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A.I.D.'s RURAL WATER PROGRAM IN LATIN AMERICA

WHAT TO DO ABOUT HIGH DEMAND

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WHAT TO DO ABOUT HIGH DEMAND

Prepared for the Office of Health,
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by

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ACRONYMS

A.I.D.	U.S. Agency for International Development
gpcd	gallons per capita per day
gpd	gallons per day
gph	gallons per hour
IEOS	Instituto Ecuatoriano de Obras Sanitarias (Ecuador)
LAD	long-term average demand
MDPF	maximum daily peaking factor
MHPF	maximum hourly peaking factor
p.v.	present value
SANAA	Servicio Autonomo Nacional de Acueductos y Alcantarillados (Honduras)
STV	storage tank volume
UNEPAR	Unidad Ejecutora del Programa de Acueductos Rurales (Guatemala)
WS&S	water supply and sanitation

EXECUTIVE SUMMARY

Massive investments in water supply and sanitation (WS&S) are under way in Latin America and other developing countries throughout the world to meet the needs of the more than 1 billion rural dwellers who were left unserved at the end of the International Drinking Water Supply and Sanitation Decade in 1990. In Ecuador, Guatemala, and Honduras where this study was conducted, A.I.D. provided grants and loans from 1980 to 1988 for rural WS&S systems totaling roughly $50 million. These were matched more than one-to-one by host governments and local communities. In Central America alone, approximately $320 million more will be spent on WS&S by 1995, of which $85 million has been promised by A.I.D.

Despite the magnitude of these investments, the standards used for deciding the capacities of A.I.D.-assisted and other projects (which in turn affect their costs) are based on assumptions and judgments almost totally lacking an empirical basis. Among other reasons, such a hard database is unavailable because rural water systems are typically constructed without meters for measuring water consumption.

Starting in fall 1989, meters were installed in 16 rural communities in Ecuador, Guatemala, and Honduras with populations of 100 to 1,200 each. During a period of two months in each town, meter readers collected data on actual consumption for 30 days. The authors made determinations of such parameters as average per capita demand, maximum daily demand, and required storage volumes needed to meet actual demands. They also performed regression analyses to develop equations for predicting the key design parameters for towns of any size in any of the three countries. Results are described in a 1992 companion report by this study's authors, WASH Technical Report No.78, "Deriving Design Standards for Rural Water Systems: Case Studies Using Water Demand Data from Ecuador, Guatemala, and Honduras."

The data in the current study showed that average per capita consumption in Ecuador and Honduras fell in the range of 50 to 60 gallons per day (gpd), whereas design standards assume 30 gpd. Average consumption in Guatemala was a little below the design standard. The authors concluded that the Guatemala systems have adequate capacity except in their networks and storage tanks, but the systems in Ecuador and Honduras are grossly underdesigned in most components and, in many cases, suffer capacity deficits almost as soon as they are placed in service. All three countries run the risk of low and negative pressures in their distribution systems due to high demand, which poses a potential threat to health.

When system capacity is inadequate, there are two ways to rectify the situation. One is to provide more capacity, which treats present demand as a requirement; the other is to ration capacity through conservation, which treats demand as a variable that can be reduced.

The authors chose a typical town with an initial population of 600 to analyze and compare the options of increasing capacity versus rationing. They found that if expansion and higher design standards were chosen for dealing with capacity deficits, per capita construction costs would increase by 50 percent, from $80 to $120. For a given construction budget, this would mean that one-third fewer people could be served with improved water supplies. However, expansion cannot be easily justified on economic grounds because the costs would far outweigh the benefits. This is a consequence of the existing tariff structure, which charges users a nominal monthly flat rate for water service.

The preferable option is to ration capacity through conservation, for which five alternatives were considered. The most expensive is metering, which would cost nearly as much as increasing capacity. However, most of the cost would be for personnel, and only $10 more per capita would be required for hardware initially. This option would double the fees that households now pay for water and would work only if communities found it acceptable. The increased cost to donors such as A.I.D. would be modest.

A second alternative, rationing with flow restrictors or special faucets that limit flow, would be less expensive, but success stories using these devices are few. They are subject to tampering and bypass and require in-house water storage, which can pose a health risk.

Enforcement of rules about nonessential use of water and reduction of waste offers a third alternate for conservation. This option is potentially effective and inexpensive. However, if the current high rates of water use are due to watering gardens and livestock upon which one's livelihood depends, and for which sources other than piped supplies are not readily available, enforcement of rules may not achieve the desired conservation.

The fourth and fifth choices are rationing by planned intermittent supply, and rationing by unplanned shortages. These two options are expensive in nonpecuniary costs and operate contrary to the goal of sustainable development. Therefore, they are unworthy of serious consideration.

This report recommends that rationing rather than increasing design flows and expanding capacity be adopted. In communities without meters, rule enforcement should be attempted. If enforcement of rules fails, metering would be the next best option. In communities with meters, redesigning the tariff to be more economical should be done. Existing and new systems should be equipped with master meters in order to develop a database for improving the design of new systems and the operating efficiency of existing systems. Studies to determine community preferences and willingness to pay should be conducted as a basis for future planning. These should examine selecting an appropriate rationing scheme, increasing cost recovery, and promoting greater self-sufficiency.

1

INTRODUCTION

In 1980, only 30 percent of the rural population in developing countries was served with an adequate water supply, and only 37 percent had adequate sanitation. That left more than 1.6 billion rural dwellers without service. The situation in urban areas was much better: more than 70 percent of the population had adequate water supply and sanitation (WS&S), leaving less than 300 million without service. In Latin America and the Caribbean, about 50 percent of the rural population in 1980 had water and about 20 percent had sanitation. More than 60 million rural dwellers were without service (Christmas and de Rooy, 1991). These conditions provided the basic motivation for the International Drinking Water Supply and Sanitation Decade, which was undertaken in the 1980s.

The international lending and donor institutions responded to the challenge of the decade by providing massive amounts of assistance, generally on a matching basis with local contributions. In Ecuador, Guatemala, and Honduras alone, the U.S. Agency for International Development (A.I.D.) from 1980 to 1988 provided grants and loans totaling nearly $50 million for rural WS&S. These were matched more than one-to-one by host governments and local communities. In the above three countries, more than 800 rural communities were served with new systems, and an additional 100 or more had their existing systems rehabilitated (Burns and Mattson, 1989, Edwards et al., 1989, and Moncada et al., 1986).

Despite the massive inputs, substantial numbers are still without adequate WS&S in rural areas. For example, near the end of the decade, only 30 percent of rural dwellers in Guatemala had adequate WS&S, and the coverage in Ecuador and Honduras was only 40 percent and 60 percent, respectively. Five countries of Central America (not including Nicaragua) had less than half of their rural populations served with WS&S. As a result, new targets have been set that will require continuing input from governments, lenders, donors, and the beneficiaries themselves. In Central America, for example, approximately 2.7 million more rural dwellers have been targeted for WS&S service by 1995, which is estimated to cost about U.S. $320 million ($100 per capita for water plus $20 per capita for latrines). Funds already committed to meet the Central America targets amount to nearly $250 million, of which $85 million has been promised by USAID (Ey, 1990).

Beneficiaries of the rural WS&S program are generally poor, with farming as the principal occupation and only modest amounts of cash income. As a result, A.I.D.-assisted projects operate on the assumption that most of the construction costs should be provided by other than the beneficiaries themselves. Typically, the local community covers 20 to 30 percent of construction cost, usually in the form of unskilled labor rather than cash contributions.

Another 20 percent or so of construction is usually covered by central government, with the rest coming from A.I.D., mostly in the form of loans plus a small amount of grant funds.

Operation and maintenance (O&M) costs, however, are usually expected to be covered by the communities themselves from revenues that are collected from households each month.

In the planning and design of A.I.D.-assisted rural WS&S projects, the beneficiaries tend not to be consulted about system details. Rather, the responsible government agencies make key decisions on their own, using A.I.D.-approved standards. For example, the design office will typically decide to provide water service through individual yard taps, not using house meters but instead charging households a flat monthly rate. The designers decide whether restrictions should be imposed on water use, such as prohibiting garden and livestock watering. They also select the source of supply and the locations and capacities of pipelines and storage tanks.

The use of such an approach to planning and design is a logical consequence of the large numbers of WS&S systems to be implemented in rural areas. To facilitate the planning process, design standards have been adopted that tend not to vary much from one country to another. For example, the designers usually assume a population growth rate of about 2 percent per year and a design period of 20 years. Using these standards, they size systems with capacity for a future design population 50 percent larger than the current population. With water distributed via yard taps, it is usually assumed that 20 to 30 gallons per capita per day (gpcd) on the average should be adequate to meet the needs of the design population. Recognizing that water use varies from one hour to another and from one day to the next, the designers typically select sources of supply with capacity equal to at least 1.5 times the average design flow, and piped distribution networks are designed to meet a peak hourly flow about 2.5 times the average design flow.

