# ABSTRACT

KIMBERLEY DENE CIZERLE. Analysis of Design Standards for Latin American Water Systems (Under the Direction of DR. DONALD LAURIA)

Design standards for rural water supply systems in Latin America were analyzed to determine their ability to select component capacities and design flows sufficient to meet actual demands. Water use data were collected from sixteen communities in Guatemala, Honduras, and Ecuador. The data were analyzed to determine actual values for design parameters, including average use rates, peaking factors and storage volumes. Regressive equations were developed for each parameter as a function of community characteristics.

For towns of 300 to 1200 persons, results indicate average use rates on the order of 13 to 32 gallons per capita per day in Guatemala and 52 to 56 gallons per capita per day in Honduras and Ecuador. These demands are 150% to 300% higher than the design standards used by AID and local ministries of health; actual peaking factors and storage volumes are also underestimated. Hence, it appears that water systems in Guatemala, Honduras, and Ecuador will not have sufficient capacities to meet actual demands at the end of design periods as planned; rather, excess capacities will be exhausted prematurely.

The underlying cause of this seems to be due largely to existing tariff structures, which are incompatible with design standards, and a lack of community awareness about water use and conservation in rural piped water systems. Various approaches for addressing the problem are recommended but not analyzed in detail.

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# ANALYSIS OF DESIGN STANDARDS FOR LATIN AMERICAN WATER SYSTEMS

Kimberley Dene Cizerle

## I. INTRODUCTION

Rural water supply coverage in the developing world is severely lacking. Throughout the world's developing countries, the World Health Organization estimates that only 29% of the rural population had piped drinking water supplies as of 1980 (WHO, 1981). Hence, the years 1981-1990 were designated the International Drinking Water Supply and Sanitation Decade in which safe drinking water and sanitation services were to be provided for all. Unfortunately, this goal was not met. For example, only 30% of Guatemala's and 56% of Honduras' rural population had received water supply systems as of 1989 (WASH, 1990).

In Latin America, the realization that water supply and sanitation services could not be constructed in all rural communities by 1990 prompted the local governments and the U.S. Agency for International Development (AID) to set more realistic coverage targets. For instance, targets were set for 44% rural water supply coverage in Guatemala and 66% coverage in Honduras by 1995 (WASH, 1990). Various bilateral agencies such as AID and the international banks have attempted to address this problem and provide funds to meet the needs. AID is spending about $50 million over five years to construct rural water systems in Guatemala, Honduras and Ecuador.

## A. MOTIVATION FOR THE STUDY

This report is concerned with the rural water systems that are planned and constructed by the Agency for International Development in conjunction with the local Ministry of Health (MOH) in various Latin American countries. The planning process employed by these organizations is similar in each country. The MOH and AID (MOH/AID) first select rural communities in which to install water supply systems. Each selected community then forms a water committee which is responsible for providing a portion of the labor and transportation required to construct the system. The MOH/AID then design the system, which is typically gravity fed, with individual yard tap connections. The MOH/AID set the water rates (usually flat monthly fees) and present the system to the water committee, which is then responsible for operating and maintaining the system and collecting the monthly fees.

The MOH/AID in each country adopt design standards which are used to select the capacities of each of the water supply system components. One such standard is the average water use rate, which is usually on the order of 20 gallons per capita per day (GPCD). Each system is designed to meet the use rate of the population that is predicted to exist about twenty years in the future. This estimated population is based on an assumed growth rate which may or may not be derived from historical data. The source works, storage tank, and distribution network are designed to meet peak demands based on assumed hourly and daily peaking factors.

## B. THE PROBLEM

The design standards used for these systems generally involve a great deal of judgement regarding expected rates and patterns of water use in each community. In most cases, rural water systems in Latin America have non-metered house connections and lack macrometers as well. Without meters, engineers and planners have not been able to measure the actual volumes of water used, and consequently have not been able to check the standards employed for design.

Given that large sums of money are expended on constructing rural water systems and that the design standards are based largely on assumptions and judgments, high potential exists to "misallocate" MOH/AID's scarce resources. For purposes herein, "appropriate" allocation implies "accurate prediction," whereby actual demands are equivalent to the design standards, and system components have sufficient capacity to meet demands. In this sense, a misallocation of resources means too little or too much excess capacity is provided in the system. This situation results if the design standards are much lower or much higher than the actual demands.

It should be noted that the problems of optimal design and maximum economic efficiency are not in question here, as these issues involve the examination of demand functions and consumer benefits, which are not addressed.

## II. GOAL AND OBJECTIVES

The goal of this project is to improve the MOH/AID rural water supply program in Latin America. Three major objectives are associated with this goal:

A. Determine actual water use rates and patterns in typical MOH/AID rural water systems.

B. Determine the required capacities of the major system components based on actual demands for water.

C. Evaluate the standards used to design water systems in various countries, with a view toward detecting the possible misallocation of scarce resources; i.e. determine the ability of existing design standards to produce systems that meet actual demands.

### A. ACTUAL WATER USE

The first objective involves collecting water use data to measure and determine use rates, peaking factors, and storage requirements in typical rural water systems throughout Latin America. A typical MOH/AID system serves between 200 and 2000 persons and includes: source works (without water treatment), storage tank, transmission main, and distribution network. To develop a broad data base, communities with different characteristics were studied in three different countries.

### B. REQUIRED CAPACITIES

The second objective is to determine system capacities required to meet actual demands. This involves analyzing the use rates, peaking factors and storage requirements to determine the required capacities of each system component. Predictive models are needed for all design parameters, so each can be estimated for a variety of communities of different characteristics. Once the models are used to make predictions about the parameters, the required capacities of the water supply system components are then determined. These are the capacities required to meet the "actual" demands (as predicted from actual data).

C. DESIGN STANDARDS

The final objective of this project is to evaluate the effectiveness of the MOH/AID design standards in terms of their ability to predict system capacities that are sufficient to meet the actual demands. This involves comparing the predicted required capacities with the design standard-generated capacities.

The accomplishment of these three objectives will help to improve MOH/AID rural water supply planning in Latin America. The information provided by this study regarding rural water use rates and patterns will either affirm the current design standards, or it will assist MOH/AID planners and engineers in the selection of more appropriate design standards for rural water supply systems.

# III. LITERATURE REVIEW

## A. CONSUMPTION DATA

There is a vast body of literature regarding typical water use rates in various parts of the world. In United States cities and towns, use rates have been found in the range of 47 to 437 GPCD (Howe and Linaweaver, 1967). Various studies found daily demands of 16 to 50 GPCD in Latin America. A 1970 World Health Organization survey found rural water use in Latin America on the order of 18 to 50 GPCD. A 1956 study of thirteen rural water systems in Venezuela found the average water use rate to be about 50 GPCD from consumption at house connections (Wagner and Lanoix, 1959). Other surveys have found average use rates of 16 GPCD in rural Guatemalan communities and 26 to 33 GPCD throughout rural Latin American communities (White, et al., 1972).

Several factors are known to influence water use, including population, climate, and culture. Use rates generally increase with higher populations and warmer climates; they have been found to vary from one culture to another due to different customs and religions (White, et al, 1972). Other factors affecting water use rates are leakage, carelessness and waste, meterage, and price.

It is recognized that most distribution systems leak (Fair, et al., 1971). Leakage frequently contributes to a large portion of the water used in a system. A leakage rate of less than ten percent is considered low (Walker, 1978); rates of 40% to 60% in developing countries are common (Yepes, 1991). One way to see if leakage is a problem is to examine the nighttime flows. If the late night and pre-dawn flows are high, it is likely the system has leaks (Fair, et al., 1971).

Carelessness and waste are also common factors contributing to high use rates, especially in developing countries. "The amount of water lost through carelessness of customers sometimes reaches staggering proportions; it is not uncommon to find towns wasting as much as 75% of the water supplied" (Wagner and Lanoix, 1959).

Metering and charging customers for the amount of water used has a substantial impact on use rates because consumers are given information about their use and the financial incentive to conserve. In a study in Boulder, Colorado, the introduction of meters and incremental water charges decreased use by 36%; it has lowered use rates by 20 to 50% in other areas. These effects vary greatly depending on the types of use. Consumers who use water for gardening are more likely to respond than those who use it for drinking and cooking alone (Clark and Goddard, 1974).

## B. WATER SUPPLY ECONOMICS

In 1967, Howe and Linaweaver published a well known study concerning the effect of price on residential water use in the United States. They found that the price of water significantly impacts the average and peak demands. This impact is measured as the price elasticity of demand, which is the percentage change in water use due to a percentage change in price. From the U.S. data, Howe and Linaweaver found a price elasticity of about -0.23, indicating that a 10% increase in price brings about a 2.3% decrease in water use.

Similar studies have been conducted in other parts of the world. For residential customers in Malaysia, price elasticities of -0.1 to -0.2 were found (Katzman, 1977). Other studies report values of -0.60 for households with piped connections and -0.78 for squatter settlements in an urban area of Sudan (Khadam, 1988). These studies show that water utilities can use price as a tool to ration water.

## C. DESIGN STANDARDS

Several design standards for rural water systems are published in the literature. For piped water supplies in developing countries, Okun and Ernst (1987) recommend use rates of:

5 - 11 GPCD in humid climates
16 - 21 GPCD in dry climates
11 - 16 GPCD average

with a maximum-daily to average ratio of 1.5 and maximum-hourly to average ratio of 2.0. They also recommend a design period of 7 to 8 years as optimal, based on average economy of scale factors and interest rates in developing countries.

Another set of standards (Unakel, 1971) for rural water systems in developing countries is:

13 - 21 GPCD average use rate
1.5 maximum daily to average ratio
4.0 maximum hourly to average ratio
10 - 15 years design period

A population growth rate of 2.6% per year was suggested

(Glennie, 1987) for an African village water supply, with an average use rate of 6 GPCD and a storage tank detention time of 8 hours.

Relationships between design standards and several different variables have been reported in the literature. For example, the average use rate is often expressed as a function of community population, number of persons per household, or climate (White, et al., 1972). Peaking factors are commonly represented as log functions of the average design flow, decreasing logarithmically as the average flow increases. For example, at 0.1 MGD, the maximum daily and hourly peaking factors are estimated as 3.0 and 5.5 respectively, and at 1 MGD they are estimated as 2.2 and 3.6. (Walker, 1978)

Design standards are generally based on studies and surveys in various parts of the developed and developing world. They are meant to give engineers and planners guidance for designing water systems in the absence of historical data. However, water use rates and patterns are very different from one area to another. To accurately determine appropriate design standards for systems in a given area, studies of actual water use must be conducted in that area.

# IV. METHODOLOGY

## A. ACTUAL WATER USE

To determine actual water use in rural Latin American communities, trips were made to Guatemala and Honduras in September, 1989 and to Ecuador in May, 1990. In each country, the project was explained to key MOH/AID personnel and the study communities were selected. The criteria used for community selection were:

a. The water system was recently constructed by MOH/AID.

b. The system was functioning properly, preferably with excess capacity, and providing water 24 hours a day.

c. The communities were in various geographic and climatic regions, including the mountains, subtropical regions, and the coast; their climate was categorized as either "cold," "temperate," or "hot."

d. The water from the system was designated for domestic consumption only. In all the communities studied, use of water for irrigation or animals was prohibited.

A complete list of the communities studied and the characteristics of each, is given in Table 1 and Appendix A.

To measure water use on a community-wide basis, several macrometers were taken to each country; they were Hersey volumetric meters with maximum 160-gallon per minute capacity and calibration in units of gallons. Specifications for this meter are in Appendix B. In the three countries of the study, ten macrometers were initially installed in ten different systems.

TABLE 1

COMMUNITIES IN WHICH METERS WERE INSTALLED

GUATEMALA

| TOWN | POPULATION | CLIMATE | TOWN NAME CODE[1] |
|---|---|---|---|
| Calera Tenerias | 348 | cold | CAL |
| Chuicotom | 372 | cold | CHU |
| Xetacabaj | 432 | cold | XET |
| Nueva Esperanza | 804 | temperate | NUE |
| La Cienaga | 840 | cold | LACI |

HONDURAS

| TOWN | POPULATION | CLIMATE | TOWN NAME CODE[1] |
|---|---|---|---|
| La Bella Vista | 140 | hot | BEL |
| La Curva | 260 | hot | LACU |
| Coloraditos | 350 | hot | COL |
| Brisas del Carmen | 408 | hot | BRI |
| Quebrada de Yoro | 819 | hot | QUE |
| Ruth Garcia | 850 | hot | RUT |
| Colonia Martinez | 960 | hot | MAR |

ECUADOR

| TOWN | POPULATION | CLIMATE | TOWN NAME CODE[1] |
|---|---|---|---|
| Unachi-Pucara | 245 | cold | UNA |
| Panzaleo | 252 | cold | PAN |
| San Vicente de Guayllabamba | 820 | temperate | SAN |
| Tandapi | 1243 | temperate | TAN |

[1] Name code by which town is referred to in all graphs and tables.

In each system, the macrometer was installed in the transmission main from the storage tank. Due to budgetary constraints, it was not possible to purchase automatic meter recorders nor to pay workers to read the meters twenty-four hours a day. Hence, two people in each community were employed to read the meter and record the readings on data forms. Samples of data forms left with the meter readers are shown in Appendix C.

It was indicated from conversations with water committee members that most of the water consumption occurred in these rural communities during the daylight hours, from just before sunrise until after sunset. Hence, the hours from 4:00 a.m. to 8:00 p.m. were selected as the meter reading time period during which two meter readers each worked eight hours, making meter recordings every fifteen minutes. The first worker recorded meter data from 4:00 a.m. until 11:45 a.m. and the second worker from 12:00 p.m. until 8:00 p.m. At the onset of the study, the meters were read every day for two weeks. After this initial period, they were read every other week for seven days straight, sixteen hours per day.

In some cases, the meters were moved to new communities after the initial meter reading term ended. As of June, 1991, water use data were collected in 16 different rural communities in Guatemala, Honduras, and Ecuador. Details, such as the times and dates of data collection and the number of days of meter readings are given in Appendix A.

The three water system components of interest in this study are the source works, storage tank, and distribution network. Thus, the water use data were analyzed to determine the parameters that affect the capacities of these components, including the average use rate, ratio of peak day to average use rate, ratio of peak hour to average use rate, and required storage volume.

Other important parameters for design purposes are the design period and population growth rate, which were not studied in this project. For the rural water systems of Guatemala, Honduras, and Ecuador, MOH/AID typically use a 20-year design period and a population growth rate of two to three percent per year.

