring. The sink-bob attaches to both rod and flapper-type seals at a point just above the flush valve. The device operates a light flush (the handle is tripped in the normal manner) for the liquid waste and a normal flush (the handle is held down during the entire flushing operation) for the solid waste.

Monterrey - Toilet

This toilet has a 100 grams lead attached to the rod or flapper-type seal. The toilet operates like the skin bob. Savings of 28 percent on the total water consumption may be obtained with it.

Save It Water Saver

This device needs to convert a toilet to dual-cycle operation with some modification and provides a reduced flush of approximately 50 percent. It consists of a pre-folded plastic sheet which is formed around the flush valve and secured with two anchor rods. When flushing occurs, the flush valve closes prematurely as approximately one-half of the water in the tank is blocked from gaining access to drain.

NIBO

This cistern is made out of the flexible thermo-plastic and is designed to reduce the number of moving parts. To flush the toilet, one presses against the body of the cistern by hand and water flows into the down pipe following the principle of physics of "connected vessels". This gives the user control over the amount of water flushed whether for solid or liquid waste. In addition, this type of cistern will not waste water through slow leaking, or if the handle is kept down as conventional models sometimes do.

Brick in the Tank

A brick or two are installed in the toilet tank to save some water every flushing.

Pedamatic

This is a conventional flush toilet that is pedal activated, a considerably more hygienic practice than hand operated mechanisms. The pedal has two positions: one that opens the flush water valve but does not open the bowl outlet, and a second, fully depressed, for opening the seal and flushing the toilet.

Norway Tank

It is a specially designed toilet that uses 5 liters per use. It is the most economical toilet discovered until now.

Showers

There are different designs, among them are the following:

Flow Limiting Shower Head

This shower head has an integral "auto-flo flow limiting orifice with a flow rate of 3.5 GPM or 2.5 GPM. It has a full-adjustable spray, integral ball joint and a face of about 2 inches diameter. There is a saving of 50 to 70 percent of water when compared with conventional shower head.

Thermostatic Mixing Valve

This is a device which permits mixing of hot and cold water to attain a desired temperature level. The proportion of hot and cold water is varied automatically by a bimetallic coil as the temperature or pressure of the incoming water is varied. It enables the bather to turn the shower off while soaping and to have the same temperature when the water is turned on for rinsing. This saves the water that would be wasted as the water temperature is readjusted before rinsing or the water that would be wasted if the shower is left on in order to avoid the problem of adjusting the temperature again.

Lavatory and Kitchen Sinks

Saving devices include the flow limiting valves, fordillas, and faucet aerators.

Flow Limiting Valves

The design is the same as the flow limiting shower heads. The flow is usually restricted to 2.5 GPM for each valve. Water savings are claimed to be up to 50 percent.

Faucet Aerator

Although intended principally as an anti-splash device, it does provide some water savings. It is estimated that faucet aerator can reduce water consumption by approximately 25 percent.

Fordilla

It is a spring-loaded faucet that cannot be held or tied open and discharges approximately 1 liter at a time.

APPENDIX D

Cost Transfer Method and Calculations For Cost Equations

Cost Transfer Method

This method calculates costs for different devices for different STL and population scale. It breaks down the cost of construction, maintenance and operation into basic components (i.e., labor, material, etc.) for each category of scale and each socio-technological level. Then, coefficients for a cost transfer equation (i.e., ratio of wage salary of skilled or unskilled on less developed countries and wage salary of skilled or unskilled on developed countries), are produced from socio-economic data collected. Once this breaking down is done, United States or other LDCs costs are used to obtain the costs for other STL and population size.

The general form of the cost transfer equation is as follows:

$C_{ij} = C_{us}[(L_1 x C_{T1}) + (L_2 x C_{T2}) + (M_C x C_{T3}) + (M_I x C_{T4})]$

C_{ij} = construction cost for STL i(i = 1,2,3,4) and scale J(j = 1,2,3,4)

C_{us} = construction costs in United States or other LDC

L_1 = percent of unskilled labor

L_2 = percent of skilled labor

C_{T1} = cost transfer for unskilled people (X_{21}/X_{22})

C_{T2} = cost transfer for skilled people (X_{31}/X_{32})