A 1992 companion report by this study's authors, WASH Technical Report No. 78, "Deriving Design Standards for Rural Water Systems: Case Studies Using Water Demand Data from Ecuador, Guatemala, and Honduras," describes a study commissioned by the WASH Project to measure the water demand, peaking factors, and storage tank requirements in 16 water systems in Ecuador, Guatemala, and Honduras. That study, whose results are summarized in Chapter 3, found that actual demands were higher than design standards in all three countries, but particularly so in Honduras and Ecuador, where average per capita water use was more than twice the standard used for design.

The purpose of the current report is to assess the consequences of actual demand exceeding design standards in Ecuador, Guatemala, and Honduras. A second and more important objective is to compare the option of increasing capacity with that of reducing water use in order to identify a preferable course of action for A.I.D. and host governments. Given the massive investments that have already been made in rural water systems and those planned for the future, the discrepancy between actual demand and design standards is a serious problem that should not be neglected.

When actual demand exceeds design standards, the expectations of the designers are not met and systems do not function as planned. Failure to meet expectations can cause a variety of problems. For example, if per capita demands are higher than design standards, certain components of the water system may have inadequate capacity, sometimes as soon as they are placed in service, even though they are designed to meet the requirements of a future population. Frequently, the most vulnerable components are the pipe network and the storage tank, and one of the most common consequences of excess demand is low or even negative distribution pressures. At a minimum, negative pressures lead to dissatisfaction among users by denying them the ability to get water when they want it. More important, negative pressures threaten health through infiltration of contaminated groundwater into the pipe network. Finally, they can induce users to abuse the system, stop paying their water bills, and seek undesirable means for getting water, such as resorting to use of unimproved sources.

Even if capacity is sufficient when new systems are started up because actual demand is not high enough to offset the extra capacity provided for the future, the system will exhaust its excess capacity prematurely (i.e., before the end of the design period).

When excess capacity is exhausted in a system that is already in operation and in which demand continues to increase, two actions can be taken: Either system capacity can be expanded, or water use can be reduced. For systems yet to be built in which the expected future demand exceeds the design standards, similar alternatives exist. Either the current design standards can be increased to provide more capacity that will enable the system to function properly after it is built and until the end of the design period, or an attempt can be made to lower the anticipated high rate of water use to bring demand into line with the design standards.

The alternative of increasing capacity, either prematurely for existing systems or with higher design standards for new systems, is expensive in terms of construction costs and is politically difficult since it usually entails giving better service to fewer communities at the expense of extending WS&S coverage to a larger number of new communities. If capacity is not expanded, it must be rationed by reducing demand, which is also expensive (although not necessarily in terms of construction costs) and has its own set of problems.

The most common method of rationing capacity is to do nothing and let demand exceed supply. This, however, can lead to health risks and counter the very purpose for which the systems are constructed. Alternatively, users might be educated to reduce waste and nonessential water use, flow restricters can be installed, or special valves that deliver measured quantities of water can be used. Another solution is to ration by price, which is the option that in principle is favored by economists, but it too has its problems.

2

CURRENT DESIGN STANDARDS AND TARIFFS

Each of the countries studied has its own design standards and tariffs for A.I.D.-assisted rural WS&S projects. The standards tend to be comprehensive and cover all the important aspects of design, but only their key elements are reported in this chapter. They include (1) the assumed rate of population growth, (2) the design period, (3) average per capita design flow, (4) maximum daily peaking factor (MDPF), (5) maximum hourly peaking factor (MHPF), and (6) storage tank detention time at average design flow.

Elements 1 and 2, the assumed rate of population growth and the design period, play an important role in determining the amount of excess capacity to be provided in a system. Increasing the current population in the community to be served by the growth rate in the standards for the number of years in the design period results in the design population to be served. (It should be noted that the standards used for A.I.D.-assisted projects make no claim that the design periods used are optimal.) The optimal amount of excess capacity also depends largely on economies of scale in construction and the discount rate (Lauria et al., 1977);

Multiplying the design population by the average per capita design flow in the standards (element 3, above) results in the average flow for which the system should be designed. The average design flow is a basic reference value that influences the design capacity of each component of the system.

The source of supply (including treatment facilities, if any) is typically designed to meet the maximum daily demand. The reason for this is that, given variation in daily demand, high demand at or near the maximum daily rate may persist during drought or other extreme conditions for several days. Design standards predict the maximum daily demand as the product of average daily demand and an assumed maximum daily peaking factor (MDPF), element 4.

The pipe network must have sufficient capacity to meet the maximum hourly demand and still maintain adequate residual pressure. The maximum hourly demand is predicted from design standards as the product of the average daily demand and an assumed maximum hourly peaking factor (MHPF), element 5.

The final major component of water systems is the storage tank. It is needed in order to meet peak hourly demand, since the source of supply typically has capacity only for maximum daily demand. Design standards usually base tank volume on an assumed detention time at average design flow, element 6, above.

The design standards for rural WS&S projects in Ecuador, Guatemala, and Honduras are shown in Table 1. The standards for Ecuador are taken from Instituto Ecuatoriano de Obras Sanitarias (IEOS) (1986), those for Guatemala are from Unidad Ejecutora del Programa de

Table 1

Current Design Standards for Rural WS&S Projects

	Ecuador	*Guatemala*	*Honduras*
Population growth, percent per year	2.0 [a]	1.5	2.0
Design period, years	20	20	20
Average per capita flow, gpcd	18	20	30
Maximum daily peaking factor [b]	1.3	1.2	1.5
Maximum hourly peaking factor [c]	2.0	1.8	2.3
Tank detention at average flow, hours	9 [a]	7 [a]	8 [a]

[a] Variable; reported value represents the average
[b] Maximum daily flow/average flow
[c] Maximum hourly flow/average flow

Acueductos Rurales (UNEPAR) (1980), and those for Honduras are from the Servicio Autonomo Nacional de Acueductos y Alcantarillados (SANAA). The table shows a single value for each standard in each country. In some cases, the standards include a range of values; the values reported in the table denote the averages.

All three countries use essentially identical methods of water distribution, namely, private yard taps. In Ecuador, some houses have taps inside, but these represent the exception more than the rule. Also in Ecuador, most houses have private meters, whereas the systems in Guatemala and Honduras are built without meters. In all three nations, use of water from the piped system is prohibited for watering gardens or providing for animals.

The tariffs that are charged to households are generally the same or almost so for all the towns within a country. Guatemala and Honduras each charge a flat monthly rate per household to cover operation and maintenance (O&M) costs. Ecuador's tariff includes a flat rate for consumption of up to 4,000 gallons per month, plus a price for each gallon used over the base amount. However, no fees were charged for excess consumption in the communities during the time of this study, which effectively resulted in a flat-rate tariff for Ecuador similar to that in the other two countries.

The tariffs for each country are shown in Table 2. They are taken from WASH evaluation reports for A.I.D.'s rural WS&S program in each country and are based on rates of exchange with the U.S. dollar at the time of report preparation.[a]

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[a] Tariff data are given in the following reports: for Ecuador, see Edwards et al. (1989); for Guatemala, see Burns and Mattson (1989); and for Honduras, see Moncada et al. (1986) and Larrea et al., (1988).

Table 2

Tariffs Charged to Households

	Ecuador	*Guatemala*	*Honduras*
Flat rate, dollars/month/connection	—	0.074 [a]	0.50 [b]
Rate for first block, dollars/month/connection	0.30	—	—
Size for first block, gal	4,000	—	—
Rate for excess, dollars/1,000 gallon	0.72	—	—

[a] In addition, households pay $0.46/month to cover capital costs

[b] Monthly fee varies from one town to another, from $0.25 to $1.25; the value in the table represents the average

3

COMPARISON OF PREDICTED REQUIREMENTS AND DESIGN STANDARDS

3.1 Capacities Based on Water Requirements

In September 1989, visits were made to Guatemala and Honduras to start collecting data on actual water demand in rural communities. Similar work began in Ecuador in May 1990. Volumetric meters with totalizing registers were installed in the water transmission mains of 16 communities: 4 in Ecuador, 5 in Guatemala, and 7 in Honduras. The existing populations of these towns ranged from 100 to 1,200, and climates ranged from cold to hot.

Rates of water use were measured every 15 minutes from 4 a.m. to 8 p.m. on an average of 30 days in each community.[b] In addition, total daily (24-hour) measurements were made the same days on which the 15-minute readings were taken, and longer-term average demands were measured over a period of 90 days. The long-term average per capita demand for Ecuador was 51 gpcd, for Guatemala 24 gpcd, and for Honduras 56 gpcd.

Statistical analyses were made of the meter readings to develop equations for predicting flows and the required capacities of system components in communities of different size in the three countries. Details of the analyses are reported by Lauria and Cizerle, WASH Technical Report No.78.

