ABSTRACT

A model was developed to determine how to serve an urban area with sewers using willingness to pay information. The model was applied to the case of Calamba, Philippines, for which willingness to pay data were available. A sensitivity analysis varied user fees and subsidies to assess their effects on deciding the parts of the city that should use the urban sewerage system. More realistic applications of the model were presented, where watershed boundaries and more realistic cost functions were considered.

The optimization model provided a basis for using the results of willingness to pay studies for planning piped sewerage systems. In Calamba, it was necessary to convert willingness to pay data obtained for census tracts to a watershed basis. It was necessary to include street sewer costs, marginal trunk sewer costs, and marginal treatment plant costs to obtain realistic results, but, by the same token, marginal operation and maintenance costs, which were ignored, should also be included. In Calamba, it also became desirable to limit candidate zones for piped sewerage to sub-areas of the city.

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ACKNOWLEDGMENTS

I would like to thank Dr. Donald Lauria for his patience, positive criticism, guidance, and endurance during the preparation of this report. I would also like to thank Dr. Dale Whittington and Dr. George Christakos for their insightful comments which greatly enhanced the final version of this report. Finally, I would especially like to thank Laura Mojonnier, John Price, and my family, without whose love and support I might not have persevered.

1 INTRODUCTION

1.1 MOTIVATION

Within the past ten years, there has been a movement toward demand-based water supply and sanitation planning (DBP) in developing countries. DBP is basically concerned with drawing target beneficiaries of a proposed endeavor more substantially into the planning process and giving them voice in getting what they want. At the heart of DBP are willingness to pay (WTP) studies, which are used to assess the demand of target beneficiaries for the proposed endeavor. Researchers have conducted several WTP studies to access demand for improved sanitation, the first in Kumasi, Ghana, in 1989 [Whittington, Lauria, Wright, Choe, Hughes and Swarna, 1993]. Although researchers have conducted numerous WTP studies to assess demand for improved sanitation, less work has been done on using the WTP results to make planning decisions.

1.2 OBJECTIVES

In Fall of 1992, the World Bank was the executing agency for a national Urban Sewerage and Sanitation Plan and Feasibility Study for the Philippines to help determine the demand for improved sanitation. Calamba, a city of 175,000 southeast of Manila, was one of five cities chosen by government to represent urban conditions in the Philippines and was the first city to be studied.

The goal of this paper is to develop a basis for using the results of WTP studies for planning urban sewerage systems. The first objective is to develop an appropriate model for determining how to serve an urban area with sewers using WTP information. The second objective is to apply the model to the case of Calamba for which WTP data are available. The third objective is to determine the kinds of planning information, such as costs, user fees, subsidies, demographic, and geographic features, needed to utilize the model in engineering practice.

1.3 ORGANIZATION

In Fall of 1992, data were collected in Calamba on the demand for improved sanitation. The WTP study which produced the demand data is introduced in Chapter 2. Section 2.1 describes the general demographic and geographic characteristics of Calamba. Section 2.2 describes the Calamba WTP study and the resulting demand functions. Section 2.3 contains illustrative calculations of how to predict both the number of households that would use the urban sewerage system and the total revenue that would be generated, using these demand functions. Section 2.4 describes the cost function used to estimate street sewer costs. Finally, Section 2.5 contains a comparison of the maximum predicted revenue and estimated costs in order to assess the financial viability of the project.

The model developed to determine how to serve an urban area with sewers is presented in Chapter 3. Section 3.1 outlines the model, and Section 3.2 contains a step by step baseline solution. Section 3.3 contains a sensitivity analysis that varies user fees and subsidies to assess their effects on deciding the parts of the city that would use the urban sewerage system. Chapter 4 presents more realistic applications of the model, where watershed boundaries and more realistic cost functions are considered. Discussion and conclusions are presented in Chapter 5.

2 CALAMBA WILLINGNESS TO PAY STUDY

2.1 CALAMBA CHARACTERISTICS

Calamba is a city of about 175,000 in the Luzon region of the Philippines, southeast of Manila. It is partially bounded on the east by Laguna de Bay, a large inland lake, and it covers nearly 14,500 hectares of land. Calamba is divided into 54 wards or political units called barangays. Population densities within the barangays vary from as many as 250 persons per hectare to as few as one person per hectare. In conducting the WTP study for Calamba, it was decided to eliminate all barangays with population densities less than 10 persons per hectare. The resulting study area had a population of approximately 121,000 with about 24,000 households, containing an average of 5.2 persons per household. Table 2.1 lists the 28 contiguous study barangays in the eastern part of the city and their characteristics, including populations, numbers of households, and areas.

Land uses in Calamba consisted of three main types: urban, non-urban without agriculture, and non-urban with agriculture. In order to choose the sample of households to receive the WTP questionnaires, it was decided to divide the study barangays into three strata based on these land uses. Barangays 1-7, which are contiguous, constituted the commercial center of the city, called Poblacion. These urban barangays were assigned to Stratum I. Barangays 22-28, non-urban areas without agricultural activities, were located

TABLE 2.1

BARANGAYS IN CALAMBA STUDY AREA

Barangay	No. of Households	Population	Area (hectares)
Stratum I: Urban/ Poblacion			
1	966	4,872	22
2	900	4,654	19
3	765	4,055	18
4	497	2,629	13
5	678	3,614	18
6	461	2,353	14
7	301	1,451	12
Subtotal	4,568	23,628	116
Stratum II: Non-Urban w/ Agricultural Activities			
8	379	2,009	155
9	842	4,241	157
10	703	3,491	134
11	829	4,286	171
12	392	2,024	92
13	1,015	4,934	183
14	2,089	10,278	286
15	450	2,378	95
16	190	1,084	77
17	797	3,997	70
18	2,504	13,092	247
19	734	3,824	27
20	696	3,750	43
21	967	5,267	142
Subtotal	12,587	64,655	1,879
Stratum III: Non-Urban w/out Agricultural Activities			
22	288	1,410	61
23	460	2,075	58
24	1,183	6,095	277
25	795	3,876	155
26	1,629	8,169	87
27	758	3,726	64
28	1,466	7,409	76
Subtotal	6,579	32,760	778
TOTAL:	23,734	121,043	2,773

along the western edge of the study area and were assigned to Stratum II. Barangays 8-21, non-urban areas with agricultural activities, were scattered throughout the study area and were assigned to Stratum III.

Stratum II and Stratum III, the non-urban strata, covered the majority of the Calamba land area and had average densities of seven or eight households per hectare. Stratum I, the urban stratum, covered less than five percent of the Calamba land area. However, due to average density of nearly 40 households per hectare, it accounted for nearly 20 percent of the households in the Calamba study area.

The Calamba study area was about 6 km long from north to south and nearly 10 km wide from east to west. A sketch of the study area is shown in Figure 2.1. Barangay boundaries are shown as thin black lines, rivers are shown as thick black lines, with arrows that indicate the direction of flow. There are two main rivers and consequently two watersheds in the Calamba study area. Both rivers flow east through the study area before discharging into Laguna de Bay. One flows through the northern portion of the study area, while the other flows through the southern portion. Each river has smaller tributaries that discharge into it.

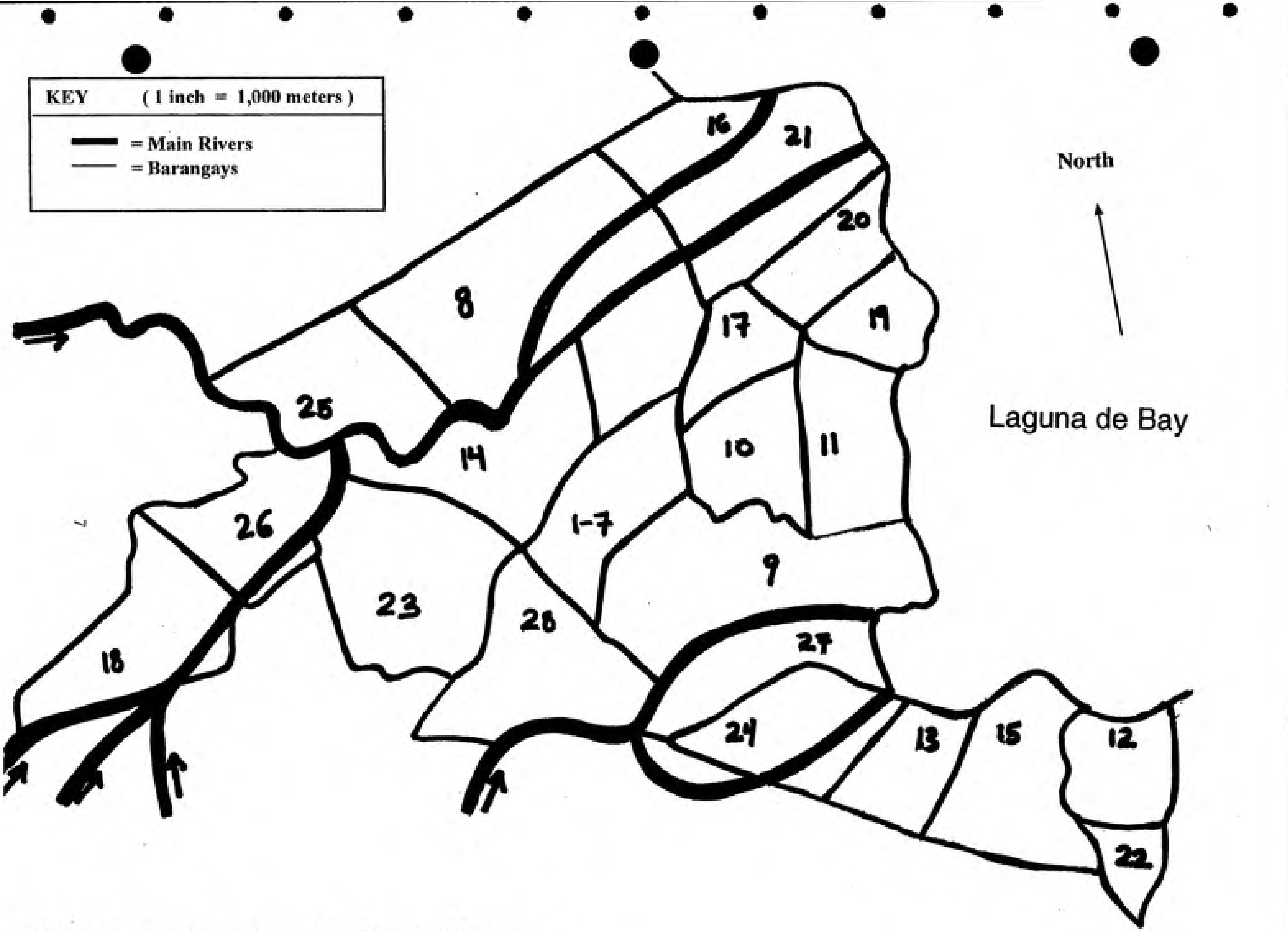


FIGURE 2.1 Calamba Study Area with Rivers and Barangays

2.2 CALAMBA WTP STUDY AND RESULTS

The WTP study was conducted in Calamba during October through December, 1992, [Lauria, Whittington, Choe, 1993] to estimate demand for improved sanitation. The demand information was obtained through household surveys using questionnaires that employed the contingent valuation method. In addition, informal interviews were conducted prior to the household surveys to collect data on existing sanitation facilities, census tracts, street configurations, sewer costs, and other items needed to plan an urban sewerage system.

The informal interviews showed that approximately 60 percent of the households in the Calamba study area owned and had the exclusive use of a flush or pour-flush latrine connected to a septic tank. For the whole city, more than 80 percent of the households used such latrines, but some were renters or shared their latrines with others. The interviews also indicated that most households in Calamba were satisfied with their on-site services.

Because such a high proportion of households in Calamba had already installed either flush or pour-flush toilets and because most households were satisfied with these on-site services, it was decided to ask about willingness to pay for a piped sewerage system, a piped sewerage system with a treatment plant, and a piped sewerage system with a treatment plant and a regional water quality management plan. In this paper, a piped sewerage system with a treatment plant is the only alternative that is considered.

In order to choose the sample of households for the WTP survey, 40 percent of the barangays were drawn from each of the three land-use strata, resulting in a total of 11 sample barangays. A random sample of 1,500 households was drawn from the sample barangays to be asked about their willingness to pay for improved sanitation. Of these households, 1104 were successfully interviewed and produced usable questionnaires, and one-third (366) were asked about a piped sewerage system with a treatment plant.

Household respondents were read a description of the improved sanitation system and asked to suppose that it was possible to connect their household to a sewer line. Household respondents were told that if they decided to connect, they would have to pay a monthly fee to the water district just like a water bill, and they were asked the following question:

"If the monthly fee to be connected to the sewer line was [25,50,100,150 or 200] Pesos(1)*, would you want to connect to the sewer line, or would you prefer not to connect?"*

---

(1)At the time of the Calamba WTP study, one U.S. dollar was equivalent to 25 Pesos.

A single respondent was not asked whether his or her household would want to connect at all five fees. Rather, one fifth of the sample households were asked whether they would connect at 25 Pesos per month, one fifth were asked whether they would connect at 50 Pesos per month, and so on. Next, household respondents were asked one or more follow-up questions in an effort to determine the maximum amount they would be willing to pay to be connected to the sewer. However, for the purposes of this paper, only the responses to the first yes/no "referendum" question are used, specifically, the raw data from the households, which are not very different from the results of a multivariate statistical analysis that was made of the data [Lauria, Whittington, Choe, 1993].

The percentages of households in each stratum that said they would connect to the sewerage system at the proposed user fees are shown in Table 2.2. The percentages for a fee of 75 Pesos per month were not obtained from the questionnaires but rather are based on interpolations using the results for fees of 50 and 100. In general, households in the non-urban barangays with agricultural activities had slightly higher willingness to pay for a piped sewerage system than households in the urban barangays or non-urban barangays without agricultural activities. For example, at a user fee of 50 Pesos/month, 65% of the households in Stratum III (non-urban with agricultural activities) were willing to pay it to use the sewers, while only 48% of the households in Stratum I (urban) and 49% of the households in Stratum II (non-urban without agricultural activities) were willing to pay it.

TABLE 2.2

WTP DISTRIBUTION BY LAND USE STRATA*

User Fee (Pesos/month)	STRATUM I Urban/ Poblacion	STRATUM II Non- Urban w/ Agricultural Activities	STRATUM III Non-Urban w/out Agricultural Activities
25	72	74	76
50	48	49	65
75	37	37.5	48
100	26	26	30
150	9	11	12
200	9	6	8

* Except for column with user fees, table entries are **cumulative percentages of households** willing to pay the user fee.

2.3 PREDICTIONS OF COVERAGE AND REVENUE

The data in Table 2.2 are plotted in Figure 2.2 to give three separate demand functions for the sewerage system, one for each stratum. Using the functions in Figure 2.2, it is possible to predict the percentage of households in each stratum that would use the system at any fee within the range that was investigated. These predictions can then be used to estimate both the total number of households that would use the system (i.e. household coverage) and the total revenue that would be generated.