The average use rate, also called the long term average demand (LTAD), is the average amount of water used by the community. It is expressed in units of gallons per hour (GPH), gallons per day (GPD), or gallons per capita per day (GPCD). The water use rates employed by the MOH/AID design standards are in the range of 15 to 30 GPCD. In this study, the LTAD was calculated as the average demand for water over the longest time period for which data were available. It is the last meter reading less the first meter reading (gallons), divided by the time interval (hours or days). A sample calculation for this parameter is given in Appendix D; this calculation was repeated for each community studied.

The nighttime use rate was also examined to obtain information regarding possible system leaks or consumer waste. This rate represents the amount of water used during the nighttime hours, between 8:00 p.m. and 4:00 a.m. (when the meters were not being read), and is equal to the 4:00 a.m. meter reading less the 8:00 p.m. reading from the previous night (gallons), divided by eight hours. Based on daily living patterns described by community officials, it was assumed that water use in this time period primarily represents leakage, wastage, and consumption for non-essential purposes. A sample calculation for the nighttime use rate is given in Appendix E.

The ratio of peak daily demand to average demand is called the maximum daily peaking factor (MDPF); it is typically combined with the LTAD to select the capacity of the source works. For MOH/AID's designs in Guatemala, Honduras, and Ecuador, a MDPF of about 1.2 is customarily employed. This means that source works are typically designed for a flow equal to 1.2 times the average design flow.

For each day of meter readings in a community, a maximum daily peaking factor was calculated by dividing the total water use for that day by the community's long term average flow (LTAD). This results in a different maximum daily peaking factor for each day of meter readings. A representative calculation for the MDPF parameter is given in Appendix F.

To select the single MDPF parameter, a frequency distribution analysis of the data was performed. A typical MDPF frequency distribution is given in Appendix G, which shows, for example, that 80 percent of the MDPF's for this community are less than or equal to 1.2. In other words, on 80 percent of the days of readings, the

MDPF was less than or equal to 1.2. The one-hundredth percentile value of the MDPF (i.e. the maximum MDPF) is 2.2. It is a matter of judgement as to which frequency should be selected for the MDPF parameter; for the purpose of this study, the eightieth percentile was used. This process was repeated for each community studied.

The ratio of peak hourly demand to long term average demand is called the maximum hourly peaking factor (MHPF) and is used with the LTAD to design the capacity of the distribution network. Typically, MOH/AID use a MHPF of 2.0-3.0 for rural water systems; networks are designed for a flow equal to 2.0-3.0 times the average design flow.

For each day of meter readings, a maximum hourly peaking factor was calculated by dividing the peak hourly demand for that day by the community's LTAD. A sample MHPF calculation is given in Appendix H. This calculation was repeated for each community studied. With a different MHPF for each day of record, the design parameter was selected from the frequency distribution at the eightieth percentile. A typical MHPF distribution is shown in Appendix I.

A storage tank is necessary in order to meet peak hourly demands. The tank fills when the use rate is less than the rate of inflow, and it empties when the use rate exceeds the inflow rate. The required volume of a storage tank (RVST) is that volume required to meet the community's peak demands. For design purposes, MOH/AID generally assume the RVST is the volume needed to provide 7 to 9 hours detention time at the average design flow.

For each day of meter readings in each community, a RVST was determined for the demands of that day at three different assumed inflow rates, viz. the LTAD, 1.2 times LTAD, and 1.4 times LTAD. A sample calculation of the RVST for a given day of record is shown in Appendix J. This calculation is based on a mass diagram analysis (i.e. Rippl method), which is commonly used for reservoir design (Fair, Geyer and Okun, 1971).

A RVST was obtained for each day of record corresponding to each assumed rate of inflow to the tank. With three different inflow rates, the analysis produced three different required volumes for each day of record in each community. The storage volume parameter was selected in essentially the same way the peaking factor parameters were selected. A frequency analysis was made of RVST values, and the volume at the ninetieth percentile was selected as the design requirement. A typical RVST frequency distribution is shown in Appendix K; this estimation was repeated for each community studied.

## B. REQUIRED CAPACITIES

The data analysis from this study produced a LTAD, MDPF, MHPF, and RVST for each town. Each of these values is needed to predict required component capacities for communities which will likely receive MOH/AID water systems in the future. This implies the need to develop predictive models for each parameter as a function of community characteristics (i.e. explanatory variables) such as population, climate, and country. These models are obtained through ordinary least squares analysis and are presented in the next chapter.

## C. DESIGN STANDARDS

The final objective of this study is to evaluate the effectiveness of MOH/AID design standards in terms of their ability to predict system component capacities sufficient to meet actual demands. To do this, communities with different design populations (viz. 300, 600, 900, and 1200 persons) were assumed and the "required" component capacities were determined based on the metered data from this study. The "required" capacities were then compared with the "predicted" capacities based on the MOH/AID design standards. This analysis was conducted for each system component, for each of the four selected design populations, in Guatemala, Honduras, and Ecuador.

# V. RESULTS

## A. ACTUAL WATER USE

The LTAD values for the 16 communities in this study are reported in Table 2. In these towns, the use rate (column 6) varies from 10 to 78 GPCD. The average for Guatemala is 24 GPCD; for Honduras, 56 GPCD; and for Ecuador, 51 GPCD.

It is expected that the LTAD increases with increasing population; a town with 1000 persons will use more water than one with 100. Although this is a general trend in the data, it is not always the case. The data presented in Table 2 are arranged by country in order of increasing population. The values in column 4 indicate that the LTAD generally increases as the population increases, but there are exceptions. The LTAD values in column 6 show that the per capita use rates are much lower in Guatemala than in Honduras and Ecuador.

The fact that the LTAD does not always increase with population and that per capita use rates are significantly different in Guatemala than in Honduras and Ecuador raises questions regarding the factors that might explain the demand (e.g. population and climate) and the origin of the demand (e.g. consumption, waste, or leakage). Each of these will be discussed in the second section of this chapter.

The MDPF values for the 16 communities are reported in Column 4 of Table 3. These values are fairly consistent from one community to another and from one country to another. They do not

TABLE 2

LONG TERM AVERAGE DEMAND VALUES*

**GUATEMALA**

| (1) TOWN | (2) POPULATION | (3) CLIMATE | (4) LTAD GPH | (5) LTAD GPD | (6) LTAD GPCD |
|---|---|---|---|---|---|
| CAL | 348 | cold | 297 | 7100 | 21 |
| CHU | 372 | cold | 425 | 10200 | 27 |
| XET | 432 | cold | 174 | 4200 | 10 |
| NUE | 804 | temperate | 1179 | 28300 | 35 |
| LACI | 840 | cold | 913 | 21900 | 26 |

**HONDURAS**

| TOWN | POPULATION | CLIMATE | LTAD GPH | LTAD GPD | LTAD GPCD |
|---|---|---|---|---|---|
| BEL | 140 | hot | 454 | 10900 | 78 |
| LACU | 260 | hot | 401 | 9600 | 37 |
| COL | 350 | hot | 651 | 15600 | 45 |
| BRI | 408 | hot | 932 | 22400 | 55 |
| QUE | 819 | hot | 2434 | 58400 | 71 |
| RUT | 850 | hot | 2157 | 51800 | 61 |
| MAR | 960 | hot | 1913 | 45900 | 48 |

**ECUADOR**

| TOWN | POPULATION | CLIMATE | LTAD GPH | LTAD GPD | LTAD GPCD |
|---|---|---|---|---|---|
| UNA | 245 | cold | 493 | 11800 | 48 |
| PAN | 252 | cold | 446 | 10700 | 43 |
| SAN | 820 | temperate | 2031 | 48800 | 59 |
| TAN | 1243 | temperate | 2804 | 67300 | 54 |

*LTAD

TABLE 3

MAXIMUM DAILY AND HOURLY PEAKING FACTOR VALUES

GUATEMALA

| (1) TOWN | (2) POPULATION | (3) LTAD | (4) MDPF[1] | (5) MHPF[2] |
|---|---|---|---|---|
| CAL | 348 | 297 | 1.1 | 3.1 |
| CHU | 372 | 425 | 1.5 | 2.8 |
| XET | 432 | 174 | 1.6 | 4.5 |
| NUE | 804 | 1179 | 1.1 | 2.7 |
| LACI | 840 | 913 | 1.1 | 3.5 |

HONDURAS

| TOWN | POPULATION | LTAD | MDPF | MHPF |
|---|---|---|---|---|
| BEL | 140 | 454 | 1.1 | 2.8 |
| LACU | 260 | 401 | 1.1 | 4.7 |
| COL | 350 | 651 | 1.2 | 3.3 |
| BRI | 408 | 932 | 2.2 | 2.7 |
| QUE | 819 | 2434 | 1.5 | 2.1 |
| RUT | 850 | 2157 | 1.1 | 1.9 |
| MAR | 960 | 1913 | 1.1 | 2.6 |

ECUADOR

| TOWN | POPULATION | LTAD | MDPF | MHPF |
|---|---|---|---|---|
| UNA | 245 | 493 | 1.3 | 2.4 |
| PAN | 252 | 446 | 1.2 | 2.5 |
| SAN | 820 | 2031 | 1.1 | 1.5 |
| TAN | 1243 | 2804 | 1.1 | 1.9 |

[1]MDPF = Maximum Daily Peaking Factor
[2]MHPF = Maximum Hourly Peaking Factor

appear to depend on either population or country. The MDPF values range from 1.1 to 2.2; the average value in both Guatemala and Honduras is 1.3; in Ecuador it is 1.2.

The MHPF values for the 16 communities are reported in Column 5 of Table 2; they range from 1.5 to 4.7. The average MHPF value is 3.3 for Guatemala, 2.8 for Honduras, and 2.1 for Ecuador. Note that the MHPF tends to be higher when the LTAD is low and lower when the LTAD is high. The reason for this seems to be that with more people using water, use is spread throughout the day rather than concentrated in one or a few short periods, dampening the peaks and smoothing the data trace for the entire community.

RVST values for the 16 communities are reported in Column 4 of Table 4. These values represent the storage volumes needed when the inflow rate is 1.2 times the long term average demand. The RVST values range from 2100 to 18,500 gallons; the required detention times (based on the average design flow) range from 1 to 15 hours. The average detention values are 9 hours for Guatemala, 7 hours for Honduras, and 3 hours for Ecuador.

As indicated by the data in Table 4, the RVST values generally increase with increasing LTAD, and seem to be related to the maximum hourly peaking factor. At larger MHPF values, more detention time is required, whereas at smaller MHPF values, much less detention time is required. This is because large MHPF values imply large hourly peaks of use, requiring larger tank volumes to

TABLE 4

STORAGE VOLUME AND DETENTION TIME VALUES

GUATEMALA

| (1) TOWN | (2) POP | (3) LTAD GPH | (4) TANK INFLOW* GPH | (5) MHPF | (6) RVST GAL | (7) DETENTION TIME hours |
|---|---|---|---|---|---|---|
| CAL | 348 | 297 | 360 | 3.1 | 3200 | 9 |
| CHU | 372 | 425 | 510 | 2.8 | 3600 | 7 |
| XET | 432 | 174 | 210 | 4.5 | 3200 | 15 |
| NUE | 804 | 1179 | 1420 | 2.7 | 7000 | 5 |
| LACI | 840 | 913 | 1100 | 3.5 | 9500 | 9 |

HONDURAS

| TOWN | POP | LTAD GPH | TANK INFLOW* GPH | MHPF | RVST GAL | DETENTION TIME hours |
|---|---|---|---|---|---|---|
| BEL | 140 | 454 | 550 | 2.8 | 4300 | 8 |
| LACU | 260 | 401 | 480 | 4.7 | 4500 | 9 |
| COL | 350 | 651 | 780 | 3.3 | 8000 | 10 |
| BRI | 408 | 932 | 1120 | 2.7 | 9500 | 8 |
| QUE | 819 | 2434 | 2920 | 2.1 | 18500 | 6 |
| RUT | 850 | 2157 | 2590 | 1.9 | 7500 | 3 |
| MAR | 960 | 1913 | 2300 | 2.6 | 14900 | 6 |

ECUADOR

| TOWN | POP | LTAD GPH | TANK INFLOW* GPH | MHPF | RVST GAL | DETENTION TIME hours |
|---|---|---|---|---|---|---|
| UNA | 245 | 493 | 590 | 2.4 | 2300 | 4 |
| PAN | 252 | 446 | 540 | 2.5 | 2100 | 4 |
| SAN | 820 | 2031 | 2440 | 1.5 | 3600 | 1 |
| TAN | 1243 | 2804 | 3370 | 1.9 | 9500 | 3 |

* Inflow = 1.2 * LTAD

meet demand. Small MHPF values mean that the hourly data trace is smoother; therefore, the rate of tank drawdown is smaller, and less volume is needed. The outflow rate exceeds the inflow rate to a greater extent when the MHPF is high than when the MHPF is low, thereby resulting in larger detention times at high MHPF values and smaller detention times at low MHPF values.