Average per capita demand was similar in Ecuador and Honduras, but was significantly higher than that in Guatemala. Consequently, one equation was developed to predict community water demand as a function of population for the first two countries, and a second equation was developed for Guatemala. Equations for predicting maximum daily and maximum hourly peaking factors in communities as a function of population were developed by pooling the data from all three countries. Similarly, storage requirements for meeting peak demand were pooled for the three countries and a single predictive equation developed as a function of tank inflow and the peak hourly outflow to be met by the tank. A list of these equations is provided in the appendix.

To illustrate use of the equations, let us consider a town with a design population of 900 in Guatemala for which the predicted average demand is 100 gallons per hour (gph), or 30 gpcd. For a town this size in Honduras or Ecuador, the predicted average demand is 2,100 gph, or 56 gpcd, as shown in Table 3. The corresponding average daily design flows are 27,000 gallons per day (gpd) in Guatemala and 50,000 gpd in Ecuador and Honduras.

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[b] The shortest period of measurement was 1 day, the longest, 54 days.

Table 3

Required Design Flows and Capacities

	Design Population			
	300	*600*	*900*	*1,200*
Guatemala				
Average design flow, gph	160	640	1,100	1,600
Average design flow, gpd	3,900	15,000	27,000	38,000
Average per capita design flow, gpcd	13	26	30	32
Maximum daily peaking factor	1.2	1.2	1.2	1.2
Maximum daily design flow, gpd	4,700	19,000	32,000	46,000
Maximum hourly peaking factor	4.2	2.9	2.5	2.3
Maximum hourly design flow, gpd	16,000	45,000	68,000	88,000
Required storage tank volume, gal	2,500	5,000	6,500	7,800
Ecuador and Honduras				
Average design flow, gph	650	1,400	2,100	2,800
Average design flow, gpd	16,000	33,000	50,000	68,000
Average per capita design flow, gpcd	52	55	56	56
Maximum daily peaking factor	1.2	1.2	1.2	1.2
Maximum daily design flow, gpd	19,000	40,000	60,000	81,000
Maximum hourly peaking factor	2.9	2.4	2.1	2.0
Maximum hourly design flow, gpd	46,000	78,000	110,000	130,000
Required storage tank volume, gal	5,000	7,200	8,900	10,000

For all three countries, the maximum daily peaking factor was found to be 1.2 irrespective of population. Hence, the predicted maximum daily demand for the Guatemala town with a design population of 900 is 32,000 gpd, and for towns this size in Ecuador or Honduras it is 60,000. Sources of water supply would therefore need these capacities.

The equation for predicting the maximum hourly peaking factor is used to determine the required capacities of piped distribution networks. For the example town in Guatemala, the factor is 2.5, which, when multiplied by the average design flow, results in a predicted maximum hourly flow of 68,000 gpd. For Ecuador and Honduras, the peaking factor is 2.1, and the corresponding maximum hourly flow is 110,000 gpd.

The required size of storage tanks is predicted from tank inflow from the source of supply, which equals the maximum daily rate of demand, and tank outflow, which is the maximum hourly rate of demand. Using the values obtained above, the corresponding required tank volume for Guatemala is 6,500 gal, and the volume for Ecuador and Honduras is 8,900 gal. Similar values for other towns with other populations also are shown in Table 3.

3.2 Capacities Based on Design Standards

The purpose of this section is to compare the requirements in Table 3 with the capacities that result from using the design standards presented in Chapter 2. The comparison is based on expected populations at the end of the design period.

3.2.1 Ecuador

Component capacities for design populations of 300, 600, 900, and 1,200 persons in Ecuador based on predictions of requirements and current standards are shown in Table 4. For example, in a community of 900, the predicted average per capita demand is 56 gpcd, but current standards design for only 17 gpcd.

For the same community, source works would need a predicted capacity of 60,000 gpd, but current standards specify only 20,000 gpd. Networks would require capacity for 110,000 gpd, but the standards design for only 31,000 gpd. Similarly, the storage tank would need a capacity of 8,900 gal, whereas current design standards provide only 5,700 gal. For every major component of the water system for towns of every size in Ecuador, the existing design standards would produce facilities with capacities that are predicted to be too small.

3.2.2 Guatemala

Let us consider the same example town in Guatemala used above, with a design population of 900. From Table 1, the average per capita design flow in the standards is 20 gpcd, on the basis of which the average design flow for the entire community is 18,000 gpd (see Table 5). The maximum daily peaking factor in the standards is 1.2, which results in a maximum daily design flow for source works of about 22,000 gpd. The maximum hourly peaking factor is 1.8, which results in a maximum hourly design flow for the network of about 32,000 gpd. Finally, the design standard for storage tanks is to provide 7 hours detention at average design flow, which results in a design volume of about 5,300 gal.

The design capacities above that are based on current standards are shown in Table 5 in the column headed "Standards". This table shows similar design capacities for towns in Guatemala with design populations of 300, 600, 900, and 1,200. For each population, an adjacent column of requirements ("Req") shows the predicted capacities that would be needed based on the results of the previous section, which are identical to those shown in Table 3.

Table 4

Component Capacity Comparisons: Predicted Requirements versus Current Standards in Ecuador (by population)

	Req. 300 *	*Standards 300*	*Req. 600*	*Standards 600*	*Req. 900*	*Standards 900*	*Req. 1,200*	*Standards 1,200*
Average per capita flow, gpcd	52	13	55	15	56	17	56	19
Average design flow, gpd	16,000	4,000	33,000	9,000	50.000	150,000	68,000	23,000
Maximum daily peaking factor	1.2	1.3	1.2	1.3	1.2	1.3	1.2	1.3
Source capacity, gpd	19,000	5,100	40,000	12,000	60,000	20,000	81,000	30,000
Maximum hourly peaking factor	2.9	3.0	2.4	3.0	2.1	2.0	2.0	2.0
Network capacity, gpd	46,000	12,000	78,000	27,000	110,000	31,000	130,000	46,000
Tank detention at average flow, hour	8	9	5	9	4	9	4	9
Tank volume, gallon	5,000	1,500	7,200	3,400	8,900	5,700	10,000	8,600

* Req. = requirements based on measured demands

Table 5

Component Capacity Comparisons:
Predicted Requirements versus Current Standards in Guatemala
(by population)

	Req. 300 *	*Standards 300*	*Req. 600*	*Standards 600*	*Req. 900*	*Standards 900*	*Req. 1,200*	*Standards 1,200*
Average per capita flow, gpcd	13	20	26	20	30	20	32	20
Average design flow, gpd	3,900	6,000	15,000	12,000	27,000	18,000	38,000	24,000
Maximum daily peaking factor	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Source capacity, gpd	4,700	7,200	19,000	14,000	32,000	22,000	46,000	29,000
Maximum hourly peaking factor	4.2	1.8	2.9	1.8	2.5	1.8	2.3	1.8
Network capacity, gpd	16,000	11,000	45,000	22,000	68,000	32,000	88,000	43,000
Tank detention at average flow, hour	16	7	8	7	6	7	5	7
Tank volume, gallon	2,500	1,800	5,000	3,500	6,500	5,300	7,800	7,000

* Req. = requirements based on measured demands

Comparison of design capacities in Table 5 based on requirements and standards shows that for a town in Guatemala with 300 persons, current standards call for an average design flow that is too large by 50 percent. Although the maximum daily peaking factor in the standards is identical to predictions based on field measurements, the resulting maximum daily design flow (or source capacity) based on the standards is more than 50 percent higher than what would be required based on predicted demand. This means that A.I.D.-assisted projects require sources of supply for Guatemalan towns with design populations of 300 to have much more capacity than they should need.

On the other hand, the maximum hourly peaking factor in the standards is far too small for a town with a design population of 300; the standards assume 1.8 compared with a predicted peaking factor of 4.2. As a result, actual field measurements suggest that the piped distribution network would need to be designed for a maximum hourly flow of 16,000 gpd, whereas the standards would design it to handle only 11,000 gpd.

In Guatemalan towns with design populations of 600, 900, and 1,200, the existing standards produce design flows and capacities that are all too small. None of the components of these systems would be sufficient to meet the predicted demands placed upon them when the design population has been reached. In the early years, the systems might have excess capacity because of the 20-year design period, but study findings indicate that capacity would be exhausted before the design population is reached.

3.2.3 Honduras

Table 6 shows required component capacities based on predictions and current design standards for Honduran communities with design populations of 300, 600, 900, and 1,200 persons. In most cases, the standards produce designs that would be insufficient to meet predicted demand.

For example, in a Honduran community of 900, the predicted average demand is 56 gpcd, but this system is designed for only 30 gpcd. Source works would need a predicted capacity of 60,000 gpd, whereas existing standards provide only 41,000 gpd. The distribution network would require a capacity of 110,000 gpd, but the standards allow for only 61,000 gpd. Only the storage tank, which is designed for 9,000 gal, would be adequate based on predictions from field data. Notably, the latter is true only for Honduran communities of 900; those with populations of 300, 600 or 1,200 would not receive the storage capacity they require, under current design standards.

