Technical Note Number 16

United Nations Development Programme
Interregional Project INT/81/047
Executing Agency: The World Bank

Sensitivity of Water Distribution Costs To Design and Service Standards: A Philippine Case Study

by Paul V. Hébert and Cesar Yniguez, Technology Advisory Group (TAG)

UNITED NATIONS
1981-1990

A joint United Nations Development Programme
and World Bank Contribution to the International
Drinking Water Supply and Sanitation Decade

LIST OF PUBLICATIONS BY THE TECHNOLOGY ADVISORY GROUP (TAG)
UNDP INTERREGIONAL PROJECT INT/81/047

WP/01 **A Model for the Development of a Self-help Water Supply Program**; by Colin Glennie.

WP/02 **Ventilated Improved Pit Latrines: Recent Development in Zimbabwe**; by Peter Morgan and D. Duncan Mara.

TN/01 **Methods for Gathering Socio-cultural Data for Water Supply and Sanitation Projects**; by Mayling Simpson-Hebert (also in French).

TN/02 **Planning of Communication Support (Information, Motivation and Education) in Sanitation Projects and Programs**; by Heli Perrett (also in Portuguese).

TN/03 **The Ventilated Improved Double-Pit Latrine: A Construction Manual for Botswana**; by John van Nostrand and James G. Wilson.

TN/04 **Pit Latrine Ventilation: Field Investigation Methodology**; by Beverley Ryan and D. Duncan Mara.

TN/05 **Social Feasibility Analysis of Low-cost Sanitation Projects**; by Heli Perrett (also in Portuguese).

TN/06 **Ventilated Improved Pit Latrines: Vent Pipe Guidelines**; by Beverley Ryan and D. Duncan Mara.

TN/07 **Community-based Workshops for Evaluating and Planning Sanitation Programs: A Case Study of Primary Schools Sanitation in Lesotho**; by Piers Cross.

TN/08 **Rural Ventilated Improved Pit Latrines: A Field Manual for Botswana**; by John van Nostrand and James G. Wilson.

TN/09 **Handbook for District Sanitation Coordinators**; by Kebadire Basaako, Ronald D. Parker, Robert B. Waller and James G. Wilson.

TN/10 **Manual on the Design, Construction and Maintenance of Low-cost Pour-flush Waterseal Latrines in India**; by A.K. Roy.

TN/11 **Monitoring and Evaluation of Communication Support Activities in Low-cost Sanitation Projects**; by Heli E. Perrett.

TN/12 **A Monitoring and Evaluation Manual for Low-cost Sanitation Programs in India**; by Ronald Parlato.

TN/13 **The Design of Ventilated Improved Pit Latrines**; by D. Duncan Mara.

TN/14 **The Design of Small Bore Sewers**; by Richard Otis and D. Duncan Mara.

TN/15 **The Design of Pour-Flush Latrines**; by D. Duncan Mara

DP/01 **Ventilated Improved Pit Latrines: Zimbabwean Brick Designs**; by Peter R. Morgan and D. Duncan Mara.

DP/03 **Involving Women in Sanitation Projects**; by Heli E. Perrett.

Technical Note Number 16

Sensitivity of Water Distribution Costs To Design and Service Standards: A Philippine Case Study

Paul V. Hébert and Cesar Yniguez, Technology Advisory Group (TAG)

UNITED NATIONS 1981 1990

A joint United Nations Development Programme
and World Bank Contribution to the International
Drinking Water Supply and Sanitation Decade

The International Bank for Reconstruction and Development/WORLD BANK
1818 H Street, NW
Washington DC, 20433, USA

PREFACE

This TAG [1/] Technical Note by Paul Hebert and Cesar Yniguez describes a study undertaken in the Philippines for the Local Water Utilities Administration and the Rural Waterworks Development Corporation to evaluate the impact of changes in design and service standards on the costs of water supply projects in selected small towns and rural areas of the Philippines. Linear regression analysis was used to evaluate the magnitude of cost reduction to various modifications in design standards.

The studies suggested that, in small urban schemes in the Philippines, the greatest cost savings could be achieved by (a) reducing minimum pipe diameters from 100 to 38 mm or 50 mm, (b) limiting the per capita use to 140 liters/day, (c) providing a mix of home connections and public faucet service, and (d) neglecting the fire demand provisions, which can be done without serious risk to the community (fire fighting equipment is usually not available or, if available, the water source is a nearby waterbody). Changes in available head in the distribution system were found to bear relatively marginal effect on cost reduction.

In rural areas, where only public faucets were installed, the analysis showed that substantial cost savings ensued from (a) using PVC pipes in lieu of galvanzied iron) and (b) limiting the per capita use to 40 liters/day. The increase of the number of households per faucet resulted in an increase, rather than a decrease, in distribution costs.

Tentative new criteria derived from these investigations are being applied in pilot studies in the Philippines; the results should be available in early 1987.

This Technical Note is one of a series of informal papers issued by TAG on various aspects of low-cost water supply and sanitation. The initial emphasis of TAG was on the promotion of policy shifts from high-cost to low-cost on-site sanitation technologies. This emphasis is now being directed progressively to a focus on institutional development for on-site low-cost sanitation program delivery.

The distribution of this document does not imply endorsement by the sector agencies, government, or donor agencies concerned with programs, nor by the World Bank or the United Nations Development Programme.

Enquiries about the TAG program and the publications available and comments on this and other TAG papers should be addressed to the Project Manager, UNDP Project INT/81/047, Water Suply and Urban Development Department, The World Bank, 1818 H Street, N.W. Washington DC 20433.

Project Manager

[1/] TAG: Technology Advisory Group operating under the United Nations Development Programme, UNDP Interregional Project INT/81/047: Development and Implementation of Low-Cost Sanitation Investment Projects (formerly Global Project GLO/78/006), executed by the World Bank.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

1.01 Water supply agencies in developing countries must plan, design, implement, and often manage both urban and rural water supply projects. To ensure that the water supply systems meet minimum requirements for technical operation, as well as satisfy the expectations of users, agencies must establish standards to which plans and detailed designs must conform.

1.02 The most basic standards are service standards, which usually refer to the convenience of distribution and the quantity of water provided to users.

1.03 Design standards or design criteria, as they are more commonly referred to, are the more detailed specifications for the design itself and include such items for piped water supply as:

(a) minimum residual pressure at private and public taps;

(b) maximum allowable pipeline pressure;

(c) minimum and maximum hydraulic gradients and velocities;

(d) design periods;

(e) flow factors, including:

(f) minimum pipe size;

  - maximum-day and peak-hour factors;
  - unaccounted-for-water;
  - non-domestic demand;
  - fire demand; and
  - storage allowance;

(g) the range of pipe sizes used in design; and

(h) materials and classes of pipelines.

The above criteria relate to distribution systems. Additionally, standards need to be set for the design of surface water treatment plants, other facilities, and civil works.

1.04 Lacking experience of their own, water agencies in developing countries often apply standard design rules from developed countries, particularly for large urban areas. Overdesign is usually the result, but in these larger towns economies of scale and high population densities keep per capita costs reasonably low. Additionally, large variations in income and water use among customers allow an agency to design tariff rates to provide cross subsidies from higher income and commercial/industrial users to lower income users, thus making service affordable to most households.

1.05 The situation is different in small towns and rural communities, where the choice of appropriate service standards and design criteria is particularly difficult. If standards are too high, systems may be too costly for the communities to afford. If they are too low, operation and service may be adversely affected. Smaller populations and lower densities mean that per capita costs are often higher than those in larger towns for the same service level. The generally lower incomes, skewed income distribution, and the lack of substantial commercial and industrial customers limit the possibility of cross subsidies. Lower and middle income users thus pay most of the water system costs, and they cannot afford systems that are "overdesigned." Even where construction is subsidized by the government, with the large backlog of service evident in most countries it is essential for water agencies to make the most of limited budgets, since systems designed to excessively conservative standards take funds from other potential projects. Thus, water agencies must select standards carefully so that systems operate efficiently and provide acceptable and affordable service to the largest possible number of users. Until recently, however, there has not been enough experience to identify the most appropriate standards and design criteria, particularly for the small towns and rural communities, which generally are the areas in the most need of water supply improvements.

1.06 Results of studies in the Philippines and in other Asian countries during the past few years [1/] clearly show that: (a) certain design factors have much more influence on project costs than others; (b) standards and detailed design criteria can often be lowered significantly without adversely affecting system operation; and (c) planners and designers need to identify and focus on those design factors that have major cost implications. Other criteria have less effect on costs and can be set more conservatively to provide factors of safety.

1.07 This paper reports results of studies undertaken during 1983/84 in the Philippines. These studies tested the sensitivity of water supply costs to alternative standards. The focus of the studies was on rural and small urban projects, rather than on large urban schemes in which engineers have adequate experience and where more conservative standards may be appropriate. Standards for rural and small urban systems are discussed separately, and only piped water schemes are considered. Although handpumps play an important role in rural water supply, other studies have dealt specifically with standards and design criteria for this technology. [2/] Primary attention is given here to water distribution. This component, which we have defined for this study to include pipelines, appurtenances, and public and private distribution devices, represents 50% or more of total project costs for most systems. Also, some attention is given to distribution storage, but not to pumping, treatment, or source development. Thus, this

---

[1/] Carried out with assistance from UNDP Projects PHI/80/015, INT/81/047, and RAS/81/001 in the Philippines, Indonesia, Thailand, Peoples Republic of China, Burma, Sri Lanka, and India. This work was based on World Bank-sponsored research carried out at The University of North Carolina, USA; field work in Asia began in 1981 when one of the authors (Hébert) was placed in Manila to assist Philippine water agencies to improve planning and design through the use of microcomputers.

[2/] See, for example, the work on laboratory and field testing of handpumps being undertaken under UNDP Project INT/81/006.

paper is not intended to be a comprehensive review of all design standards and criteria used in rural and small urban water supply design. Rather, the aim is to look at major design assumptions that are likely to influence project costs most significantly. As background, the paper begins with a brief discussion of the Philippine water sector and the standards and criteria it used until about 1983.