For example, from Table 2.2 and Figure 2.2, if Calamba decided to charge a fee of 75 Pesos/month, the predicted percentages of households in each stratum that would use the sewerage system are as follows:

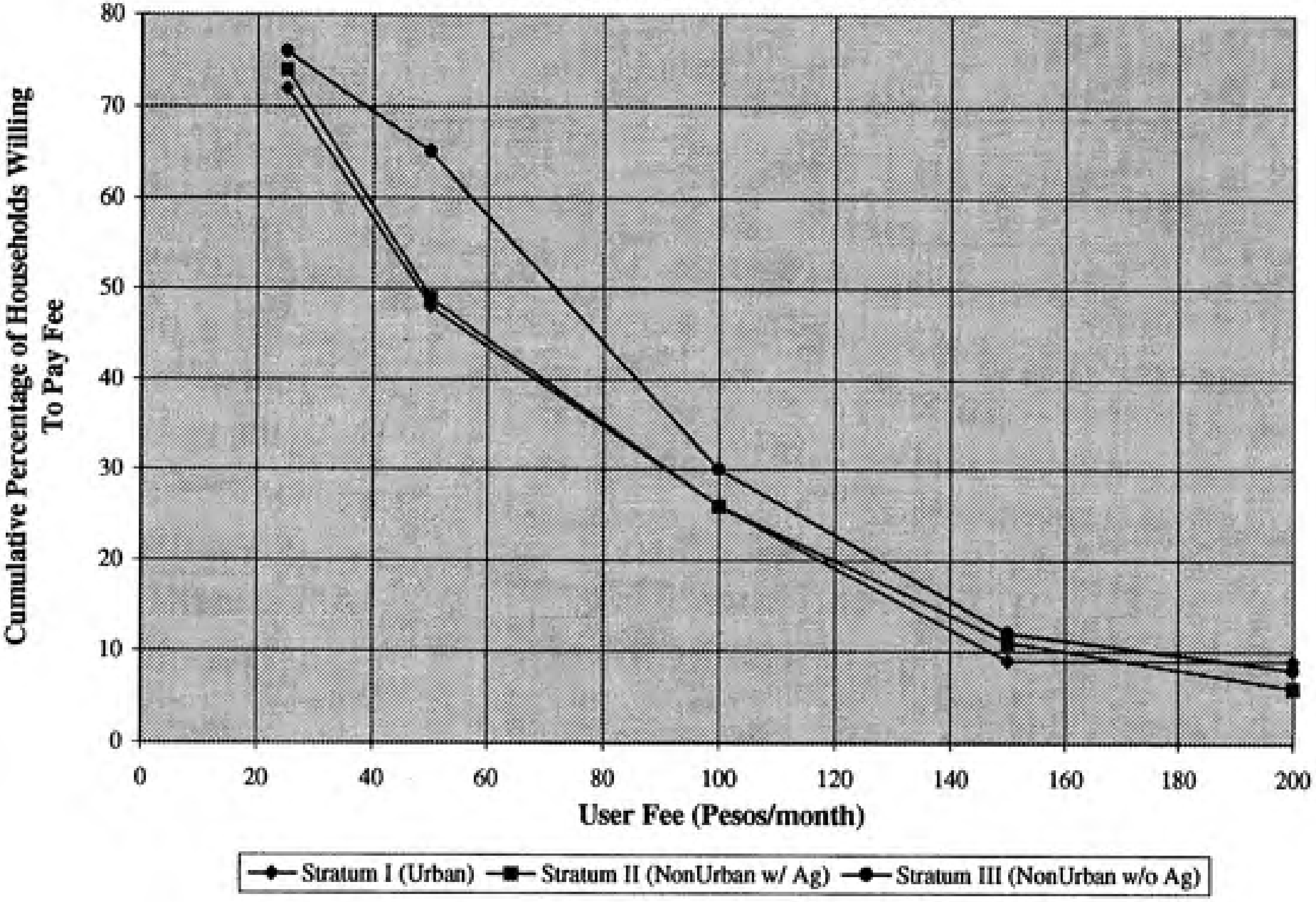
Stratum I:	37%
Stratum II:	37.5%
Stratum III:	48%

Furthermore, from Table 2.1, the total number of households in Stratum I, Stratum II, and Stratum III are:

Stratum I:	4,568 households
Stratum II:	12,587 households
Stratum III:	6,579 households

FIGURE 2.2

PIPED SEWERAGE DEMAND FUNCTIONS



To estimate the number of households within each stratum that would use the sewerage system at a given fee, the total number of households in each stratum is multiplied by the percentage willing to pay that fee, as follows:

$$HC_i = P_i * N_i \tag{2.1}$$

where:

HC_i = household coverage in stratum i,

P_i = predicted percentage of households in stratum i willing to pay the user fee, and

N_i = total number of households in stratum i.

Hence, at a user fee of 75 Pesos/month, the estimated household coverages in Stratum I, Stratum II, and Stratum III are:

Stratum I:	(0.37 * 4,568)	= 1,690
Stratum II:	(0.375 * 12,587)	= 4,720
Stratum III:	(0.48 * 6,579)	= 3,158

Total household coverage for this scenario is then the sum of the households in the three strata:

$$HC = (HC_I + HC_{II} + HC_{III}) \tag{2.2}$$

where:

HC = total household coverage in Calamba.

At a fee of 75 Pesos/month, the total number of households that would use the piped sewerage system is estimated to be:

$$HC = (1{,}690 + 4{,}720 + 3{,}158) = 9{,}568.$$

The revenue that would be generated in each stratum is estimated by multiplying the number of households willing to pay the fee by that fee:

$$\mathbf{R_i = (P_i * N_i * W)} \qquad \mathbf{(2.3)}$$

where:

R_i = revenue generated in stratum i, and

W = user fee (Pesos/month/household).

At a user fee of 75 Pesos/month/household, the estimated revenues for Stratum I, Stratum II, and Stratum III are:

Stratum I: $(0.37 * 4{,}568 * 75) = 126{,}762$ Pesos/month

Stratum II: $(0.375 * 12{,}587 * 75) = 354{,}009$ Pesos/month

Stratum III: $(0.48 * 6{,}579 * 75) = 236{,}844$ Pesos/month

The total revenue (R) for this scenario is the sum of the revenues for the three strata:

$$\mathbf{R = (R_I + R_{II} + R_{III})} \qquad \mathbf{(2.4)}$$

$$= (126{,}762 + 354{,}009 + 236{,}844)$$

= 717,615 Pesos/month,

say 718,000 Pesos per month.

2.4 STREET SEWER COSTS

Estimating the costs of sewers in Calamba was not a straight forward procedure. The main determinant of sewer cost is the length of pipe. However, street maps for the study area did not exist, making it impossible to estimate sewer length from street measurements.

Alternatively, the Calamba Water District had maps of its water distribution network that were used to estimate the length of water main per household. The water distribution network serves approximately 20 percent of the Calamba population. The Calamba Water District's maps indicated an average of 4.4 meters of pipe per household connection, but, significantly, this factor did not vary much from one stratum or barangay to another, and was independent of population density. This is probably not a typical result, but it greatly simplified the estimation of sewer costs in Calamba.

For estimating sewer costs, it was assumed that 5.0 meters of pipe would be required per household throughout the study area. If piped sewerage were offered in a barangay, pipes would need to be laid on most or all of the streets to provide access for those who might want to use the sewerage system. Hence, the total length of street sewers needed in each barangay was estimated by multiplying the total number of households in each barangay to be served by 5.0 meters per household.

Local contractors in Calamba said that the approximate price of supplying and installing the eight-inch diameter sewers needed in most of Calamba would be around 3,000 Pesos/meter of length. Sewer costs were very uncertain, however, and some contractors indicated that they could be 2,000 Pesos/meter or even lower. Furthermore, sewer cost estimates were based on all construction work being done by the contractor. Costs might be further reduced by using local labor for building the system. For example, ditches could be dug by the beneficiaries of the system. Another possibility would be to use a less expensive technology such as small-bore sewers, in which case cost might drop to around 1,000 Pesos/meter.

For the purpose of this paper, it was assumed that the cost of street sewers was 1,000 Pesos/meter, including furnishing and installing the pipe and making house connections. It was further assumed that the contribution of local labor and/or the use of a lower-cost technology would not affect the willingness to pay data in Table 2.2. Operation and maintenance (O&M) costs were ignored. Hence, street sewer costs in any barangay (C_i) could be estimated by multiplying the number of households in the barangay by 5.0 meters of pipe per household and by the price of 1,000 Pesos/meter:

$$\mathbf{C_i = (N_i * 5.0\ meters/household * 1{,}000\ Pesos/meter)} \qquad \mathbf{(2.5)}$$

2.5 COMPARISON OF REVENUE AND SEWER COST

The principles in Sections 2.3 and 2.4, enable estimation of the revenue that would be generated at any user fee, as well as associated sewer costs, which in turn can be annualized. These values can then be compared to determine whether revenues are sufficient to cover costs, keeping in mind that operation and maintenance (O&M) is ignored.

Consider a user fee of 75 Pesos/month. The total estimated revenue is 718,000 Pesos/month. With about 24,000 households in the Calamba study area, a requirement of 5.0 meters per household, and a price of 1,000 Pesos/meter, sewer cost in Calamba would be about:

$$C = (24{,}000 * 5.0 * 1{,}000) = 120 \text{ million Pesos.}$$

Assuming a loan is obtained for constructing the system with a cost recovery factor of 0.01/month (=0.12/year), the equivalent monthly (amortized) street sewer costs would be 1.2 million Pesos/month.

Hence, at a user fee of 75 Pesos/month, the revenue would be less than the amortized costs. This same result was found for all five user fees in Table 2.3, indicating that willingness to pay for piped sewerage in Calamba was low and would not cover costs. If a piped sewerage system were to be constructed in Calamba, subsidies would be needed.

TABLE 2.3

MAXIMUM POTENTIAL REVENUE
COMPARED TO STREET SEWER COSTS

User Fees (Pesos/month)	Maximum Potential Revenue (million Pesos/month)	Street Sewer Costs (million Pesos/month)
25	0.44	1.2
50	0.63	1.2
75	0.71	1.2
100	0.64	1.2
150	0.39	1.2
200	0.34	1.2

3 PIPED SEWERAGE PLANNING MODEL

3.1 MODEL DEVELOPMENT

Calamba is divided into geographical areas (barangays), and only one type of sanitation improvement is under consideration, piped sewerage. The planning problem is to decide which areas to serve. The first step in developing a model for sewerage planning is to introduce a decision variable to determine whether any zone i should be served or not. Let Z_i be a 0,1 integer decision variable such that:

$$\mathbf{Z_i = 1} \quad \textbf{if zone i is served, or}$$

$$\mathbf{Z_i = 0} \quad \textbf{if zone i is NOT served.}$$

The assumed objective in this paper for planning the piped sewerage system in Calamba is to maximize the total number of households served by the improved system. Recall that the number of households willing to pay any proposed user fee (W) in zone i was estimated by multiplying the percentage of households willing to pay the fee (P_i) by the total number of households in the zone (N_i). Hence, to maximize the total number of households (HC) served by the piped sewerage system, the objective function is:

$$\textbf{Maximize} \qquad HC = \Sigma (P_i * N_i * Z_i) \tag{3.1}$$

where the summation is over all zones (i) in Calamba.

For financial self sufficiency, total net revenue (i.e. the difference between total revenue and total amortized cost) must equal or exceed zero. That is

$$\Sigma (W * P_i * N_i * Z_i) - \Sigma (5.0 \text{ meter/household} * N_i * Z_i * C/L * CRF) \geq 0 \qquad (3.2)$$

where summations are over all zones (i) and:

W = proposed user fee for the piped sewerage system (Pesos/month/household),

C/L = unit construction cost of sewers (1,000 Pesos/meter), and

CRF = cost recovery factor (0.01/month).

Note that the constraint (3.2) pools all revenues and costs and thus implicitly allows cross subsidies from those zones with a net revenue surplus to other zones that can pay part but not all of the cost of the sewerage system. Note further that the constraint on total net revenue can be relaxed by allowing a negative value on the right hand side of equation 3.2, which would be required in the case of Calamba since the amortized cost of sewers exceeds revenue at any proposed user fee. Such a negative net revenue would correspond to a subsidy, possibly from government or a donor agency. For example, suppose that a subsidy of 150,000 Pesos/month were available in Calamba. Equation 3.2 would be altered such that total net revenue would equal or exceed -150,000 Pesos/month rather than zero. In the solution to this model, the Z_i indicate which zones to serve. For the time being, the costs of trunk sewers and treatment facilities are ignored.

Formulas for the number of households in each zone willing to pay a given user fee, the cost of the sewer system in each zone (Equation 2.5), the number of households served in each zone (Equation 3.1), and the net revenue in each zone (Equation 3.2) were entered into the spreadsheet Excel. Additional columns were allocated for the number of households in each zone, the user fee, the percentage of households willing to pay it in each zone, and the decision variables, Z_i. The spreadsheet was linked to a Solver Function in Excel to maximize household coverage subject to a constraint on total net revenue. The decision variables, Z_i, were constrained to integer values of 0 or 1 to decide whether zone i should be served ($Z_i = 1$) or not ($Z_i = 0$). The result was a 0,1 integer programming model for sewerage planning.

3.2 BASELINE SOLUTION

Assume Calamba decides to charge each household a fee of 50 Pesos/month to use the piped sewerage system and that a subsidy of 150,000 Pesos/month is available. The optimal result of the 0,1 integer program is in Table 3.1. A total of 4,946 households should be served, located in the ten barangays numbered 8, 16, 17, and 22-28, as shown in Table 3.1 and on the map in Figure 3.1.