## B. REQUIRED CAPACITIES

The principal determinant of system capacity is long term average demand. To determine required system capacities for towns with populations in the range of those studied herein, the LTAD data were pooled and regressed against population based on the apparent association in Table 2. The resulting equation, in which LTAD has units GPH, is:

$$LTAD = -231 + 2.3\ (POP) \qquad (1)$$

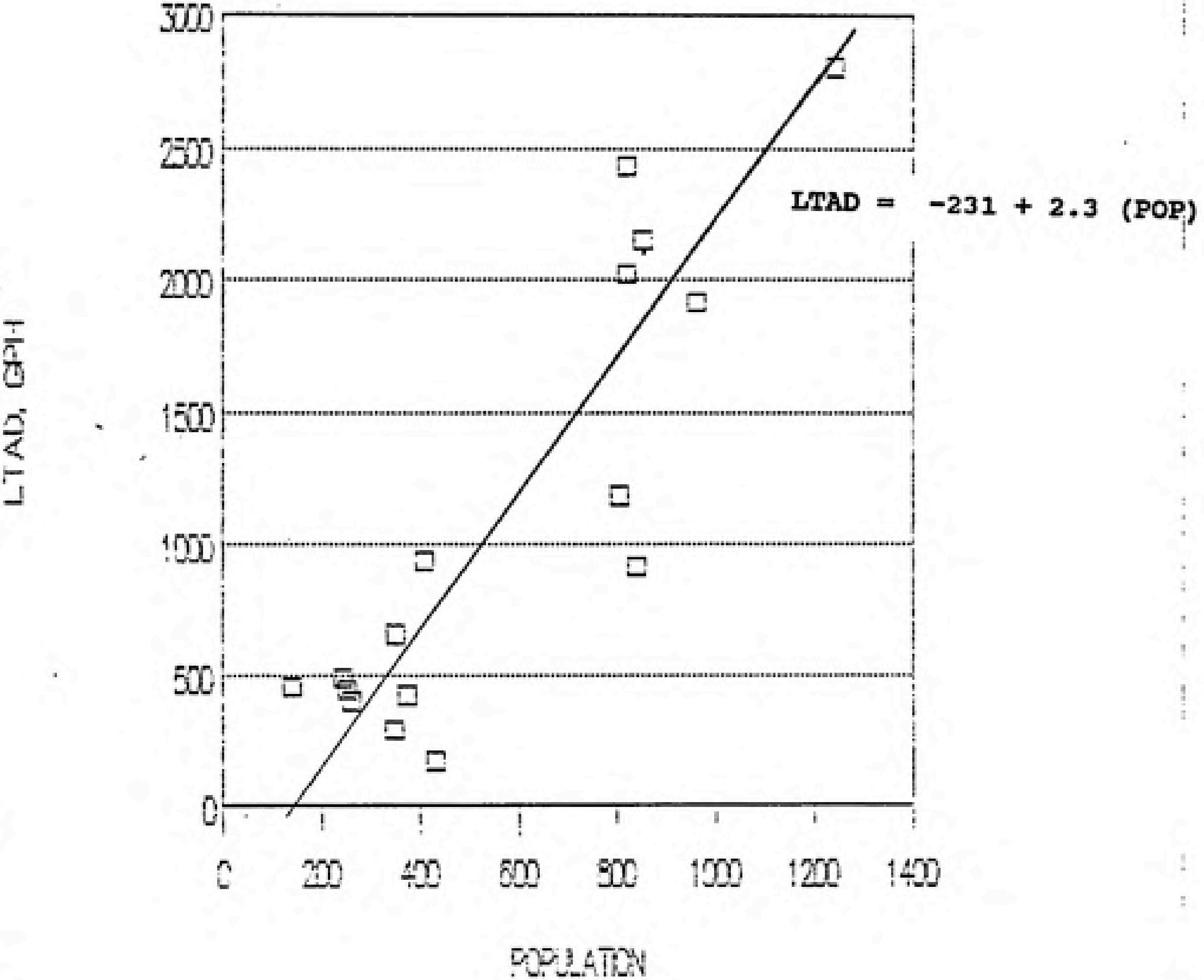
$$t\text{-calc} = 7.1,\ N=16,\ df=14 \qquad R^2 = 0.78$$

A graphical presentation of these data is given in Figure 1, where LTAD is plotted as the dependent variable and the population is on the abscissa. Equation 1 fits the data fairly well with an R-squared value of 0.78, indicating that 78 percent of the variation in LTAD is explained by the variation in population. The question remains, however, as to whether other explanatory variable(s) account for variation in LTAD.

Table 2 shows the LTAD values for the 16 study communities and the climate type of each. These values indicate that the cold-

FIGURE 1

# LONG TERM AVERAGE DEMAND AS A FUNCTION OF POPULATION



climate communities generally have lower use rates than the temperate- and hot-climate communities. For this reason, a regression was performed with both population and climate as the explanatory variables. Climate is represented as a 0/1 dummy variable, where CLIM=1 indicates a cold climate and CLIM=0 indicates a temperate or hot climate. The resulting regression equation and statistics for this data show that the addition of the climate variable improves the R-squared value:

$$LTAD = 144 + 2.0\ (POP) - 529\ (CLIM) \qquad (2)$$

t-calc = 6.8, 2.7, N=16, df=13 $\qquad R^2 = 0.86$

Further examination of the data in Table 2 indicates that the use rates in Guatemala are much lower than the use rates in Honduras and Ecuador. In Guatemala, the average LTAD is 24 GPCD, but it is 56 GPCD in Honduras, and 51 GPCD in Ecuador. Therefore, a regression was performed with population and country as the explanatory variables. The country designation is a 0/1 dummy variable, where COUN=1 represents Guatemalan towns, and COUN=0 represents non-Guatemalan towns. The resulting regression equation and statistics are:

$$LTAD = 3 + 2.3\ (POP) - 699\ (COUN) \qquad (3)$$

t-calc = 11.9, 5.3, N=16, df=13 $\qquad R^2=0.93$

Both population and country coefficients are statistically significant. However, nothing is gained by adding climate to the model, as shown below:

$$LTAD = 63 + 2.2\ (POP) - 120\ (CLIM) - 626\ (COUN) \qquad (4)$$

t-calc = 10.1, 0.66, 3.6 ,N=16; df=12 $\qquad R^2 = 0.93$

With this analysis, it is determined that the variations in LTAD are sufficiently explained due to variations in population and country and not to climate. A regression analysis was performed with just the Honduras and Ecuador data, showing that use rates are not significantly different in these two countries. Thus, for predicting the values for communities with different populations, two equations are used.

Guatemala: $LTAD = -318 + 1.6(POP)$ (5)

t-calc = 4.1, N=5 df=3 $R^2 = 0.85$

Honduras and Ecuador: $LTAD = -66 + 2.4\ (POP)$ (6)

t-calc = 11.7, N=11, df=9 $R^2 = 0.94$

A graphical presentation of this data is given in Figures 2 and 3.

In the Guatemala LTAD equation, the population coefficient is 1.6, implying a predicted average daily use rate of 1.6 GPH per capita, or 38 GPCD. For Honduras and Ecuador, the population coefficient is 2.4 GPH/capita, indicating average daily demand of 58 GPCD.

LTAD values can be predicted with the above equations, but these equations do little to explain demand. Whether average demands are due to leaking systems, water wasting, or actual use is not known.

Many distribution systems have high leakage rates, and therefore it was suspected that leakage might be a factor that

FIGURE 2

# LONG TERM AVERAGE DEMAND AS A FUNCTION OF POPULATION FOR GUATEMALA

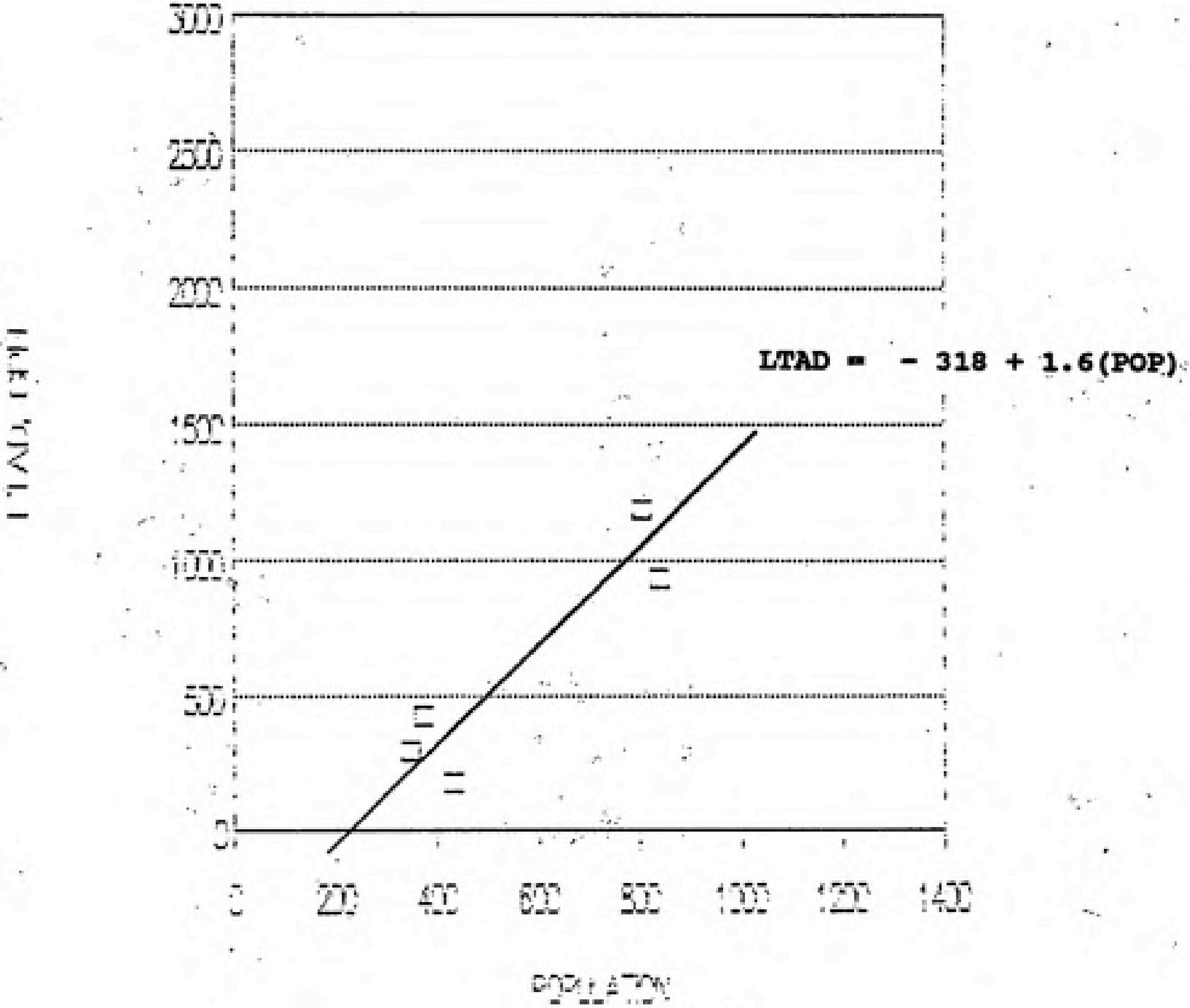
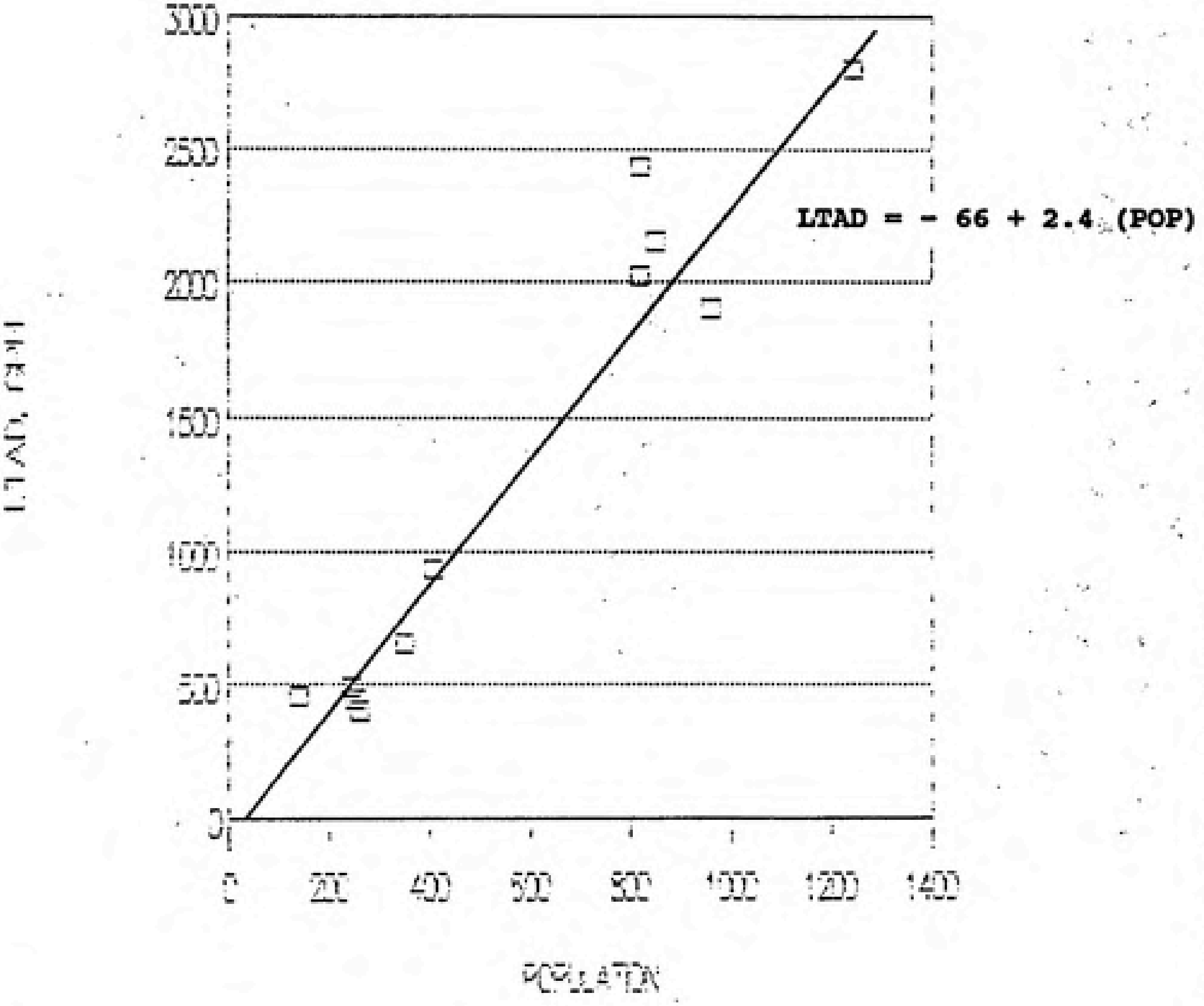


FIGURE 3

# LONG TERM AVERAGE DEMAND AS A FUNCTION OF POPULATION FOR HONDURAS & ECUADOR



contributes to higher demands in the Honduran and Ecuadorian communities. To investigate this possibility, the nighttime use rates (between 8:00 p.m. and 4:00 a.m.) were calculated and examined. A summary of the nighttime use rates in each of the communities is presented in Table 5. If the minimum nighttime use rate (in gallons per minute) ever gets near zero, then can be concluded that leakage is not a major determinant of demand.

The flow rate from an open tap is generally between 3 and 5 GPM. In the many cases where the minimum nighttime use rate is small and the maximum nighttime use rate is large (i.e. where the standard deviation or coefficient of variation is large), it is concluded that the nighttime use is due to consumers consciously or wastefully using water overnight; that is, it appears that users are turning the valves to use water.