II. PROGRAMS, STANDARDS, AND DESIGN CRITERIA IN THE PHILIPPINES

The Provincial Urban and Rural Programs

2.01 In the mid-1970s, the Philippines launched an ambitious water supply program to provide clean water to provincial urban towns. By the late 1970s, the government had embarked upon an equally ambitious program to improve water supplies for the more than 30,000 rural **barangays** (villages) located throughout the country. Responsibility for provincial urban water development was given to the Local Water Utilities Administration (LWUA), and the rural program was given to the Rural Waterworks Development Corporation (RWDC).

2.02 Prior to establishment of these organizations, responsibilities for water supply development, operation, and maintenance rested with numerous agencies. Standards of service and design criteria varied depending upon which agency was responsible.

2.03 At its inception, the heart of LWUA's program was, and still continues to be, the development of local, autonomous water districts, which are responsible for implementation, management, operation, and maintenance of water systems. These systems are intended to be financially self-sustaining and affordable to even low-income residents. LWUA provides financial support in the form of loans and a minimum capital subsidy (20%) and technical assistance in developing the project. LWUA is also responsible for developing standards and design criteria for its projects.

2.04 The RWDC program is centered around the development of Rural Water and Sanitation Associations (RWSAs) at the **barangay** level (the lowest political unit). RWDC provides loans and technical assistance to the RWSAs and assists the provincial and municipal engineering and development offices in planning and designing the rural schemes. Like LWUA, RWDC establishes standards and design criteria for its projects.

The Initial Standards and Design Criteria

2.05 General service standards were set at the national level in the late 1970s and include three service categories: Level I is a point source, which is either a driven well with a handpump or a developed spring. Level II is a piped system serving users with public faucets. The objective here is to provide at least one tap for about every four to six households. Level III provides users with individual connections. The user is responsible for all plumbing from the property line to the house, and the type of connections vary considerably within each town, ranging from a simple single outdoor tap to multiple indoor taps, showers, and flush toilets. In its major Water Supply Development Strategy paper of 1980, the government stated the general policy of providing Level III service to **poblaciones** (urban areas) and Level II service to higher density, more populated rural **barangays**. Others would receive Level I service, at least as an interim measure. Establishment of more detailed standards and criteria for design was left to LWUA and RWDC. LWUA has attempted to implement Level III service throughout the **poblaciones** and adjacent **barangays**, while RWDC has implemented only Level II and Level I systems in rural **barangays**.

2.06 **Urban Standards.** Initial standards established by LWUA were strongly influenced by expatriate consultants from the United States (U.S.) and Europe, who were hired in the early phases of the program. The standards were formalized and presented in a Technical Standards Manual and in Methodology Manuals developed by the foreign consultants. Table 1 lists some of the more important standards adopted by LWUA and used until about 1982 for designing water distribution systems. Standards used by other water agencies in the South and East Asia regions and by two municipalities in the U.S. are included for comparison.

2.07 In general, LWUA's standards are higher than those of the other Asian water agencies and come the closest to those used by the two U.S. municipalities. This can be seen from the high target for individual service (90% house connections), large minimum pipe size (100 mm), the high minimum pressure standard (14 metres), and the allowance for fire protection (11 litres per second [lps] from each of two adjacent hydrants in a residential area). These standards are lower than those typically used for urban water design in the U.S., which suggests that such standards were not applied directly by LWUA and their consultants to Philippine municipalities but that some tailoring at least took place. The other Asian agencies attempt to provide from 50% to 80% of customers with individual connections, generally provide minimum residual pressures of 12 metres or less, and do not design the systems to satisfy typical fire demands. LWUA's other standards do not differ significantly from those used by Indian state water agencies, except for the design period of facilities, which is only about 10 years compared to 30 years in India. All of LWUA's standards and those of the Indian agencies are higher than those used by Cipta Karya, the national water supply and sanitation agency of Indonesia, in its water supply program for small urban areas.

2.08 The greatest difference between the U.S. municipal standards and those of the Asian agencies is per capita usage, in which the two U.S. municipalities provide 3.6 to 4.5 times more water per capita than that provided by any Asian agency. The two U.S. municipalities also use larger minimum pipe sizes (150-200 mm), a larger fire flow (required by state or local regulations to satisfy insurance requirements), and about double the minimum pressure used by the Asian agencies (mainly to satisfy the needs of multi-level buildings found in most U.S. towns and cities). It is worth noting that about 45% of the per capita allowance of 640 litres per capita per day (lcpd) in the city of Denver is used for lawn watering and car washing. This brings the more essential per capita usage down to about 288 lpcd, about twice the allowance used by LWUA and about 1.6 times the allowance used by the Indian state agencies. For the small town of Steamboat Springs in Colorado (with a population of about 7,000), estimates of water use for lawn watering,

TABLE 1: Initial Standards and Criteria for Urban Schemes

Criteria	1975-82 LWUA, Phil.	Cipta Karya Indo.	Uttar Pradesh, India	Tamil Nadu, India	Kerala, India	Metro Denver, U.S.A.	Stmbt. Springs U.S.A.
Service level							
HC (%)	90	50	70	60	80	100	100
PS (%)	10	50	30	40	20	0	0
Demand							
Average Per Capita Use (lpcd)	140	45*	175	70	128	640	760
Max. day/Ave. day demand	1.3	1.1	1.25	1.2	1.2	1.7	2.0
Peak-hour/Ave. day demand	2	1	2	2	2.5-3.0	4.25	3.0
Comm/Ind.(%)	10-15	5	NA	NA	15	34	<10
Minimum Residual Pressure (m)	14	10	12	8	8	28	28
Maximum Pressure (m)	70	70	NA	NA	NA	77	98
Fire Flow (LPS)	11	none	none	none	none	63	31.5
Unaccounted-for-water (%)	30	15	20-30	30	20-30	6	NA
Minimum Pipe Size (mm)	100	25	90	90	90	150	200
Pipe Material							
C.I	x		x	x	x		
A.C	x				x		x
PVC	x	x	x	x	x		x
Steel	x				x		
Ductile Iron						x	x
Design Period (years)							
Pipelines	10	5	30	30	30	20	20
Other	10	5	15	15	15	NA	20

NA - Information not available
NC - Not considered in design
HC - House connection
PS - Public standpost
mm - millimetre

C.I. - Cast Iron
A.C. - Asbestos Cement
PVC - Polyvinyl Chloride
lpcd - litre per capita per day

* - 60 lpcd for House Connections with Flow Restrictions
30 lpcd for Public Standposts

car washing, and other outdoor, non-essential uses is estimated to be greater than 60% of total per capita use. It is also worth noting that the standards used for water system design in the town of Steamboat Springs are in some cases greater than those used for the greater Denver area. The standards used by both Denver and Steamboat Springs are essentially those presented in standard sanitary engineering texts (for instance, see Fair, Geyer, and Okun, **Water and Wastewater Engineering**, Volume 1, 1968).

2.09 **Rural Standards.** RWDC standards and criteria for Level II schemes are shown in Table 2, along with standards for design of rural schemes recommended by the World Health Organization (WHO), the International Reference Centre (IRC), and those of the State of Kerala, India. RWDC assumes a higher per capita use for public faucets and fewer persons served per faucet than either IRC or Kerala. The minimum pipe size of 25 mm is smaller than that used in Kerala, India (90 mm). RWDC also uses eight commercially available sizes in preparation of designs (25 mm, 30 mm, 38 mm, 50 mm, 63 mm, 75 mm, and 90 mm and 110 mm); 110 mm is the maximum size required for design of rural schemes. RWDC standards were developed from analysis of those used by the Ministry of Public Works in previous programs and from results of a few projects established in the late 1970s. The RWDC standards are significantly lower than those used by LWUA in its provincial urban program. Major differences are for per capita use (60 lpcd compared to 140 lpcd for LWUA designs), minimum pipe size (25 mm compared to 100 mm), minimum residual pressures (3.5 metres compared to 14 metres), design period (5 years compared to 10 years), and, most importantly, in the level of service (100% public faucets compared to only 10% public faucets assumed in LWUA designs). The lower per capita consumption figure is explained by the use of public faucets instead of house connections. Lower minimum residual pressures can also be allowed since all public faucets are at ground level. It is worth noting that the maximum day and peak hour flow factors used by LWUA and RWDC are essentially the same. However, officials of LWUA and RWDC admit that the assumptions for these factors have not been verified with hard field data.

Problems with Standards and Criteria

2.10 LWUA standards were established with larger urban projects in mind. As soon as feasibility studies were undertaken for smaller towns, problems of high per capita costs and affordability became acute. The solution to the increasing number of infeasible projects narrowed to two alternatives: either lowering project costs by modifying standards and criteria or providing more subsidy and/or more liberal financing. The realities of scarce project funding left LWUA no choice but to re-examine design standards. LWUA believed that several of its standards might be lowered without adversely affecting system performance or project acceptability. These standards, which were therefore selected for investigation in our study, included minimum pipe size, fire flow requirements, minimum residual pressure, and service level standard.

TABLE 2: Standards and Criteria for Piped Rural Schemes

	RWDC	IRC Recommendations	Kerala, India Type of Area	
			Stable	Developing
Service Level				
HC %	0	0	20	50
PS %	100	100	80	50
Persons/PS	24-36	40-70	200	200
Average Demand (lpcd)				
PS	60	20-30	40	40
HC	---	40	80	150
Max-day (ratio)	1.3	1.1-1.3	1.3	1.3
Peak-hour (ratio)	2.5	1.5-2.0	2.5-3	2.5-3
Commercial (%)	0	0	15	15
Residual Pressure (m)	3.5	NA	3	8
Unaccounted-for-water (%)	20	NA		25
Minimum Pipe Size (mm)	25	NA	90	90
Pipe Material				
PVC	x	NA	x	x
G.I. or C.I.	x	NA	x	x
A.C.		NA	x	x
Design Period (years)				
Pipeline	5	NA	30	30
Other Facilities	5	NA	15	15

HC - House Connections
PS - Public Standpost
(m) - metres
(mm) - millimetres
NA - Information Not Available

PVC - Polyvinyl Chloride
G.I. - Galvanized Iron
C.I. - Cast Iron
A.C. - Asbestos Cement
lcpd - litres/per capita/per day

2.11 In 1983/84 RWDC began to experience similar problems with the affordability of its Level II projects. This, together with the general desire to review the standards for possible change, prompted a similar study for this organization. For rural schemes, it was decided to investigate the assumptions for numbers of available pipe sizes, the public faucet service standard, pipe material, per capita demand, and minimum residual pressure.