TABLE 3.1

0,1 Integer Programming Model Results for Piped Sewerage Planning in Calamba, Philippines

W (P*/month)	C/L of Street Sewer (P*/meter)
50	1000

i	Ni TOTAL No. of HHs in Barangay i	Pi % of HHs WTP Fee, W in Barangay i	Ni * Pi No. of HHs WTP Fee, W in Barangay i	W WTP Bid (P*/month)	Ci** Sewer Costs in Barangay i (P*/month)	Zi*** Coverage Decision Variable	Ni * Pi * Zi No. of HHs Served in Barangay i	[(W*Ni*Pi)-Ci] * Zi Net Revenue (Pesos)
1	966	48	464	50	48300	0	0	0
2	900	48	432	50	45000	0	0	0
3	765	48	367	50	38250	0	0	0
4	497	48	239	50	24850	0	0	0
5	678	48	325	50	33900	0	0	0
6	461	48	221	50	23050	0	0	0
7	301	48	144	50	15050	0	0	0
8	379	49	186	50	18950	1	186	-9665
9	842	49	413	50	42100	0	0	0
10	703	49	344	50	35150	0	0	0
11	829	49	406	50	41450	0	0	0
12	392	49	192	50	19600	0	0	0
13	1015	49	497	50	50750	0	0	0
14	2089	49	1024	50	104450	0	0	0
15	450	49	221	50	22500	0	0	0
16	190	49	93	50	9500	1	93	-4845
17	797	49	391	50	39850	1	391	-20324
18	2504	49	1227	50	125200	0	0	0
19	734	49	360	50	36700	0	0	0
20	696	49	341	50	34800	0	0	0
21	967	49	474	50	48350	0	0	0
22	288	65	187	50	14400	1	187	-5040
23	460	65	299	50	23000	1	299	-8050
24	1183	65	769	50	59150	1	769	-20703
25	795	65	517	50	39750	1	517	-13913
26	1629	65	1059	50	81450	1	1059	-28508
27	758	65	493	50	37900	1	493	-13265
28	1466	65	953	50	73300	1	953	-25655
							MAXIMIZE TOTAL COVERAGE	**ST TOTAL NET REVENUE >=-150,000**
							4,946	**-149,966**

* P = Pesos

** Ci = [Ni * (5 meters/HH) * (1,000 Pesos/meter) * 0.01/month]

*** Zi = 1 indicates that the households in Barangay i should be connected to the sewer system

Zi = 0 indicates that the households in Barangay i should NOT be connected to the sewer system

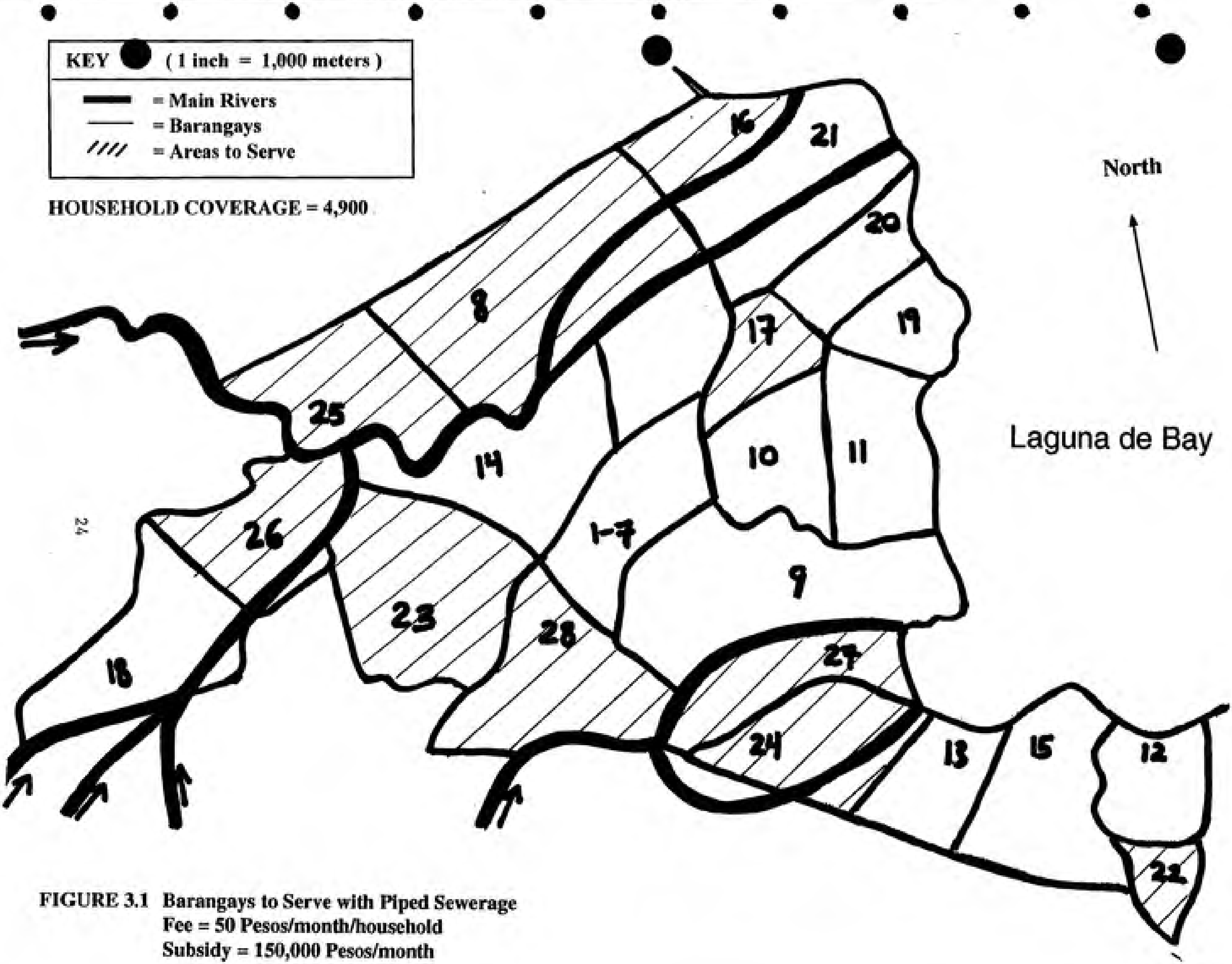


FIGURE 3.1 Barangays to Serve with Piped Sewerage
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

3.3 SENSITIVITY ANALYSIS

A limited sensitivity analysis that varied user fees and subsidies was conducted to determine the optimal solutions of the sewerage planning model. User fees of 25, 50, 75, and 100 Pesos/month were investigated, plus subsidies of 30,000; 60,000; 90,000; 120,000; 150,000; and 200,000 Pesos/month.

The results of the sensitivity analysis are shown in Table 3.2. The highest household coverage for a given subsidy was obtained at a user fee of 50 Pesos/month. For example, consider the results when it was assumed a subsidy of 150,000 Pesos/month was available for the sewerage system. At a fee of 25 Pesos/month, the model returned a solution with 3,600 households that could be served. When the fee was raised to 50 Pesos/month, coverage increased to 4,900 households, but further increases in the fee resulted in decreases in coverage.

It was expected that total household coverage might be maximized at the lowest user fee of 25 Pesos/month since the percentage of households willing to use the piped sewerage system was highest at this fee. This was not the case, in part because the higher percentage of households willing to pay a fee of 25 Pesos/month was not enough to make up for the loss in revenue resulting from the lower fee. At fees of 75 and 100 Pesos/month, piped sewerage costs significantly exceeded the total amount of revenue that

TABLE 3.2

SENSITIVITY ANALYSIS RESULTS

Household User Fee (Pesos/month)							
25		50		75		100	
Household Coverage	Available Subsidy	**Household Coverage**	Available Subsidy	**Household Coverage**	Available Subsidy	**Household Coverage**	Available Subsidy
0	0	**0**	0	**0**	0	**0**	0
700	30	**1,100**	30	**1,000**	30	**400**	30
1,500	60	**2,200**	60	**2,100**	60	**900**	60
2,200	90	**3,300**	90	**3,000**	90	**1,300**	90
2,900	120	**4,400**	120	**3,600**	120	**1,700**	120
3,600	150	**4,900**	150	**4,100**	150	**2,200**	150
4,800	200	**5,800**	200	**5,000**	200	**2,700**	200

Household Coverage Measured in (No. of HHs Served), Available Subsidies Measured in (1,000 Pesos/month) could be generated through user fees. As a result, the total number of households that could use the system was significantly lower than at a fee of 50 Pesos/month.

The areas of Calamba that should be served by the piped sewerage system according to the model were scattered throughout the study area. Table 3.3 lists the barangays that should be served with a user fee of 50 Pesos/month at each of the six different subsidies. Note that for subsidies of 30,000; 60,000; and 90,000 Pesos/month all the barangays that should be served by the piped sewerage system were in Stratum III (non-urban without agricultural activities). If the subsidies were increased to 120,000 or 150,000 Pesos/month, the barangays that should be served included all those previously served in Stratum III plus others in Stratum II (non-urban with agricultural activities).

This indicates that the best strategy in building the piped sewerage system would be to first serve areas in Stratum III, and, when all those are served, to choose areas in Stratum II, and lastly, to choose areas in Stratum I (urban). This result could have been predicted based on the WTP data in Table 2.2. Overall, Stratum III had the highest level of willingness to pay for piped sewerage, Stratum II had the next highest level of willingness to pay, and Stratum III had the lowest level of willingness to pay. This ranking was identical to how the model chose barangays to serve as the subsidy increased, but only because the cost in each barangay was based on the same length of street sewer per household (5.0 meters) and the same unit cost (1,000 Pesos/meter). If the cost of serving each barangay depended on street sewer lengths that varied from one barangay to

TABLE 3.3

BARANGAYS TO SERVE WITH PIPED SEWERAGE

(User Fee = 50 Pesos/month)

Subsidy (Pesos/month)	Barangays Served	Associated Strata
0	None	None
30,000	23, 24	III
60,000	24, 27, 28	III
90,000	22, 23, 24, 25, 26, 27	III
120,000	16, 22, 23, 24, 25, 26, 27, 28	III
150,000	8, 16, 17, 22, 23, 24, 25, 26, 27, 28	III, then II
200,000	10, 14, 19, 23, 24, 25, 26, 27, 28	III, then II

another, the barangays selected to be served would not necessarily be in the strata with the highest level of willingness to pay.

Household coverage increased as the level of subsidy increased for all four user fees, indicating that available subsidies would constrain the numbers of households that could be served by the improved system. For example, at a user fee of 50 Pesos/month, a subsidy of 30,000 Pesos/month would enable 1,100 households to be served. A subsidy four times larger (120,000 Pesos/month) would enable the increase of household coverage by a factor of four, from 1,100 to 4,400 households, indicating that a targeted level of household coverage could be obtained by choosing the appropriate subsidy.

Marginal returns of coverage (i.e. the number of additional households served by the piped sewerage system per unit increase in subsidy (households/Peso/month)) can be used to evaluate the sensitivity of total household coverage to changes in the level of subsidy. Table 3.4 shows that the marginal returns of coverage were relatively constant for the range of subsidies investigated. At the user fee of 50 Pesos/month, marginal returns of coverage remained at about 0.04 households/Peso/month for subsidies in the range of 30,000 - 120,000 Pesos/month. When subsidies were increased to 150,000 and 200,000 Pesos/month, marginal returns of coverage decreased to about 0.02 households/Peso/month. Thus, higher subsidies would provide only marginally higher household coverages.

TABLE 3.4

MARGINAL RETURNS OF COVERAGE FOR VARIED FEES AND SUBSIDIES

Household User Fee (Pesos/month)							
25		50		75		100	
Mgl. Return Coverage	Available Subsidy	**Mgl. Return Coverage**	Available Subsidy	**Mgl. Return Coverage**	Available Subsidy	**Mgl. Return Coverage**	Available Subsidy
0.02	30	**0.04**	30	**0.03**	30	**0.01**	30
0.03	60	**0.04**	60	**0.03**	60	**0.02**	60
0.02	90	**0.04**	90	**0.03**	90	**0.01**	90
0.02	120	**0.04**	120	**0.02**	120	**0.01**	120
0.02	150	**0.02**	150	**0.02**	150	**0.02**	150
0.02	200	**0.02**	200	**0.02**	200	**0.01**	200

Marginal Returns of Coverage Measured in (households/Peso/month), Available Subsidies Measured in (1,000 Pesos/month)

The household survey provided a basis for determining how large subsidies needed to be in order to cover costs. However, it did not resolve the issue of how large subsidies should be, or whether they should be provided at all, especially if financial self sufficiency is a goal of planning. In principle, government would have to decide on either the total subsidy it was willing to allocate for piped sewerage or the level of coverage it wanted to achieve. For the purposes of this report, it was assumed that the total subsidy available for covering the costs of the piped sewerage system was 150,000 Pesos/month. This subsidy would enable total household coverage approximately equal to that of the Calamba water distribution network, and it showed only a minor decrease in the marginal returns of coverage from those for lower subsidies. The subsidy could be provided either on a monthly basis or as an equivalent up-front payment of 15 million Pesos.

4 MODEL APPLICATIONS

4.1 WATERSHED ZONES ANALYSES

In the previous analyses, the barangay boundaries did not necessarily conform to watershed boundaries. This might lead to practical problems when trying to use model results in making planning decision. For example, if model results indicated that barangays 8, 16, 24, and 28 (see Figure 2.1) should be served with sewers, these results would be infeasible since there is no realistic way to construct a sewer to serve these barangays. As a result, it was necessary to determine whether model results using barangays would provide a basis for a piped sewerage system that could realistically be constructed. The approach followed was first to: (1) restructure the 28 study-area barangays in Calamba into watershed zones, (2) rework the willingness to pay data in light of the new watershed zone boundaries, (3) modify the piped sewerage planning model to account for the division of Calamba into watershed zones, and (4) conduct analyses comparing model results based on watershed zones with the results based on the barangays of Chapter 3. This analysis was then followed by expansion of the model to consider trunk sewers and treatment.

Piped sewerage systems are normally designed to follow as direct a route to the treatment plant or outfall as topographical conditions and street layouts permit. As a result, flow in a well-designed sewerage system normally takes the path of surface runoff, or the path of least resistance, and is driven by gravity rather than pumps. Existing barangays were therefore restructured into 25 watershed zones such that wastewater in each zone would flow by gravity through street sewers to a trunk sewer, which would then convey the wastewater to the outfall.

Figure 4.1 shows how the 28 Calamba study-area barangays were restructured into 25 watershed zones. The main northern and the southern rivers are represented by solid lines, with arrows indicating the direction of flow. The study area contains two separate watersheds, one draining to the northern river and the other draining to the southern river. The boundary between the two watersheds follows the northern boundaries of zone 5 and zone 20, as shown by the dotted line.

Table 4.1 shows the resulting correspondence of barangays to watershed zones. Nine of the new watershed zones are identical to an existing barangay, eight watershed zones consist of a portion of a single barangay, and eight other watershed zones consist of portions of two adjacent barangays. Note that several zones contain land from two different strata and consequently are represented by two different demand functions. Table 4.2 lists the resulting characteristics of the 25 new watershed zones in the Calamba study area, including numbers of households, populations, and areas.

In light of the restructured boundaries, it was necessary to rework the willingness to pay data for the piped sewerage system. Recall that there are three demand functions in