In the case of Guatemala, the minimum nighttime use rates are small, as are the maximum nighttime use rates. In these communities, consumers are probably not wasting water, using it improperly overnight, or losing it through system leaks. In this way, the Guatemalan water demands are very different than those of Honduras and Ecuador.

In both Honduras and Ecuador, the majority of the communities have small minimum nighttime use rates and large maximum nighttime use rates. This implies that the communities do not lose water through system leakage. Instead, the consumers probably leave their taps open overnight -- either by neglecting to turn them off from earlier use or by consciously deciding to do something with

TABLE 5

NIGHTTIME USE RATES

GUATEMALA

| (1) TOWN | (2) AVERAGE GPM | (3) STANDARD DEVIATION | (4) MINIMUM GPM | (5) MAXIMUM GPM |
|---|---|---|---|---|
| CAL | 0.4 | 0.6 | 0.0 | 2.8 |
| CHU | 3.6 | 0.5 | 3.2 | 6.0 |
| XET | 0.2 | 0.8 | 0.0 | 4.6 |
| NUE | 9.3 | --- | --- | --- |
| LACI | 2.5 | 1.2 | 0.9 | 4.7 |

HONDURAS

| TOWN | AVERAGE GPM | STANDARD DEVIATION | MINIMUM GPM | MAXIMUM GPM |
|---|---|---|---|---|
| BEL | 2.0 | 2.6 | 0.0 | 15.0 |
| LACU | 0.3 | 0.1 | 0.2 | 0.4 |
| COL | 1.7 | 0.8 | 0.8 | 3.9 |
| BRI | 10.9 | 2.6 | 7.1 | 14.4 |
| QUE | 36.0 | 11.4 | 0.1 | 56.9 |
| RUT | 24.0 | 2.6 | 18.4 | 27.6 |
| MAR | 11.5 | 4.6 | 1.1 | 25.3 |

ECUADOR

| TOWN | AVERAGE GPM | STANDARD DEVIATION | MINIMUM GPM | MAXIMUM GPM |
|---|---|---|---|---|
| UNA | 6.2 | 2.2 | 1.6 | 11.9 |
| PAN | 3.6 | 2.8 | 0.0 | 9.4 |
| SAN | 25.2 | 5.7 | 1.3 | 40.4 |
| TAN | 32.2 | 5.2 | 21.4 | 43.9 |

the water during the nighttime hours (perhaps irrigate). Therefore, the LTAD measurement adequately reflects the real consumer use rates, and is used as the predictive parameter for the system capacity.

The LTAD values, expressed in GPD, represent required system capacity to meet demands; various predicted LTAD values based on equations 5 and 6 are given in row 1 of Table 6. For a community of 900 persons in Guatemala, the predicted average use rate is 30 GPCD, or 27,000 GPD, or 1100 GPH. A community with a design population of 900 persons in Guatemala needs a capacity of 27,000 GPD in order to meet average demands. For a community with a design population of 900 persons in Honduras or Ecuador, the predicted LTAD is 56 GPCD, or 50,000 GPD, or 2100 GPH.

Required source works capacity is based on maximum daily demands, which are equal to the MDPF times the LTAD. It would be expected that the MDPF decreases as LTAD increases, from relationships observed in other studies. In the communities of this study, however, this was not the case. As shown in Table 3, the MDPF does not vary with LTAD. A regression of MDPF on LTAD shows that there is no relationship between the two parameters:

$$MDPF = 1.23\ (LTAD)^{-0.034}$$

t-calc = 4.3, N=16 df=14 $R^2 = 0.02$

The plot of MDPF as a function of LTAD depicted in Figure 4 shows that the MDPF relationship can be represented by a horizontal line,

**FIGURE 4**

# MDPF AS A FUNCTION OF LTAD

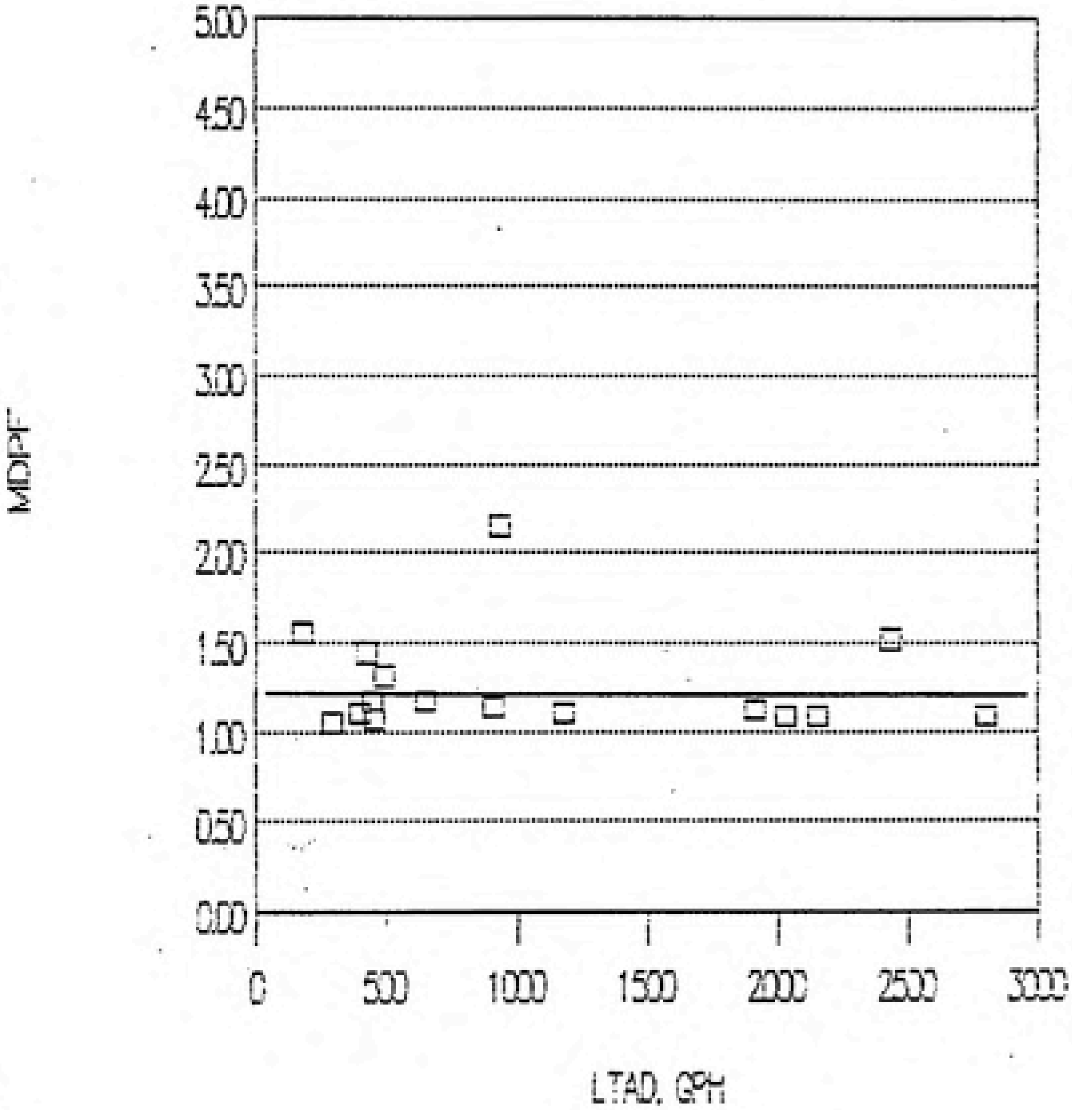


TABLE 6

STUDY-PREDICTED PARAMETERS AND CAPACITIES

**GUATEMALA**

| (1) POPULATION: | (2) 300 | (3) 600 | (4) 900 | (5) 1200 |
|---|---|---|---|---|
| (1) LTAD (GPH) | 160 | 640 | 1100 | 1600 |
| (2) LTAD (GPD) | 3900 | 15000 | 27000 | 38000 |
| (3) LTAD (GPCD) | 13 | 26 | 30 | 32 |
| (4) MDPF | 1.2 | 1.2 | 1.2 | 1.2 |
| (5) MDD (GPD) | 4700 | 19000 | 32000 | 46000 |
| (6) MHPF | 4.2 | 2.9 | 2.5 | 2.3 |
| (7) MHD (GPD) | 16000 | 45000 | 68000 | 88000 |
| (8) RVST | 2500 | 5000 | 6500 | 7800 |

**HONDURAS AND ECUADOR**

| POPULATION: | 300 | 600 | 900 | 1200 |
|---|---|---|---|---|
| (1) LTAD (GPH) | 650 | 1400 | 2100 | 2800 |
| (2) LTAD (GPD) | 16000 | 33000 | 50000 | 68000 |
| (3) LTAD (GPCD) | 52 | 55 | 56 | 56 |
| (4) MDPF | 1.2 | 1.2 | 1.2 | 1.2 |
| (5) MDD (GPD) | 19000 | 40000 | 60000 | 81000 |
| (6) MHPF | 2.9 | 2.4 | 2.1 | 2.0 |
| (7) MHD (GPD) | 46000 | 78000 | 110000 | 130000 |
| (8) RVST | 5000 | 7200 | 8900 | 10000 |

at a value of about 1.2. Hence, a value of 1.2 is recommended for the MDPF design standard, in either of the three countries, regardless of the LTAD (within the domain of 0 to 3000 GPH).

The source works capacity is based on the maximum daily demand (MDD), which is equal to the MDPF times the LTAD. Various MDD values were calculated for populations of 300, 600, 900, and 1200 persons in Guatemala, Honduras, and Ecuador. These values represent the source capacities required to meet maximum daily demands. As shown in column 4 of Table 6, a town with a design population of 900 persons in Guatemala, has an expected MDD of 32,000 GPD; in Honduras or Ecuador, it is 60,000 GPD.

Required pipe network capacity is based on maximum hourly demands (MHD), which are equal to the MHPF times LTAD. A predictive equation for MHPF was developed so it could be estimated for communities with different populations.

The data in Table 3 indicate that MHPF might be associated with LTAD; the MHPF generally decreases as LTAD increases. The regression model that fits the data shows that MHPF is a log-log function of LTAD:

$$MHPF = 16.7\ (LTAD)^{-0.27} \qquad (7)$$

t-calc = 4.3, N=16, df=14 $\qquad R^2 = 0.57$

This relationship is depicted graphically in Figure 5; LTAD statistically significant. As expected, LTAD and MHPF values are

FIGURE 5

# MHPF AS A FUNCTION OF LTAD

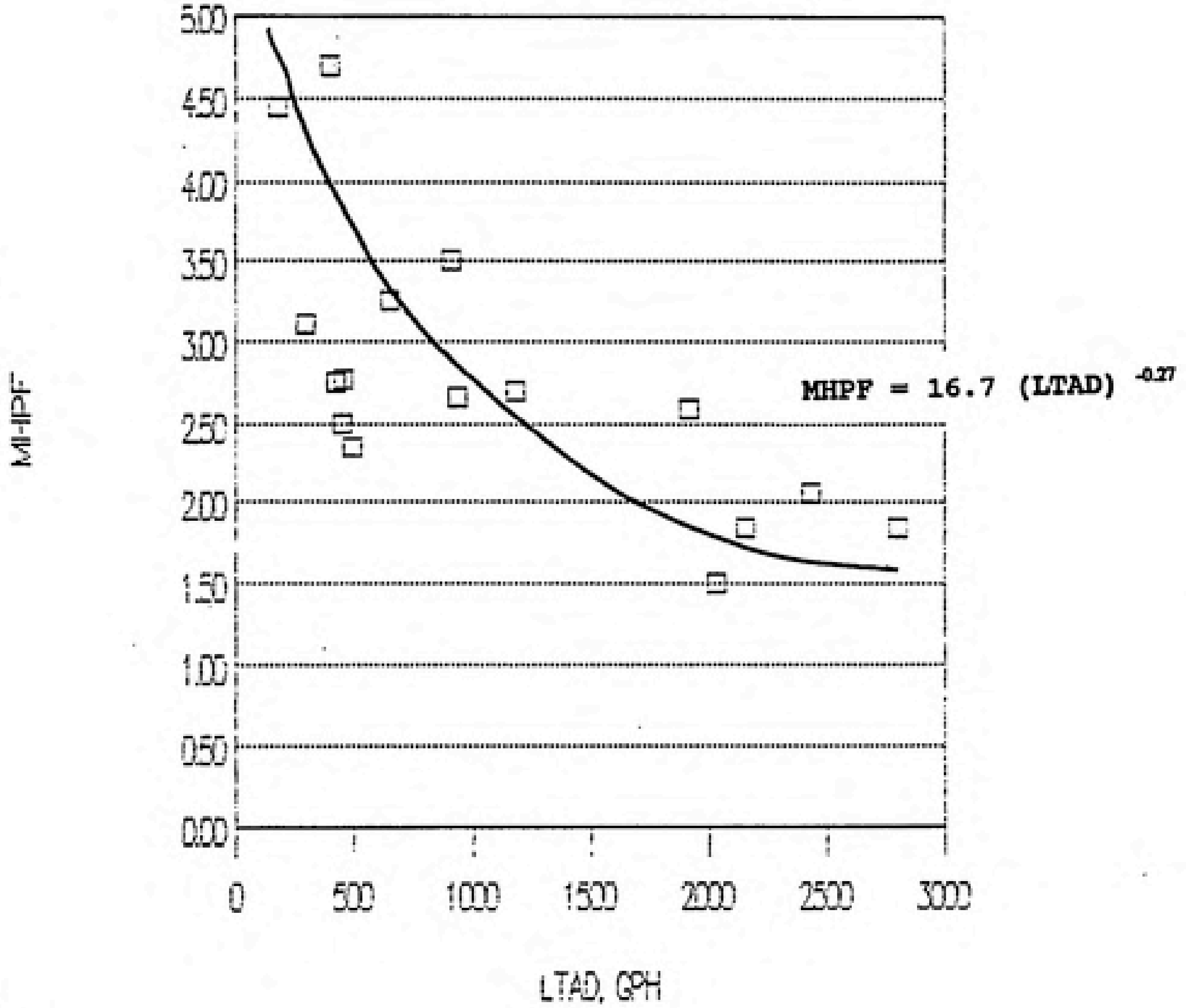


TABLE 7

COMPONENT CAPACITY COMPARISONS

STUDY-PREDICTED VS. DESIGN STANDARD VALUES

**GUATEMALA**

| (1) POPULATION: | (2) STUDY 300 | (3) MOH/AID 300 | (4) STUDY 600 | (5) MOH/AID 600 |
|---|---|---|---|---|
| LTAD (GPH) | 160 | 250 | 640 | 500 |
| LTAD (GPD) | 3900 | 6000 | 15000 | 12000 |
| LTAD (GPCD) | 13 | 20 | 26 | 20 |
| MDPF | 1.2 | 1.2 | 1.2 | 1.2 |
| MDD (GPD) | 4700 | 7200 | 18000 | 14000 |
| MHPF | 4.2 | 1.8 | 2.9 | 1.8 |
| MHD (GPD) | 16000 | 11000 | 45000 | 22000 |
| RVST | 2500 | 1800 | 4900 | 3500 |
| HRS DET | 16 | 7 | 8 | 7 |

**GUATEMALA**

| POPULATION: | STUDY 900 | MOH/AID 900 | STUDY 1200 | MOH/AID 1200 |
|---|---|---|---|---|
| LTAD (GPH) | 1100 | 750 | 1600 | 1000 |
| LTAD (GPD) | 27000 | 18000 | 38000 | 24000 |
| LTAD (GPCD) | 30 | 20 | 32 | 20 |
| MDPF | 1.2 | 1.2 | 1.2 | 1.2 |
| MDD (GPD) | 32000 | 22000 | 46000 | 29000 |
| MHPF | 2.5 | 1.8 | 2.3 | 1.8 |
| MHD (GPD) | 68000 | 32000 | 88000 | 43000 |
| RVST | 6500 | 5300 | 7800 | 7000 |
| HRS DET | 6 | 7 | 5 | 7 |

inversely related, as indicated by the negative exponent for LTAD in the regression equation. Predicted MHPF values are given in row 6 of Table 6.