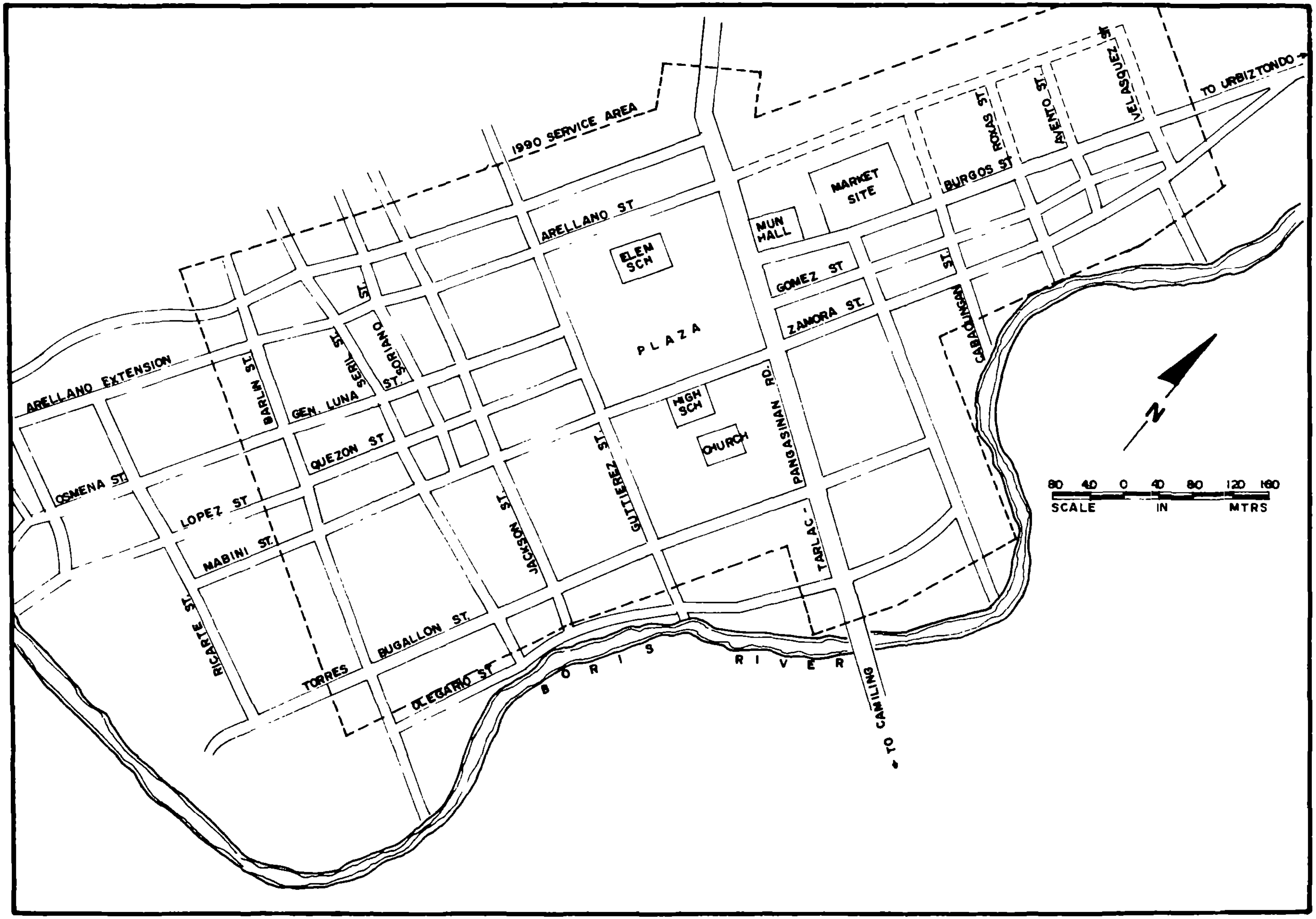

Figure 1: 1990 Service Area Mangatarem, Pangasinan

III. STUDY OF ALTERNATIVE STANDARDS FOR SMALL URBAN AREAS

Study Approach

3.01 Studies concentrated on two small urban centers (**poblaciones**), Mangatarem and Candaba, both located in Central Luzon in the Philippines. Mangatarem has a projected population for 1990 of 7114, or about 1186 households. Candaba has an expected population in 1994 of 9044, or about 1292 households. Sketch maps of the two communities are shown as Figures 1 and 2. Both are typical of small towns now being considered for projects under the LWUA program. Both are primarily residential with several public schools, churches, a public market, and a few commercial establishments, but no industries. The terrain is essentially flat for both.

3.02 The following design standards were varied to determine the effect on the cost of distribution and the total project:

(a) minimum pipe size;

(b) fire demand;

(c) minimum residual pressure and available head; and

(d) service level and per capita consumption

LWUA's experience with different pipe materials was examined as well. But, because LWUA has for some time used PVC pipe for most projects, no cost comparisons were made with other pipe materials.

3.03 An HP-87A and a COMPAQ personal computer were used to prepare the alternative designs and to analyze the results. The use of the microcomputers was essential to carry out this study for two reasons. First, it was necessary to design the systems as precisely as possible to the different standards and criteria, and this could be done only with the aid of a computer. Secondly, it would have been too time-consuming to prepare the range of alternative designs without the aid of the computers. The distribution layouts for the two towns are shown in Figures 3 and 4 (pages 11 and 12). The distribution network simulation program "LOOP" was used to design the small urban schemes. This program was developed under the UNDP/World Bank Technical Assistance Projects PHI/80/015 and INT/81/047. A simple linear regression program called REGRESS was used for some data analysis. These programs are available from the World Bank as a part of the package **Microcomputer Programs for Improved Planning and Design of Water Supply and Waste Disposal Systems** (see para. 6.03). The design work was carried out by LWUA engineers and the UNDP technical assistance staff.

Study Results

3.04 **Minimum Pipe Size.** The initial LWUA standard for minimum pipe diameter of 100 mm (4 inches) is only one standard size smaller than the typical minimum used for water systems designed in most industrialized countries. The rationale for using the large minimum size is presumably to ensure adequate pressure for fire fighting and also to obviate the need for