3.2.4 Summary for Guatemala, Honduras, and Ecuador

Ecuador's current design standards provide too little capacity compared with the predicted requirements for every major component in all towns. Furthermore, the discrepancy is substantial for sources and networks, which would generally require capacities three to four times larger than what the standards allow to meet predicted demand.

Table 6

Component Capacity Comparisons:
Predicted Requirements versus Current Standards in Honduras
(by population)

	Req. 300 *	*Standards 300*	*Req. 600*	*Standards 600*	*Req. 900*	*Standards 900*	*Req. 1,200*	*Standards 1,200*
Average per capita flow, gpcd	52	25	55	25	56	30	56	30
Average design flow, gpd	16,000	8,000	33,000	15,000	50,000	27,000	68,000	36,000
Maximum daily peaking factor	1.2	1.5	1.2	1.5	1.2	1.5	1.2	1.5
Source capacity, gpd	19,000	11,000	40,000	23,000	60,000	41,000	81,000	54,000
Maximum hourly peaking factor	2.9	2.3	2.4	2.3	2.1	2.3	2.0	2.3
Network capacity, gpd	46,000	17,000	78,000	34,000	110,000	61,000	130,000	81,000
Tank detention at average flow, hour	8	8	5	8	4	8	4	8
Tank volume, gallon	5,000	3,000	7,200	5,000	8,900	9,000	10,000	12,000

* Req. = requirements based on measured demands

The current design standards for Guatemala designate sources with too much capacity compared with predicted requirements in towns with design populations below 500. For larger towns, the standards call for sources with insufficient capacity. For all other water system components in towns with any design population, the standards call for sources with inadequate capacities compared with predicted requirements. The amount of underdesign is worse for pipe networks, which can have negative pressures at times of peak hourly demand. While sources and tanks based on the current standards would all have too little capacity, the amount of underdesign might not be serious.

In Honduras, the standards call for storage tanks with adequate capacities compared with predicted requirements in towns with design populations greater than 900. In towns smaller than this size, however, standard-designed tanks would be too small. Average design flows, sources of supply, and pipe networks would all be underdesigned by existing standards compared with the requirements of towns of any size. Unlike Guatemala, the amount of underdesign would be serious. Networks and sources in particular would have far too little capacity.

3.3 Initial Excess Capacity

The conclusion from the previous section is that the capacities of most water system components for nearly all towns in all three countries studied are expected to be inadequate to meet the demands placed upon them when their design populations are reached. These predictions are made for 20 years in the future when existing systems will be nearing the end of their design periods. The predictions also assume that population growth rates (which were not studied in this research) in the design standards of Chapter 2 are correct. The question addressed in this section is: How much excess capacity do current design standards provide for new systems when they are placed in service? The following examples should indicate.

If one considers a town in Guatemala with a design population of 900, the design standards in Table 1 assume a population growth rate of 1.5 percent per year and a design period of 20 years. Hence, the initial population of this town is 670 persons; i.e., a town of 670 will have a population of 900 in 20 years if its annual growth rate is 1.5 percent.

The design capacities for the major water system components for such a town are shown in Table 5. By comparison, it would be interesting to estimate the demands of the initial population of 670 in order to predict how much initial excess capacity, if any, the standards provide. Such estimates can be made using the predictive equations in the appendix.

Equation A1 is used to estimate long-term average demand in Guatemala. For a population of 670, the average demand is 754 gph, or 18,100 gpd. By comparison, the average design flow based on existing standards for a design population of 900 is 18,000 gpd. Hence, the initial average demand is predicted to exceed slightly the average design flow.

Based on equation A3, which measures the maximum hourly peaking factor, the maximum daily demand for a town with an initial population of 670 in Guatemala is predicted to be about 21,700 gpd. Based on the standards in Table 5, the required capacity of the source of supply for the design population of 900 is 22,000 gpd. Hence, the source of water supply would have slightly more capacity than the amount needed to meet the predicted demand of the initial population.

Based on equation A4, which calculates storage tank volume, the maximum hourly demand for a town in Guatemala with an initial population of 670 is predicted to be approximately 50,500 gpd. Current standards call for the required capacity of the piped distribution network for the design population of 900 to be 32,000 gpd. Hence, initial peak demands are predicted to exceed network capacity by a substantial margin.

Finally, let us consider the storage tank for the above town. From equation A5 (see appendix), a volume of 5,300 gallons would be required to meet the predicted initial peak hourly demand of 670 persons, assuming that inflow to the tank is equal to the design capacity of the source for 900 persons using current standards. Table 5 shows that the standards would designate a tank volume of 5,300 gal for a design population of 900. Hence, the requirement for meeting the initial predicted demand would exactly equal the capacity provided in the standards.

The above results are given in Table 7, which also illustrates similar comparisons for Honduras and Ecuador, based on the design standards in Table 1 and the predictive equations in the appendix. The capacity surplus column in Table 7 indicates the ability of components to meet predicted initial demands based on existing design standards. For the Guatemala example, the pipe network would have a substantial deficit (shown in parentheses), the source of supply would have a small surplus, and the tank would have neither a surplus nor a deficit.

In the case of Honduras, both the source and the tank would have excess capacities for meeting initial demands. However, the country's network would have a large capacity deficit. In Ecuador, all major components would have capacity deficits, especially the network.

Table 7

Initial Excess Capacities for Towns with Design Populations of 900

	Initial Demand	*Initial Capacity*	*Capacity Surplus* *
Guatemala			
Population	670	900	230
Average flow, gpd	18,100	18,000	(100)
Source, gpd	21,700	22,000	300
Network, gpd	50,500	32,000	(18,500)
Tank, gal	5,300	5,300	0
Honduras			
Population	600	900	300
Average flow, gpd	33,000	27,000	(6,000)
Source, gpd	39,600	41,000	1,400
Network, gpd	78,300	61,000	(17,300)
Tank, gal	6,900	9,000	2,100
Ecuador			
Population	600	900	300
Average flow, gpd	33,000	15,000	(18,000)
Source, gpd	39,600	20,000	(19,600)
Network, gpd	78,300	31,000	(47,300)
Tank, gal	16,400	5,700	(10,700)

* Capacity deficits are shown in parentheses

4

ANALYSIS OF POLICY OPTIONS

The results in Chapter 3 suggest that most water systems either have capacity deficits when they are placed in service, or will have soon thereafter, at least in some of their components. This finding was confirmed in discussions with local engineers associated with A.I.D.'s rural water program. Despite the 20-year design period that is assumed in current design standards, the water systems are predicted to exhaust their excess capacities long before their design populations are reached (assuming the population growth rate in the design standards is correct). This would violate a basic planning principle that A.I.D. and governments have adopted for the rural water program.

As mentioned earlier, when excess capacity is exhausted but demand continues to increase, there are two ways to deal with the situation. One is to provide more capacity, which is a structural solution that addresses the problem from the supply side and treats demand as a requirement. The other is to ration capacity by adopting measures for conservation; this approach treats the supply side (i.e., capacity) as given and addresses the problem from the demand side. Section 4.1 examines these options for systems to be built in the future, and Section 4.2 considers them for existing systems.

In order to make rough cost comparisons for both sets of options, a typical water system that has the characteristics shown in Table 8 is used for illustration. Several assumptions will be made for the cost analysis. Current design standards, including the average per capita design flow, the population growth rate, and the design period for the example given are assumed to be those used for A.I.D.-assisted systems in Honduras, namely 30 gpcd, 2 percent per year, and 20 years, respectively, as shown in Table 8. The per capita construction cost is $80, which is approximately the cost of new water systems in the three countries studied (Burns and Mattson, 1989). This cost applies to systems with a design population of 900, but it is assumed to decrease for larger systems, due to economics of scale. Also, capacity expansions of existing systems are assumed to be less expensive in per capita cost than new systems. The assumed annual discount rate is 10 percent. For cost comparisons, the water system is treated as a whole without separate components, and capacities are based on average rather than peak flows. Whenever excess capacity permits, the average per capita demand is assumed to be 55 gpcd, which was the finding from field measurements in Ecuador and Honduras (see Table 3). However, whenever demand at 55 gpcd would exceed capacity, the total amount of water consumed is assumed to be equal to total system capacity. Expansions are assumed to be implemented instantaneously, and O&M costs are assumed to depend on the number of users in a system but not on its flow capacity. Inflation of costs is ignored but can readily be taken into account if desired.