MHD values were estimated for communities with 300, 600, 900, and 1200 persons in Guatemala, Honduras, and Ecuador. These values, reported in row 7 of Table 6, represent network capacity required to meet maximum hourly demands. For a town with a design population of 900 persons in Guatemala, the MHD is 68,000 GPD; in Honduras or Ecuador, it is 110,000 GPD.

Storage tank volume is dependent on the outflow from and the inflow to the tank. For purposes of predicting the RVST, a regression analysis was performed of the data, where RVST (gallons) is a function of the maximum outflow rate (MHD) and the inflow rate. The resulting regression equation is:

$$RVST = 0.37\ (OUT)^{2.32}\ (INF)^{-1.20} \qquad (8)$$

t-calc = 8.2, 5.6, N=48, df=45 $\qquad R^2 = 0.70$

Note that both OUT and the INF variables are statistically significant.

The predicted RVST values are shown in row 8 of Table 6. Inflow to the tank is from the source of supply, and source works are designed for the MDD. Thus, for the RVST predictions herein, the inflow rate is estimated as the MDD, and the outflow rate is estimated as the MHD.

The values in row 8 show that RVST (GAL) increases with increasing demand, indicating that more storage volume is required in larger communities. Also, relatively more volume is required in Honduras and Ecuador than in Guatemala because of higher LTAD values in the former countries. For a community of 900 persons in Guatemala, the required storage volume is 6500 gallons, providing 6 hours detention time at average flow (LTAD) of 1100 GPH. For a similar community in Honduras and Ecuador, a storage volume of 8900 gallons is required, providing 4 hours detention time at an average flow of 2100 GPH.

In summary, to determine required design flows and capacities, the design population and the country in which the water supply system will be installed are first selected. The appropriate LTAD predictive equation is used to determine the expected average use rate, which indicates required system capacity for the community. A factor of 1.2 is used for the MDPF, but LTAD must be used to predict the MHPF. MDD values determine the source work capacity, and MHD values determine the distribution network capacity. The MDD and the MHD values are then used to predict the RVST for the system. These are the required capacities of the system components, needed to meet the predicted demands for water.

It is important to note that a general predictive equation for LTAD was not developed in this study due to the significant differences in demand from one country to another. This implies that there exists no single equation which can be used to predict water use rates in all the countries of Latin America (based on predict a LTAD of 30 GPCD, whereas MOH/AID would design a water supply system with a capacity of 20 GPCD for such a community. MOH/AID would appropriately estimate the MDPF as 1.2, but underestimate the MHPF as 1.8 instead of the required 2.5. Hence, the required source works capacity of 32,300 GPD would not be reached with the MOH/AID design standards; based on their standards, a capacity of only 22,000 GPD would be provided.

The MOH/AID distribution network capacity would also be insufficient. The required capacity, based on the predicted MHD, would need to deliver 68,000 GPD, but the MOH/AID-designed system would design network capacity for only 32,000 GPD. The Guatemala MOH/AID would provide 7 hours detention time for storage in this system, which would result in a tank of 5300 gallons at the selected average and maximum flows. The models from this study suggest that a volume of 6500 gallons is required, providing a detention time of 6 hours at an average flow of 1100 GPH.

None of the components in these systems would be sufficient to meet the actual demands, due to the underestimation of the use rate and max hourly peaking factor in the design standards. Thus, in general, the design standards employed by MOH/AID in Guatemala are not sufficient because they do not design systems that will adequately meet the actual demands.

In each of the cases mentioned here, it is important to note that the populations and flows are the **design** populations and flows. These water supply systems have a design period of twenty years, and thereby expect to have excess capacity for twenty years into the future. However, this study indicates the systems will run out of excess capacity before the end of the design period. When the design population is reached, the systems will not be sufficient to meet the demands.

Table 8 shows the predicted component capacities and MOH/AID design standards for the Honduran communities of 300, 600, 900, and 1200 persons. The values in the first column show the design parameters and required capacities as indicated by this study. The values reported in the right column are those that would be used by the Honduran MOH/AID. In most cases, these standards produce designs that are not sufficient to meet the actual demands.

For example, in a Honduran community of 900 persons, this study indicates a LTAD of 56 GPCD, but MOH/AID would design this system for 30 GPCD. Study results indicate that a community of 900 persons would have a MDPF of 1.2 and MHPF of 2.1. In designing this system, MOH/AID would overestimate these parameters at 1.5 and 2.25 respectively. However, the LTAD is so severely underestimated that the resulting MDD and MHD values are underestimated as well.

Study results show required source works capacity (based on the MDD) of 60,000 GPD, whereas the MOH/AID design standards would select source works for only 41,000 GPD. For the distribution network, the models herein indicate a required capacity of 110,000 GPD, but the MOH/AID design standards would specify a network

TABLE 8

COMPONENT CAPACITY COMPARISONS

STUDY-PREDICTED VS. DESIGN STANDARD VALUES

HONDURAS

| (1) POPULATION: | (2) STUDY 300 | (3) MOH/AID 300 | (4) STUDY 600 | (5) MOH/AID 600 |
|---|---|---|---|---|
| LTAD (GPH) | 650 | 310 | 1400 | 630 |
| LTAD (GPD) | 16000 | 8000 | 33000 | 15000 |
| LTAD (GPCD) | 52 | 25 | 55 | 25 |
| MDPF | 1.2 | 1.5 | 1.2 | 1.5 |
| MDD (GPD) | 19000 | 11000 | 40000 | 23000 |
| MHPF | 2.9 | 2.3 | 2.4 | 2.3 |
| MHD (GPD) | 46000 | 17000 | 78000 | 34000 |
| RVST | 5000 | 3000 | 7200 | 5000 |
| HRS DET | 8 | 8 | 5 | 8 |

HONDURAS

| POPULATION: | STUDY 900 | MOH/AID 900 | STUDY 1200 | MOH/AID 1200 |
|---|---|---|---|---|
| LTAD (GPH) | 2100 | 1100 | 2800 | 1500 |
| LTAD (GPD) | 50000 | 27000 | 68000 | 36000 |
| LTAD (GPCD) | 56 | 30 | 56 | 30 |
| MDPF | 1.2 | 1.5 | 1.2 | 1.5 |
| MDD (GPD) | 60000 | 41000 | 81000 | 54000 |
| MHPF | 2.1 | 2.3 | 2.0 | 2.3 |
| MHD (GPD) | 110000 | 61000 | 130000 | 81000 |
| RVST | 8900 | 9000 | 10000 | 12000 |
| HRS DET | 4 | 8 | 4 | 8 |

capacity of only 61,000 GPD. Hence, the source works and network capacity for this system would not be sufficient to meet the actual demands.

For a community of 900 persons, the predicted data show a required storage detention time of 4 hours. For this situation, the Honduras MOH/AID would design a storage tank to provide 8 hours of detention time at average flow. Because the detention time is overestimated by 200 percent in this case, sufficient storage volume is provided, even though the MDD and MHD values are underestimated. This detention time overestimation only applies to communities of 900 and 1200 persons. All the other parameters are underestimated as discussed above.

The design standards and component capacities for design populations of 300, 600, 900, and 1200 persons in Ecuador are shown in Table 9. The values in the left column show the design standards and required capacities as predicted by the regression equations obtained through this study. The values in the right column are those that would be employed by the Ecuadorian MOH/AID. In the case of Ecuador, the design standards employed always result in component capacities that are not sufficient to meet the expected demands for water.

For example, in a community of 900 persons in Ecuador, study results indicate LTAD of 56 GPCD, but MOH/AID would design for 17 GPCD for this community. The data show that a community of 900 persons in Ecuador should be designed with a MDPF of 1.2 and a MHPF of 2.1. MOH/AID appropriately estimates the peaking factors at 1.3 and 2.0 respectively, but the LTAD standard is so severely underestimated that the resulting MDD and MHD values are much too small.

The required MDD for this system is 60,000 GPD, but MOH/AID would estimate the MDD as 20,000 GPD. The MHD based on this study is 110,000 GPD for a 900-person community; MOH/AID would design for 31,000 GPD. The source works and network capacities determined by the Ecuador MOH/AID design standards would not be sufficient to meet actual demands.

The study results show that 4 hours detention time at average flow is required to fill the storage tank in this system, whereas the MOH/AID standards estimate a detention time of 9 hours. The predicted data estimate that this tank should have a capacity of 8900 gallons, whereas the MOH/AID design standards would provide a tank of only 5700 gallons. The resulting MOH/AID storage tank is too small because the average, max daily, and max hourly flows are severely underestimated.

TABLE 9

COMPONENT CAPACITY COMPARISONS

STUDY-PREDICTED VS. DESIGN STANDARD VALUES

ECUADOR

| (1) POPULATION: | (2) STUDY 300 | (3) MOH/AID 300 | (4) STUDY 600 | (5) MOH/AID 600 |
|---|---|---|---|---|
| LTAD (GPH) | 650 | 160 | 1400 | 380 |
| LTAD (GPD) | 16000 | 4000 | 33000 | 9000 |
| LTAD (GPCD) | 52 | 13 | 55 | 15 |
| MDPF | 1.2 | 1.3 | 1.2 | 1.3 |
| MDD (GPD) | 19000 | 5100 | 40000 | 12000 |
| MHPF | 2.9 | 3.0 | 2.4 | 3.0 |
| MHD (GPD) | 46000 | 12000 | 78000 | 27000 |
| RVST | 5000 | 1500 | 7200 | 3400 |
| HRS DET | 8 | 9 | 5 | 9 |

ECUADOR

| POPULATION: | STUDY 900 | MOH/AID 900 | STUDY 1200 | MOH/AID 1200 |
|---|---|---|---|---|
| LTAD (GPH) | 2100 | 640 | 2800 | 950 |
| LTAD (GPD) | 50000 | 15000 | 68000 | 23000 |
| LTAD (GPCD) | 56 | 17 | 56 | 19 |
| MDPF | 1.2 | 1.3 | 1.2 | 1.3 |
| MDD (GPD) | 60000 | 20000 | 81000 | 30000 |
| MHPF | 2.1 | 2.0 | 2.0 | 2.0 |
| MHD (GPD) | 110000 | 31000 | 130000 | 46000 |
| RVST | 8900 | 5700 | 10000 | 8600 |
| HRS DET | 4 | 9 | 4 | 9 |

## VI. CONCLUSIONS

In Guatemala, Honduras, and Ecuador, the design standards employed by MOH/AID result in component capacities that are not sufficient to meet actual demands. Based on these standards, MOH/AID provide too little excess capacity in their water system components. The information presented in this report regarding actual water use rates and patterns can be used to improve rural water supply planning in Latin America.

The actual water use data collected in this study are used to develop predictive models for various design parameters, including average use rate, daily and hourly peaking factors, and storage volumes. These models estimate use rates on the order of 13-32 GPCD in Guatemala and 52-56 GPCD in Honduras and Ecuador. The predicted MDPF is about 1.2 for all communities; the MHPF is estimated from 2.3 to 4.2 for Guatemalan towns, and 2.0 to 2.9 for Honduran and Ecuadorian towns. Predicted storage tank detention times range from 5 to 16 hours in Guatemala, and from 4 to 8 hours in Honduras and Ecuador.

Based on these predicted values, actual average demands are 150% to 300% higher than MOH/AID design standard values. Maximum daily and hourly demands are 140% to 380% higher, and required storage volumes are 110% to 330% higher than design standard estimates. This implies that the design standards are inappropriate because they select source works, network, and storage tank capacities that are not large enough to adequately meet demands; systems will run out of excess capacity much sooner than expected. If action is not taken to augment the supply or reduce the demands, consumers will experience low flows, intermittent supplies, and negative or low pressures in the pipes.

The principal cause of the capacity underestimation is the low average use rate value estimated by the design standards, as the other parameters are estimated fairly closely to the required values. One reason the actual use rates are likely to be so high is because consumers in the MOH/AID water systems pay a low, flat, monthly fee, irrespective of the quantities they consume. There is no reason for them to make economic decisions about how much water to use and no financial incentive to conserve. This study shows that the differences in demands between Guatemala and Honduras/Ecuador are the high nighttime uses (not attributable to leakage) in the latter countries, implying illegal or careless water use. Charging flat fees, or inappropriately setting consumption blocks on incremental fees, is likely to encourage wasteful behavior and result in average use rates that are much higher than expected.

It is not known exactly why rural consumers in Guatemala use about half as much water as those in Honduras and Ecuador. It is possible that the water committees work better in Guatemala and properly enforce water use restrictions. It is also likely that several socioeconomic characteristics explain water use patterns in these countries, but such information cannot be obtained with the macro-level study conducted here.