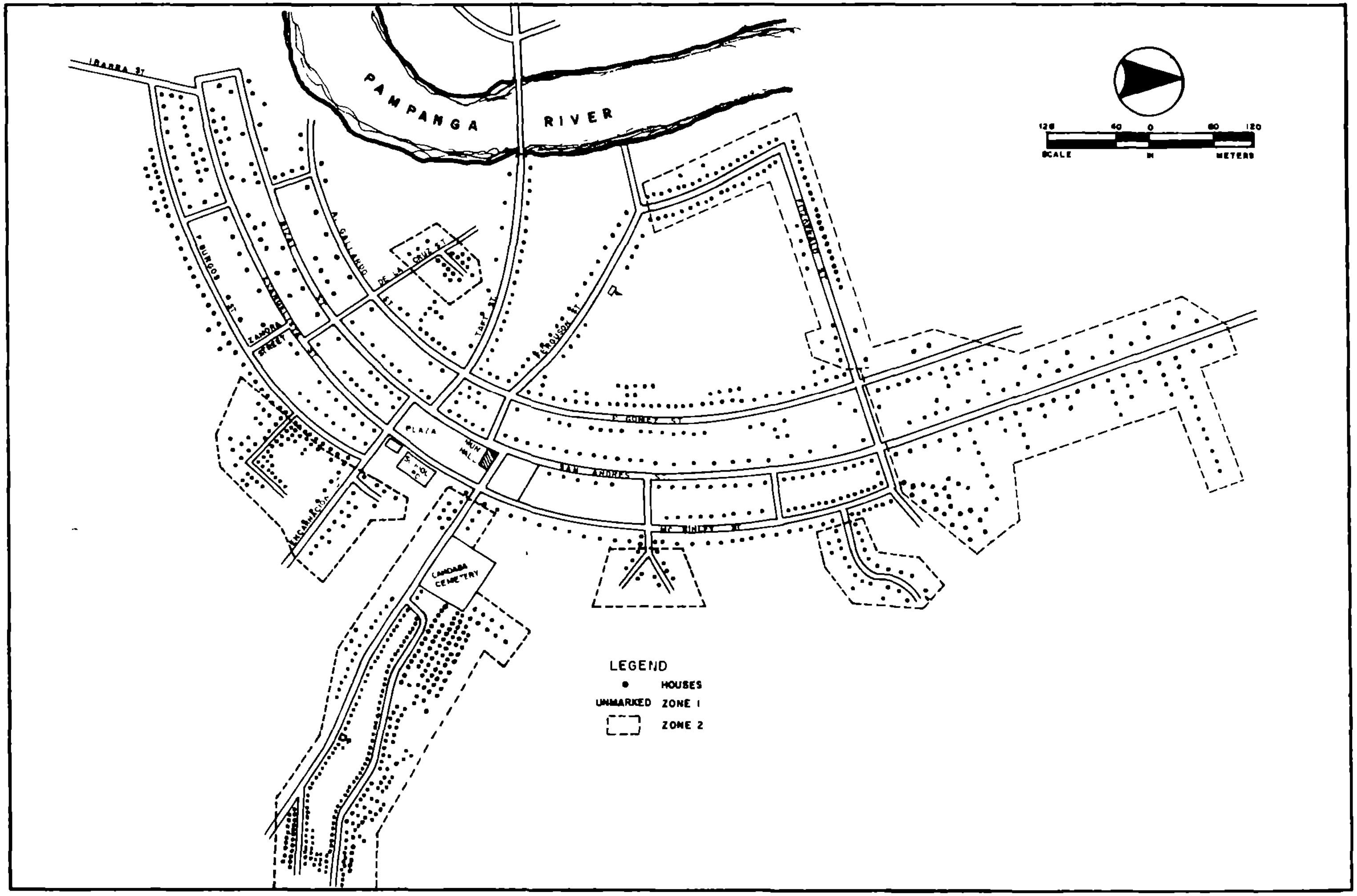

Figure 2: Household Location Map of Candaba, Pampanga

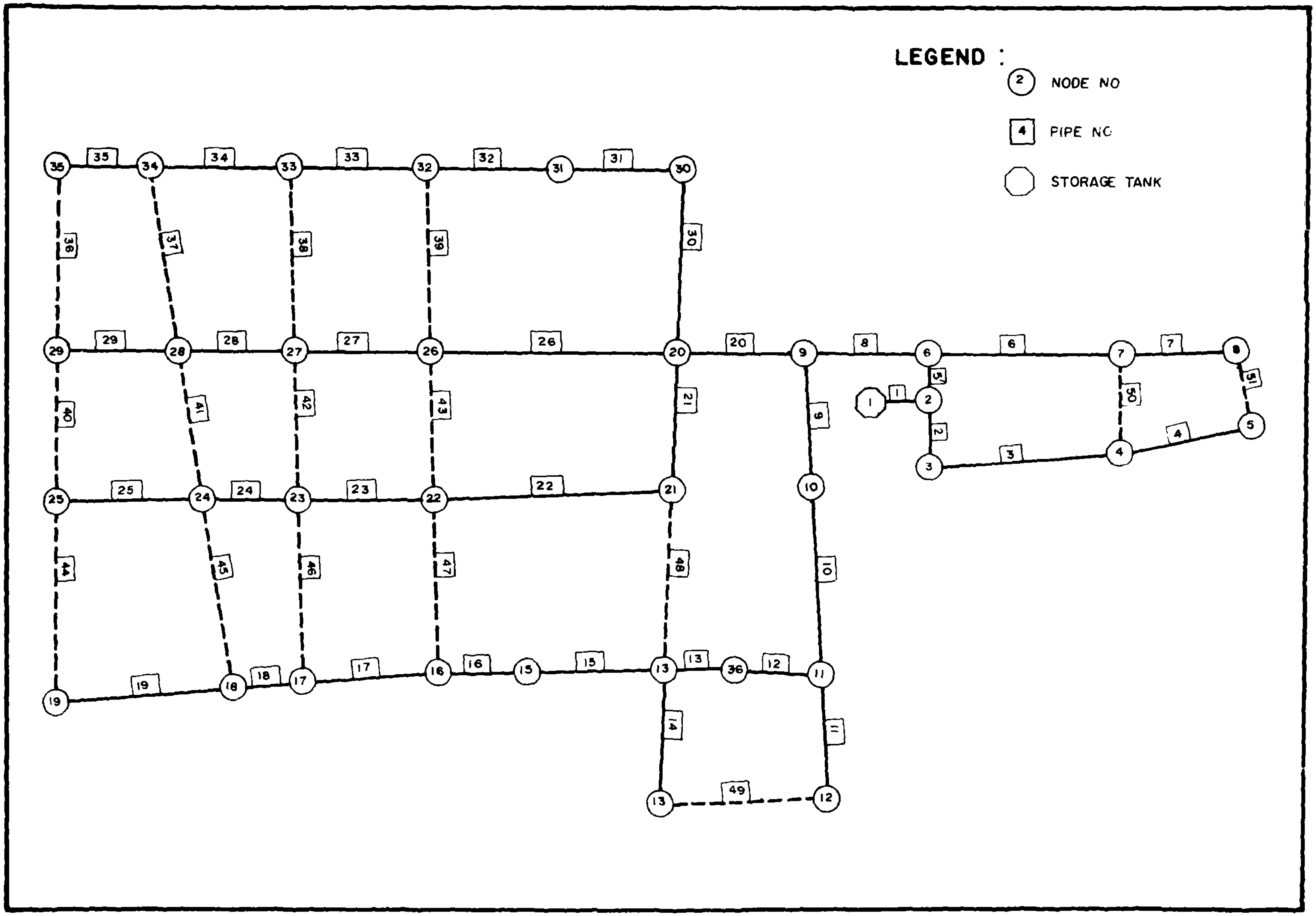

Figure 3: Mangatarem Distribution Layout

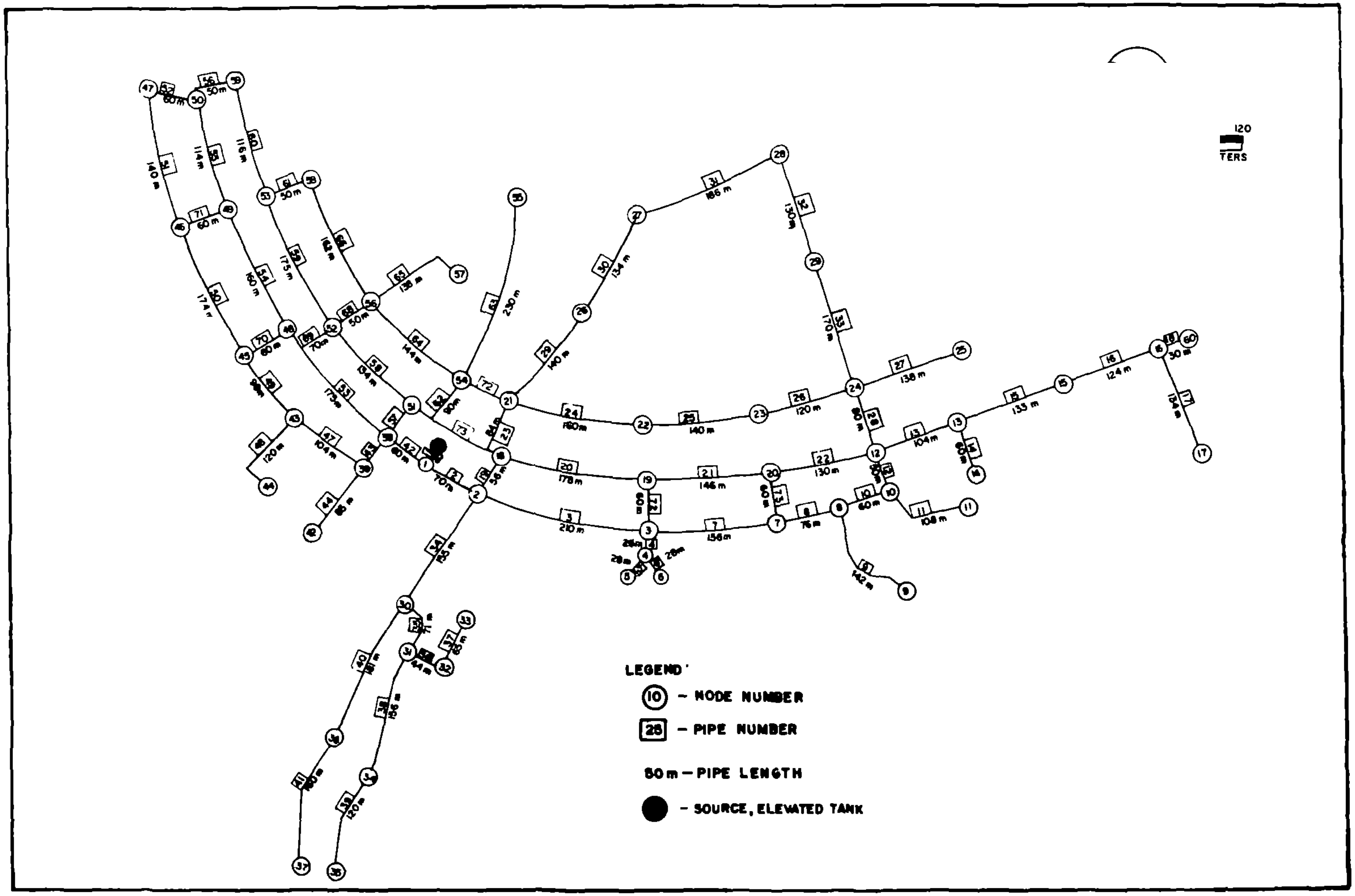

Figure 4: Location of Proposed Candaba Water Supply Facilities

laying parallel mains in the future as demand on the system grows. Engineers have rationalized that only small economies are achieved by using smaller pipe sizes. However, data provided by LWUA (Table 4, page 15) show that the installed cost per metre of 100 mm PVC pipe is more than double that of 50 mm diameter pipe. The pipeline cost equation, developed from the cost data, and also shown in Table 3, indicates that unit pipeline costs vary with diameter raised to the exponent 1.32 (the exponent shows the approximate percentage change in unit cost with a 1% change in diameter, and is often referred to as the economy of scale factor). For instance, a doubling of the pipe diameter would suggest an increase in unit cost of about 2.5 times. The unit cost data suggest that if a large proportion of the network can be of sizes smaller than 100 mm (and satisfy expected demand and pressure requirements), then the cost savings should be significant. In our study, the Mangatarem and Candaba systems were designed using progressively smaller minimum sizes to test the effect on costs while retaining LWUA's original per capita use criterion of 140 lpcd. The results are shown in Table 4. Relaxation of the minimum size from 100 mm to 75 mm, 50 mm, and 38 mm resulted in cost reductions of 27%, 37%, and 45%, respectively (a relaxation to 25 mm shows no appreciable reduction, as this size was too small for the Mangatarem system and comprised only 9% of the network for the Candaba system).

