RESEARCH PROJECT TECHNICAL COMPLETION REPORT

Project No. A-038-PR

PEAK RATIOS AND ALTERNATE MODEL FACTORS FOR RESIDENTIAL WATER USE IN PUERTO RICO

by

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The author wishes to express his gratitude to the Puerto Rico Aqueduct and Sewer Authority for their cooperation by allowing our project assistants to have access to the required water-use data for individual dwelling units in sampled housing areas of San Juan, Ponce and Mayaguez, Puerto Rico. To the University of Puerto Rico for allowing our project personnel the use of their computing facilities to perform the computer analyses required in the study, and to all others who directly or indirectly cooperated in the conduction of this project.

He specially wishes to express his gratitude to the University of Puerto Rico Water Resources Research Institute, under whose auspices this study was conducted.

ABSTRACT

This study was conducted with the objectives of investigating the impact of residential water-use factors (other than assesed property valuation) on residential water-use in Puerto Rico, and estimating peak ratios for their application to the average water-use estimators previously developed (7).

To this end, data from sampled dwelling units in the cities of San Juan, Ponce and Mayaguez (on socio-economic factors and water usage) was subject, among other analyses, to: computer-generation of transformed water use data (water-use indices) to serve a basis for graphical analysis and model building; graphical analysis of the relationship between alternate water use factors (number of bedrooms per dwelling, equivalent index of bathroom water-using fixtures, number of people per dwelling unit, and number of people per bedroom), and the generated water-use indices; computer-generation of model parameters and the corresponding water-use models for each alternate factor whose impact on residential water use was found "significant", on the basis of a factorial experiment conducted regression plot back analysis to determine the fitness and reliability of model parameters for each significant alternate factor; and the determination of maximum to average water-use indices.

The analyses showed that, out of the four potential-alternate residential water-using factors studied, only two were found significant, namely: number of bedrooms per dwelling unit and the equivalent index of bathroom water-using fixtures. In both cases, the relationship between each alternate factor and the corresponding water-use index may be approximated by an exponential function, with the alternate factor as the independent variable and water use as the "response" variable.

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CHAPTER I - INTRODUCTION

1.1 Alternate Water-Use Factors

Practical functional-relationship models to estimate residential water on the basis of some socio-economic factors were recently developed as a result of various studies conducted in the Island of Puerto Rico (5,7).

For "private" urbanization dwellings, the factor studied was the assessed property value of individual dwelling units. This factor was considered as a practical indicator of the general economic level of the family using each dwelling unit. This factor was considered as a practical indicator of the general economic level of the family using each dwelling unit. In this sense, the assessed property value acts as a "concomitant" variable that reflects the effect on residential water use, of factors such as the number, and kind of home water-using fixtures, land and/or garden areas, automobile washing requirements; and such socio-economic factors as habit, education and effective family buying income.

Although the assessed property value is an acceptable water-use estimation factor under normal conditions, situations arise where the required assessed value data might not be available before hand to serve as a basis for prediction, or it may not be regarded as reliable enough to be used for such purposes.[1]

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[1] Due to this fact, the present study should be considered as a complement to the previous main study (7), and reference should be made to it for additional details on the procedures employed and results obtained. A copy of the previous main study (7) is available, upon request, from the Water Resources Research Institute, University of Puerto Rico, Mayaguez Campus, Mayaguez, Puerto Rico; 00708.

This points to the desirability of developing alternate residential water-use estimation models, based on other water-use influencing factors.

Four potential alternate water-using factors were considered in this study:

1- Number of bedrooms per dwelling unit

2- Equivalent index of bathroom water-using fixtures

3- Number of people per dwelling unit

4- Number of people per bedroom

In order to make all factors quantitative, a suitable conversion table was arbitrarily set-up to convert bathroom facilities into "equivalent indices". Under this conversion table a shower fixture is equivalent to 1/2 unit (or 0.50 unit), a toilet is 1/4 unit (or 0.25 unit), a wash-basin is 1/4 unit, and a bidet is also 1/4 unit. The index for total sanitary facilities is called "equivalent index of bathroom water-using facilities" and is formed by adding up the indices of the individual fixtures. For example a bathroom with a shower, a wash-basin and a toilet has a total index of 1/2 + 1/4 + 1/4 which add up to 1.00. If in addition to these fixtures, this bathroom has a bidet, the total index would be 1.25 instead.

1.2 Peak Water-Use Demands

Peak water-use demands are very important in the design of water distribution systems, since the specified water supply and distribution facilities must be able to meet them. The design of a distribution system without regard to the actual peak demands in a dwelling area could lead to inadequacies in the distribution system, causing too low or too high pressure conditions; underdesign or overdesign situations.