Table 8

Typical Water System Characteristics

Initial population	600
Persons per household	5
Initial number of Households	120
Population growth rate, percent per year [a]	2
Average per capita design flow, gpcd [a]	30
Design period, years [a]	20
Design population [a]	900
Design number of households [a]	180
Average design flow, gpd [a]	27,000
Cost per person, [b] dollars/capita	80
Construction cost, dollars [b]	48,000
Annual discount rate, percent	10
Average per capita demand if unconstrained by capacity	55

[a] Based on current standards
[b] Based on initial population = 600, current standards, and new construction (i.e., not an expansion)

4.1 Future Systems

The first consideration is of systems to be built in the future, since they constitute the greatest challenge to governments and donors such as A.I.D. Given the evidence that users want to consume 55 gpcd while existing design standards designate only 30 gpcd, either standards can be raised, which is considered in Section 4.1.1, or new systems can be designed using current standards but with a program for rationing, which is considered in Sections 4.1.2 through 4.1.7. Section 4.2 considers these options for existing systems.

4.1.1 Higher Design Standards

Let us consider the town described in Table 8 with a design population of 900. If the standard for average design flow is increased from 30 to 55 gpcd, the capacity of a new system for the town would have to be 49,500 gpd instead of 27,000 gpd. How much would a system with this capacity cost?

It is well known that rural water systems in developing countries exhibit economies of scale, which means that their average cost decreases as their scale or capacity increases (Demke and Lauria, 1992). A typical economy-of-scale factor for rural water supplies in Latin America, 0.7, which implies that a 1 percent increase in capacity roughly results in a 0.7 percent increase in cost (Lauria et al., 1977). If such a factor applies to the countries where this study was conducted, it follows that an equation for predicting the construction cost of new systems for the example town would be as shown below, where C = construction cost ($) and Q = average design flow (gpd).[c]

$$C = 38\ Q^{0.7}$$

This equation can be used to predict the cost of a new system for the illustrative town based on the higher average per capita design flow of 55 gpcd. Substituting 49,500 gpd for Q, the resulting cost is approximately $73,500. That is, by increasing the design standard so that the capacity of a new system would be more in line with predicted demand, the cost would increase from $48,000 to $73,500 (about 35 percent) for a typical project. The average per capita construction cost of the larger system based on the initial population of 600 is about $122. Since O&M cost is assumed to depend on the number of users and not on system capacity, it can be eliminated from further consideration in making cost comparisons. Note that the estimated cost for this option is a present value (p.v.) since it would be incurred entirely at the start of the project. Costs for this option are summarized in Table 9.

4.1.2 Rationing with Meters

The next five sections consider the following options for rationing capacity, assuming design flow is based on the standard of 30 gpcd: (1) metering, (2) flow restricters, (3) enforcement of rules, (4) unplanned shortages, and (5) planned intermittent supply.

A.I.D. and governments believe the current standard of 30 gpcd provides an adequate amount of water to meet basic needs. Because predicted demand is nearly twice this value, the task of a metering program would be to control usage at or below the design flow of 30 gpcd. By so doing, systems designed with the standards would have sufficient capacity for their full 20-year design period, assuming that predicted population growth of 2 percent per year is accurate.

In principle, a metering program can control water use to a target value. While use cannot be precisely controlled to 30 gpcd, it can probably come quite close. Such a program needs three components: (1) installation of meters, (2) an appropriate tariff, and (3) enforcement of the tariff, including meter reading, billing, collecting revenues, and terminating service.

The simplest way to control water consumption to a target value is through use of a two-part block tariff. The amount of water for the first block is based on the target. For the illustrative example with an initial population of 600 and an initial target consumption of 18,000 gpd, if the water system has 120 connections (at five persons each on average), the amount of water for the first block should be 150 gpd, or 4,500 gal per month per connection. Whether a price or flat fee is charged for this amount is not particularly important given that the objective is to limit use rather than recover cost. Even a very low price or fee could be used such as those

[c] Note that if Q = 27,000 gpd, which is the average design flow for the illustrative town using current standards, then C = $48,000, which agrees with the cost in Table 8.

Table 9

Cost of Using Higher Design Standard versus Using Existing Standard while Rationing with Meters (Future Systems)

1. Higher standard (average design flow = 49,500 gpd)

	Cost			
	Total	Present Value	A.I.D.	Community
Construction	$73,500	$73,500	$44,100	$18,400

2. Existing standard with meters (average design flow = 27,000 gpd)

	Cost			
	Total	Present Value	A.I.D.	Community
Construction	$48,000	$48,000	$28,800	$12,000
Meters, year 1	7,500	7,500	4,500	1,900
Meters, year 10	9,500	3,700	5,700	2,400
Meter reading at $1,200/year	24,000	10,200	0	24,000
Total project	$89,000	$69,400	$39,000	$40,300

already in existence. However, for excess usage above the target amount of water in the first block, a price should be charged that is sufficiently high to discourage excess usage (i.e., to ration system capacity). The price for the excess may have to be set through trial, with subsequent increases if the initial price still results in substantial use beyond the target.

It is interesting to examine the current tariff for Ecuador in light of these principles. Table 2 shows that the first block is 4,000 gal per month. If households have on average five persons, this amount would provide 27 gpcd. However, the average per capita design flow for Ecuador from Table 1 is 18 gpcd. Hence, the tariff does not appear to be compatible with the design standard.[d] Furthermore, since actual average demand for the towns studied in Ecuador is about 50 gpcd, it is clear that tariff enforcement is weak, which Edwards et al. (1989) confirm.

The cost of a metering program for the illustrative town would have to include two components: installation of meters, and personnel for reading, billing, collecting, and so on. In addition to the metering program, of course, would be the cost of the water system, which from Table 8 would be $48,000 based on existing design standards.

We can assume that houses have five persons on average, which implies 120 initial households for the illustrative community of 600 persons. We can also assume that meters have a useful life of 10 years, after which time they must be discarded and replaced. If predictions of population growth that are assumed in the design standards are accurate, the number of households after 10 and 20 years would be 150 and 190, respectively. For simplicity, we can assume that the costs of all 150 meters needed for the first 10 years are incurred in year 1, the costs of all 190 meters needed for the next 10 years are incurred in year 10, and that the cost of furnishing and installing a meter is $50. Hence, the cost of meters would be $7,500 at project inception plus $9,500 at the end of year 10.

For reading, billing, and collecting, it is assumed that only one person is needed if meters are read only once every two months. Assuming this person works a total of 160 hours per month, he can devote 2.7 hours to each connection in year 1, and in year 20 he can devote 1.8 hours per connection. At a salary of $5 per 8-hour day, the annual cost of reading is $1,200. Hence, the total cost of the option of not increasing design standards but using a metering program to limit consumption to 30 gpcd is $89,000, as shown in Table 9. Clearly, this option is more expensive in raw cost than the previous option of raising standards and enlarging capacity, which cost $73,500.

It is worthwhile to examine this cost from different perspectives. First, we can consider its equivalent present value assuming an annual discount rate of 10 percent. From Table 9, the construction cost of the project ($48,000) and the cost of meters for the first 10 years ($7,500) are already present values since they are incurred at project inception. The p.v. cost of meters for the second 10 years is $3,700, and the p.v. cost of reading and billing over the 20-year life of the project is $10,200. Hence, the total p.v. cost of this project is $69,400.

Yet another cost analysis is useful, namely the cost to the local community and the cost to the donor. As noted in Chapter 1, A.I.D. typically contributes 50 to 60 percent of project implementation costs in the form of grants, loans, and other assistance. The local community contributes about 25 percent of implementation costs plus 100 percent of O&M costs. Assuming the A.I.D. contribution to the illustrative project is 60 percent of implementation cost, including project construction plus the cost of meters, the required amount would be $39,000 as shown in Table 9. The community, on the other hand, would have to contribute

[d] When systems are placed in service, the first block can be enlarged to make full use of capacity. However, when the design population is reached, the block must be adjusted to the target value if a capacity deficit is to be avoided.

$16,300 to implementation plus the entire amount ($24,000) for meter reading and billing. In the first year of operation for the example community with 120 households, the cost of meter reading alone would be about $0.80 per household per month, which would roughly double the fees that households are currently paying for water.

The task now is to compare the option of raising the design standard, as presented in Section 4.1.1, with the option of leaving the design standard unchanged but introducing meters. The benefits of metering are in general equal to the cost savings brought about by reducing consumption (Saunders and Warford, 1976). However, the savings should be reduced by the benefits lost from reducing consumption from 55 gpcd, the predicted amount that households would use in the absence of metering, to 30 gpcd, the target amount with metering.

To determine whether the investment in meters can be justified, the present value cost of a new water system for the illustrative town with metering should be compared with the present value cost of a new system for the town without metering. For now, let us ignore the loss in benefits that would result from decreased consumption due to a metering program.