TABLE 3: Unit Costs for Material and Installation of Pipelines, LWUA Estimates (mid-1983)

Diameter (mm)	PVC Pipe Cost/metre (pesos)
38	51
50	62
75	95
100	138
150	266
200	433
250	550

Regression equation: $C/L = .36\ D^{1.32}$ $R^2 = 0.99$

C/L is the cost in pesos per linear metre of pipeline
D is the diameter of the pipeline in millimetres

mid-1983: 14 pesos = US$1.00

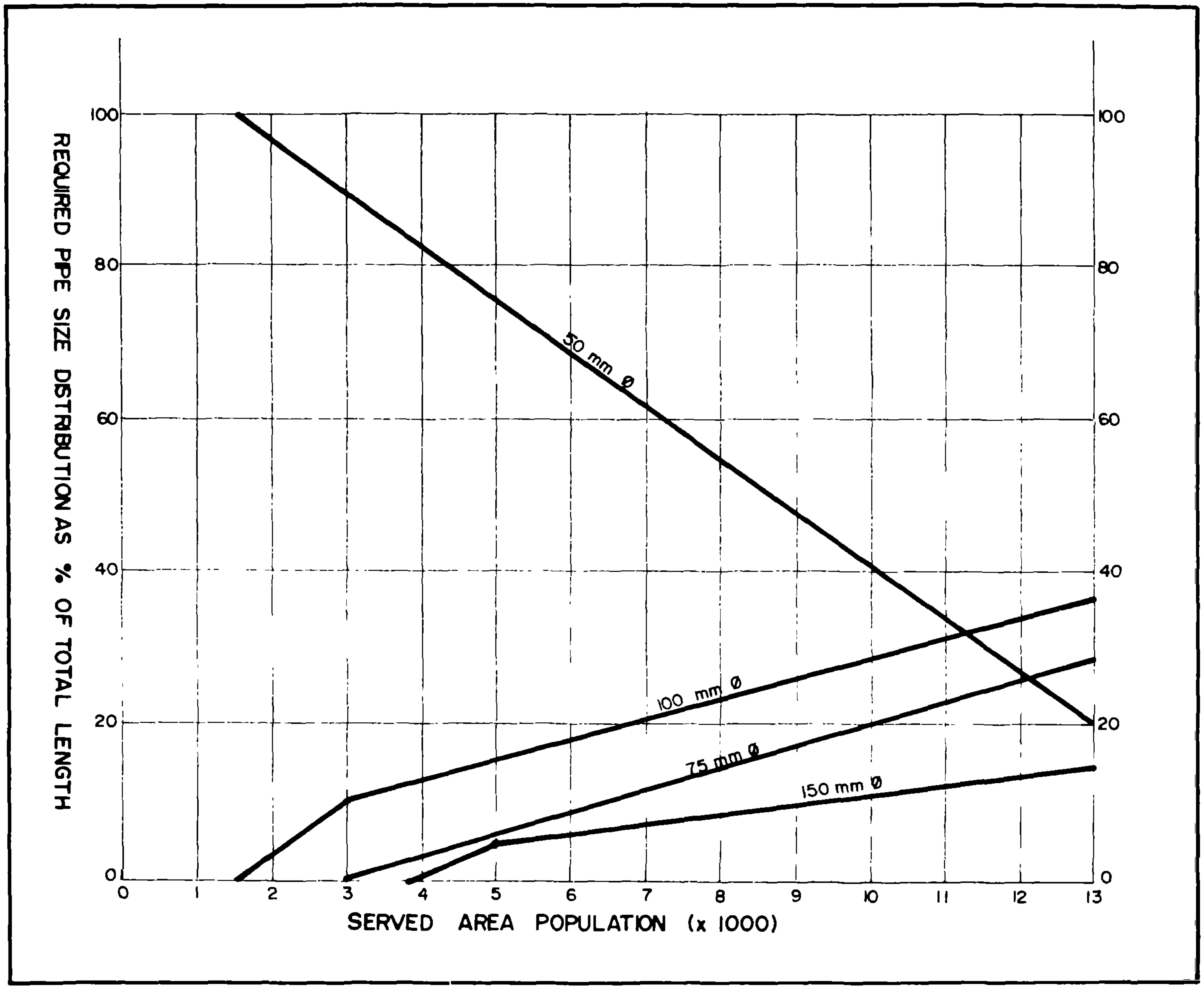

Figure 5: Distribution of Pipeline Sizes
Required for Different Service Area Populations

TABLE 4: Cost Sensitivity to Mimimum Pipe Size

Minimum Diameter(mm)	Network Per Capita Cost (pesos)		Percent of Pipeline with Minimum Size	
	Mangatarem	Candaba	Mangatarem	Candaba
100	112.0	117.4	97	100
75	82.3	83.6	88	95
50	70.8	64.0	59	71
38	62.2	60.0	45	41
25	-	59.5	-	9

3.05 In addition to the very significant cost reductions, two important observations are worth noting. First, about 90% of the network could be smaller than the 100 mm diameter specified minimum size without affecting performance under peak flow conditions (140 lpcd times a factor of 2.0); in fact, 60 to 70% of pipelines could be 50 mm or smaller. This result clearly called for a revision of this design standard. Standard minimum pressures of 14 m (10 psi) were maintained throughout the network under peak-flow conditions for the design year (1994). The results for Candaba, also reported in Table 4, show similar relative cost reductions.

TABLE 5: Populations and Fire Flow as Percentage of Maximum-day Demand

Population	Fire Demand as Percentage of Maximum-day Demand (lpcd)
40,000	26.00
80,000	13.00
160,000	6.50
200,000	3.25

3.06 Clearly, the savings for a particular project depend on several factors, including the total population served, per capita demand, population density, and pipeline economy-of-scale. The results above suggest that, for small urban projects in the Philippines, the savings are likely to be significant. Figure 5 was developed from analysis of computerized distribution designs for five **poblaciones** with different populations (and thus different total water demand) to aid LWUA engineers in making preliminary pipeline size and cost estimates. The graph shows estimates of pipeline requirements for towns with populations ranging from about 1,500 to 13,000. It suggests that the percentage of pipeline below 100 mm will vary from 40% of total pipe length (population 13,000) to 100% (population 1,500). Given unit pipeline costs and total required pipe length, Figure 5 can be used to estimate pipeline costs for communities with different populations and can also show potential cost reductions by adopting different minimum pipe sizes.

3.07 **Fire Demand.** Water distribution pipelines for urban areas are sized to supply peak-hour demand, which for most small- to medium-size towns is about twice the average flow. LWUA then checks these designs to determine how the system performs under the standard for critical fire flows of 11 lps from each of two adjacent hydrants (135-200 m apart) in residential zones or 22 lps from each of two adjacent hydrants in commercial zones. This LWUA standard was based on recommendations of expatriate consultants and was applied to both larger and smaller urban towns.

3.08 For medium and large towns with served populations above about 40,000, experience shows that hydrants located on lines of 100 mm or larger can deliver the above fire flow, and pressures will remain at acceptables levels at other distribution points under maximum-day demand conditions for most cases. Fire demand, however, represents only a fraction of total demand for these towns.

3.09 In these larger urban areas, fire demand for residential zones is only about 3%-26% of maximum-day demand and therefore exerts only a small additional demand on the distribution system. For small towns like Candaba and Mangatarem, however, the standard fire demand is more than the total domestic demand (22 lps fire demand compared to about 19 lps maximum-day demand).

3.10 For Candaba, simulated fire demands were made of 11 lps from two adjacent hydrants in the central town and in residential areas, assuming both peak-hour and maximum-day domestic demand at other points to test system performance. When fire demands were simulated in the center of town near the storage reservoir, along 100 mm pipelines, pressures were acceptable at the nodes delivering the fire flows, as well as at all other nodes in the network assuming maximum-day demand. At peak-hour demand (twice the average flow), however, pressures dropped to as low as 3 metres at the extremities of the system (30% of the nodes had pressures below 7 m). When the same fire demands were simulated in residential areas away from the town center, along 75 mm pipelines at both peak hour and maximum-day demand, pressures were insufficient at the points of withdrawal of the fire flow (below 5 m) and negative at all points downstream. To increase pressure to acceptable levels required increasing all pipelines upstream of the fire demand withdrawals to 100 mm or 150 mm diameter. Table 6 shows headloss per kilometre (gradient) for flows of 11 lps-44 lps for pipelines of 50 mm-200 mm diameter to give some idea of the losses that would be expected for these conditions. For pipelines below 100 mm, headloss is excessive. In order to keep pipeline pressure drop to reasonable levels, a much reduced level of flow for fire fighting would have to be acceptable in areas where minimum size pipes below 100 mm are used.

TABLE 6: Headloss Along Pipelines of Different Diameters for Different Simulated Fire Flows

Pipeline Diameter (mm)	Headloss (m/km) Simulated Fire Flow (lps) 11	 22	 33	 44
50	583.00	2101.00	-	-
75	81.00	292.00	618.0	1052.0
100	20.00	72.00	153.0	259.0
150	2.80	10.10	21.4	36.4
200	.76	2.50	5.2	8.8

3.11 It is important to note that modern fire fighting equipment is not available in most small **poblaciones** in the Philippines, even for those that have a piped water supply. Where equipment is available in larger towns, it is also the practice to use pumper trucks to withdraw water from the hydrants or from lakes, rivers, or ponds. The results of the above analysis, combined with the lack of equipment, suggested that in order to reduce distribution costs the standard for fire demand should be lowered or eliminated altogether, at least for small towns.

3.12 **Residual Pressure and Optimal System Head.** The minimum residual pressure was another standard that appeared to be set too high for small urban projects. The initial 14 m standard (20 psi) assumed the need to supply water to at least the second level of commercial establishments and residences. However, in small Philippine towns, most residences and commercial buildings have only a single level, suggesting that a lower pressure, say of 7 metres, would probably be adequate. Lowering the minimum residual pressure translates to an increase in available head (the amount of pressure that can be lost due to pipeline friction between the source or sources and the points of withdrawal), assuming that the input pressure remains unchanged. For small water systems in the Philippines, water is first delivered to an elevated storage reservoir by direct pumping or by gravity. Tanks are usually 20-30 m high, measured from the tank outlet; 20 m is the most common height. If 14 m of pressure is to be maintained throughout the system, 6 m of head can be dissipated through friction losses from the tank to the network extremities (assuming flat terrain and a 20 m tank height). If the standard is lowered to 7 m, then 13 m of head is available. With more available head, smaller pipes can be used and thus cost reduced. In our study, distribution pipes for Candaba were sized assuming available head from between 5 and 15 m to test the effect on per capita distribution cost. Costs of the resulting distribution systems are shown in Table 7.

TABLE 7: Cost Sensitivity of Distribution Network to Available Head in Candaba

Residual Head (m)	Available Head (m)	Network Per Capita Cost (pesos)
5	15	47.4
7	13	49.5
10	10	51.2
12	8	54.1
15	5	66.3

Notes: Tank height = 20 m
Per capita demand = 140 lpcd (gross)

Linear regression analysis of the design results shows that costs vary as a function of available head raised to the negative power 0.29, with average per capita demand of 140 lpcd. The regression equation is shown below:

$$C/P = 103.6\, H^{-0.29}$$

where: C/P = distribution cost per capita in pesos
H = available head in metres

3.13 The value -0.29 indicates the approximate percentage change in distribution cost with a 1% change in available head. For Candaba, the equation suggests that a decrease from 14 m to 7 m residual head (an increase from 6 m to 13 m available head) results in network cost reduction of about 20%. However, a further decrease in minimum pressure to 5 m (the minimum that is likely to be acceptable for in-house service) reduces the costs by another 3% only. Every 10% change in available head will result in approximately a 3% change in distribution costs. Clearly a change from the 14 m standard to a 7 m standard would result in significant distribution savings.