1.3 Previous Investigations

Several studies conducted in the past have revealed that residential water use is influenced by factors which are mainly of a socio-economical nature.

Dunn (3) reported that in addition to the amount of water required for normal needs of life, domestic water use varied with the general metering of water service, automobile washing demands, habit and social requirements, as well as the number and kind of home water-using appliances. The study also revealed that the posession of home water-using equipment increases residential water-use significantly, and that demographic and socio-economic factors strongly influence the posession of such facilities. The author clearly states that, because of the demographic and socio-economic nature of the factors involved, the specific results are only valid for the area or region included in the study, and these are not necessarily transferable to other regions.

Porges (4) also found in a previous study, variations in water consumption for several parts of the United States.

Similar results were obtained by Hansen, Ross, Larson and Hudson (2, 6).

More recent studies (1) have confirmed the above results and have stressed the importance of one individual factor which usually accounts for a large proportion of the quantity of water used around the house: lawn and garden sprinkling.

Irrigation requirements for lawn are usually satisfied by sprinkling from the water distribution system, from rainfall, and by water stored in the grass-root zone. An amount of this water coming in contact with the lawn is lost by runoff, by deep percolation away from the root zone, and through evapotranspiration.

The average sprinkling demands in dry climates are higher than in moist ones. This is so because in dry climates, or during long dry periods, when little or no rainfall occurs, the evapotranspiration from lawn or irrigable areas, must be compensated by sprinkling from the distribution systems. Peak lawn-sprinkling demands in some urban water distribution systems have caused water tanks to empty, and low pressure conditions to occur. In the design of water distribution systems for residential areas, one major consideration is that it should be capable of meeting maximum daily as well as peak hourly demand rates. The supply system from a reservoir or river should be capable of supplying water at the maximum daily demand rate and the pumping stations and transmission mains between reservoirs in the distribution system must be designed for flows in excess of the maximum daily demand. This excess depends on the capacity of the distribution system to satisfy the hourly variations in water demand.

The Federal Housing Administration in its Minimum Design Standards of 1965 (criteria for the design of water distribution systems) recommends: the use of an average demand of 100 gallons per capita daily (100 gpcd) with 4 persons per dwelling unit; a maximum daily demand of 200% of this average demand, a maximum hourly demand of 500% of average in areas where lawn sprinkling is not critical and 700% in areas where extensive lawn sprinkling is required. The corresponding figuresin gallons per day per dwelling unit (gpd) for an average 4-person unit would be: 400 gpd average demand; 800 gpd maximum daily demand and 2,000 gpd peak hour regular, with 2,800 gpd peak hour in highly demanding sprinkling areas.

Two recent studies conducted in the Island of Puerto Rico (5,7) show results that are somehow lower in average magnitudes than those recommended by F.H.A. The average use in the city of Mayaguez was 63 gallons per capita daily with an average population density of 5.1 persons per dwelling unit. The corresponding figures for the city of Ponce were 67 gpcd and 4.6 people per dwelling unit. In the gallons per day per dwelling unit case the average for Mayaguez was 237 gpd and for Ponce 300 gpd. In San Juan, the average uses were 78 gpcd and 320 gpd, with and average of 5 persons per dwelling unit.

CHAPTER II - DATA COLLECTION

In order to obtain the required data for this and other studies, residential areas in San Juan, Ponce,and Mayaguez, P.R. were sampled (7, pp. 5-6, 75-76).

A suitable questionnaire was designed to cover data on socio-economic and demographic factors which are known to influence residential water use (7, pp. 6, 10).

Information collected via this questionnaire, together with assessed property valuations data and water use data, secured from the Puerto Rico Bureau of the Property Assessment and the Puerto Rico Aqueduct and Sewer Authority, served as the basis for the determination of equivalent water-use design indices and model-building purposes in previous studies (5,7).

In order to simplify data manipulation, all the information from the filled questionnaires was codified and punch into computer cards. These cards were then processed to produce the required water-use indices, preliminary water-use models, water-use ratios and graphical base data (7 pp. 15).

Since the assessed property value is not used as a factor in the present study, the data collected did not include any reference to it. As mentioned before, the data considered in this study is that which refers to the number of bedrooms per dwelling unit, the equivalent index of bathroom water-using facilities, the home density (number of people per dwelling unit), and the bedroom density (number of people per bedroom in each dwelling unit).

In one of the previous studies (5), water quality and pressure were also analyzed to determine if they had any influencing effect on residential water usage. In that study the term water quality was intended to mean "the degree of hardness". Investigations revealed that it was controlled to a point of "no significant effect" on water use.

To study the possible effect of water pressure on water usage, data was collected to reflect variations in water pressure for several weeks in eight private urbanizations in Mayaguez, P.R. The data thus collected was subject to analysis of variance under a "nested hierarchical" experiment (5, pp. 17-20).