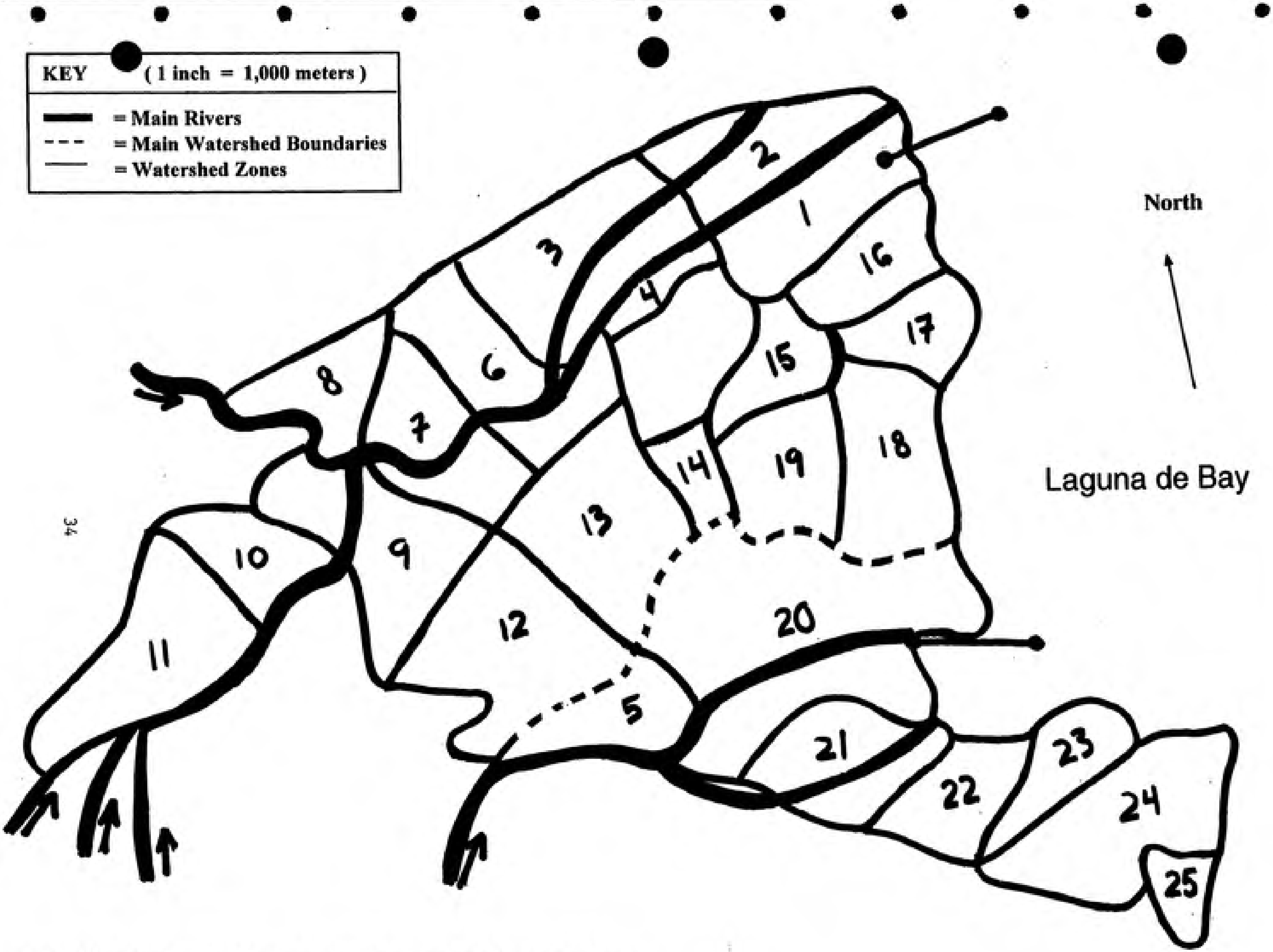


FIGURE 4.1 Calamba Study Area with Rivers and Watershed Zones

TABLE 4.1

CORRESPONDENCE OF BARANGAYS TO WATERSHED ZONES

Watershed Zone	Corresponding Barangay(s)	Percent Areas of Barangay(s) in Watershed Zone
1	21	0.65(Brgy 21)
2	16 and 21	1.0(Brgy 16) + 0.35(Brgy 21)
3	8	0.55(Brgy 8)
4	8	0.10(Brgy 8)
5	28	0.50(Brgy 28)
6	8 and14	0.35(Brgy 8) + 0.25(Brgy 14)
7	25 and 14	0.45(Brgy 25) + 0.35(Brgy 14)
8	25	0.55(Brgy 25)
9	23 and 26	0.40(Brgy 26) + 0.50(Brgy 23)
10	26	0.60(Brgy 26)
11	18	1.0(Brgy 18)
12	23 and 28	0.50(Brgy 23) + 0.50(Brgy 28)
13	1-7 and 14	0.40(Brgy 14) + 0.75(Brgys 1-7)
14	1-7	0.25(Brgys 1-7)
15	17	1.0(Brgy 17)
16	20	1.0(Brgy 20)
17	19	1.0(Brgy 19)
18	11	1.0(Brgy 11)
19	10	1.0(Brgy 10)
20	9 and 27	1.0(Brgy 9) + 1.0(Brgy 27)
21	24	1.0(Brgy 24)
22	13	1.0(Brgy 13)
23	15	0.40(Brgy 15)
24	15 and 12	0.60(Brgy 15) + 1.0(Brgy 12)
25	22	1.0(Brgy 22)

TABLE 4.2

WATERSHED ZONES IN CALAMBA STUDY AREA

Watershed Zone	No. of Households	Population	Area (hectares)
1	629	3,424	92
2	528	2,927	127
3	208	1,105	85
4	38	201	16
5	733	3,704	38
6	655	3,273	126
7	1,089	5,342	170
8	437	2,132	85
9	882	4,305	64
10	977	4,901	52
11	2,504	13,092	247
12	963	4,742	67
13	4,262	21,832	201
14	1,142	5,907	29
15	797	3,997	70
16	696	3,750	43
17	734	3,824	27
18	829	4,286	171
19	703	3,491	134
20	1,600	7,967	221
21	1,183	6,095	277
22	1,015	4,934	183
23	180	951	38
24	662	3,451	149
25	288	1,410	61
TOTAL	23,734	121,043	2,773

Calamba that conform to census tract boundaries. To estimate the willingness to pay of each watershed zone based on the data collected for barangays, the estimated percentage of barangay land area within each zone (shown in Table 4.1) is multiplied by the numbers of households willing to pay the household user fee within each respective barangay. In other words, assuming that households are evenly distributed throughout each barangay, the number of households willing to pay a certain fee in watershed zone i is estimated as follows:

$$\textbf{No. of Households Willing to Pay in Zone i} = \Sigma (LA_j * P_j * N_j) \qquad \textbf{(4.1)}$$

where the summation is over all barangays (j) that lie in zone i and:

LA_j = percentage of barangay j land area in zone i,

P_j = percentage of households in barangay j willing to pay the selected fee, and

N_j = total number of households in barangay j.

For example, consider watershed zone 7, which consists of about 45% of the land area of barangay 25 (LA_{25}) and 35% of the land area of barangay 14 (LA_{14}). From Table 2.1, there are 2,089 households in barangay 14 (N_{14}) and 795 households in barangay 25 (N_{25}). Assuming the households are evenly distributed in each barangay, there would be a total of 1,089 households in the new watershed zone, 731 (= 0.35 * 2,089) from barangay 14 and 358 (= 0.45 * 795) from barangay 25. Note that barangay 14 is in the non-urban stratum with agricultural activities (Stratum III), while barangay 25 is in the non-urban stratum without agricultural activities (Stratum II) and that each stratum has a unique demand function. Consider a fee of 50 Pesos/month. In barangay 25, the percentage of households willing to pay it is 65 (P_{25}), while in barangay 14, the percentage of households willing to pay it is 49 (P_{14}). So at a user fee of 50 Pesos/month, the total number of households in watershed zone 7 willing to pay it would be 591, of which 358 (= 0.49 * 731) are from barangay 14 and 233 (= 0.65 * 358) are from barangay 25. The corresponding numbers of households in the watershed zones willing to pay the four different fees are shown in Table 4.3.

To account for watershed zones in the model, each zone was assigned a decision variable, Z_i, to determine whether it should be served with piped sewerage ($Z_i = 1$) or not ($Z_i = 0$). The objective remained unchanged, to maximize the total number of households served by the piped sewerage system. The objective function was subjected to a constraint that required the difference between total revenue from user fees and the costs of the improved system not to exceed a given subsidy. Revenue and costs were estimated as described in Chapter 2.

Suppose that Calamba designed a tariff that resulted in an average charge for each household of about 50 Pesos/month to use the piped sewerage system and that a subsidy of 150,000 Pesos/month were available to cover the difference between revenue and cost. Figure 4.2 shows the watershed zones that should be served for this scenario based on a

TABLE 4.3

NUMBERS OF HOUSEHOLDS WILLING TO PAY PROPOSED FEES

Watershed Zone	Numbers of Households Willing To Pay Fee			
	Household User Fee (Pesos/month)			
	25	50	75	100
1	465	308	236	163
2	391	259	198	137
3	154	102	78	54
4	28	19	14	10
5	557	476	352	220
6	485	321	246	170
7	813	591	446	297
8	332	284	210	131
9	670	573	423	265
10	743	635	469	293
11	1853	1227	939	651
12	732	626	462	289
13	3086	2054	1581	1108
14	822	548	423	297
15	590	391	299	207
16	515	341	261	181
17	543	360	275	191
18	613	406	311	216
19	520	344	264	183
20	1199	906	680	446
21	899	769	568	355
22	751	497	381	264
23	133	88	68	47
24	490	324	248	172
25	219	187	138	86

model solution. The total number of served households is 4,900. Comparison of Figure 4.2 to Figure 3.2, which had the same proposed user fee and subsidy but was based on barangays rather than watershed zones, showed that while household coverage is about the same, restructuring the barangays into watershed zones had an important effect on the parts of Calamba that should be served by the improved system. When watershed zones were used in the model, most of the areas selected to receive piped sewerage were located along the western edge of the study area (Figure 4.2), whereas when barangays were used, some of the areas were in the center of the study area and others were along the northern and western edges.

Figures 4.3 -4.5 show the watershed zones that should be served with the improved system assuming a subsidy of 150,000 Pesos/month and user fees of 25, 75, and 100 Pesos/month, respectively; the total number of served households is shown on each figure. For all four user fees, the total number of served households in the watershed zones are about the same as when barangays were used. For example, at a fee of 25 Pesos/month, both the barangay and watershed models selected about 3,600. If the fee was increased to 50 or 75 Pesos/month, both models selected about 4,900 and 4,100 households, respectively. If the fee was increased to 100 Pesos/month, the watershed model selected about 2,100 households compared to the barangay model, which selected about 2,200 households.

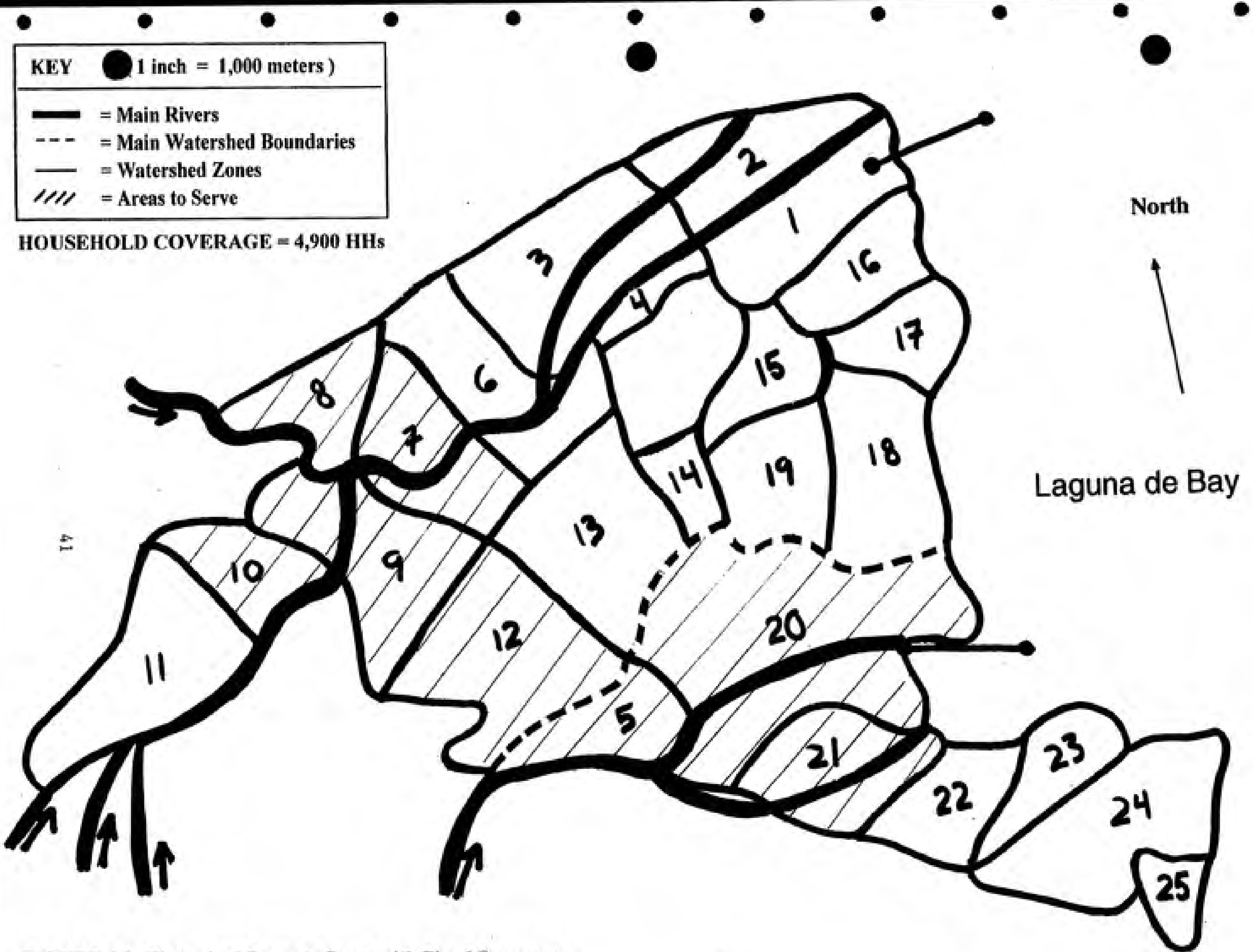


FIGURE 4.2 Watershed Zones to Serve with Piped Sewerage
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

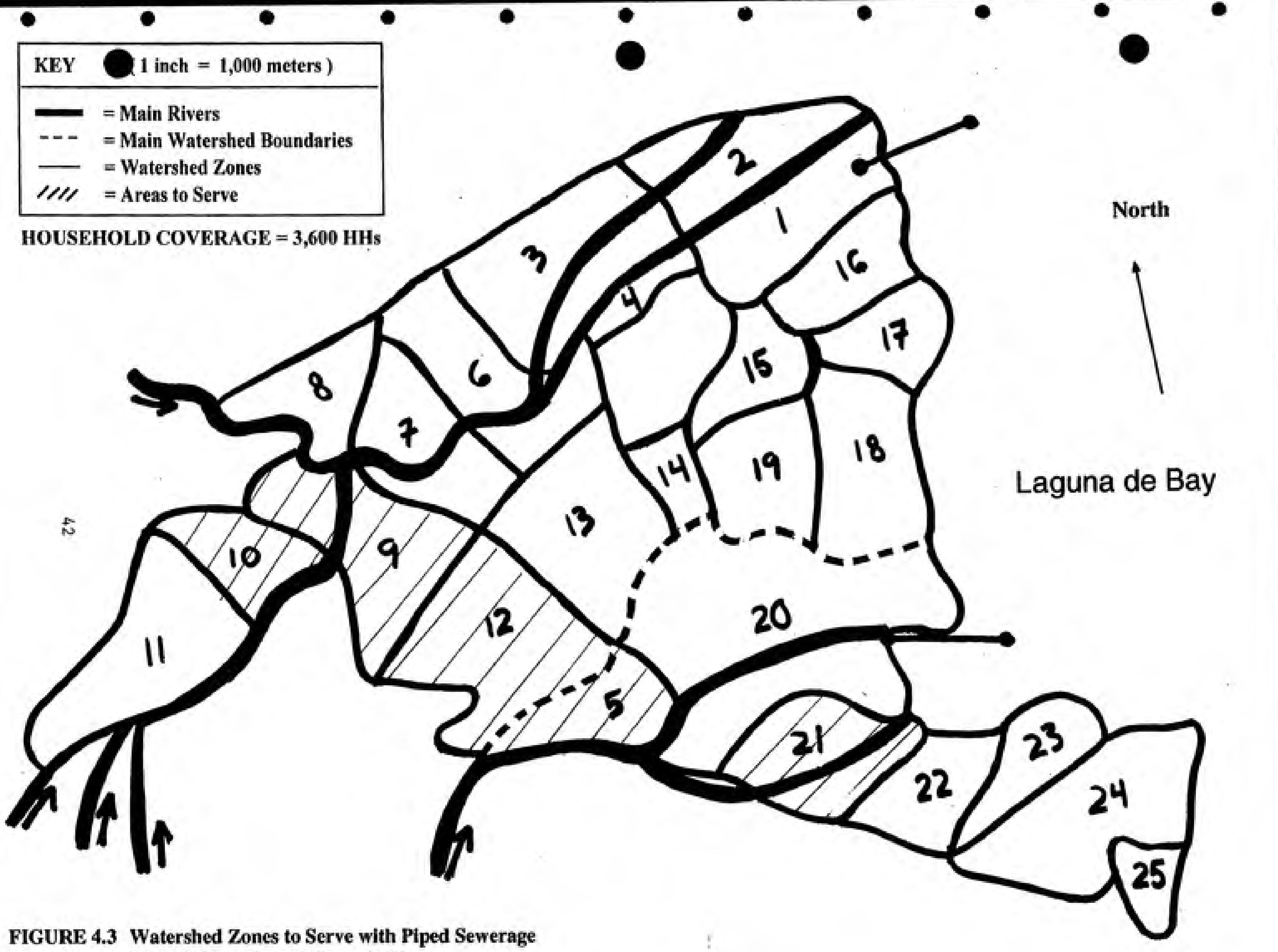


FIGURE 4.3 Watershed Zones to Serve with Piped Sewerage
Fee = 25 Pesos/month/household
Subsidy = 150,000 Pesos/month