3.14 The results show the sensitivity of distribution costs to the available head, but give no indication of the most economical pumping head or the optimal height of the storage reservoir. An analysis was carried out that included the cost of energy for pumping and the cost of the storage tank. It was found that including the cost of the pumping equipment did not affect the optimal pumping head. Annual energy costs were calculated for a 10-year period, assuming unit energy costs of 1 peso/kilowatt-hour (kwhr). Costs were converted to present value using a 10% discount rate. The well depth for Candaba was estimated to be 30 m, and the height of the tank (H) was varied from 12 m to 22 m. Therefore, the pumping head ranged from 47 m to 57 m, (allowing an additional 5 m from the tank bottom to the inlet). The storage tank costs were estimated from the following equation developed from data supplied by local contractors:

$$C = 2813Q^{0.92} \, H^{0.25}$$

where: C = cost of the tank in pesos

Q = the tank volume in cubic metres

H = tank height in metres

The distribution network, storage tank, present value energy, and total present value costs are shown in Table 8. The most striking observation is the small difference in present value costs between available heads of 5 and 10 m (about 1%). The most economical head is about 8 m. This suggests that with a minimum pressure of 7 m the outlet of the storage tank should be about 15 m above the service area, or about 5-15 m less than the standard height. The cost of energy was varied from 0.5 to 2 pesos/kwhr and the discount rate from 10% to 15%. For these ranges, the most economical available head remained between 5 and 10 metres. Although the most economical tank height is about 15 metres, there may be other arguments in favor of higher storage tank heights. Most importantly, more height would result in better system flexibility as the service area develops and expands in the future. Minimum pressures in expanded areas might be maintained with little or no additional tanks or booster pumping. Storage tanks, especially reinforced concrete, are permanent structures that may last 50 years and whose capacity and height cannot be easily modified once constructed.

TABLE 8: Comparison of Present Value Costs for Different Pumping Heads and Tank Heights

Pumping Head(m)	Tank Height(m)	Available Head(m)	Present Value Costs (per capita) Network	Energy	Tank	Total
47	12	5	66.30	72.17	87.16	225.63
50	15	8	54.10	76.78	92.16	223.04
52	17	10	51.20	79.85	95.09	226.14
55	20	13	49.50	84.46	99.03	232.99
57	22	15	47.40	87.53	101.42	236.34

Minimum pressure = 7 m
Tank volume = 15% of max-day demand (223 m^3)
Design population = 9044
Average energy cost = P1/kwhr
Discount rate = 10%
Pump efficiency = 60%
Well depth = 30 m
Period of analysis = 15 years

3.15 A similar analysis was carried out for Mangatarem with similar results. Distribution costs had the same relative sensitivity to changes in the available head, varying with H raised to the negative power 0.27. The most economical pumping head was also found to be between 5 and 10 m.

3.16 The distance from the source to the extremities in both Candaba and Mangatarem varied from about 500 m to 1000 m. The most economical average gradient (headloss per kilometer), therefore, varied from about 5 m/km to 20 m/km (assuming available heads of 5-10 m are acceptable). These values are generally higher than the range recommended by LWUA consultants (1.0 - 10 m/km).

3.17 **Service Level and Per Capita Demand.** In many of the smaller municipalities in the Philippines, it is not feasible for all households to have individual connections. The water rates are too high for low-income users to afford the monthly payments, even when project costs are reduced by lowering design criteria (lowering minimum pressure requirement; using smaller minimum pipe size; and disregarding fire demand). A test was made of the effect of lowering the design standard from 100% individual connections to a mix of 60% individual connections and 40% public faucets. Gross per capita demand of 140 lpcd was assumed for those using house connections and 40 lpcd for those using public faucets, which lowered total demand by 30% (we assumed 30% losses). Table 9 summarizes the design assumptions. The mixed service level system was found to be about 25% less costly than the system providing all house connections (shown in Table 10). Costs were reduced through reductions in total demand and therefore the scale of facilities, and also in the sizes and length of pipelines and in the distribution devices. In fact, the largest saving (33%) was for the service connections. Elevated storage cost was reduced by 30%. Distribution costs were lowered by about 23%. The use of the mixed service level would have another positive result for low-income residents, who would ordinarily be unable to afford an individual connection and the monthly user charges. A low-income household served by a public faucet would use less water and thus incur a smaller monthly water bill even if rates per cubic metre used were the same as for individual service. Therefore this lower service would more likely be affordable to the lower income groups in small towns.

TABLE 9: Design Assumptions For Service Levels (Mangatarem)

Assumption	House Connections	Mixed
Average Demand (lps)	11.83	8.39
Number House Connections (Demand =140 lpcd)	1,204	659
Public Faucets (Demand = 40 lpcd)	0	90
Average Per Capita Demand (lpcd)	140	100
Minimum Pressure (m)	7	7
Minimum Pipe Size (mm)	50	50

Demands include about 30% losses

TABLE 10: Per Capita Costs for Alternative Services

Item	Per Capita Costs (pesos) House Connections	Mixed	Cost Difference (percent)
Deepwell	14.05	14.05	0
Pump Station	44.96	36.53	19
Storage	56.20	39.34	30
Disinfection	2.11	2.11	0
Service Connections	86.26	58.30	32
Distribution Network	74.04	57.18	23
Total	277.60	207.50	25

3.18 To give a more general indication of how the per capita demand assumption affects distribution costs, the net per capita use was varied from 66 lcd to 198 lcd for Candaba. The lower figure corresponds to supplying most of the community with individual yard taps rather than by house taps or physically restricting flow to the house. The upper figure is the actual gross production reported for some of the large provincial towns in the Philippines.

3.19 With residual pressure held constant at seven metres and a tank height of 15 m, the per capita costs of distribution were found to vary from P42.38 (66 lpcd) to P66.60 per capita (198 lpcd). Results are given in Table 11.

TABLE 11: Per Capita Distribution Costs with Varying Per Capita Use--Candaba

Per Capita Use (lpcd)	Cost/capita (P)
66	42.39
100	49.35
132	54.11
198	66.60

Available Head = 8 m
Design Population = 9044 (1994)
$C = 7.64Q^{0.40}$
Where: C = cost in pesos
Q = per capita demand in litres per capita per day.

3.20 The data were used to develop a predictive cost model also shown in Table 11. The equation suggests that distribution costs are a function of the per capita demand raised to the power 0.40. Therefore, a 50% reduction in per capita consumption should give a 25% decrease in distribution network costs. The model suggests network costs are more sensitive to changes in per capita demand than to available head. A 10% change in per capita demand should give approximately a 4% change in distribution costs, compared to a 3% change for changes in available head.

3.21 Other facilities, such as storage tanks, pumping stations, and treatment plants, are usually more sensitive to changes in scale (production capacity) than the distribution system. Their cost sensitivity can be estimated from cost functions for those facilities. For instance, the elevated storage tank has the cost equation:

$$C = 2183Q^{0.92} H^{0.25}$$

where: Q = capacity in m^3

H = height in meters

and C = cost in pesos

A 50% reduction in the storage requirement would have the effect of lowering storage tank cost by $0.50^{0.92}$, or by about 47%. The costs of pumping facilities and water treatment plants usually vary with the quantity of water produced raised to the power 0.7-0.8. Therefore, a 50% reduction in demand would have the effect of reducing the cost of these facilities by about 40%.

3.22 **Pipe Material.** Since 1982, LWUA has used PVC for mains 250 mm and smaller in most of its systems. For small urban towns, PVC pipe makes up nearly 100% of all lines. Exceptions are bridge crossings and transmission lines, which are usually lined with steel or ductile iron. Asbestos cement pipe was used extensively prior to 1982 and was priced competitively with PVC in most sizes. However, AC pipe was banned from use for domestic water supplies in 1983 due to concern and controversy over the potential health hazard of asbestos fibres in drinking water. Even before the controversy, LWUA had poor experience with AC pipe, including a high rate of pipeline damage during loading, delivery, and unloading. Some projects experienced 70% losses due to damage (50% during transport and 20% during testing). Cost comparisons of PVC with Galvanized Iron are discussed in more detail in paragraph 4.03 below.

IV. STUDY OF STANDARDS AND CRITERIA FOR RURAL SCHEMES

Study Approach

4.01 For the study of standards and design criteria for rural schemes, five rural **barangays** were selected with populations ranging from 306 to 2250 (about 50-274 households) and with areas ranging from 5.9 to 128.5 hectares. The characteristics of the **barangays** are given in Table 12. These five are typical of others in the Philippines. Each **barangay** has one main road and a few branch roads along which all houses are located. All have essentially flat terrain.

TABLE 12: Description of the Rural **Barangays**

Name	Population	No. of Households	Area (ha.)
San Juan	306	50	5.9
Bolisong	1304	249	70.0
San Roque	812	134	128.5
Anuling	1158	198	46.0
Boot	2250	274	115.0

4.02 The following design assumptions were varied to determine their effect on distribution network costs:

(a) the number of pipe sizes permitted for design;

(b) pipe material;

(c) spacing of public faucets;

(d) per capita demand; and

(e) minimum pressure

4.03 All the distribution networks were laid out in a branching configuration, and pipelines were sized according to the different criteria using the computer program BRANCH. This program selects the least-cost combination of pipe sizes given by the designer for the given flow conditions and minimum pressure requirements. This program is contained in a package of computer programs available from the World Bank, **Microcomputer Programs for Improved Planning and Design of Water Supply and Waste Disposal Systems**, prepared by the Technology Advisory Group (TAG) for a specific target group. In all, 47 different designs were prepared for the five **barangays**. RWDC provided unit costs for commercially available pipe sizes in PVC and G.I. materials, shown in Table 13. Cost functions developed from the data are also given in Table 13.

TABLE 13: Unit Costs for Material and Installation of Pipelines
RWDC Estimates
(mid-1984 costs)

Diameter (mm)	Cost per Metre (pesos)	
	PVC	G.I
25	10	32
32	16	42
38	25	51
50	38	72
63	48	117
75	72	145
90	103	---
110	154	206
160	284	355

Regression equations from installed pipe cost data:

$C/L = 0.0316D^{1.79}$ (PVC Pipe)
$C/L = 0.41D^{1.33}$ (G.I. Pipe)
C/L is the cost of pipelines in pesos per linear metre installed.
D is the diameter in millimetres.