The tests of hypothesis conducted did not show any significant effect of water pressure on residential water use in the areas studied.

In the collected data, the term "private urbanization dwelling" refer to the Puerto Rico Bureau of the Property Assessment Building classification code 6, use types A or B, construction class three, subclasses 3, 4, 5 or 6 (7. pp. 7).

CHAPTER III - EQUIVALENT WATER-USE INDICES

To transform water-meter readings data into a form suitable for the required analyses two water-use indices were generated: The equivalent "gallons per day per dwelling unit" and the "equivalent gallons per capita daily". These units are referred-to in this document as gpd and gpcd,respectively.

These indices are determined by converting the periodic (monthly or bi-monthly) water-use in cubic meters to its equivalent in gallons as related to the per dwelling or per capita units (7, pp. 14-18).

A periodic cycle of 60.6 days was estimated as the most suitable time period for the determination of the required indices.

These indices are then associated to the periods of average and maximum water usage, and thereafter referred-to as "gpd in AVEMO". These stand for gallons per day per dwelling unit computed from the average or maximum water metering periods, respectively. Many concerned computer print-outs, tables, charts and graphs make reference to them.

The indices gpd and gpcd are important parameters in the design of water distribution systems.

CHAPTER IV - GRAPHICAL ANALYSIS OF ALTERNATE MODEL FACTORS

Water-use index data together with alternate factors information are subject to graphical analysis in order to disclose possible functional relationships.

4.1 Water-Use Index Trends as a Basis for the Appraisal of Significant Relationships.

The method employed for the graphical analysis of water use index data was based on the plotting of trend curves and scattergrams.

Some of these charts were constructed directly from basic water-use index data. Others were built on the basis of stratified data; each strata being represented by the average magnitude of the corresponding water-use index, and formed around each level of the alternate water use factor under consideration.

It could be seen, from the observation of most of the water-use-index trend charts in this chapter, that water-use in gallons per day per dwelling unit, tends to increase in a definite upward linear trend when going from lower alternate factor values to higher ones. This happens in equivalent months of average water use (AVEMO) and the corresponding maximum (MAXMO) . Something similar happens to water-use in gallons per capita daily but with a lesser upward trend. This behavior points towards the existence of a significant functional relationship between water use and some of the alternate water-use factors studied.

The factorial analysis of Chapter V shows, that only two of the alternate water-use factors studied, turned out to be significant, namely: the number of bedrooms per dwelling unit, and the equivalent index of bathroom water-using fixtures.

4.2 Dwelling and Bedroom Population Density

The results of the factorial analysis of Chapter V point towards the fact that the number of bedrooms per dwelling unit has a significant effect on water usage when accompanied by an equally high number of people per dwelling unit to insure adequate occupancy of most bedrooms.

In order to investigate further about this fact, the collected samples were analyzed and the average number of people per dwelling and per bedroom were related to the number of bedrooms per dwelling unit.

Figures 4.1 to 4.3 present the graphical forms of the observed relationship for San Juan, Ponce and Mayaguez, respectively. Figure 4.4 shows a graphical comparison of the three factors, for the samples collected in the three cities mentioned above. Table 4.1 present a comparative summary of the same factors.

The results presented in figures 4.1 to 4.4 show that as the average number of bedrooms per dwelling unit increases, there is a corresponding increase in the average number of people per dwelling unit, even though the average number of people per bedroom somehow diminishes. These results give another strong indication of the significant effect of the number of bedrooms per dwelling unit on residential water usage, and go along with the results obtained in the factorial analysis of Chapter V, as presented on Table 5.3.

4.3 Water Use in Relation to the Number of Bedrooms per Dwelling

In order to preliminarily ascertain the form of the relationship between water use and the number of bedrooms per dwelling unit, graphs were also plotted.

Figures 4.5 to 4.10 present the plotted graphs for San Juan, Ponce, and Mayaguez, respectively, in the gallons per day per dwelling unit and gallons per capita cases, and in the equivalent months of average and maximum water use. Figures 4.11 and 4.12 show a graphical comparison of the relationship in the three cities studied. Tables 4.2 to 4.5 also depict these results.

It could be inferred from the observation of these graphs that as the number of bedrooms per dwelling unit increases there is a correspondingly strong increase in the amount of residential water usage in gallons per day per dwelling unit. A light relationship is in addition suspected, on the average, for the gallons per capita daily case, mainly in the equivalent month of average water use (AVEMO). These graphical results, correlate well with those derived from the analysis of Chapter V.