For the metering alternative, the present value cost of the water system designed for 30 gpcd from Table 8 is $48,000, and the present value cost of the metering program from Table 9 is $21,400, resulting in a total present value cost of $69,400. Without metering, the new system would have to be designed for 55 gpcd, which, from Section 4.1.1, would have a present value costs of $73,500. Hence, metering has lower p.v. costs than enlarging capacity, by $4,100. In other words, it would be less expensive in p.v. costs to retain the current design standards and introduce metering than to expand capacity to meet higher demand in the absence of metering.

As noted above, this savings should be reduced by the loss of benefits from lowering consumption from 55 gpcd to the metered target of 30 gpcd. However, this loss would appear to be negligible because of the flat-rate tariff that is charged and the failure of systems to charge for the actual amount of water consumed. That is, users now pay nothing for consumption above 30 gpcd, which suggests that the value to them of such consumption is small.

Another argument in favor of metering over raising design standards (at least from the donor's standpoint) is it costs the donor less. Under the assumptions of this example, the required A.I.D. contribution for the option of a higher design standard is $44,100 (60 percent of $73,500). For the option of metering with current standards, the required donor contribution for the example is $39,000, from Table 9.

Although the rough cost analysis suggests that meters can be justified and would be preferable cost wise to raising standards, a key question is whether households would be willing to pay a monthly fee twice as high as the amount they now pay. In fact, the viability of the metering option rests on its acceptability by the community. If consumers object to the use of meters, if they would not pay the fees required for reading and billing, if they would tamper with or bypass the meters, and if sufficient will were lacking to enforce the tariff (which is the only basis on which the metering option would work), then this alternative would fail, despite its attractiveness in terms of monetary cost.

4.1.3 Rationing with Flow Restricters

Meters are not the only way to ration capacity. Many communities in developing countries routinely install flow restricters in house connections to limit the amount of water that can be used. Various restricters in a range of designs are available, from a few cents to several dollars each. Success stories on the use of restricters are not easy to find, however, because the devices are plagued by four common problems: (1) they require relatively high line pressure, (2) they can clog easily if water flowing through is not entirely free of debris, (3) homeowners can remove them or install bypasses around them, and (4) they require in-house storage, which introduces a risk to health from contamination.

One of the most widespread uses of restricters in recent years occurred in Indonesia, which equipped hundreds of rural water systems with them. All of the above problems were cited, and most of the systems broke down. However, plans were under way recently to employ a more effective restricter developed in the Netherlands. Success using the improved device is unknown.

An alternative to restricters are special spring-loaded faucets that deliver a measured amount of water (about one liter) with each push. They have found limited application in Latin America. However, in principle they overcome the problems of clogging and needing high pressure for operation. Like restricters, they require in-house water storage with its attendant problems, and they are not tamper-proof. Additionally, such faucets can cost several times more than restricters.

Restricters and special faucets seldom solve capacity rationing problems on their own. Their installation would not necessarily meet the target of 30 gpcd. They are most effective when consciously chosen by the communities where they are installed, and accompanied by education campaigns regarding their use. A cost of $25 or more per service connection is not uncommon.

4.1.4 Enforcement of Rules

In all the communities studied, existing rules prohibit waste and the use of water for gardens and livestock. Furthermore, A.I.D.'s rural water programs include an education component to instruct households in proper water use and personal hygiene. Despite this, high demands in Latin America suggest that the rules are not being followed and that the education campaign may not be entirely successful. The reasons for this are unknown. It is conceivable that restrictions on water use for gardens and livestock are unreasonable and unenforceable if they threaten one's livelihood. As with other rationing options, community acceptability is the key to success.

In the short term, enforcement of the rules and putting increased emphasis on proper water use in education campaigns may be the most cost-effective option for reducing high demand and rationing capacity, assuming that garden and livestock needs can be met from sources other than the piped system. The marginal cost of increasing the education component could be very low; perhaps only a change would be required in reallocating teachers' time from some less important topics to water conservation. Likewise, maybe increased attendance by community members at training sessions would produce the desired effect.

Enforcement of rules would not necessarily be expensive. Using one or a few people to patrol communities need not be costly, especially if the patrols are done periodically rather than continuously. Organizing neighbors into groups for the purpose of self-surveillance could build awareness of the importance of conservation and give community members a greater sense of ownership of the problem and its solution. Enforcement might be enhanced by the installation of meters in the transmission mains that feed systems, which would cost only a few hundred dollars each. Also teaching the community how to make meter readings could provide not only increased awareness of the problem of high demand but also promote improved maintenance and ultimately provide a better database for design. If widespread use of macrometers proves impossible, selected use in some communities might be plausible. As with flow restricters and special faucets, rules enforcement would not necessarily ensure reduction of high demand to the target of 30 gpcd.

4.1.5 Rationing by Unplanned Shortages

This option is the one most commonly "chosen" in developing countries when demand exceeds capacity; it results from doing nothing. The typical sequence of events in and the consequences of doing nothing are well documented (Saunders and Warford, 1976). Common symptoms of trouble are low pressures and low faucet flows at periods of peak water use. The data in Table 7 show that in every case, the largest capacity deficits are associated with pipe networks, which means that low pressures and low flows are the first symptoms to appear.

Low pressures in time usually degenerate into negative pressures and always pose a risk to health by enabling polluted groundwater to enter the distribution network. Moreover, the first strategy that households usually adopt in dealing with low pressures is to increase the number of containers for storing water in the house. In addition to the relatively high cost of individual storage drums (say, $10 per connection), the containers themselves and the way they are used pose additional health threats.

As negative pressures and intermittent service become more commonplace, some households try to reduce their demand, but the evidence is clear that this is not a practical solution. Without incentives, households simply do not see the advantage of conserving unless all system users do so, which is unlikely.

When low and negative pressures persist for long periods, households that are able to frequently change their water use habits. For example, some people will bathe and fill storage containers in the middle of the night when pressures are higher. However, for some members of the community (the very young, the elderly, households with few or no family members), such behavioral changes are not possible or cause substantial inconvenience.

The wealthier members of a community are better able to deal with the unreliability associated with capacity deficits. A common solution for them is to install booster pumps that withdraw water directly from the distribution network. Almost everywhere, this practice is illegal, however, because it further reduces network pressure and promotes infiltration of contaminated groundwater into the system, thereby threatening health.

As the quality of water service deteriorates, the risk is run that households will lose confidence in those responsible for providing and operating the system, and many or most may stop their monthly payments. This almost always leads to a steadily declining cycle of further deterioration and eventual breakdown of the system. It is usually at this stage that water vendors enter the scene, selling water of doubtful quality at very high prices. In the absence of vendors, households frequently revert to traditional sources.

In conclusion, rationing by shortage is costly and inefficient. Only some of the costs are pecuniary. Nonpecuniary costs are widespread, for example, the risk to health, inconvenience, and more time spent collecting water. Furthermore, the costs are uneven, frequently having a greater impact on the poor, women, and children. In the final analysis, rationing by shortage cannot lead to sustainable development.

4.1.6 Rationing by Planned Intermittent Supply

This option is a variation on the theme of rationing by shortage. Whereas the latter method allows events to proceed on their own, resulting in low pressures and intermittent service at unpredictable times, rationing by intermittent service involves deliberate decisions about when, where, and for how long the system is shut down each day. This option can remove the uncertainty for users about when water will be unavailable and therefore enable them to plan for meeting demand.

Uncertainty is removed at the expense of paying an operator to turn the valves. In the rural water systems of concern, this cost would probably be modest in most cases. However, the nonpecuniary costs would be similar to those of rationing by shortage: increased risk to health from periodically reducing the pressure in the network and storing water in the house, inconvenience to consumers, and more time spent collecting water. As with rationing by shortage, households would need to purchase water storage containers.

4.1.7 Comparison of Rationing Options

Metering, which is the most expensive of the rationing options in terms of pecuniary cost, is less expensive in total present value cost and in donor cost than the option of increasing capacity by raising the design standard. A summary of results from the analysis of all five rationing options is shown in Table 10. Only three of the options have a high likelihood of reducing existing demand to the design flow in current standards, thereby rationing capacity as required. Furthermore, the two remaining options, rationing by shortages and by intermittent supply, pose a potentially serious risk to health and would not result in sustainable development. They also have high nonpecuniary costs that cannot be quantified, but because these options are so contrary to the spirit of the rural water program in Latin America, they should be removed from further consideration.

Metering is probably the best of the three remaining alternatives for achieving the target reduction of high water use rates. However, it is expensive. Nevertheless, several favorable factors mitigate the cost:

1. Metering is the only option that holds the promise of ensuring that the resources invested in rural water system are used efficiently. While none of the water systems is likely to adopt a policy of marginal cost pricing in the near future to ensure efficiency, if they are ever to do so, meters sooner or later will have to be installed.

2. Metering, probably more than any other option, encourages increased self-sufficiency and sustainable development. With meters, households can learn that water is an economic good, and revenues can be generated to pay for its supply.

3. Although the total cost of a metering program is high, the meters themselves are not. For the initial project, meters would increase costs only $10 per capita, from $80 to $90, an increase of only 13 percent.