C_{T3} = cost transfer for in-country materials

C_{T4} = cost transfer for imported materials

M_C = percent of in-country materials

M_I = percent of imported materials

X_{21} = hourly wage unskilled labor in less developed countries

X_{22} = hourly wage unskilled labor in developed countries

X_{31} = hourly wage skilled labor in less developed countries

X_{32} = hourly wage skilled labor in developed countries

The cost transfer equation for operations and maintenance costs is as follows:

$$O \& M_{ij} = O \& M_{us}[(P_1 x C_{T1}) + (P_2 x C_{T2}) + (M_c x C_{T3}) + (M_I x C_{T4})]$$

where:

$O \& M_{ij}$ = operation and maintenance costs for a STL i and scale j

$O \& M_{us}$ = operation and maintenance costs in U.S. or any other LOC

P_1 = percent of unskilled labor in O & M

P_2 = percent of skilled labor in O & M

C_{T1}, C_{T2}, C_{T3}, C_{T4}, M_c and M_I as defined above.

Cost Equations Calculations

This part consists on getting cost equations for the different system components, where possible. Obtaining reliable costs on construction and operation and maintenance is the most difficult task. Price increases, overpriced currencies, subsidies, etc., are among the reasons for this condition.

Data Available

Data available were gathered from different sources and different years. Table 35, shows a list of those data and their source and year. A detailed explanation of those data follows:

Pumping

Source: "Standarized Procedure for Estimating Costs of Conventional Water Supplies," Black and Veatch Consulting Engineers, Kansas City, Missouri, 1963.

CAPITAL COSTS (1963)

Design Capacity (MGD)	Capital Cost (U.S. Dollars)	O & M* Costs /1000 Gal.
0.1	30,000	.050
0.2	32,000	.039
0.5	40,000	.027
1.0	52,000	.020
2.0	75,000	.015
5.0	135,000	.012
10.0	220,000	.011
20.0	375,000	.009

*Not considering electrical power and for pumping head of 100 feet.

Distribution

Source: Deb, Arun K. and Evans, Michael P., "Dual Distribution Systems," AWWA, Feb. 1980. He calculated the following equations:

TABLE 35

Availability of Costs Data by Component
Place of Origin and Year

System Component	Place	Year
Pumping	USA	1963
Distribution	USA	1979
Storage	USA	1979
Hand Pumps	Costa Rica	1976
Stan Posts	Cameroon Western Africa	1979
Storage (Individual)	Mexico	1982
Roof Catchment	Botswana	1979
Dug Wells	Botswana	1979
Drilled Wells	Botswana	1979
Wind Mills	Botswana	1979
Saving Devices	USA	1975

$$\text{Capital Cost} = 5332.8\ K_d^{1.29}\ KLM\ P_D^{-0.458}\ POP_1^{1.084}$$

$$\text{O \& M Cost (\$/year)} = 33.63\ K_d^{1.29}\ K_{LM}\ P_D^{-0.458}\ POP_1^{1.084}$$

Where

K_d = Coefficient for average cost diameter

KLM = Coefficient for length

P_D = Population density (People /sq. mi.)

POP_1 = Population in base year in thousands

<u>Storage Tanks</u>

1. Public

Source: Dansby, J. W. Verbal Communication, on Bids Received for Storage Tanks at El Reno, Oklahoma.

Ground Capacity (Gals)	Capital Cost ($, 1979)	O & M Cost ($/year)
250,000	47,000	-
300,000	55,000	-
400,000	63,000	-
500,000	75,000	3,026
750,000	100,000	3,865
1,000,000	113,000	4,239

Elevated

Capacity Gal	Capital Costs (Dollars, 1979)	O & M Cost Dollars/year
200,000	143,000	964
300,000	178,000	-
400,000	260,000	-
500,000	370,000	-
1,000,000	506,000	1956
1,860,000	-	4546

Private

Source: "Price List for Storage Tanks." Tuberias Sanitarias, Monterrey, Mexico (1982).

Capacity Liters	Capital Cost U.S. Dollars	O & M Cost U.S. Dollars
400	63.60	0
700	88.50	0
1100	136.10	0

Hand Pumps

Source: Potts, Phillip W., Kermit, M. C., Justin, W. H., and Thomas, C. F. _Final Report on the Utilization/Evaluation of an AID Hand-Operated Water Pump_. Office of International Programs, Georgia Institute Technology, 1979.