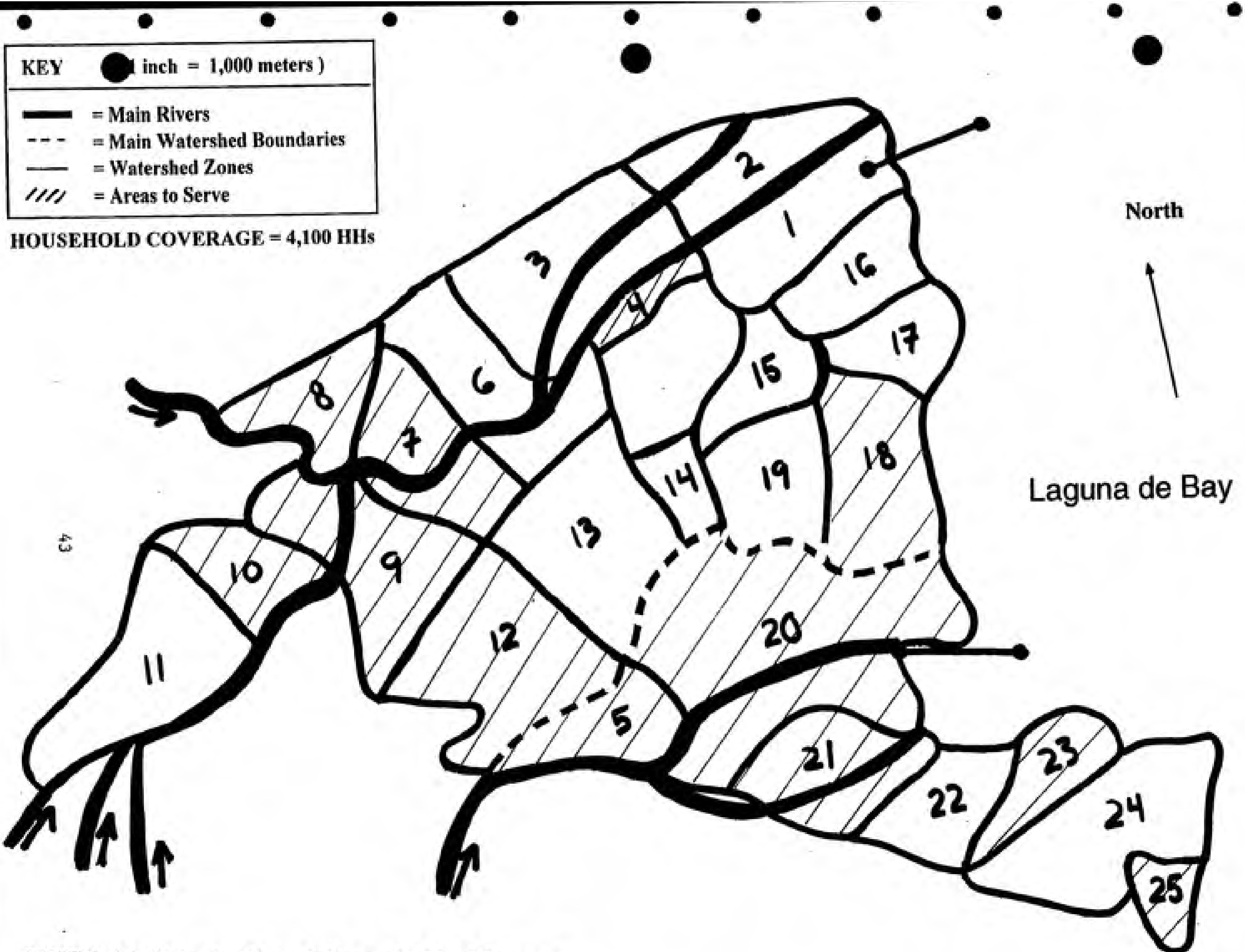


FIGURE 4.4 Watershed Zones to Serve with Piped Sewerage
Fee = 75 Pesos/month/household
Subsidy = 150,000 Pesos/month

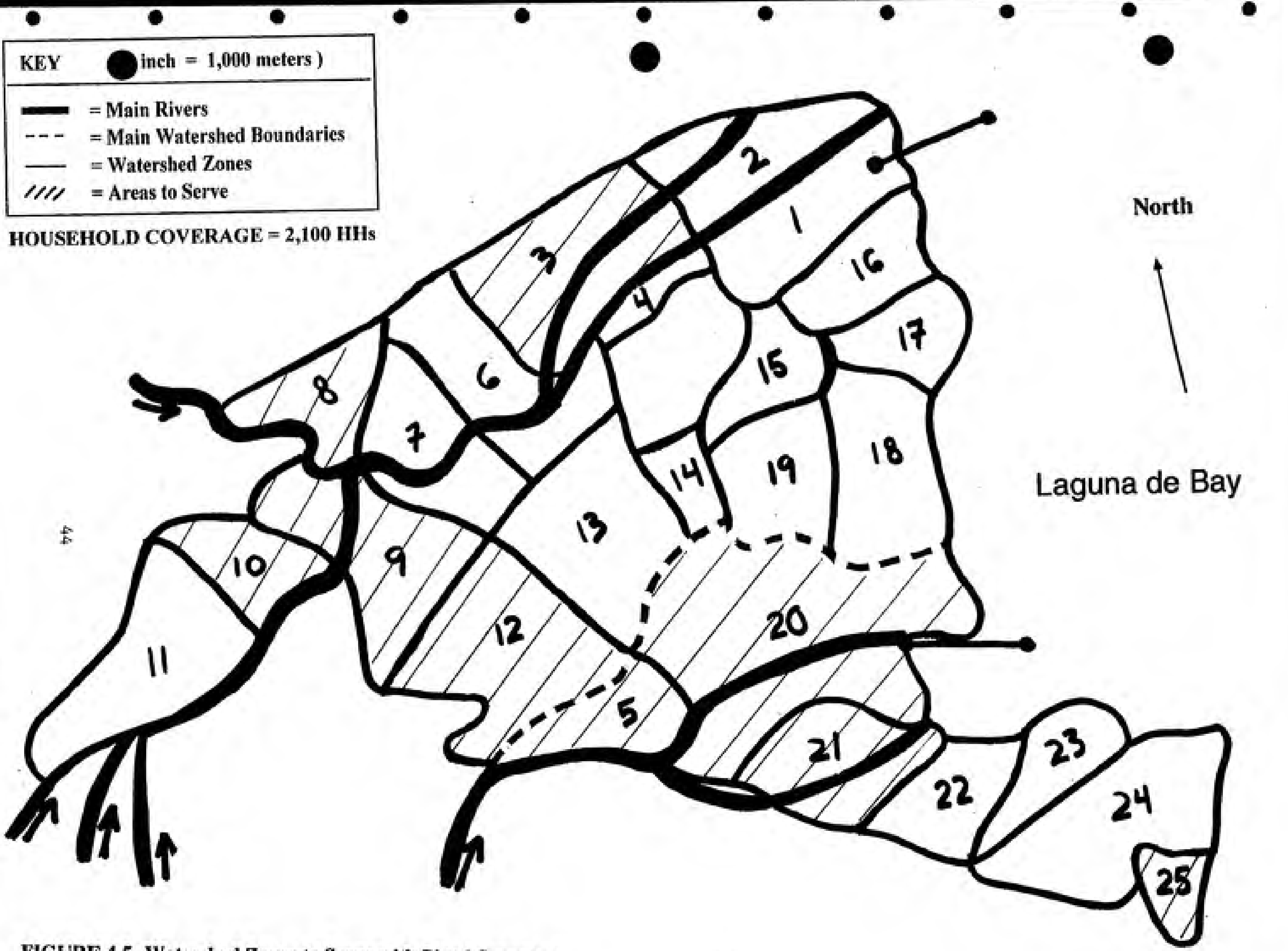


FIGURE 4.5 Watershed Zones to Serve with Piped Sewerage
Fee = 100 Pesos/month/household
Subsidy = 150,000 Pesos/month

The important conclusion from this analysis is that the use of barangays produced quite different geographical results than the use of watershed zones. However, the total number of households served were about the same in both models. Hence, formulation of the planning model with barangays might be satisfactory for estimating coverage associated with different user fees, but it would not be satisfactory for indicating the parts of the city that should be served with the improved system.

In all four model runs with watershed zones, the majority of the areas selected for piped sewerage were located along the western edge of the study area. Figures 4.2 - 4.5 show that the areas selected consistently spanned both the northern and the southern watersheds. Such a situation would require lengthy and expensive trunk sewers, whose costs were not taken into account in the above analyses; the next section addresses this problem.

4.2 ACCOUNTING FOR TRUNK SEWERS

Trunk sewers convey wastewater from neighborhoods (i.e. watershed zones) to the treatment plant or outfall. Consideration of their costs would be expected to affect model results. For example, in Section 4.1 when only street sewer costs were included in the model, the households served with the improved system were located for the most part along the western edge of the study area, far from the outfalls. The model chose these zones because this was where willingness to pay was highest. However, to serve them, two separate trunk sewer and treatment systems would be needed.

Trunk sewers and their associated costs are incorporated into the planning model in this section to obtain more realistic solutions. The approach followed was to: (1) layout a trunk sewer system for the Calamba study area, (2) estimate trunk sewer costs, (3) modify the cost function in the piped sewerage planning model to account for trunk sewer costs, and (4) conduct analyses comparing predicted household coverages and areas served with and without trunk sewer costs.

Recall that there were two separate watersheds in the Calamba study area, one draining to the northern river and the other draining to the southern river before emptying into Laguna de Bay. As a result, two separate trunk sewers and outfalls would be required; one for the northern watershed and one for the southern watershed.

The layout of the proposed trunk sewer system is shown in Figure 4.6. Trunk sewers are represented by solid lines, with arrows indicating the direction of flow. Within each zone, wastewater would flow by gravity through the street sewers to the trunk sewer that would convey it to the outfall. Since wastewater flow needed to be driven by gravity, trunk sewers were located along the areas of minimum elevation (i.e. along the rivers). Nodes N1 - N31 in Figure 4.6 indicate the intersection of the trunk sewers with watershed

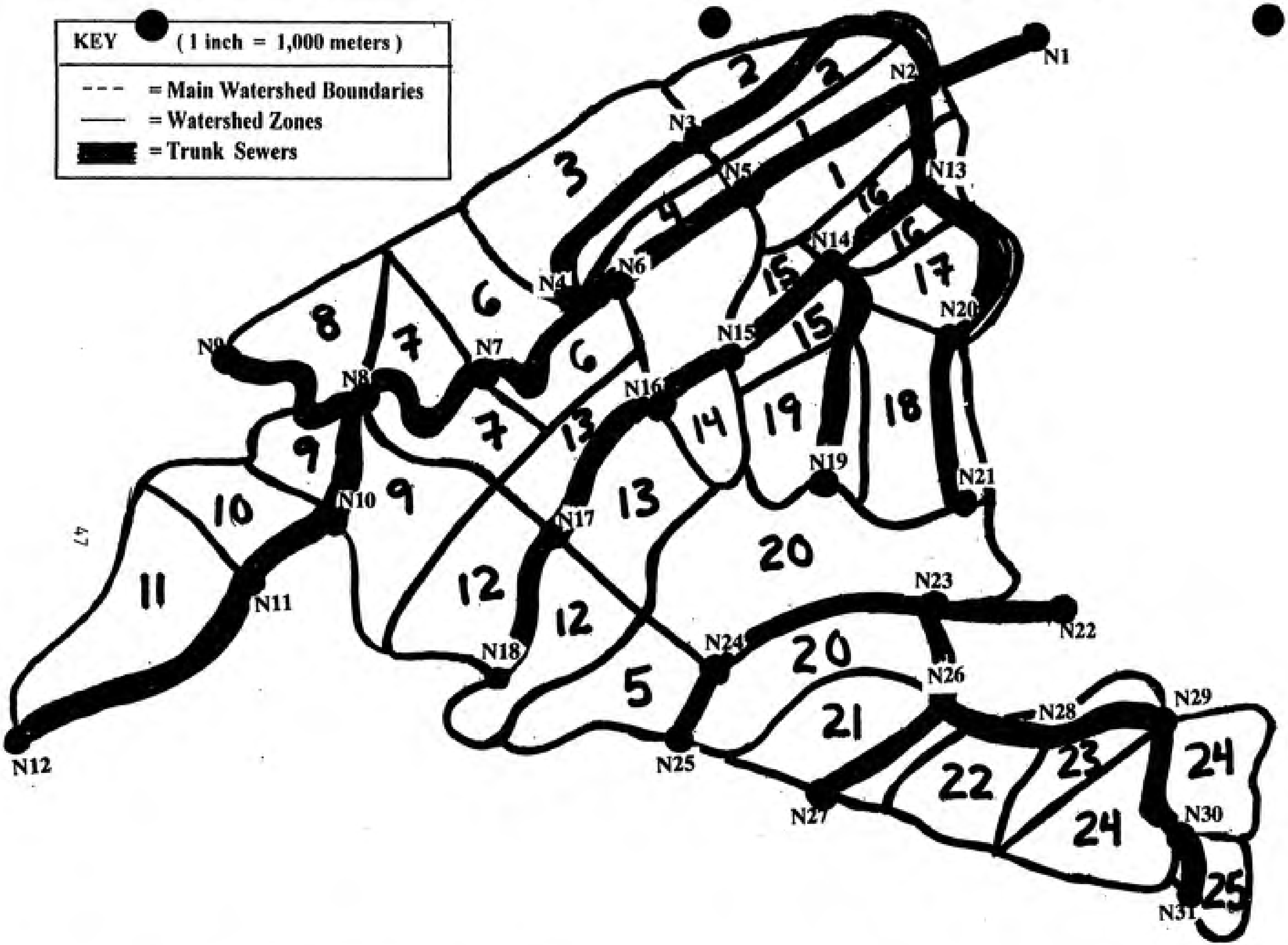


FIGURE 4.6 Trunk Sewer Layout and Watershed Zones

zone boundaries. The distances between adjacent nodes (i.e. the lengths of trunk sewer within each zone) are shown in Table 4.4.