Study Results

4.04 **Number of Pipe Sizes.** RWDC stocks PVC pipe in nine sizes and G.I. pipe in eight sizes (shown in Table 13). Materials are procured in bulk: these are stored and then delivered to project sites when needed. A reduction in the number of stocked pipe sizes would reduce work in procurement, warehousing, shipping, and construction, as well as simplify design. It would also reduce the variety of fittings, tees, valves, and other appurtenances needed. It is expected that the trade-off would possibly be a more costly system since fewer sizes would be available to use in the design.

4.05 To test the effect of using fewer pipe sizes, alternative designs were prepared for **barangays** Anuling and San Roque. Results are given in Table 14. For the Anuling design, the computer program selected from among eight diameters (G.I. pipe); the least-cost design included six (25 mm, 32 mm, 38 mm, 50 mm, 63 mm, and 75 mm) with a cost of P64.50 per capita. The system was redesigned allowing only four sizes (25 mm, 38 mm, 50 mm, 75 mm). Per capita cost increased to P65.30, or by about 1%. With only three sizes (25 mm, 50 mm, and 75 mm), the cost increased to P68.80 per capita, 6% more than the original design. For San Roque, a decrease from six sizes to only four resulted in less than a 1% increase in cost. These results strongly suggest that reducing the number of different diameters available for design will have an insignificant effect on network costs, while achieving considerable potential benefits by reducing the inventory of materials. It was found necessary to include the minimum hydraulically feasible size and the maximum size required in the computer designs, but only one or two sizes in-between.

TABLE 14: Relationship Between Number of Pipe Sizes and Per Capita Distribution Costs (**Barangays** Anuling and San Roque)

Barangay	No. of Pipe Sizes	Sizes (mm)	Per Capita Costs (pesos)	Percent Cost Increase
Anuling	6	75,63,50,38,32,25	16.5	---
	4	75,50,38,25	17.0	0.8
	3	75,50,25	18.1	6.0
San Roque	6	75,63,50,38,32,25	15.2	---
	4	75,50,38,25	15.3	0.1

4.06 **Pipe Material.** Until recently, engineers, contractors, and end users have been slow to accept the use of plastic pipe for rural schemes in the Philippines. In general, they have been unfamiliar with PVC materials, and are often unaware of its cost and other advantages over galvanized and cast iron pipe. Locally extruded PVC pipe has a lower per unit installed cost in all sizes below 150 mm, and, due to its smoother interior surface, results in less friction loss as water flows through pipelines and allows, on average, smaller size pipes to be used.

4.07 Table 13 shows that installed costs of locally manufactured G.I. pipes are about 2-3 times more than locally extruded PVC pipe for sizes of 25 mm to 75 mm. For sizes of 110 mm to 160 mm, G.I. pipe is only 1.25-1.30 times more expensive. Typically, rural schemes can satisfy demands at required minimum pressures with most pipelines sized at 50 mm and smaller. Therefore, in the Philippines, a distribution system that uses PVC pipe should cost 50% to 70% less than a system that uses G.I. pipe, considering only differences in unit costs. We also tested what additional advantage PVC pipe has over G.I. pipe due to its smoother interior surface. In this analysis, we unrealistically assumed that PVC and G.I. pipes cost the same, so as to isolate the hydraulic benefits. The cost of the network for Anuling designed with PVC pipe (Hazen-Williams friction coefficient of 140) was 21% less than the design assuming G.I. pipe (Hazen-Williams friction coefficient of 100). The average pipe diameter with G.I. pipe was 43 mm; the average diameter with PVC was only 39 mm. For San Roque, the cost of the network designed with PVC pipe was 28% less than the same system designed with G.I. pipe. Since the same unit costs were used, these differences were due solely to the difference in frictional head loss, which allowed smaller size pipes to be used. The results suggest that use of PVC in place of G.I. pipe should reduce distribution costs by 60%-80% considering the differences in both unit costs and frictional resistance.

4.08 In addition to the greater cost of G.I. pipe, locally manufactured pipes corrode easily in the Philippine tropical environment, having an economic life of only 5-10 years. Handling, transportation, and installation of PVC pipes are easier than for G.I. or pipes of other materials. There are some circumstances, however, where use of PVC pipe is not so practical. In very rocky terrain, PVC pipes can easily be damaged when buried and backfilled improperly. Also, PVC pipe should not be laid above ground because it will quickly deteriorate when exposed to ultraviolet light (varieties of plastic pipes are now being developed that are not affected by exposure to ultraviolet light).

4.09 **Public Faucet Service Standard.** RWDC public faucet systems provide on average one faucet for every 4-6 households, or about one faucet for every 30-40 persons. This is well above the WHO suggested standard of one public faucet for every 100 persons. Examples of advantages of serving only a few houses with a single faucet are: (a) less wastewater due to the small number of users; (b) better maintenance because users take more responsibility for the shared faucet when only a few families are served; and (c) easier and more efficient collection of water fees from the user households. In higher density, low-income urban areas, some investigators have observed that distribution costs could be reduced significantly by spacing public faucets more widely (serving more persons per faucet).[3] The savings result primarily by reducing the length of pipeline and secondarily by reducing the number of faucets.

4.10 To test the effect on distribution costs of decreasing service convenience, we analyzed the effect of increasing the number of households served by each faucet (see Table 15). In **barangay** Boot, we increased the number of households served from 8 to 15 and in **barangay** Bolisong we increased those served from 6 to 9. We retained the assumed per capita consumption of 60 lpcd. The results show that distribution costs actually increase with a decrease in service convenience for both communities. In **barangay** Boot, with nearly twice as many houses served by each faucet, distribution costs increased by 40%. In **barangay** Bolisong, with a 50% increase in the number of households served by each faucet, distribution costs increased by about 30%.

TABLE 15: Relationship Between Cost Per Capita and Number of Households/Persons Served

Barangay	No. of Households per Faucet	Persons per Faucet	Cost per Capita (P)
Boot	8	48	8.6
	15	90	12.2
Bolisong	6	36	32.6
	9	54	39.0

---

[3] See World Bank Publication, **Design of Low-Cost Water Distribution Systems**, by Donald T. Lauria, P. U. Report No. RES 11(a), 1979 (World Bank internal report).

4.11 These cost increases occur because with fewer public faucets flows are less dispersed throughout the distribution system. With fewer points of draw-off, pipes must carry a proportionately larger flow, assuming total demand is the same. With fewer public faucets, one would normally expect less pipe length, which should reduce cost. But, in the Philippines, the linear layout of the **barangays** results in very little reduction in pipe length even with fewer faucets. The faucets are merely spaced more widely along the same pipelines, and the only cost reduction is due to the fewer number of faucets. However, because public faucets are of very simple construction (a pipe extending vertically, sometimes but not always secured in concrete, and with a simple tap), costing only P100-P200 each, the cost reduction is small. In **barangay** Bolisong, for instance, although public faucet cost dropped from P17/household (at 6 households per faucet) to P11/household (at 9 households per faucet), this change resulted in an increase in network costs from P195.60/household to P273/household. The results suggest that, at least for rural Philippine **barangays**, decreasing service convenience alone will not reduce project costs.

4.12 **Cost Model for Demand and Available Head.** To determine the sensitivity of distribution costs to per capita demand and available head (system pressure), multiple linear regression analysis was used with design results pooled from the five **barangays**. Although it was not possible to obtain an adequate predictive equation from the pooled results, using the design results of **barangay** Anuling (assuming use of PVC pipe) an excellent predictive model for network costs was obtained as a function of flow factors and available head. Alternative designs were prepared assuming per capita use from 36 lpcd to 96 lpcd, and available head from 6.5 to as high as 56.5 m. The wide range of available heads, though clearly not realistic, was assumed in order to establish the trend in cost changes with changes in this design criterion. The Hazen-Williams friction coefficient was varied from 80 to 140 to examine the effect on cost also, but unit cost for PVC pipe was used for all designs.

4.13 The design results are shown in Table 16. The best-fit regression model from the data was found to be:

$$C/P = 34.6\ (PF \times Q/CV)^{0.55}\ H^{-0.33}$$

where: C/P = Cost per capita in pesos

PF = Ratio of peak-hour to average-day flow

Q = Per capita demand, m^3

CV = Hazen-Williams friction coefficient

H = Available head (headloss that can occur from the source to extremities of the network), m

TABLE 16: Relationship Between Per Capita Distribution Cost and Water Use, Available Head, and the Hazen-Williams Coefficient

Water Use lpcd	Available Head, m	Hazen-Williams Coefficient	Distribution Cost/Capita (pesos)
36	16.5	100	12.5
60	6.5	100	24.7
60	11.5	100	18.5
60	16.5	80	18.6
60	16.5	100	16.5
60	16.5	120	14.1
60	16.5	140	13.0
60	16.5	160	12.1
60	36.5	100	13.0
60	46.5	100	12.4
60	56.5	100	11.5
72	56.5	100	12.0
96	16.5	140	17.5
96	56.5	100	13.9

4.14 **Demand Factors.** Distribution networks are sized to deliver the peak-hourly demand. Design flow is a function of average per capita use, the peak-hourly flow factor, and the population in the design year. The equation in paragraph 4.13 suggests that a reduction in per capita production from 60 lpcd to 30 lpcd should reduce network cost from 16.8 P/capita to 11.4 P/capita, or by about 32% (assumes PF = 2.5, CV = 140, H = 10 m). The exponent 0.55 indicates approximately the percentage change in costs with a 1% change in flow. For instance, the equation suggests that a 10% change in per capita production results in a 5.5% change in distribution costs. It should be noted that costs of rural systems designed by RWDC are more sensitive to per capita consumption than the urban schemes discussed in the previous section. This is explained by the observation that pipeline costs reported by RWDC show less economy of scale than those of LWUA. The exponent in the cost function for PVC pipes developed from LWUA's data was 1.33 compared to 1.79 for the cost function developed from the RWDC data. Results of recent surveys undertaken by RWDC consultants suggest that the current demand assumption may be excessive, and that a gross per capita use of 40 lpcd from public faucets may be more realistic. A reduction of design flow from 60 to 40 lpcd would reduce distribution cost for Anuling from P16.81 to P13.45 per capita, or by about 20%. The uncertainty regarding per capita water use and peak flow factors for piped rural schemes and the potential for reducing project costs suggested that RWDC undertake field studies to verify demand assumptions.