Shallow Wells (1979)

# Pumps	Cost/Pump (U. S. Dollars)	O & M*
20	128.00	0
100	126.50	0
200	125.50	0
500	124.25	0
1000	120.00	0

Deep Wells (1979)

Pumps #	Cost/Pump (U.S. Dollars)	O & M Cost* (U.S. Dollars)
20	139.00	0
100	137.75	0
200	136.60	0
500	135.25	0
1000	130.00	0

*O & M costs are considered zero in the case of private wells. In the event of public wells, an operation and maintenance cost of $120.00 per year must be utilized.

Standposts

Source: World Health Organization, Water Dispensing Devices and Methods for Public Water Supply in Developing Countries, Interim Report, The Hague Netherlands, International Reference Centre for Community Water Supply (I.R.C.), No Date.

Estimated Investment Costs for Standpipes (US $)

Western Africa (1974)

	Mechanism Only	Including Basic Unit*
1. Ordinary taps	1 - 3	500 - 1000
2. Springloaded taps		
Neptune	200	500
3. Self closing valves		
Tylor	5 - 7	500 - 700
Fordilla	10 -12	500 - 700**
Tropicale	250	600
4. Float mechanisms		
Siphoide	1500	2000
Bedouin	-	-
5. Special Types		
Bayard	300	600

*) Cost estimates based on situations existing in the countries which were visited

**) If Fordilla valve is used as a public standpipe

Roof Catchment

Source: Malkano, J. Gilbert and Nyberg, L., (Rainwater Catchment in Botswana". Rural Water Supply in Developing Countries, Proceedings, Zomba, Malawi, (1980).

Capacity (M^3)	Capital Cost U.S. Dollars	O & M Costs
10	343	0
15	411	0
20	468	0
25	537	0

Dug Wells

Source: Kashoro, N. Y., "Shallow Wells Project, Shin Yanga Region" *Rural Water Supply in Developing Countries, Proceedings*, Zomba, Malawi, (1980).

Manpower Required

Four laborers

Two wells/month

Salaries P 4.00/day

$$\frac{P4.00 \times 4 \times 30}{2} = P240 = \$309.60 \quad (P1 = U.S.\ \$1.29) \quad 0.76$$

Material

$100.00 0.24

$410.00

Drilled Wells

Source: Kashoro, N. Y. "Shallow Wells Project, Shinyango Region," *Rural Water Supply in Developing Countries, Proceedings*, Zomba, Malawi, (1980).

Manpower Required

One Foreman

Eight Laborers

Two wells/week

Salaries P4.00/day
P12.50/day

$$\frac{8 \times 4.0 \times 7 + 1 \times 12.5 \times 7}{2} = P155.75$$

or 200.92 U.S. Dollars

Material

6" PVC Pipe	20ft x 5.00 =	100.00
6" screen	10ft x 7.00 =	70.00
		$170.00

TOTAL = 370.92 U. S. Dollars/well

Wind Mills

Source: Carothers, R. "An Assessment of Water Pumping Technologies Using Local Available Energy Resources, Botswana," Rural Water Supply in Developing Countries, Proceedings, Zumba, Malawi, (1980).

Southern Cross - Seneschal, 7.5 m. Diameter

Efficiency	15 - 31%	
Energy Delivery per day	24.6 - 49.1 KW -h/day	
Cost Capital	P5700	$7353
O & M	P2870	$3702

Saving Devices

Source: Reid, W. George. "An Exploratory Study of Possible Energy Savings as a Result of Water Conservation Practices," The Bureau of Water and Environmental Research, The University of Oklahoma, Norman, Oklahoma (1976).

Device	Type	Cost (1976)
Toilet	Dual Cycle Water Closet	$14.00
Faucet Kitchen	Flow Limiting	$16.99 (1983)*
Shower	Faucet Aerator	$ 4.99 (1983)*
Lavatory		$14.99 (1983)*

*Retail prices on Sears Roebuck Co., Sooner Fashion Mall, Norman, Oklahoma.

Calculation of Cost Equations

Updating of Costs

Data gathered were from different years. It was necessary to convert all data for the year 1970. In the case of United States costs, they were corrected using cost index from Engineering News Record. In the case of LDCs, costs were adjusted using standard rates of inflation shown in Statistical Abstracts.