To explain the demands beyond the population and country variations described in this report, micrometers must be installed at each connection and water use studied on a household level. This will illuminate other explanatory variables for water use rates and provide the opportunity to develop a single predictive equation for water demand in rural Latin American water systems.

## VII. DISCUSSION AND RECOMMENDATIONS

### A. THE PROBLEM

The results of this study show that actual demands in MOH/AID-designed water systems are much higher than the design standards. Hence, these systems will run out of excess capacity before the end of the twenty-year design period if present rates of water use persist and communities grow as anticipated. For the most part, the systems are currently functioning properly. Because they are relatively new (most are less than five years old) and have excess capacity, they have not experienced problems delivering water twenty-four hours per day.

If system capacities are exceeded, it could result in periodic interruptions in service and negative pressures in the pipe networks, possibly causing infiltration of groundwater and contamination of water quality. In Guatemala, MOH/AID acknowledges that the storage tanks have already exhibited some problems of insufficient capacity. New water systems constructed in the future might also develop similar problems, assuming current design standards are employed and demands in new areas are similar to those observed in this study.

There are several ways MOH/AID might choose to address these issues. Possible strategies for existing and new systems are discussed herein.

B. EXISTING SYSTEMS

One option is to let communities handle the problems of insufficient capacity (viz. low or negative pressures, low flows, intermittent supply) on their own. This implies that the problems would not be addressed until excess capacity is exhausted, at which time the communities would voluntarily reduce their demands or pay to augment system capacities. This may not be a good option because allowing systems to function improperly could cause public health problems, which the systems were constructed to overcome. Furthermore, it is unlikely that communities could increase system capacity without professional assistance, which is in short supply and would be difficult to obtain.

A second option is for MOH/AID to increase the capacities of existing systems to handle the higher-than-expected demands. This would be difficult because it appears that MOH/AID does not have the designers, contractors and resources available to return to old systems for expansion when there are so many communities without systems to date. Consequently, it is unlikely that expansions could be made before excess capacity is exhausted, which would result in the intermittent service, negative pressures and public health risk described above.

Other options involve attempts to decrease the demands in existing systems. In principle, this can be achieved with mechanical flow restrictors, higher water prices, and community education campaigns. In fact, mechanical restrictors are usually ineffective because they need high pressures to work properly and they often clog. Another drawback is that people often remove or tamper with them.

The option of charging prices to reduce water use is a substitute for the flat monthly fees that most consumers currently pay. An effective pricing scheme based on the volume of water consumed would encourage people to be more conservative and at the same time provide funds to increase system capacity to meet demands.

In recent years, AID has begun to investigate the possibility of cost recovery from its water supply systems, the capital costs of which are currently provided by AID funds. The monies collected from monthly fees stay in the communities to pay for operation and maintenance expenses. An effective pricing scheme would charge consumers for the water they use, thereby encouraging conservation and providing funds for capital cost recovery. In addition, a system of water prices would enable the community to send a clear signal when it is ready to pay for system expansion.

The implementation of this option is a matter for further study because it would involve installing meters and selecting water tariffs. Cost-benefit analyses would be needed to determine the value of metering, and willingness to pay studies would probably be needed to help select appropriate water tariffs and determine required subsidies.

The nighttime use rate analysis presented in this report shows that a significant portion of the water use (not due to leakage) in these communities occurs overnight, presumably from proscribed or careless use. In fact, the principal difference in the demands between Guatemala and those of Honduras and Ecuador is the high nighttime use rate in the latter countries. The pricing option would in principle decrease the nighttime demands by charging consumers for the water used.

Establishing water prices in communities where systems are already in place may be controversial and difficult to implement. A different approach to decreasing demands could involve working with village water committees to encourage water use restrictions. This would involve ensuring that consumers turn off their taps when not in use and enforcing restrictions on water use for irrigation or animals. A proper community education and conservation program would enable consumers to understand the importance of reducing nonessential consumption without eliminating or decreasing necessary uses such as bathing. A possible way to implement such a program would be through use of PVO (private voluntary organization) community workers. A pilot program would be needed to determine if education is a practical way to reduce water use in these communities.

## C. NEW SYSTEMS

In new systems not yet designed or constructed, it would be possible for MOH/AID to leave their design standards unchanged. However, assuming that new communities behave like the ones studied here, this might not be desirable since it is known that current standards do not select capacities sufficient to meet demands.

One option is to change the design standards to accommodate higher use rates and provide required capacities. This would provide a higher level of service, but given AID's fixed budget, fewer communities would be served. For example, if the design standards were doubled (from, say, 25 to 50 GPCD), system costs would increase by about 60%, assuming a cost function of the form K * capacity$^{\alpha}$, where $\alpha$=0.7 as in Guatemala.

The average capital cost of systems in Guatemala is about $40,000. If the design standards are increased to raise costs by 60%, capital costs would increase to about $64,000. For a budget of, say $50 million, which is the approximate amount AID is spending in Guatemala, Honduras and Ecuador, 1250 water systems can be constructed with the old standards. However, only 780 systems could be constructed with revised standards, which is a reduction of about 40%.

MOH/AID should consider revising its design period from 20 years to something less, possible between 7 and 10 years. Economic theory suggests that a shorter period would be more nearly optimal, especially in light of the high opportunity cost of capital in Latin America.

Another option for MOH/AID is to adopt pricing schemes for new water systems, with a view towards cost recovery, conservation, and appropriate signals for expansion. In this way, consumers would pay for the water they use, thereby making economic decisions about how much to consume. The flat monthly fee currently charged does not encourage such behavior. This option should be studied further because it could allow MOH/AID to recover at least part of the costs of the systems they design and construct, providing consumers with the level of water service they want and are willing to pay to receive.

## D. FUTURE WORK

It is recommended that pilot conservation and education campaigns be conducted in various communities. Consumers should be told how to decrease their water use rates, and they should be educated in the importance of doing so. Such pilot programs would require careful evaluation to determine their effectiveness prior to full-scale adoption.

A second recommendation is to conduct a study of water use on a household level by collecting data from micrometers at each connection. This type of study could provide a better understanding of household water use and the various socioeconomic factors that explain it.

It is also recommended that cost data be collected for various

MOH/AID water systems and the implications of design standard and price changes studied in detail. This would involve collecting data on the costs of providing water systems in rural Latin American communities and performing sensitivity analyses to determine the effects of changing the various determinants of the costs. This information would be important for cost-benefit analyses and for designing pricing schemes. Analyses should be made to determine optimal design periods based on economies of scale, interest rates, growth rates in demand, and other pertinent variables.

A final recommendation is to conduct a pilot study to determine the effects of price changes on water use. This would involve determining actual price elasticities of demand. Such a study might be conducted by actually changing prices from one community to another or possibly by determining consumers' willingness to pay based on contingent valuation studies.

## VIII. REFERENCES

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# IX. APPENDICES

A. Dates and Times of Meter Readings

B. Specifications for Hersey MVR-160 Meter

C. Data Forms for Guatemala, Honduras, and Ecuador

D. Sample Long Term Average Demand Calculation

E. Sample Nighttime Use Rate Calculation

F. Sample Maximum Daily Peaking Factor Calculation

G. Maximum Daily Peaking Factor Frequency Distribution

H. Sample Maximum Hourly Peaking Factor Calculation; Daily Demand Pattern

I. Maximum Hourly Peaking Factor Frequency Distribution

J. Sample Required Storage Volume Calculation

K. Required Storage Volume Frequency Distribution

## APPENDIX A

## DATES AND TIMES OF METER READINGS

### GUATEMALA

| TOWN | START DATE | END DATE | DAYS OF DATA | TIMES METER READ |
|---|---|---|---|---|
| CAL | 26AUG90 | 4NOV90 | 35 | 4 a.m. - 8 p.m. |
| CHU | 14OCT90 | 23DEC90 | 35 | 4 a.m. - 8 p.m. |
| XET | 4JAN90 | 20JAN91 | 34 | 4 a.m. - 8 p.m. |
| NUE | 5JAN90 | 18JAN90 | 1 | 6 a.m. - 9 p.m. |
| LACI | 3JAN90 | 16JAN90 | 13 | 5 a.m. - 8 p.m. |

### HONDURAS

| TOWN | START DATE | END DATE | DAYS OF DATA | TIMES METER READ |
|---|---|---|---|---|
| BEL | 30SEP90 | 13JAN91 | 46 | 4 a.m. - 8 p.m. |
| LACU | 1OCT89 | 6OCT89 | 4 | 5 a.m. - 8 p.m. |
| COL | 1OCT89 | 15NOV89 | 15 | 5 a.m. - 8 p.m. |
| BRI | 1DEC89 | 14JAN90 | 14 | 5 a.m. - 8 p.m. |
| QUE | 30SEP90 | 13JAN91 | 43 | 4 a.m. - 8 p.m. |
| RUT | 1OCT89 | 13NOV89 | 15 | 5 a.m. - 7 p.m. |
| MAR | 30SEP90 | 20JAN91 | 54 | 4 a.m. - 8 p.m. |

### ECUADOR

| TOWN | START DATE | END DATE | DAYS OF DATA | TIMES METER READ |
|---|---|---|---|---|
| UNA | 3JUN90 | 26AUG90 | 38 | 4 a.m. - 8 p.m. |
| PAN | 3JUN90 | 26AUG90 | 35 | 4 a.m. - 8 p.m. |
| SAN | 3JUN90 | 26AUG90 | 47 | 4 a.m. - 8 p.m. |
| TAN | 3JUN90 | 26AUG90 | 49 | 4 a.m. - 8 p.m. |

# Hersey

## MVR-160

### DESCRIPTION

The Hersey Model MVR series Magnetic Drive (Vertical) Turbine Meters come equipped with an exclusive patented RETRO-THRUST* feature which provides for a longer life over a wider range of accuracies. At low flow rates the rotor's tungsten carbide thrust bearing floats against the sapphire bearing located in the meter casing. As flow rates increase the retro thrust feature allows the rotor to float away from the sapphire. At high flow rates the rotor's stainless steel shaft floats against the upstream sapphire bearing, thereby minimizing wear and thus assuring extended operating life.

The Dura-Dri® register is permanently hermetically sealed between a glass dome and metal housing.

The register cover is constructed of cycolac plastic. The register is held in place by a polypropylene clamp band which allows for positioning the register in the most convenient reading position. The register is available with center sweep hand, straight reading indicating cubic feet, U.S. gallons, or cubic metres.

The measuring chamber is composed of a noryl plastic inlet hub, polypropylene rotor and strainer in the MVR-30-50 and 100. The measuring chambers in the MVR-160-350-650 are composed of a noryl plastic inlet hub, and polypropylene rotor and stainless steel ring strainer.

The MVR will operate at temperatures from 32° to 130°F, and will operate with particles of sand in the water. Outer cases are time-proven cast bronze.

Bottom plates are available in both bronze and enamel coated cast iron. Bronze only on the MVR-160-350-650.

A full Buna-N rubber liner for the MVR 30-50 and 100 bottoms and an EPT liner for the MVR-160 are provided for corrosion protection.

The Hersey MVR Magnetic Drive Turbine Meters are also available in compact models with varying spud sizes.

**MVR-160**

Length - (female) - 15 1/4"
- (2-bolt flanged) - 17"
- (Compact) - 10 1/2"

Width - (female) - 5 3/8"
- (2-bolt flanged) - 5 15/16"

Height - 6 1/4"

Net Weight - (female) - 15 lbs
- (2-bolt flanged) - 20 lbs
- (Compact) - 14 lbs

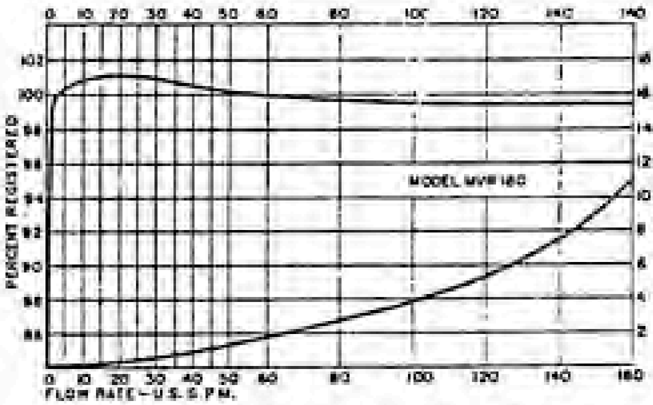
Centerline to base of meter - 3"

End detail screwed: internal (female) 2" NPT threads

End detail flanged: 2-bolt oval type (may be ordered with either bronze or cast iron flanges)

Pressure loss (Maximum)
MVR 160 11.0 psi @ 160 GPM

**MVR-160**




OPERATING RANGE: 3-160 GPM
LOW FLOW REGISTRATION: 95% @ 2 GPM

## SPECIFICATIONS

Magnetic Drive Turbine Meters, sizes 30-50-100-160-350-650 shall have bronze outer cases. The register lid and clamp band shall be made of high-impact-resistant plastic to protect the register. The clamp band shall hold the register and lid in place by means of one stainless steel fastener and nut. Both the fastener and clamp band shall be drilled to receive sealing wire. The clamp band shall allow for positioning the register in the most convenient reading position.

The register shall be completely separated from the water-way and shall be available with center sweep hand, straight reading indicating cubic feet, U.S. gallons or cubic metres. The register shall be permanently hermetically sealed between a glass dome and metal housing. The register shall be driven by a ceramic magnet.

The measuring chamber in MVR 30-50-100 shall be composed of a plastic inlet hub, rotor and strainer where as the measuring chamber in the MVR 160-350 and 650 shall be composed of a plastic inlet hub and rotor and a stainless steel ring strainer. The chamber shall be held in place with (4) four stainless steel screws. It shall not be adversely affected by temperatures from 32°F. to 130°F. or by particles of sand. The meter shall incorporate a patented Retro-Thurst* design to assure maximum operating life. The rotor thrust bearings shall be sapphires and the bushings, graphitar.

The bottom plate shall be either bronze or enamel coated cast iron on the MVR 30-50-100, bronze only on the MVR 160. The MVR 30-50-100 and 160 bottoms shall be protected with a thick rubber liner.