4.15 **Available Head.** As in the case of small urban systems designed by LWUA, RWDC's public faucet systems are designed for fill and draw operation: water is first pumped or fed by gravity to an elevated tank and from there released to the distribution system. Twelve metres is the usual tank height for most RWDC schemes, which is the practical limit since tank costs increase significantly beyond this height. Minimum residual pressure for the Level II rural schemes is 3.5 metres, which, assuming flat terrain, gives an available head of about 8.5 metres for most systems. It would be technically feasible to lower the minimum residual pressure to 1.5 m (increasing available head to about 10.5 m) and still provide adequate flow from public faucets. The regression equations suggest that with a change of minimum residual pressure from 3.5 to 1.5 m, distribution costs would be reduced by about 7% from about P17.7 per capita to about P16.5 per capita, not a significant amount for the reduced pressure that would result.

4.16 The most critical problem reported by RWSAs regarding operation of Level II systems is the increasing cost of operating pumps due to rising energy costs. Another problem is the increasing cost of fabricated elevated storage tanks. Energy cost could be reduced by lowering the tank height to reduce the pumping head (tank costs would also be reduced). Results from analysis of the small urban systems suggest that present value costs (considering operating and construction costs) change very little with available heads between 5 and 10 metres. A similar analysis carried out for Anuling showed that for the prevailing energy cost of about 1 P/kwhr, the most economical available head is about 7 metres, considering both network and energy costs. The optimal available head was less than 5 metres when the cost of the storage tank was included. The present value costs for different available heads for **barangay** Anuling are included in Table 17. The results suggest that a storage tank height of about 8 to 10 metres is more economical than the current 12 metre standard (assuming a well depth of 30 metres and a reduction of pumping head from 42 to 38 metres).

TABLE 17: Present Value (PV) Costs Per Capita for Different Available Heads, **Barangay** Anuling (pesos/capita)

Tank Height (m)	Available Head (m)	Pump Head (m)	Network Cost (pesos)	PV Energy Cost (pesos)	Tank Cost (pesos)	Total PV Costs	
						W/Tank (pesos)	W/O Tank (pesos)
8.50	5	43.50	21.12	31.43	79.27	131.80	52.55
10.50	7	45.50	18.91	32.88	83.50	135.30	51.79
13.50	10	48.50	17.40	35.04	88.99	141.40	52.44
15.50	12	50.50	16.30	36.49	92.11	144.90	52.79

V. SUMMARY AND IMPLICATIONS OF RESULTS FOR WATER SYSTEM DESIGN IN THE PHILIPPINES

Summary of Results

5.01 **Small Urban Schemes.** Results of the study suggest that greatest project cost savings are achieved by:

(a) reducing minimum pipe diameter from 100 mm to 38mm or 50mm;

(b) designing only for peak hourly flows and not for fire demands;

(c) providing a mix of house connection and public faucet service; and

(d) reducing per capita water use.

5.02 Reducing the minimum pipe size from 100 mm to 38 mm or to 50 mm should reduce distribution costs by about 40% for small systems with populations under 10,000 without sacrificing system performance. To design small distribution systems to carry the fire flows prescribed in the LWUA Technical Standards Manual would require that the minimum 100 mm pipe size standard be retained. Reducing the service standard from nearly 100% coverage with house connections to a mix of house connections and public faucets (about a 50% mix of each) reduced total project costs by about 25% for our case study. Net average per capita use was reduced from 140 lpcd to about 100 lpcd. Our design results show that each 10% change in per capita water use results in a 4% change in distribution costs, a 9% change in storage costs, and a 7%-8% change in pump station costs.

5.03 Distribution costs were found to be less sensitive to changes in available head than to the other factors investigated. However, a rather large change from the standard minimum residual pressure of 14 metres to 7 metres is possible for residential areas, which would result in an increase in available head from about 6 metres to 13 metres for most systems, and would result in a pipeline cost reduction of about 20%. It was found that a 10% change in available head results in about a 3% change in distribution costs. Although a standard of 5 metres might be acceptable in residential areas, the additional cost saving is only about 3% with this standard. It was evident also that the optimal elevated tank height is about 15 metres for the small systems with flat terrain compared to the standard height of 20m-30m. This gives an optimal available head of about 8 metres assuming a minimum pressure of 7 metres. However, the total present value costs of energy, distribution, and storage were found to change very little between available heads of 5-15 metres, which means that the designer should evaluate carefully the trade-offs among the costs of distribution, storage, and energy for pumping before deciding on the appropriate tank height. A larger available head will result in a less costly distribution system, but more costly elevated storage and a higher recurrent cost for pumping.

5.04 **Rural Schemes.** The results of studies of the five **barangays** show that the greatest cost savings will be achieved by using PVC in place of G.I. pipe for all rural piped projects. Where pipes must be laid above ground, coated ductile iron pipe would be preferable to G.I. pipe because of its much longer economic life. A change in per capita use could have a telling effect on lowering project costs if the water use could be lowered by a significant amount. It was found that every 10% change in per capita production results in about a 5.5% change in distribution costs. The considerable uncertainty regarding actual per capita use for rural piped schemes suggests that current estimates should be verified with field studies.

5.05 Lowering other standards and criteria was found to have little effect on project costs, due in part to the fairly low standards already used. However, several of the findings were quite interesting and have relevance to RWDC's considerations for standards revision. First, RWDC could reduce its material inventories by using fewer pipe sizes in designing rural schemes without much effect on the cost of those schemes. The savings in procurement, warehousing, shipping, construction, and design could be significant, and it would not be necessary to stock as many pipe sizes, sizes of fittings, valves, specials, and other appurtenances. Increasing public faucet spacing from the current standard of between 4 to 6 households per faucet will increase, rather than decrease, distribution costs. The other advantages of serving only a few houses with each faucet (better maintenance, less wastewater, and easier collection of monthly fees), strongly suggest that the standard should remain the same. The study results also suggest that few savings can be achieved from lowering the minimum residual pressure from 3.5 m to 2 or 1.5 m. However, the standard tank height of about 12 m could be lowered to about 8-10 m, which gives a slightly more economical pumping head, reduced recurrent energy costs for pumping, and reduced elevated tank cost.

Revised Standards and Criteria in the Philippines

5.06 **LWUA's Revised Standards.** By mid-1984, LWUA had revised several of its design standards, based partly on the results of the study described in this paper. The minimum pipe size now used in design is 50 mm, and in recent feasiblility studies for six small municipalities 38 mm pipe was used as the minimum size. Fire flows are not now considered in design of any water distribution systems; also, no provision is made for emergency storage or storage for fire demands, which in some cases has reduced storage tank costs by as much as 50%. A standard of mixed service is not yet considered routinely, though designs prepared for six small municipalities used a mix service standard as a test case. The percentage of public faucets was varied for these towns depending on the results of housing and income surveys. The minimum residual pressure standard is now 7 m for all residential areas; elevated tank height remains at about 20 mm for most systems. LWUA is now initiating a pilot study funded by UNDP to test the use of these lowered standards, as well as low-cost construction techniques. The low-cost system will be closely monitored to evaluate performance, user acceptance, and any operational problems.

5.07 **RWDC Standards.** By 1984, RWDC was using PVC pipe in most of its piped rural water supply schemes. However, it had not reduced its inventory of pipe sizes, nor made other changes in its standards. RWDC's consultants are now preparing recommendations for adopting more flexible standards for per capita use. Because of the high cost of elevated tanks, RWDC is also considering the use of pneumatic tanks in their place. Studies are also underway to verify design parameters including per capita use and peak-flow factors.

VI. IMPLICATIONS FOR OTHER DEVELOPING COUNTRIES

6.01 The experience in the Philippines has shown that standards used for design of large urban water supply systems in their own country and the standards used in developed countries are not usually appropriate for small urban schemes, due mainly to resulting high project costs. The studies undertaken by LWUA and RWDC with the help of UNDP have demonstrated which standards can be modified and have a significant impact on reducing project costs. The results of the studies agree with some of those found by others (see the reference in footnote 3 on page 26). For instance, present results agree reasonably well with the sensitivity of distribution costs to per capita demand and available system head in the above referenced study, as well as with results of less rigorous studies undertaken in other Asian countries (Indonesia, India, and Sri Lanka). This is expected because the physical laws that govern the flow of water through pipelines and the loss of energy through pipelines do not change from system to system. The configuration of the distribution systems appears to have a minor effect on determining the sensitivity of cost to those design assumptions. Present studies were for areas with flat terrain, and results might change for towns with more varied terrain. The differences in economy of scale of pipelines explain the variations in cost sensitivity from country to country more than any other factor. However, cost sensitivity to other factors may be quite different for communities in other countries.

6.02 With the aid of a microcomputer and distribution network design programs, a water agency can easily determine the sensitivity of water supply project costs to variations in design and service standards. The basic methodology used in the studies reported here can be duplicated by any engineering office that has access to a computer, design and data analysis programs, and data from one or more urban or rural water supply schemes. It would be extremely difficult to duplicate the study without the use of a microcomputer.

6.03 The computer programs used in the studies reported in this paper are available from the World Bank, Technology Advisory Group, Washington, D.C. 20433, U.S.A. The programs have been written for the IBM-PC and compatible microcomputers for the MS-DOS operating systems, in the BASIC language, and are available at present to a specific target audience.

6.04 The problems encountered in the Philippines with setting appropriate standards for design of small urban and rural water supply schemes suggest a need to test and evaluate design standards and criteria through pilot and demonstration projects. This approach would allow the acceptability of service levels and other criteria to be tested before being applied on a wider scale and verification of design assumptions such as per capita water use for different service levels and the peak flow factors. As mentioned in paragraph 5.06, LWUA is now undertaking such a study, and it is hoped that some of the monitoring data will be available by early 1987.

6.05 Although design standards and criteria are important in determining project costs, other important factors should be considered by water agencies. Using self-help labor, local materials, standard designs, simple planning methods, and realistic construction standards are but a few ways to reduce project costs. Also, innovative and flexible methods of financing will be necessary to increase affordability of small urban and rural systems.