Application of Cost Transfer Methods

Once all cost data are under the same year (1970), they were translated to the same country. The cost transfer method was utilized. The cost transfer coefficients

(C_{T1}, C_{T2}, C_{T3}, and C_{T4}) used are the ones utilized by Reid, (Tables 36 and 37). People related to the water supply construction industry in Mexico were interviewed to get data on unskilled labor (L_1), skilled labor (L_2), in-country material (M_C) and imported materials (M_I) percentages for each system component. Results are shown in Tables 38 and 39.

Costs from U. S. were translated to costs in Central America. Costs from LDCs like the African countries were translated to Central America costs. In this last situation, cost transfer coefficients for materials (C_{T3} and C_{T4}) were supposed to be equal. The only correction made was for wages (C_{T1} and C_{T2}).

Equations

The least square method was utilized to obtain cost equations where possible. Then, the equation was corrected for updating and cost transfer. In the event where only one data was available, no equation was obtained but corrections for updating and cost transfer were applied. Results obtained are shown in Table 33. No attempts were made to present equations neither for every STL nor every population scale. Coefficients utilized were for a population size of 15,000 to 50,000 and STL 3.

TABLE 36

Manpower Transfer Coefficient Costs for Different STL and Population Size

Population Size	CT_1 STL I	CT_1 STL II	CT_1 STL III	CT_1 STL IV	CT_2 STL I	CT_2 STL II	CT_2 STL III	CT_2 STL IV
Less than 2500	0.08	0.25	0.33	1.0	1.50	1.50	1.33	1.0
2500 - 15000	0.08	0.25	0.33	1.0	1.50	1.50	1.33	1.0
15000 - 50000	0.08	0.25	0.50	1.0	1.50	1.33	1.17	1.0
50000 -100000	0.08	0.25	0.50	1.0	1.50	1.33	1.17	1.0

CT_1 = Cost transfer for unskilled people (X_{21}/X_{22})

CT_2 = Cost transfer for skilled people (X_{31}/X_{32})

TABLE 37

Material Transfer Coefficient Costs for Different Population Sizes

Population Size	CT_3	CT_4
Less than 2500	0.50	1.5
2500 - 15000	0.50	1.5
15000 - 50000	0.67	1.5
50000 -100000	0.67	1.5

CT_3 = Cost transfer for in-country materials

CT_4 = Cost transfer for imported materials

TABLE 38

Ratios of Manpower and Material Utilization
for Different System Components
in Construction

System Component.	L	L_1	L_2	M	M_C	M_I
Individual wells	40	30	10	60	60	0
Roof Catchment	43	24	19	57	57	0
Hand Pumps	30	20	10	70	60	10
Pumping	40	10	30	60	20	40
Piping	50	35	15	50	40	10
Standposts	60	30	30	40	30	10
Water Saving devices	10	10	0	90	0	90
Storage	60	30	30	40	30	10

L = Labor as percent of LDC Construction Cost

L_1 = Percent unskilled labor

L_2 = Percent skilled labor

M = Materials as percent of Construction Cost

M_C = Percent in-country materials

M_I = Percent out-country materials

TABLE 39

Ratio of Manpower to Material Costs for Different System Components in Operation and Maintenance

System Component	L	L_1	L_2	M	M_C	M_I
Individual Wells	0	0	0	0	0	0
Roof Catchment	0	0	0	0	0	0
Area Catchment	100	90	10	0	0	0
Hand Pumps	30	20	10	70	60	10
Pumping	40	10	30	60	20	40
Piping	50	35	15	50	40	10
Standposts	60	30	30	40	30	10
Water Saving Devices	0	0	0	0	0	0
Storage	60	30	30	40	30	10

APPENDIX E

QUESTIONNAIRE USED TO DEFINE MANPOWER CAPABILITIES

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

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 university in the local community?

__________ (1) Yes __________ (2) No

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

__________ (1) Yes __________ (2) No

13. Is unemployment widespread?

__________ (1) Yes __________ (2) No

14. 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

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

__________ (1) Yes __________ (2) No

16. 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

17. Does the government dominate the labor market?

__________ (1) Yes __________ (2) No

18. Are public employment services readily available?

__________ (1) Yes __________ (2) No