PROYECTO I.E.O.S. – AID – 518-0051

COMUNIDAD : PANZALEO CANTON: MEJIA Página 34

NOMBRE DEL OPERADOR : Quishpe Patricio FECHA : 26 JUL 1990

NUMERO DE CONEXIONES DOMICILIARES EN SERVICIO : 41

APPENDIX C-1

| HORA | DE LA PARTE BLANCA | | | | | DE LA PARTE NEGRA | DE LA FLECHA ROJA | | ESTA LLOVIENDO |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | (si o no) |
| 04h00 | 0 | 0 | 7 | 0 | 7 | 9 | 0 | 8 | NO |
| 04h15 | 0 | 0 | 7 | 0 | 7 | 9 | 1 | 8 | NO |
| 04h30 | 0 | 0 | 7 | 0 | 7 | 9 | 2 | 9 | NO |
| 04h45 | 0 | 0 | 7 | 0 | 7 | 9 | 4 | 2 | NO |
| 05h00 | 0 | 0 | 7 | 0 | 7 | 9 | 5 | 0 | NO |
| 05h15 | 0 | 0 | 7 | 0 | 7 | 9 | 6 | 0 | NO |
| 05h30 | 0 | 0 | 7 | 0 | 8 | 0 | 7 | 0 | NO |
| 05h45 | 0 | 0 | 7 | 0 | 8 | 0 | 5 | 0 | NO |
| 06h00 | 0 | 0 | 7 | 0 | 8 | 0 | 8 | 3 | NO |
| 06h15 | 0 | 0 | 7 | 0 | 8 | 1 | 2 | 2 | NO |
| 06h30 | 0 | 0 | 7 | 0 | 8 | 1 | 9 | 0 | NO |
| 06h45 | 0 | 0 | 7 | 0 | 8 | 2 | 3 | 6 | NO |
| 07h00 | 0 | 0 | 7 | 0 | 8 | 3 | 6 | 0 | NO |
| 07h15 | 0 | 0 | 7 | 0 | 8 | 4 | 4 | 0 | NO |
| 07h30 | 0 | 0 | 7 | 0 | 8 | 7 | 1 | 0 | NO |
| 07h45 | 0 | 0 | 7 | 0 | 8 | 7 | 8 | 2 | NO |
| 08h00 | 0 | 0 | 7 | 0 | 8 | 9 | 9 | 5 | NO |
| 08h15 | 0 | 0 | 7 | 0 | 9 | 2 | 8 | 0 | NO |
| 08h30 | 0 | 0 | 7 | 0 | 9 | 5 | 4 | 8 | NO |
| 08h45 | 0 | 0 | 7 | 0 | 9 | 7 | 0 | 5 | NO |
| 09h00 | 0 | 0 | 7 | 0 | 9 | 8 | 4 | 3 | NO |
| 09h15 | 0 | 0 | 7 | 7 | 0 | 0 | 5 | 0 | NO |
| 09h30 | 0 | 0 | 7 | 7 | 0 | 2 | 0 | 7 | NO |
| 09h45 | 0 | 0 | 7 | 7 | 0 | 3 | 4 | 5 | NO |
| 10h00 | 0 | 0 | 7 | 7 | 0 | 4 | 9 | 5 | NO |
| 10h15 | 0 | 0 | 7 | 7 | 0 | 6 | 6 | 3 | NO |
| 10h30 | 0 | 0 | 7 | 7 | 0 | 7 | 6 | 3 | NO |
| 10h45 | 0 | 0 | 7 | 7 | 0 | 9 | 0 | 8 | NO |
| 11h00 | 0 | 0 | 7 | 7 | 1 | 0 | 2 | 0 | NO |
| 11h15 | 0 | 0 | 7 | 7 | 1 | 1 | 4 | 5 | NO |
| 11h30 | 0 | 0 | 7 | 7 | 1 | 2 | 7 | 9 | NO |
| 11h45 | 0 | 0 | 7 | 7 | 1 | 3 | 9 | 0 | NO |

DIVISION DE SANEAMIENTO DEL MEDIO - P.S.C.I.S.N.

## APPENDIX C-2

## ESTUDIOS DE DEMANDA DE AGUA POTABLE RURAL

COMUNIDAD: Xetacataj MPIO: San Cristobal DEPTO: Totonicapán

NOMBRE LECTOR: Trinidad Aguilar Mejía FECHA: 6/2/90

No. CONEXIONES DOMICILIARES EN SERVICIO: 73 FIRMA: Trini Trinidad Aguilar M.

| HORA: | PARTE BLANCA | | | | | PARTE NEGRA | FLECHA ROJA | | ESTA LLOVIENDO? | OBSERVACION |
|---|---|---|---|---|---|---|---|---|---|---|
| 04:00 | 0 | 1 | 7 | 5 | 6 | 0 | 5 | 1 | No | |
| 15 | 0 | 1 | 7 | 5 | 6 | 0 | 5 | 1 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 6 | 0 | 5 | 4 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 6 | 0 | 5 | 5 | ″ | |
| 05:00 | 0 | 1 | 7 | 5 | 6 | 0 | 6 | 0 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 6 | 0 | 7 | 0 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 6 | 0 | 7 | 6 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 6 | 0 | 8 | 4 | ″ | |
| 06:00 | 0 | 1 | 7 | 5 | 6 | 1 | 0 | 8 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 6 | 1 | 2 | 6 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 6 | 1 | 5 | 9 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 6 | 2 | 1 | 8 | ″ | |
| 07:00 | 0 | 1 | 7 | 5 | 6 | 2 | 7 | 1 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 6 | 3 | 7 | 8 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 6 | 5 | 2 | 8 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 6 | 6 | 7 | 0 | ″ | |
| 08:00 | 0 | 1 | 7 | 5 | 6 | 7 | 4 | 3 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 6 | 8 | 0 | 0 | ″ | / |
| 30 | 0 | 1 | 7 | 5 | 6 | 8 | 5 | 0 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 6 | 9 | 0 | 9 | ″ | |
| 09:00 | 0 | 1 | 7 | 5 | 6 | 9 | 7 | 6 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 7 | 1 | 0 | 4 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 7 | 2 | 1 | 9 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 7 | 3 | 0 | 3 | ″ | |
| 10:00 | 0 | 1 | 7 | 5 | 7 | 4 | 4 | 5 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 7 | 6 | 7 | 0 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 7 | 8 | 9 | 4 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 8 | 1 | 0 | 6 | ″ | |
| 11:00 | 0 | 1 | 7 | 5 | 8 | 1 | 8 | 2 | ″ | |
| 15 | 0 | 1 | 7 | 5 | 8 | 2 | 8 | 7 | ″ | |
| 30 | 0 | 1 | 7 | 5 | 8 | 3 | 4 | 6 | ″ | |
| 45 | 0 | 1 | 7 | 5 | 8 | 4 | 4 | 1 | ″ | |
| [illegible] | | | | | | | | | | FECHA: |

PROYECTO DE AGUA Y SANEAMIENTO RURAL

SANAA-AID

APPENDIX C-3

ESTUDIO DE DEMANDAS DE AGUA POTABLE

H O N D U R A S

COMUNIDAD Col. Martínez MPIO. Omoa DEPTO. Cortés

HORARIO DE TRABAJO: DE 4:00 HRS. A 12:00 HRS.

FRECUENCIA DE LECTURA: CADA 15 MINUTOS

Nº DE CONEXIONES DOMICILIARIAS EN SERVICIO 160

NOMBRE DEL OPERADOR Dimas martinez FECHA 13-12-90

| HORA | DE LA PARTE BLANCA | | | | | DE LA PARTE NEGRA | DE LA FLECHA ROJA | | ESTA LLOVIENDO | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SI | NO |
| 4:00 | 2 | 0 | 3 | 5 | 9 | 3 | 3 | 0 | | ✓ |
| 4:15 | 2 | 0 | 3 | 5 | 9 | 3 | 8 | 0 | | ✓ |
| 4:30 | 2 | 0 | 3 | 5 | 9 | 4 | 1 | 5 | | ✓ |
| 4:45 | 2 | 0 | 3 | 5 | 9 | 5 | 2 | 4 | | ✓ |
| 5:00 | 2 | 0 | 3 | 5 | 9 | 6 | 5 | 0 | | ✓ |
| 5:15 | 2 | 0 | 3 | 5 | 9 | 7 | 3 | 0 | | ✓ |
| 5:30 | 2 | 0 | 3 | 5 | 9 | 8 | 7 | 5 | | ✓ |
| 5:45 | 2 | 0 | 3 | 6 | 0 | 0 | 4 | 1 | | ✓ |
| 6:00 | 2 | 0 | 3 | 6 | 0 | 2 | 6 | 0 | | ✓ |
| 6:15 | 2 | 0 | 3 | 6 | 0 | 5 | 9 | 0 | | ✓ |
| 6:30 | 2 | 0 | 3 | 6 | 1 | 1 | 1 | 5 | | ✓ |
| 6:45 | 2 | 0 | 3 | 6 | 1 | 3 | 2 | 5 | | ✓ |
| 7:00 | 2 | 0 | 3 | 6 | 2 | 1 | 4 | 0 | | ✓ |
| 7:15 | 2 | 0 | 3 | 6 | 3 | 1 | 8 | 0 | | ✓ |
| 7:30 | 2 | 0 | 3 | 6 | 3 | 7 | 7 | 8 | | ✓ |
| 7:45 | 2 | 0 | 3 | 6 | 4 | 5 | 1 | 0 | | ✓ |
| 8:00 | 2 | 0 | 3 | 6 | 5 | 4 | 6 | 2 | | ✓ |
| 8:15 | 2 | 0 | 3 | 6 | 6 | 2 | 0 | 0 | | ✓ |

ES LA ULTIMA PAGINA? SI (NO)

Dimas martinez
OPERADOR RESONSABLE

APPENDIX D

## SAMPLE LONG TERM AVERAGE DEMAND CALCULATION

**Panzaleo, Ecuador**

| | |
|---|---|
| First meter reading on 3JUN90: | 177178 gallons |
| Last meter reading on 26AUG90: | 1077035 gallons |
| Number of days from first to last reading: | 84 days |
| Population of Panzaleo: | 252 persons |

$$\text{LTAD} = \frac{(\text{Last reading} - \text{First reading})}{\text{Time Period}}$$

$$= \frac{(1077035 - 177178)\ \text{gallons}}{84\ \text{days}}$$

$$= 10713\ \text{GPD}$$

$$= 446\ \text{GPH}$$

$$= 43\ \text{GPCD}$$

## APPENDIX E

### SAMPLE NIGHTTIME USE RATE CALCULATION

**Panzaleo, Ecuador**

Meter reading at 8:00 p.m. on 13JUN90: 293548 gallons

Meter reading at 4:00 a.m. on 14JUN90: 296011 gallons

$$\text{Nighttime Use Rate} = \frac{(\text{4 a.m. reading} - \text{8 p.m. reading})}{\text{8 hours}}$$

$$= \frac{(296011 - 293548)\ \text{gallons}}{\text{8 hours}}$$

$$= 308\ \text{GPH}$$

$$= 5\ \text{GPM}$$

## APPENDIX F

### SAMPLE MAXIMUM DAILY PEAKING FACTOR CALCULATION

**Panzaleo, Ecuador**

Meter reading at 4:00 a.m. on 12JUN90: 272430 gallons

Meter reading at 4:00 a.m. on 13JUN90: 284313 gallons

$$\text{Daily Demand Rate} = \frac{(\text{13JUN reading} - \text{12JUN reading})}{\text{1 day}}$$

$$= \frac{(284313 - 272430)\ \text{gallons}}{\text{1 day}}$$

$$= 11883\ \text{GPD}$$

$$= 495\ \text{GPH}$$

$$\text{Maximum Daily Peaking Factor} = \frac{(\text{Daily demand rate})}{\text{LTAD}}$$

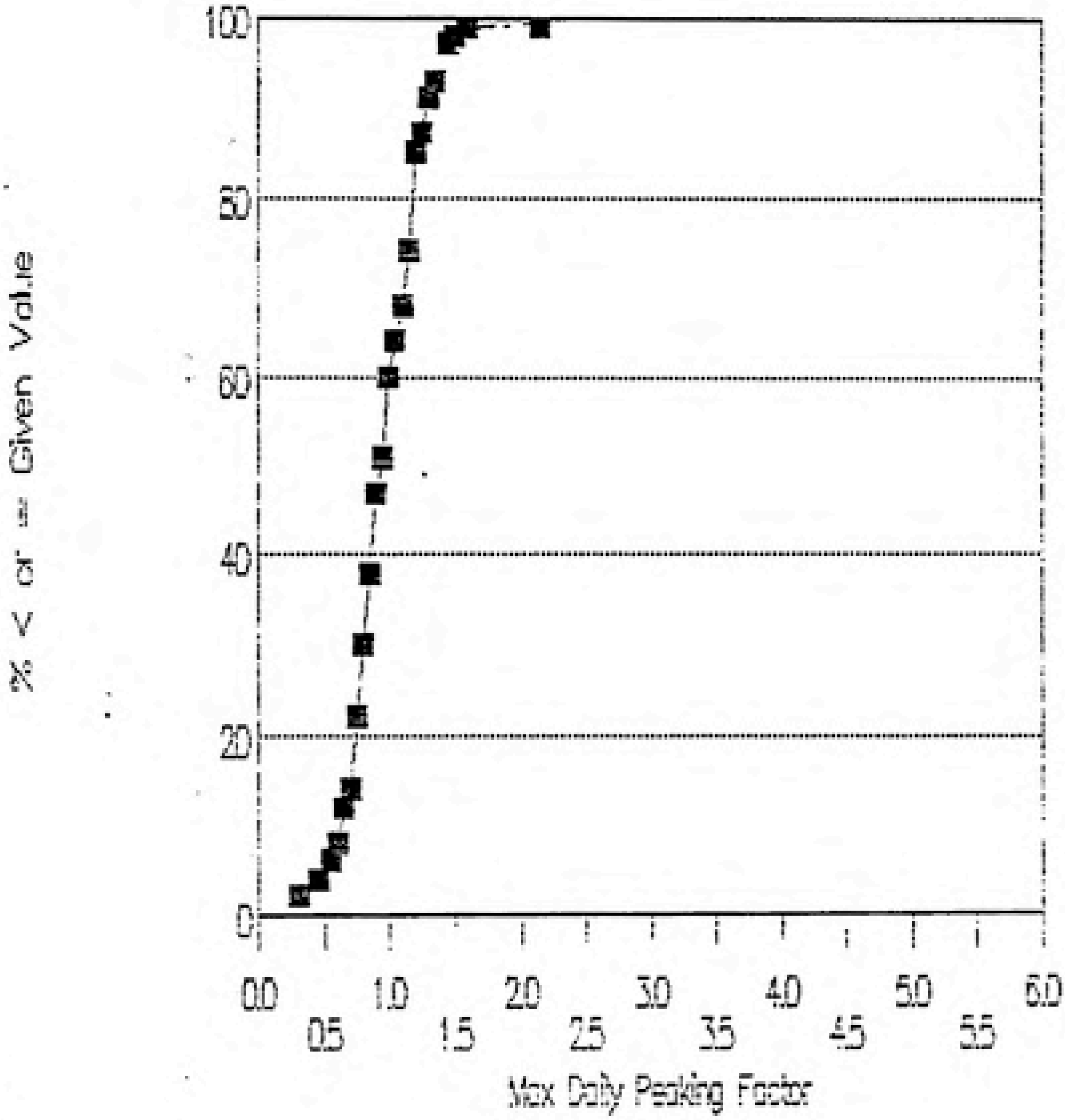
$$= \frac{495\ \text{GPH}}{446\ \text{GPH}}$$

$$\text{MDPF} = 1.1$$

APPENDIX G

# MAXIMUM DAILY PEAKING FACTOR

# PANZALEO, ECUADOR



## APPENDIX H-1

## SAMPLE MAXIMUM HOURLY PEAKING FACTOR CALCULATION

**Panzaleo, Ecuador**

Examination of daily demand pattern (Appendix H-2) shows maximum hourly rate of demand of 900 GPH occurs at 11:00 a.m. on 4JUN90.