The success of metering would largely depend on community acceptability. Would households be willing to double fees they now pay? Would they tamper with or bypass the meters? Would the community be able to enforce the tariff? The answers to these questions are unknown, and therefore the viability of this option requires further study.

Between the other two rationing options, flow resticters and rules enforcement, neither of which would necessarily achieve the target reduction in demand, enforcement of rules is probably the least expensive and the option that should be tried first. Furthermore, it may be the one that is most acceptable to users if existing high demand is due primarily to waste or to gardens and livestock, for which other water supply options exist.

The last option for rationing capacity is to use meters or restricters/special faucets. Choosing between them could appear difficult, as the capital costs of faucets and meters do not differ remarkably ($8 vs. $10 per capita, respectively, at least at the outset). However, if the tariff cannot be implemented and enforced, meters alone will not achieve the goal of capacity rationing. Yet, if the community is to become more self-sufficient and made aware that water is an economic good, metering is the best option.

Table 10

Comparison of Rationing Options

Option	Description	*Total Cost ($1,000)* Raw	P.V.	*Cost/Cap ($)* Raw	P.V.	*Control Demand to 30 gpcd?*	*Remarks*
1	Metering	38,000	19,400	63	32	Yes	Community needs to agree; user fees will double
2	Restricters	4,500	3,600	8	6	No	Community needs to agree; some health risk
3	Rules enforcement	—	—	—	—	No	Use volunteers for enforcement
4	Shortages	1,800	1,500	3	3	Yes	High nonpecuniary cost
5	Intermittent supply	1,800	1,500	3	3	Yes	High nonpecuniary cost

4.2 Existing Systems

Hundreds of rural water systems are operating in Ecuador, Guatemala, and Honduras, and most if not all likely will require expansion or rationing before their 20-year design periods are reached, due to higher-than-expected demand. The results from Section 4.1 indicate that for new systems, the combination of existing design standards with rationing is preferable to greater capacity without rationing. The question for this section is whether a similar policy should be followed for existing systems.

4.2.1 Expanding Existing Systems

Consider the example described in Table 8, with initial and design populations of 600 and 900, respectively. Based on current design standards, such a system would have an average design capacity of 27,000 gpd. However, assuming that the system is in operation, when it first started up with 600 users, the average amount of water available was 45 gpcd, which is more than the 30 gpcd assumed by the standards, but less than the 55 gpcd that field data indicate the users want to consume. Hence, from the time the system was first placed in operation, it would not have had any excess capacity. If the assumptions for predicting population growth in the design standards are correct, after five years of operation the number of users would have increased to about 660, and average per capita consumption would have dropped to 41 gpcd had the system continued to operate at full capacity.

If users were to try to obtain more than this amount of water, specifically if they were to try to get 55 gpcd as assumed in this example, then low or negative pressures in the distribution network would result, with all the related problems described in Section 4.1. One way to resolve this difficulty would be to expand capacity, which is the option considered herein. Assuming then that in the fifth year of its life the example project is expanded so that it will be able to supply 55 gpcd to a design population of 900, its average capacity would have to be increased from 27,000 to 49,500 gpd, a jump of 22,500 gpd.

The question here, as in Section 4.1.1, is How much will the expansion cost? Expansions generally cost less than new construction. Some of the smaller-diameter pipes in the transmission main and distribution network would have to be replaced with larger ones, some new parallel pipes might have to be installed, the source of supply might require additional headworks and expansion, and the storage tank would probably need to be enlarged or replaced. However, such changes would cost less than constructing an entirely new system with equivalent capacity.

For this example, it is assumed that the equation for predicting expansion costs is similar to the equation in Section 4.1.1 for new systems, with the same economy-of-scale factor (0.7). However, the coefficient is expected to be about 23 instead of 38, which assumes that an expansion costs only 60 percent as much as a new system, other things being equal. Substituting the capacity of the expansion (22,500 gpd) for Q, the resulting cost is $25,600. That is, it would cost this amount to increase capacity in the fifth year so that the system could supply at least 55 gpcd until the 20th year, at which time excess capacity would be exhausted.

Note that if the fifth year is used as a datum for cost comparisons, the expansion cost of $25,600 is a present value as of that date. Figure 1 shows the expansion path of facilities and the predicted demand for this example during the 20-year planning period.

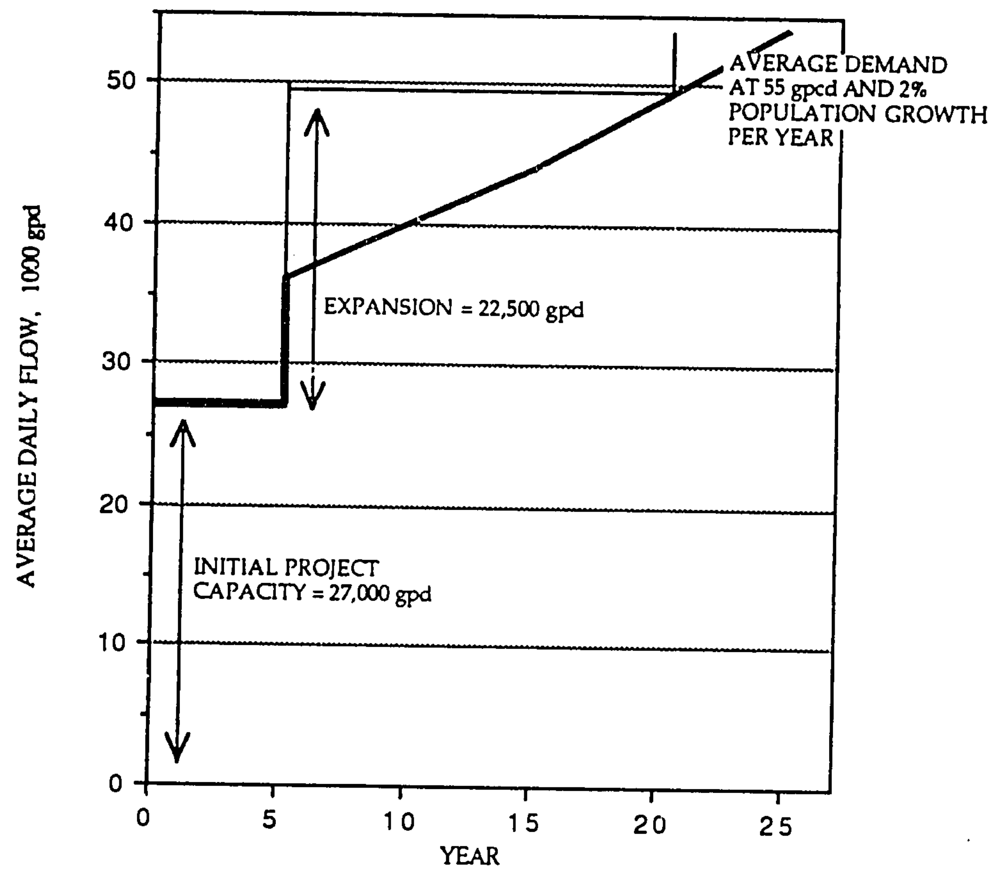

Figure 1

Expansion of Existing Systems

4.2.2 Rationing in Existing Systems Using Meters

One alternative to expanding the capacity of existing systems is to install meters. Most of the assumptions for this case are the same as in Section 4.1.2. For example, the metering program is begun in the fifth year of project life, the cost of furnishing and installing meters is assumed to be $50 each, and the annual cost of meter reading and billing is assumed to be $1,200. However, for this case it is assumed that meters have a useful life of only seven or eight years, after which time they must be replaced. Assuming that meters are installed in the fifth year of the project, 155 would be required initially, and 190 more would be required about seven years later.

Table 11

Cost of Expansion versus Rationing by Using Meters (Existing Systems)

1. Expansion (average design flow = 22,500 gpd)

	Cost			
	Total	Present Value	A.I.D.	Community
Expansion	$25,600	$25,600	$15,400	$6,400

2. Rationing with meters

	Cost			
	Total	Present Value	A.I.D.	Community
Meters, year 5	$ 7,800	$ 7,800	$ 4,700	$ 1,900
Meters, year 12	9,500	4,900	5,700	2,400
Meter reading at $1,200/year	18,000	9,100	0	18,000
Total project	$35,300	$21,800	$10,400	$22,300

The estimated costs for this option are shown in Table 11. The initial and subsequent costs of meters are $7,800 and $9,500, respectively, and the cost of reading/billing during the 15-year period from year 5 to year 20 is $18,000, bringing total raw costs to $35,300. Clearly, this option is more expensive in total cost than expanding capacity.