Estimating trunk sewer costs in Calamba was difficult for two reason: (1) economies of scale, and (2) uncertainty prior to model solution about which zones to serve. Because of economies of scale, the average trunk sewer cost per household is not constant but decreases as the number of households served increases. The average unit cost of a trunk sewer decreases as its capacity increases, making it is less expensive to enlarge the diameter of the trunk sewer at the outset than to add a new trunk sewer in the future. To minimize these uncertainties, an approach was used that considered only the portion of trunk sewer cost associated with the marginal capacity required for serving individual watershed zones. This involved assuming that a fixed-charge function would represent the cost of trunk sewers, and that the fixed (set-up) cost of building the trunk sewers would be paid by government. Correspondingly, the model includes only the marginal transport cost for each zone. One rationale for this is that trunk sewers provide public benefits and consequently their set-up cost should be paid for with public funds.

To determine the marginal costs of trunk sewers, suppose that nearly the entire Calamba study area population of about 100,000 (about 20,000 households) decided to connect to the piped sewerage system. Assuming an average wastewater flow of 150 liters/capita/day, the total average flow for Calamba would be about 175 liters/second. Assuming that the maximum flow is 3.0 times the average, the maximum (design)

TABLE 4.4

TRUNK SEWER LENGTHS

Watershed Zones and Outfalls	Trunk Sewer Link(s) in Watershed Zone	Length of Trunk Sewer Link(s) in Watershed Zone (meters)
Northern Outfall	N1-N2	1000
Southern Outfall	N22-N23	1000
1	N2-N5	1600
2	N2-N3	2300
3	N3-N4	2000
4	N5-N6	1200
5	N24-N25	600
6	N6-N7	1500
7	N7-N8	1400
8	N8-N9	1600
9	N8-N10	1000
10	N10-N11	900
11	N11-N12	2200
12	N17-N18	1400
13	N16-N17	1300
14	N15-N16	800
15	N14-N15	1100
16	N2-N13, N13-N14	800, 1000
17	N13-N20	1500
18	N20-N21	1400
19	N14-N19	1800
20	N23-N24, N24-N25	1900, 600
21	N23-N26, N26-N27	700, 1400
22	N23-N26, N26-N28	700, 900
23	N28-N29	800
24	N29-N30	1300
25	N30-N31	500

wastewater flow for Calamba would be 0.5 cubic meters/second. Assuming for the present that the entire flow could be collected at a single outfall, that the design velocity for the outfall is about 0.7 meters/second, and that the sewer would flow about three-quarters full, the required area of the sewer would be about 1.0 square meter, which implies a design diameter of about 42 inches.

In Section 2.4, an 8-inch diameter sewer was estimated to cost 1,000 Pesos/meter. The cost of a sewer is typically proportional to its diameter raised to a power between 1 and 2. Raising to a power of 1.5, the cost of a 42-inch diameter trunk sewer would be about 12,000 Pesos/meter. It was assumed that the smallest diameter ever used for a trunk sewer would be 12 inches, and its cost under these assumptions would be about 1,800 Pesos/meter. A 12 inch sewer could serve about 1,500 households.

Marginal trunk sewer cost is the difference in cost between the maximum (42-inch) and minimum (12-inch) sized trunk sewer pipes (12,000 - 1,800 = 10,200 Pesos/meter) divided by the difference in capacity (20,000 - 1,500 = 18,500 households), which amounts to about 0.6 Pesos/meter/household. Assuming a capital recovery factor of 0.01 per month, the amortized (monthly) marginal trunk sewer cost is about 0.006 Pesos/meter/month/household (i.e. 6.0 Pesos/meter/month per 1,000 households served).

To account for trunk sewers in the planning model, their marginal cost was simply added to street sewer costs. Consider zone 7. From Figure 4.6, the trunk sewer links needed to serve it include N8-N7, N7-N6, N6-N5, N5-N2, and N2-N1, and from Table 4.4, the total length of these links is 6,700 meters. Hence, the marginal (amortized) cost of the trunk sewer for serving zone 7 is 40,200 Pesos/month per 1,000 households that use the system. From Table 4.3, the number of households in zone 7 that would use the system if the user fee were, say, 50 Pesos/month is 591. Hence, the marginal cost of the trunk sewer for serving zone 7 is 23,800 Pesos/month, which, when added to the street sewer cost of 29,600 Pesos/month, results in total street sewer plus trunk sewer cost of 53,400 Pesos/month. Similar marginal trunk sewer costs for all the watershed zones in Calamba with different user fees are shown in Table 4.5.

Suppose Calamba decided to charge each household a fee of 50 Pesos/month to use the sewerage system and that a subsidy of 150,000 Pesos/month were available. Figure 4.7 shows the number of households that should use the system and the areas that should be served when marginal trunk sewer costs are included in the model. The total number of households served decreased from 4,900 when the trunk sewer cost was ignored to 2,700 when the trunk sewer cost was included. Comparison of Figure 4.7 and Figure 4.2 shows that including the trunk sewer cost favored serving zones closer to the outfalls, as expected. However, these zones still spanned both the northern and the southern watersheds; one zone is located in the north and five are located in the south. To serve these zones, it would be necessary to build 2,600 meters of trunk sewer in the northern watershed plus 9,100 meters of trunk sewer in the southern watershed, for a total of 11,700 meters.

TABLE 4.5

MARGINAL TRUNK SEWER COST AT DIFFERENT USER FEES

Watershed Zone	Trunk Sewer Length Required To Serve Watershed Zone (meters)	Marginal Trunk Sewer Cost For Different User Fees (Pesos/month)			
		25	50	75	100
1	2,600	7,300	4,800	3,700	2,500
2	3,300	7,700	5,100	3,900	2,700
3	5,300	4,900	3,200	2,500	1,700
4	3,800	600	400	300	200
5	3,500	11,700	10,000	7,400	4,600
6	5,300	15,400	10,200	7,800	5,400
7	6,700	32,700	23,800	17,900	11,900
8	8,300	16,500	14,100	10,500	6,500
9	7,700	31,000	26,500	19,500	12,200
10	8,600	38,300	32,800	24,200	15,100
11	10,800	120,100	79,500	60,800	42,200
12	7,400	32,500	27,800	20,500	12,800
13	6,000	111,100	73,900	56,900	39,900
14	4,700	23,200	15,500	11,900	8,400
15	3,900	13,800	9,100	7,000	4,800
16	2,800	8,700	5,700	4,400	3,000
17	3,300	10,800	7,100	5,400	3,800
18	4,700	17,300	11,400	8,800	6,100
19	4,600	14,400	9,500	7,300	5,100
20	3,500	25,200	19,000	14,300	9,400
21	3,100	16,700	14,300	10,600	6,600
22	2,600	11,700	7,800	5,900	4,100
23	3,400	2,700	1,800	1,400	1,000
24	4,700	13,800	9,100	7,000	4,800
25	5,200	6,800	5,800	4,300	2,700

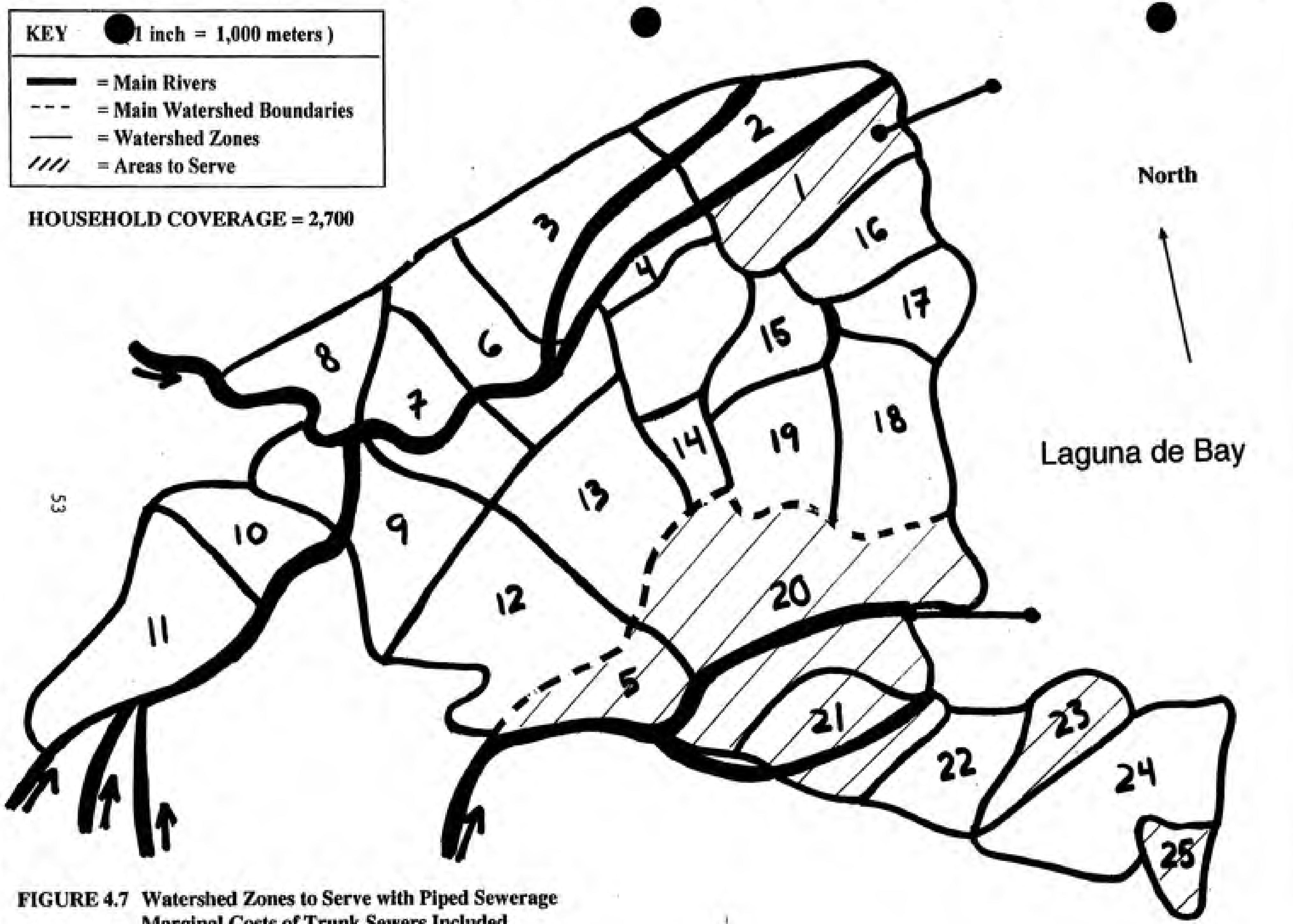


FIGURE 4.7 Watershed Zones to Serve with Piped Sewerage
Marginal Costs of Trunk Sewers Included
Northern and Southern Watersheds Considered
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

The fixed (set-up) cost of trunk sewers is about 1,800 Pesos/meter, which is the cost of the minimum diameter trunk sewer, 12 inches. Assuming a capital recovery factor of 0.01/month, the amortized fixed costs of trunk sewers would be 18 Pesos/meter/month. To supply the 11,700 meters of trunk sewers needed, the fixed cost would be about 211,000 Pesos/month, which has equivalent present value (i.e. loan value) of 21 million Pesos (US$844,000).

This analysis implies that government would be willing to pay the fixed cost of constructing the entire trunk sewer network wherever it might be needed, such that any zone could have access if it were selected to connect to the piped sewerage system. Had the model selected zones from the far western edge of the city, it would have been necessary to extend the trunk sewer to serve them. This was the result of letting the model select among all 25 zones in the Calamba study area. However, if government is not willing to pay the set-up cost of constructing an entire trunk sewer network, then the entire set of zones should not be pooled as candidates for piped sewerage, which is considered in the next section.

4.3 SEPARATE WATERSHED ANALYSES

In light of the above results, three additional analyses were performed. In the first, only the zones in the northern watershed were considered as candidates, which implied that government was prepared to pay the set-up trunk sewer cost for that watershed but not for the one in the south. The model was run assuming a user fee of 50 Pesos/month and a subsidy of 150,000 Pesos/month.

Figure 4.8 shows the total number of households and the areas that should be served when only zones in the northern watershed are considered as candidates. Total coverage decreased from 2,700 households (both watersheds) to 2,100 households in this case. Two of the zones selected by the model were located along the western edge of the study area, far from the outfall. Total trunk sewer length required to serve these zones would be 16,400 meters, with a fixed cost of 295,000 Pesos/month, more than when both watersheds are considered jointly. The results are summarized in the second row of Table 4.6.

In the second analysis, only the zones in the southern watershed were considered as candidates, which implied that government would pay the set-up trunk sewer cost only for that watershed but not for the one in the north. Again, a fee of 50 Pesos/month and a subsidy of 150,000 Pesos/month were assumed. Figure 4.9 shows the total number of households and the areas that should be served. Total coverage was about 2,700 households, the same as when both watersheds were jointly considered. Not only was the household coverage higher in the southern watershed than in the northern watershed, but the total trunk sewer length required to serve the zones was shorter (6,500 meters). As a result, associated fixed costs would be considerably lower (117,000 Pesos/month, see Table 4.6 for comparison).

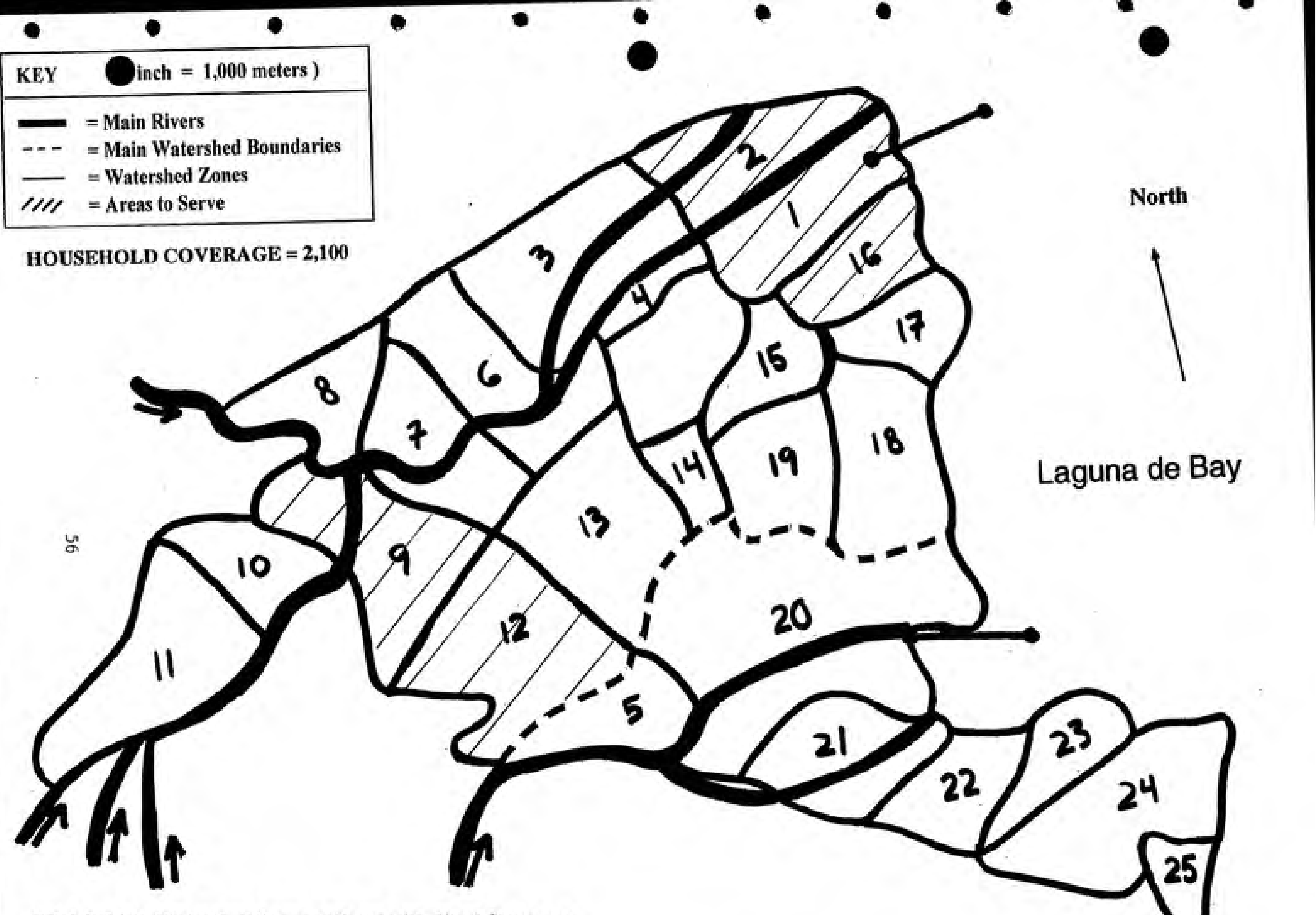


FIGURE 4.8 **Watershed Zones to Serve with Piped Sewerage**
Marginal Costs of Trunk Sewers Included
Northern Watershed Only Considered
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