$$\text{Maximum Hourly Peaking Factor} = \frac{\text{(Max hourly demand rate)}}{\text{LTAD}}$$

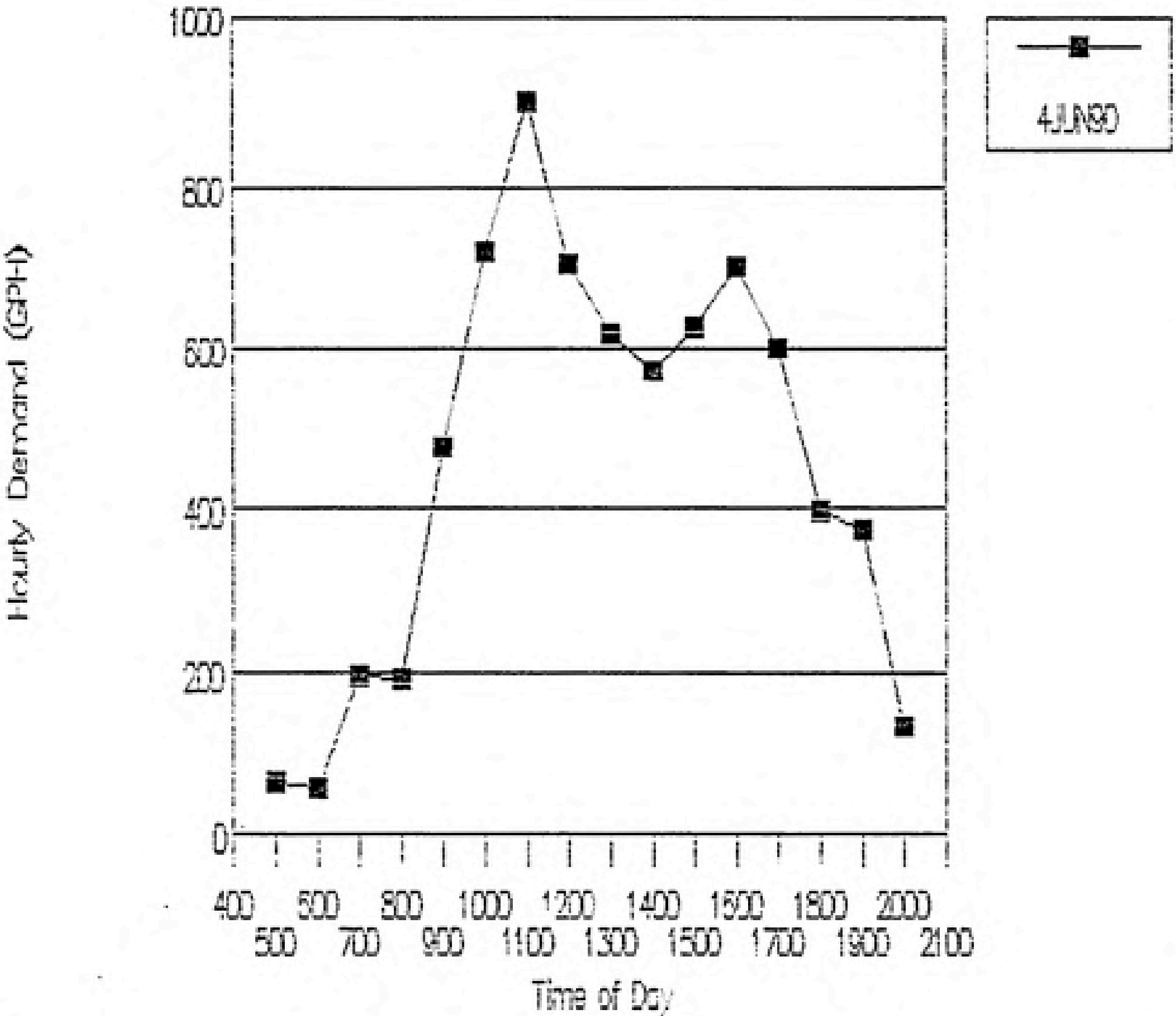
$$= \frac{900 \text{ GPH}}{446 \text{ GPH}}$$

$$\text{MHPF} = 2.0$$

**APPENDIX H-2**

# DAILY DEMAND PATTERN

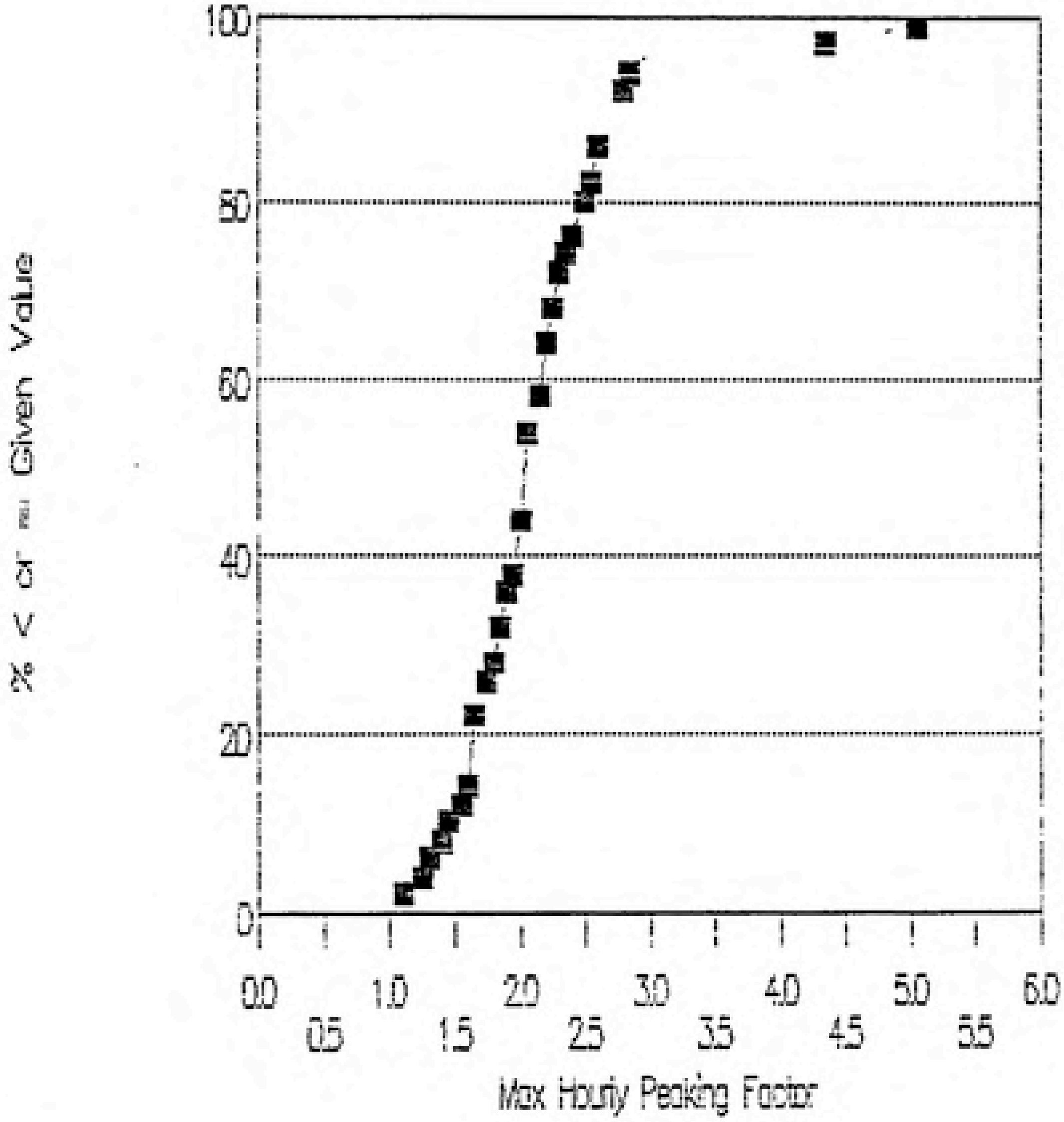
# PANZALEO, ECUADOR



APPENDIX I

# MAXIMUM HOURLY PEAKING FACTOR

# PANZALEO, ECUADOR



# APPENDIX J-1

## SAMPLE REQUIRED STORAGE VOLUME CALCULATION

**Panzaleo, Ecuador**

Proposed inflows to the tank:

LTAD (GPH)
1.2 * LTAD
1.4 * LTAD

Outflow from the tank:

hourly demand (GPH)

Examination of daily demand pattern (Appendix J-2) shows for an inflow = 1.2 * LTAD,

tank fills until 9:00 a.m.
tank empties from 9:00 a.m. to 5:00 p.m.
tank fills after 5:00 p.m.

Required storage volume = area under the curve from 9:00 a.m. to 5:00 p.m.

RVST = 1150 gallons

$$\text{DETENTION TIME} = \frac{\text{RVST}}{\text{LTAD}}$$

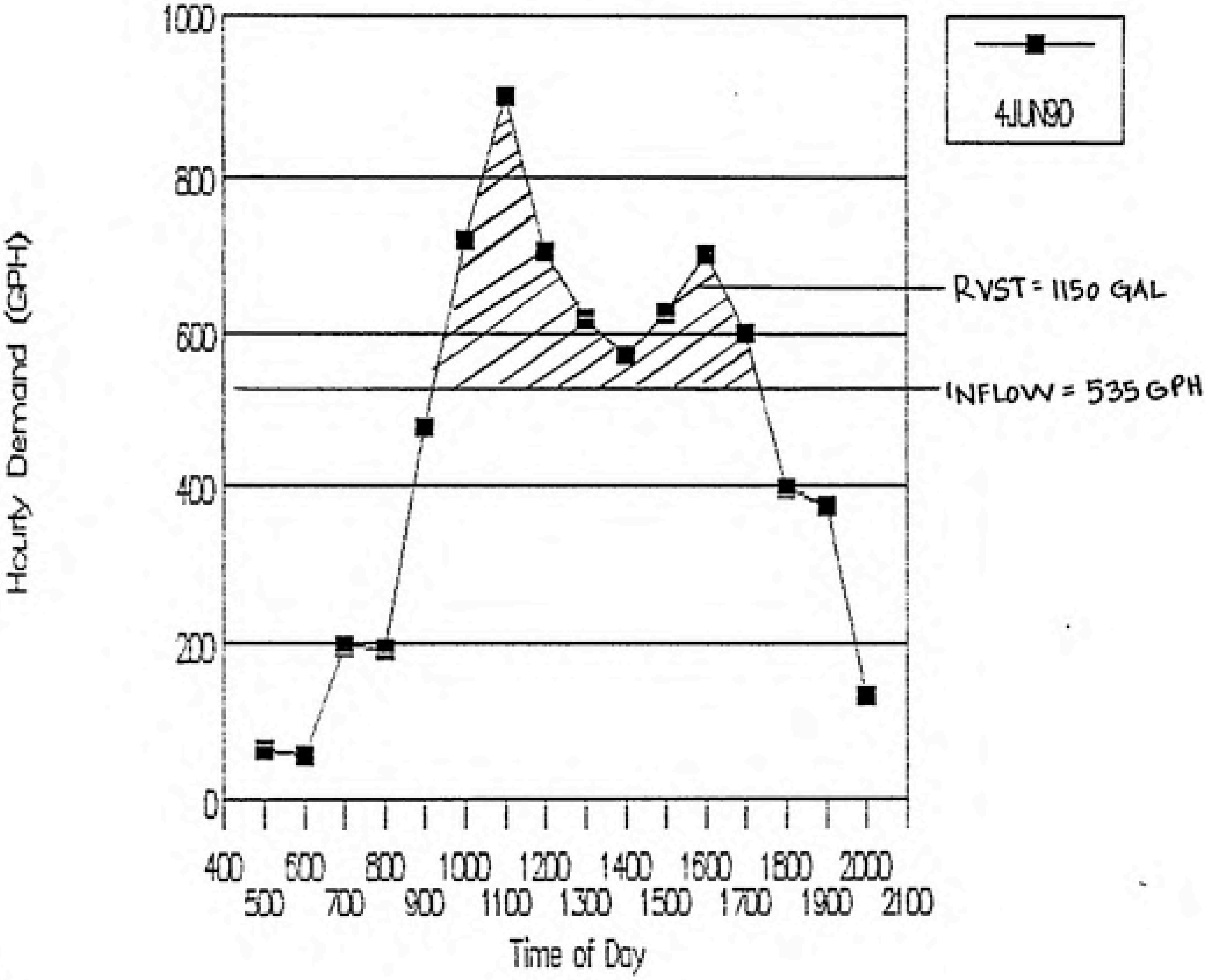
$$= \frac{1150 \text{ GAL}}{446 \text{ GPH}}$$

$$= 3 \text{ hours}$$

# APPENDIX J-2

# DAILY DEMAND PATTERN

# PANZALEO, ECUADOR



APPENDIX K

# REQUIRED STORAGE VOLUME

# PANZALEO, ECUADOR