As in Section 4.1.2, it is useful to compare present value costs. Using the fifth year after the illustrative project is placed in service as the datum, the expansion option has a p.v. cost of $25,600 compared with metering with a total p.v. cost of $21,800, as shown in Table 11. Hence, metering is less expensive on this basis. It is also useful to compare the costs to the donor and local community. Using the same assumptions as in Section 4.1.2 (A.I.D. pays 60 percent of implementation cost and the community pays 25 percent of implementation plus 100 percent of meter reading and billing), the cost comparisons are as shown in Table 11. The costs to A.I.D. of the expansion and metering options would be $15,400 and $10,400, respectively. However, the respective costs for the same two options would be $6,400 and $22,300 to the local community.

Conclusions that can be drawn from these cost comparisons are similar to those in Section 4.1. The total undiscounted cost of metering exceeds the cost of expansion, but on a present value basis, it is lower. The expansion option would be 50 percent more expensive to A.I.D. than metering, but metering would be three times more expensive to the local community, assuming all the reading and billing costs were paid for locally. Monthly household fees with metering would have to double, but there is no evidence that such an increase would be acceptable. Indeed, the viability of metering cannot be determined without additional information on community preferences and willingness to pay.

The option of expanding capacity cannot be justified on the basis of economic efficiency, when only private user benefits are considered. Economic theory indicates that in order to maximize efficiency, the price of water should be set equal to its marginal cost. If this principle were followed, users would signal through the price they pay that systems should be expanded when their excess capacity is exhausted. However, for the operating systems considered herein, the price charged for water use is zero, due to the nature of existing flat-rate tariffs. Hence, the cost of expansion would outweigh the benefits that directly accrue to users, making expansion inadvisable. Of course, other benefits could possibly strengthen the argument for expansion, such as general improvements to public health and the reduction of migration from rural areas to cities.

4.2.3 Other Rationing Schemes for Existing Systems

Metering is the most expensive of the five rationing schemes considered herein, but it has the advantage of affording control of water use to a target amount, and it can promote responsible and efficient systems management. Nonetheless, some communities may be unwilling to pay the costs of metering. It would be desirable to assess community preferences in order to select an appropriate rationing scheme, and if increased cost recovery from the beneficiaries were an objective, such an assessment would be highly recommended. However, short of conducting willingness-to-pay studies, the rationing alternative that should probably be tried first is enforcement of local rules regarding conservation. In some respects, this option resembles willingness-to-pay studies, since contacting local users about their preferences lies at the core. Neither unplanned shortages nor intermittent supply should be considered as viable rationing options for existing systems.

5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

Because average per capita demands in the countries studied exceed design values, new systems will not have the capacity to meet demands for 20 years as originally planned, and existing systems will face premature shortages, some of which are already evident. Hence, the original expectations and goals for these systems cannot be met. Some components of the water systems have capacity deficits from the time they are first placed in service, most notably the piped distribution network, which in all three countries has a capacity predicted to be insufficient to meet initial peak hourly demand with residual pressures. The current design standards for sources of supply and storage tanks show mixed performance, in some cases providing adequate capacity but in others deficits.

Two options are available for dealing with high demand and related capacity deficits: Either capacity must be increased or it must be rationed if existing design standards are retained. Increasing capacity would raise system costs by 50 percent, from $80 to $120 per capita for new systems. As a result, for a given budget, the number of persons that could be served with piped water systems would have to be cut by one-third.

The costs of rationing capacity range from almost nothing to more than the cost of expansion. Some options for rationing have very low pecuniary costs, especially to the public sector, such as doing nothing. However, the nonpecuniary costs for such options are known to be very high.

5.2 Conclusions

Action must be taken to address the existing and imminent problems in the rural water program in Latin America. Whatever option is selected, costs will be incurred. If it is decided to do nothing, the pecuniary costs will be modest and will not accrue to government. However, the nonpecuniary costs will be high in terms of user dissatisfaction, health risk, loss of confidence in government, and failure to attain sustainable development.

Expansion of systems is economically inefficient and will not necessarily solve the problem of capacity deficits. Per capita water usage may continue to increase, calling for even further expansion. Expansion of existing systems when numerous communities do not have improved water supplies would be inadvisable.

Rationing is a step toward more efficient use of the resources invested in rural water systems. Efficient use requires that beneficiaries pay a price for water equal to the marginal cost of producing it. Households are not now paying anything near the marginal cost, and the discrepancy between their payments and costs would be even greater if the systems were to be expanded.

Little consideration has been given in the rural water program to cost recovery from beneficiaries, which is an extremely important item. Governments and donors are quite high-handed in selecting design standards, levels of service, and tariffs, and the communities themselves play a relatively minor role in planning, probably in part because governments and donors are paying most of the cost. However, if sustainable development and self-sufficiency are goals of the rural water program, communities must be more involved and take greater ownership of systems planning and operation. They must learn that an improved water supply is not free but rather is an economic good that carries a cost. Steps should be taken to obtain information from the communities that reflect how much water is worth to them. Metering is a logical choice for achieving increased self-reliance.

5.3 Recommendations

Based on the findings of this report, the following recommendations are made for dealing with high demand in A.I.D.'s Latin American rural water program:

1. Governments and A.I.D. should decide to do something about the current high demands in rural water systems. It would be a mistake to ignore this problem.
2. In the short term, they should reject the alternative of increasing design flows and expanding capacity. Instead, they should ration capacity.
3. The options of rationing by shortage (i.e., doing nothing) and rationing by planned intermittent supply should be abandoned. They pose health risks and are incompatible with the goal of sustainable development.
4. In Ecuador, for those communities with individual house meters, the block tariff should be redefined to achieve the goal of rationing, and steps should be taken to enforce the tariff through meter readings, billings, collections, and so on.
5. In Guatemala, Honduras, and other communities without meters, the first step toward rationing capacity should be enforcement of rules on prohibition of waste, irrigation, and giving water to livestock.
6. If enforcement of rules fails to achieve the goals of conservation, consideration should be given to use of flow-restricting faucets and meters. In choosing between faucets and meters, governments and A.I.D. should carefully consider community characteristics and preferences, particularly the community's ability and will to enforce the tariff.
7. Studies should be conducted in Ecuador, Guatemala, and Honduras to determine community preferences and the maximum amounts of money beneficiaries are willing to pay for improved water supplies. Results of such studies should be used to plan more self-sufficient and sustainable systems and determine how government and donor

subsidies can be reduced so that more communities can be served with improved water systems using available resources.

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EQUATIONS FOR PREDICTING REQUIRED FLOWS AND CAPACITIES

Long-Term Average Demand

The equation for predicting long-term average demand (LAD) in towns of Guatemala is

$$LAD = -318 + 1.6\ (POP) \tag{A1}$$

where LAD = gallons per hour (gph) and POP = population, for sample size N = 5, R^2 = 0.85. For example, if POP = 900, LAD = 1,122 gph. The corresponding equation for Ecuador and Honduras is

$$LAD = -66 + 2.4\ (POP) \tag{A2}$$

for which N = 11 and R^2 = 0.94. If POP = 900 then LAD = 2,094 gph.

Maximum Daily Peaking Factor

The maximum daily peaking factor (MDPF) is the ratio of maximum daily demand to LAD. MDPF was found to be independent of community size based on a regression analysis that included data from 16 study sites. The predictive equation is

$$MDPF = 1.2 \tag{A3}$$

For a town in Guatemala with POP = 900, the predicted maximum daily demand is LAD x MDPF = 1,122 x 1.2 = 1,346 gph, and for a town in Honduras or Ecuador with POP = 900, the predicted maximum daily demand is 2,513 gph.

Maximum Hourly Peaking Factor

The maximum hourly peaking factor (MHPF) is the ratio of maximum hourly demand to LAD. The predictive equation based on pooled data from 16 communities is

$$MHPF = 16.7\ (LAD)^{-0.27} \tag{A4}$$

where LAD = gallons per hour, N = 16, and R^2 = 0.57. For the town in Guatemala with POP = 900 and LAD = 1,122 gph, MHPF = 2.51, which, when multiplied by LAD, results in a predicted maximum hourly flow of 2,813 gph. For the Honduras/Ecuador example, MHPF = 2.12 and maximum hourly flow is 4,436 gph.

Storage Tank Volume

Required storage tank volume (STV) depends on the average rate of inflow to the tank (INF) and the peak rate of tank outflow (OUT). Typically, INF is the flow rate from the source of supply, which is equal to the maximum daily demand (from Equation A3 above), and OUT is the peak hourly demand (from Equation A4 above). The predictive equation is

$$STV = 0.37\ (OUT)^{2.32}\ (INF)^{-1.20} \qquad \text{(A5)}$$

where STV = gallons, OUT = gph, and INF = gph. For this equation, which was developed from pooled data from 16 communities, N = 48 and R^2 = 0.70. For the Guatemala example, where OUT = 2,813 gph and INF = 1,346 gph, STV = 6,538 gallons. For the Honduras/Ecuador example, where OUT = 4,436 gph and INF = 2,513 gph, STV = 8,892 gallons.