TABLE 4.6

COST COMPARISONS FOR WATERSHED ZONE ANALYSES

Proposed User Fee = 50 Pesos/month

Assumed Available Subsidy = 150,000 Pesos/month

Scenario	**Total Coverage** (HHs Served)	**Street Sewer Cost** (Pesos/month)	**Trunk Sewer Length** (meters)	**Marginal Cost of Trunk Sewer** (Pesos/month)	**Trunk Sewer Fixed Cost** (Pesos/month)	**Average Subsidy Per Household** (Pesos/month/HH)
Northern and Southern Watersheds Considered Jointly	2,700	135,000	11,700	190,000	211,000	56
Northern Watershed Only	2,100	105,000	16,400	207,000	295,000	71
Southern Watershed Only	2,700	135,000	6,500	105,000	117,000	56
Subset of Northern Watershed	2,000	100,000	10,500	126,000	189,000	75

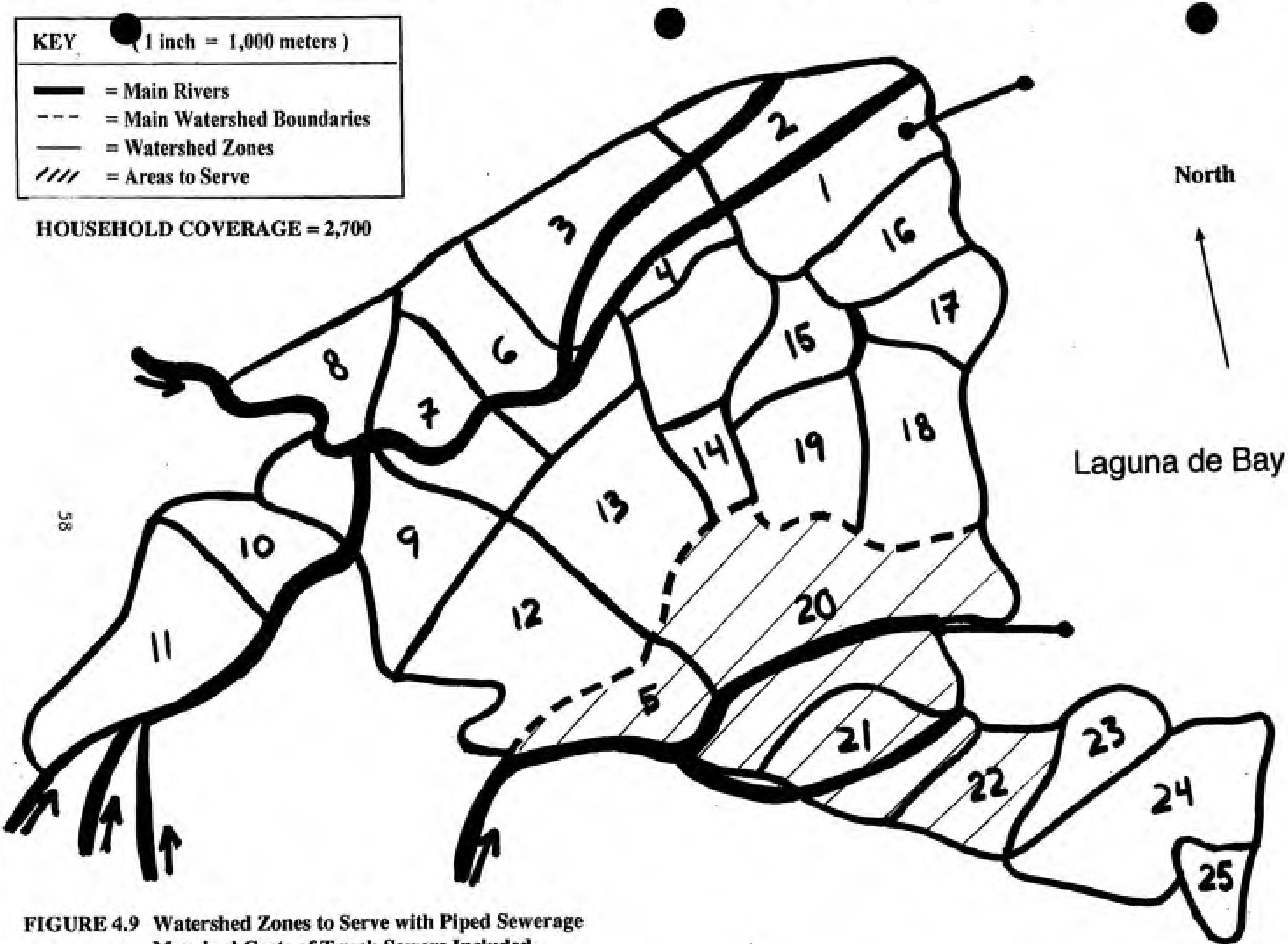


FIGURE 4.9 Watershed Zones to Serve with Piped Sewerage
Marginal Costs of Trunk Sewers Included
Southern Watershed Only Considered
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

Serving the northern watershed (Figure 4.8) was less desirable than serving the southern watershed (Figure 4.9) for two reasons. First, total household coverage was lower in the north, and second, the total marginal and fixed costs of the trunk sewer were higher, mainly due to serving zones on the western edge of the city far from the outfall. This suggested a third alternative, which was to consider a subset of zones near the outfall and thus limit trunk sewer length and associated costs. The subset chosen included zones 1-4 and 14-19. Figure 4.10 shows the total number of households and the areas that should be served for this case. Figure 4.11 compares household coverage for the three analyses. Total coverage decreased from 2,100 households when all zones in the north were considered to 2,000 households when only the zones closer to the outfall were considered. The trunk sewer length required to serve the zones was 10,500 meters, with associated fixed costs of 189,000 Pesos/month (Table 4.6). Thus, serving the southern watershed appears to be the best option among those considered.

4.4 INCLUDING TREATMENT PLANT COSTS

Treatment plant costs have not been included up to this point; hence, the tasks of this section are to: (1) estimate the costs of a treatment plant for Calamba, (2) modify the model to include the cost of a treatment plant, and (3) conduct analyses including street sewer, trunk sewer, and treatment plant costs under similar conditions to the previous analyses. Note that the pattern of work in this report was first to assume that the subsidy only had to cover street sewer costs, next it had to cover both street sewer costs and

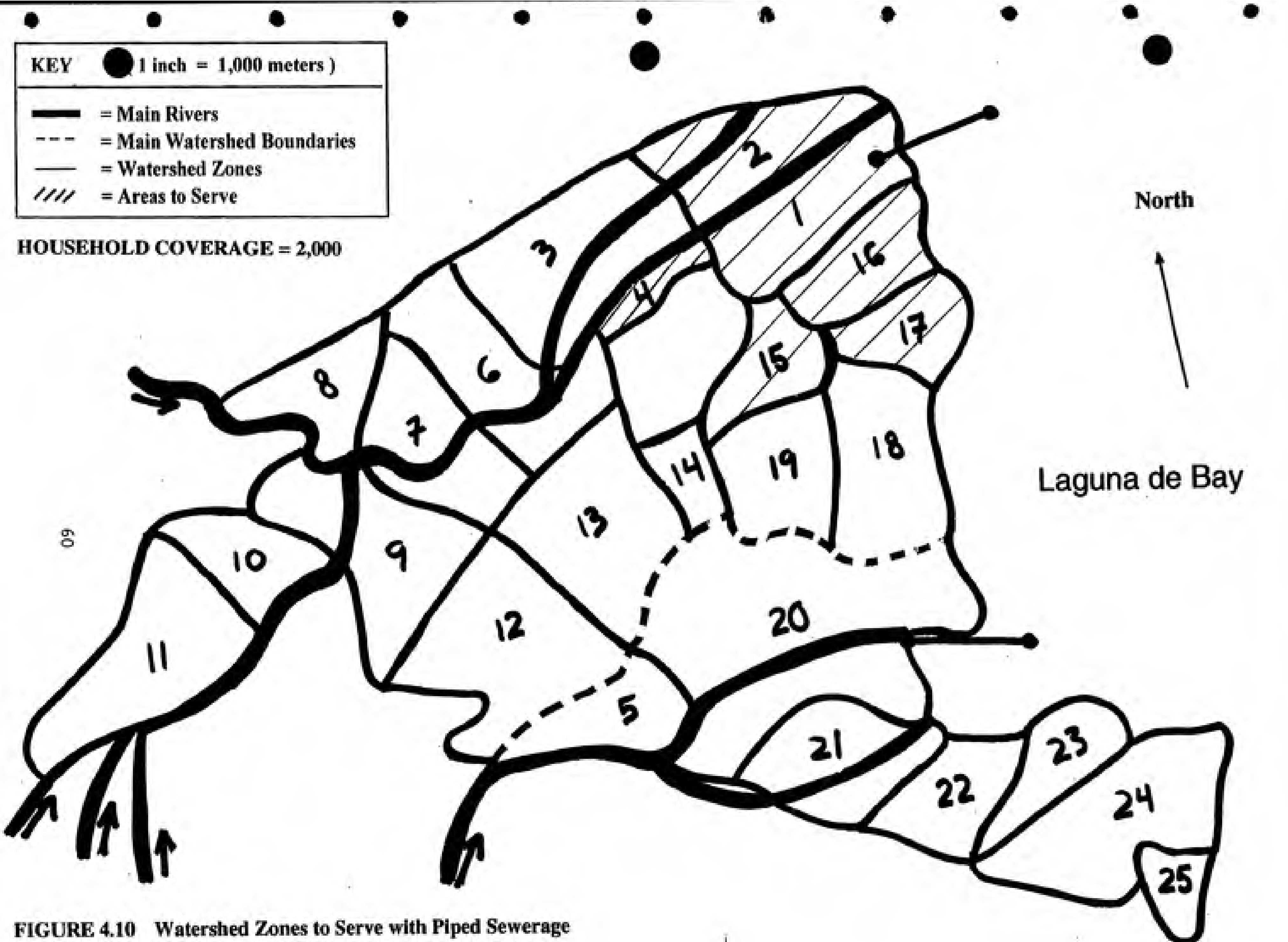
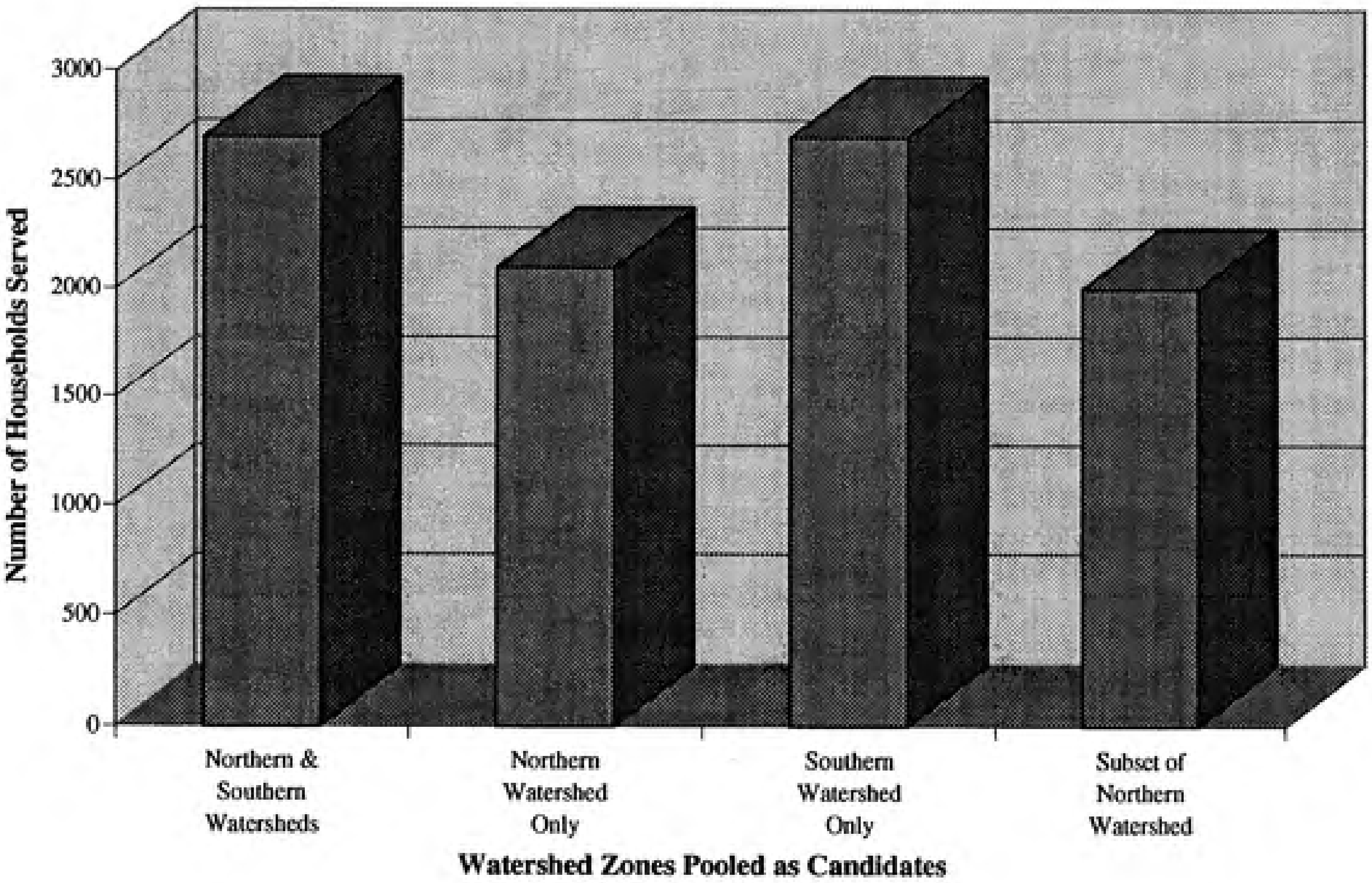


FIGURE 4.10 **Watershed Zones to Serve with Piped Sewerage**
Marginal Costs of Trunk Sewers Included
Subset of Northern Watershed Considered
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

FIGURE 4.11

COMPARISON OF HOUSEHOLD COVERAGE FOR THE WATERSHED ZONE ANALYSES



marginal costs of trunk sewers, and in this section, it has to cover street sewer costs, marginal costs of trunks sewers, and marginal costs of treatment.

Because of economies of scale, the cost per household of a treatment plant is not constant but decreases as the number of households served increases. The approach used herein considered only the portion of treatment plant cost associated with the marginal capacity required to treat wastewater from individual watershed zones, similar to the approach used for trunk sewers. It was therefore assumed that fixed treatment plant costs would be paid for by government, the rationale being that the set-up cost of treatment plants provides public benefits and consequently should be paid for with public funds. A typical treatment plant cost model is:

$$C = \alpha Q^{\beta} \tag{4.3}$$

where:

C = treatment plant cost (Pesos), and

Q = design capacity, measured in households served.

A typical value for β is 0.7. To determine α it was assumed that a lagoon would be the treatment system required for Calamba, and that such a facility with capacity to serve 5,000 households would cost 12,500,000 Pesos (i.e. US$100 per household, or US$500,000). This implies α = 32,000 Pesos, or equivalently, 320 Pesos/month.

It was assumed that the minimum number of households that would ever be served was 2,000 (i.e. about ten percent of the study area population) and that the maximum number of households that would ever be served was 10,000 (i.e. about half the study area population). Marginal treatment plant costs were then the difference in cost between a lagoon for the maximum number that would ever be served and a lagoon for the minimum number of households, divided by the difference in capacity (measured in households), which amounts to 17 Pesos/month/ household [2]. It was decided to limit the candidate zones to those in the southern watershed only.

Figure 4.12 and Table 4.7 show the total number of households and the areas that should be served by including marginal treatment costs in the model. The total number of households served decreased from 2,700 for the case that ignored treatment costs, to 2,200 households when all three cost components were included: street sewers, trunk sewers, and treatment. Fixed trunk sewer costs are slightly higher when treatment plant costs are included than when they are ignored.

The average subsidy per household served when treatment plant costs were included was 68 Pesos/month. Hence, assuming that government charged a fee of 50

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(2) Marginal treatment plant costs are calculated as follows $[(32{,}000 * (10{,}000)^{0.7} - 32{,}000 * (2{,}000)^{0.7})/(10{,}000 - 2{,}000)] = 1{,}700$ Pesos/household, or equivalently, 17 Pesos/month/household.

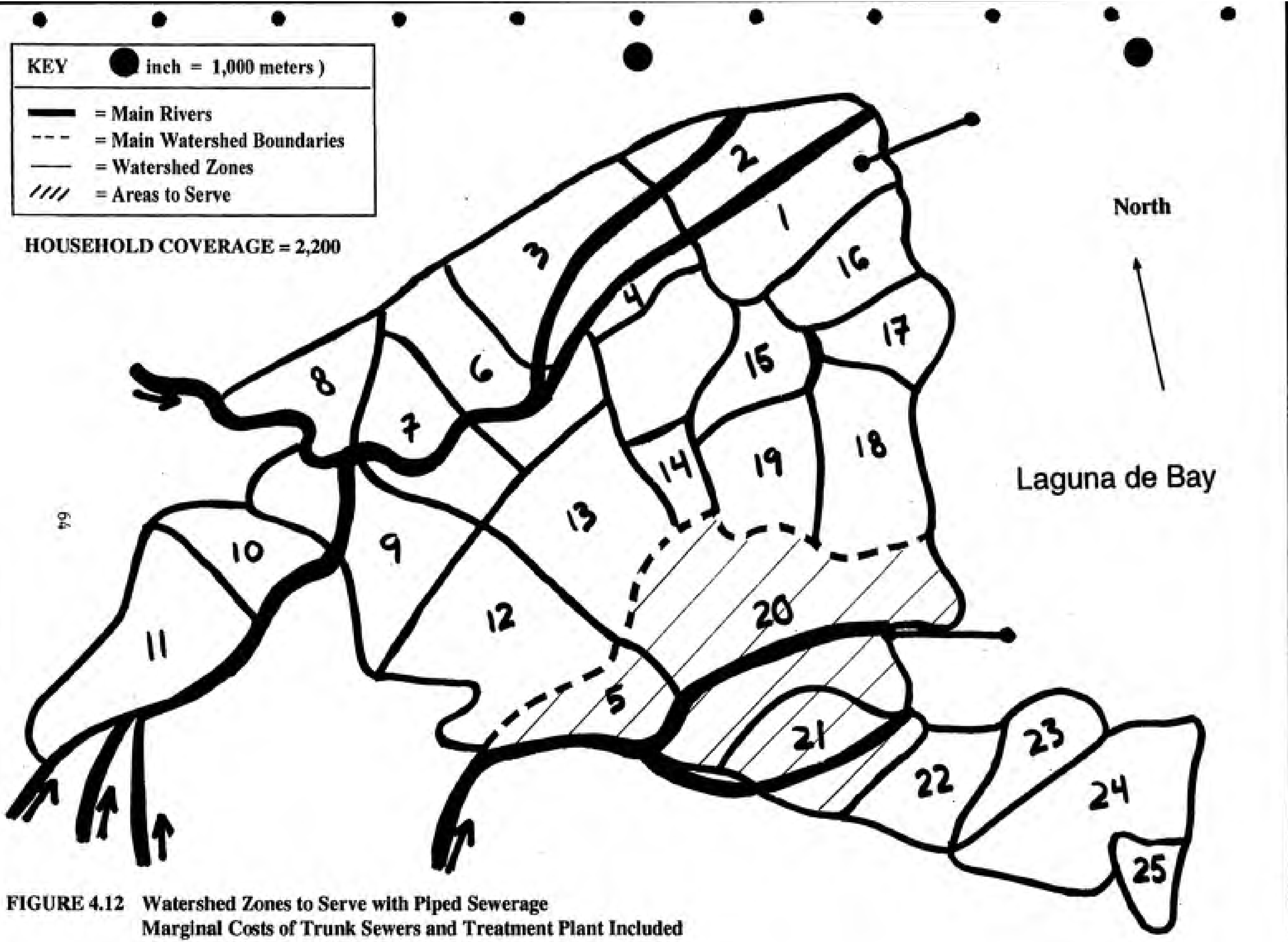

FIGURE 4.12 Watershed Zones to Serve with Piped Sewerage
Marginal Costs of Trunk Sewers and Treatment Plant Included
Southern Watershed Only Considered
Fee = 50 Pesos/month/household
Subsidy = 150,000 Pesos/month

TABLE 4.7

0,1 Integer Programming Model Results For Piped Sewerage Planning in Calamba, Philippines

W (P*/month)	C/L of Street Sewer (P*/meter)	Amortized MC of Trunk Sewer (P*/month/meter/1000 HH)	Amortized MC of Treatment (P*/month/HH)
50	1000	6	17

i	Ni TOTAL No. of HHs in Zone i	%i % of HHs WTP Fee, W in Zone i	Xi = Ni * %i No. of HHs WTP Fee, W in Zone i	W WTP Fee (P*/month)	Ci*** Cost of Sewer System for Zone i (P*/month)	Zi** Coverage Decision Variable	Xi*Zi No. of HHs Served in Zone i	(W*Xi-Ci)Zi Net Revenue (Pesos)
1	0	49	0	50	0	0	0	0
2	0	49	0	50	0	0	0	0
3	0	49	0	50	0	0	0	0
4	0	49	0	50	0	0	0	0
5	733	65	476	50	54755	1	476	-30933
6	0	49	0	50	0	0	0	0
7	0	54	0	50	0	0	0	0
8	0	65	0	50	0	0	0	0
9	0	65	0	50	0	0	0	0
10	0	65	0	50	0	0	0	0
11	0	49	0	50	0	0	0	0
12	0	65	0	50	0	0	0	0
13	0	48	0	50	0	0	0	0
14	0	48	0	50	0	0	0	0
15	0	49	0	50	0	0	0	0
16	0	49	0	50	0	0	0	0
17	0	49	0	50	0	0	0	0
18	0	49	0	50	0	0	0	0
19	0	49	0	50	0	0	0	0
20	1600	57	912	50	114656	1	912	-69056
21	1183	65	769	50	86525	1	769	-48077
22	1015	49	497	50	66964	0	0	0
23	180	49	88	50	12299	0	0	0
24	662	49	324	50	47762	0	0	0
25	288	65	187	50	23423	0	0	0

MAXIMIZE TOTAL COVERAGE	ST TOTAL NET REVENUE >=-150,000
2,157	**-148,066**

* P = Pesos

** Zi = 1 indicates that the households in Zone i should be connected to the sewer system

Zi = 0 indicates that the households in Zone i should NOT be connected to the sewer system

*** Ci = [((C/L) * (5 meters/HH) * Ni)+ MC trunk sewers in zone] *[CRF / (12months/year)]

Pesos/month to use the sewerage system and that a subsidy of 150,000 Pesos/month were available, users would pay approximately 40 percent of the cost of street sewers, the marginal costs of trunk sewers, and the marginal costs of treatment. Fixed trunk sewer and treatment plant costs plus the subsidy would have to be paid by others.

4.5 SOCIAL BENEFITS

Recall that we chose the level of subsidy used in the analyses based on diminishing marginal returns to increasing coverage and that no measurable objective criterion was available to indicate what the total subsidy actually should be. Hence, the final analysis in this paper is aimed at determining whether or not the subsidy of 150,000 Pesos/month was justifiable. Implicitly, the fixed cost of trunk sewers and treatment do not have to be paid for by the subsidy if it is assumed that these facilities provide social benefits beyond Calamba (i.e. public health or economic externalities).

An approach was used that compared consumer surplus to required subsidy. If consumer surplus for those served by the system was equal to or exceeded the required subsidy, it would be argued that the subsidy was justifiable. If consumer surplus was less than the required subsidy, the subsidy might need to be reduced.

Consumer surplus is the difference between total willingness to pay (i.e. total social benefits) and total cost to users, which is the area under the demand curve at a given user fee. For the purpose of this analysis, it was decided to roughly estimate total willingness to pay and to divide by the total cost to users at a given fee to determine the ratio of total benefits to user cost, from which consumer surplus can be estimated.

Consider Table 2.2, which shows the distribution of willingness to pay in Calamba. The last row indicates that at least 6% of the study area households were willing to pay 200 Pesos/month. Hence, with, say, 24,000 households in the study area, 1,440 households (= 0.06 * 24,000) were willing to pay 200 Pesos/month for a total of 288,000 Pesos/month (= 1,440 *200).

Now consider a user fee of 150 Pesos/month in Table 2.2. At least 9% of the households in the study area were willing to pay it, (i.e. 2,160 households (= 0.09 * 24,000)). However, 1,440 of these households were willing to pay the higher fee of 200 Pesos/month. Hence, the marginal number of households willing to pay 150 was 720 (= 2,160 - 1,440), and their willingness to pay was 108,000 Pesos/month (= 720 * 150).

At a fee of 100 Pesos/month, Table 2.2 shows that at least 26% of the study area households (i.e. 6,240 households) would pay it. However, 2,160 of these households were willing to pay 150 or more. Thus, the marginal willingness to pay of these households is 408,000 Pesos/month (= (6,240 - 2,160) * 100). Making similar calculations for user fees of 75 and 50 Pesos/month using the data in Table 2.2, the estimated total benefits associated with a user fee of 50 Pesos/month is 1,134,000

Pesos/month, as shown in Table 4.8. Total user costs at this fee are 576,000 Pesos/month (= 0.48 * 24,000 * 50). Hence, the approximate ratio of total benefits to total costs at a fee of 50 is 1.97, say 2.0.

Consider the last solution of the model shown in Figure 4.12 and Table 4.7 that included street sewer and treatment plant costs at a user fee of 50 Pesos/month. The planning model selected about 2,200 households to be served. The amount they would have to pay is 110,000 Pesos/month (= 2,200 * 50). Using the above multiplier, their estimated total willingness to pay is about 220,000 Pesos/month. Hence, consumer surplus is about 110,000 Pesos/month (= 220,000 - 110,000), which is 40,000 Pesos/month less than the assumed subsidy. Thus it might be argued that the assumed subsidy is a little too high.

5 DISCUSSION AND CONCLUSIONS

The case study described in this report is rough, and its main value is illustration. Many of the underlying assumptions are too crude to suggest much realism. For example, operating and maintenance costs were ignored, the bases for determining the required sewer length and diameter in each barangay and watershed zone need to be examined, the willingness to pay data upon which the case was based were raw results rather than values from an econometric analysis, and the subsidies were assumed without much basis (e.g. a subsidy per household served might be more reasonable than a lump sum, as assumed in this report). Nevertheless, several important conclusions can be drawn from application of the model to the case of Calamba. The most important conclusion is that the optimization model in this report provides a basis for using the results of WTP studies for planning piped sewerage systems. Also, it is probably necessary to convert willingness to pay data obtained from barangays or census tracts to a watershed basis. Census tract or political boundaries do not necessarily conform to watershed boundaries. When used in the planning model, they led to results where the areas to be served were scattered throughout the study area and did not provide a basis for a piped sewerage system that could realistically be constructed. Although only one conversion was made of barangays to zones, in principle, several different conversions could be made and each one could be tested to determine the zone configuration that would maximize coverage.

Converting WTP data to a watershed basis proved to be necessary but not sufficient for obtaining realistic results. Analyses that used watershed zones in the piped sewerage planning model but ignored marginal trunk sewer costs and marginal treatment plant costs still resulted in scenarios where the areas to be served by the piped sewerage system were scattered throughout the study area. Analyses that accounted for marginal trunk sewer costs but ignored marginal treatment plant costs favored serving areas closer to the outfalls but resulted in erroneous determinations of the numbers of households and zones that should be served. Hence, it was necessary to include street sewer costs, marginal trunk sewer costs, and marginal treatment plant costs to obtain realistic results, but by the same token, marginal operation and maintenance costs, which were ignored herein, should also be included.

In analyses where the model was allowed to select among all 25 watershed zones in Calamba, the areas that the model selected to serve with piped sewerage spanned two separate watersheds. In Calamba, there was no way to transport wastewater between the two watersheds without expensive pumping. Hence, it became desirable to limit candidate zones for the piped sewerage system to one watershed or the other. In Calamba, it was found that limiting the candidate zones to the southern watershed resulted in household coverages that were the same as when both watersheds were jointly considered, but with considerably lower fixed costs.

It was expected that the total household coverage might be maximized at the lowest user fee of 25 Pesos/month since the percentage of households willing to pay for piped sewerage was highest at this fee. This was not found to be the case. Total household coverage was maximized at a user fee of 50 Pesos/month, with further increases in the user fee resulting in decreases in household coverage. Hence, the total number of households that could use the piped sewerage system would actually increase if a higher fee of 50 Pesos/month were charged.

Marginal returns of coverage were relatively constant for the range of subsidies investigated. For example, at a user fee of 50 Pesos/month, marginal returns of coverage remained at 0.04 households/Peso/month for subsidies in the range of 30,000 - 120,000 Pesos/month. When subsidies were increased to 150,000 and 200,000 Pesos/month, marginal returns of coverage decreased to 0.02 households/Peso/month. Thus, higher subsidies would provide decreasing marginal returns in terms of coverage, with the WTP data providing some basis for determining how large subsidies needed to be in order to cover costs. However, they did not resolve the issue of how large subsidies should be. In principle, government would have to decide on either the total subsidy it is willing to allocate or the level of coverage it wants to achieve.

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