4.4 Water Use in Relation to the Equivalent Number of Bathroom Water-Using Facilities

As in the case of the number of bedrooms per dwelling unit, the equivalent number of bathroom water-using facilities (as explained in section 1.1) were graphically analyzed. Figures 4.13 and 4.14 depict a sample result of this analysis. Table 4.6 summarize the corresponding numerical results. The sample shown pertains to the analysis of the Mayaguez, Puerto Rico case. Similar results correspond to Ponce and San Juan, Puerto Rico.

Again these graphs exhibit a relationship by which water usage increases as the equivalent number of bathroom water-using fixtures increases. This result agrees strongly with the highly significant relationship obtained for this water-use factor in the factorial analysis of Chapter V.

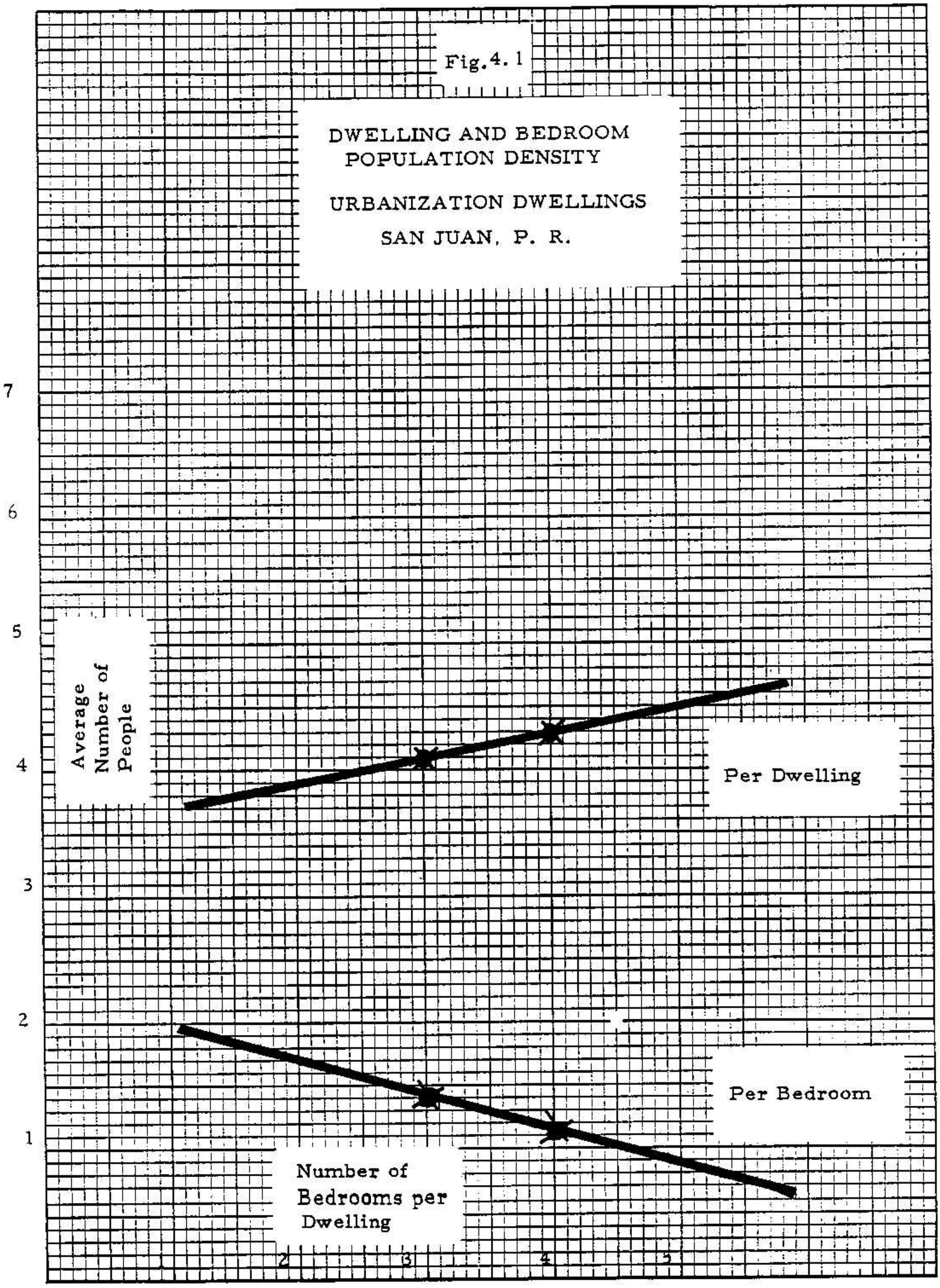


Fig. 4.1

DWELLING AND BEDROOM POPULATION DENSITY

URBANIZATION DWELLINGS

SAN JUAN, P. R.

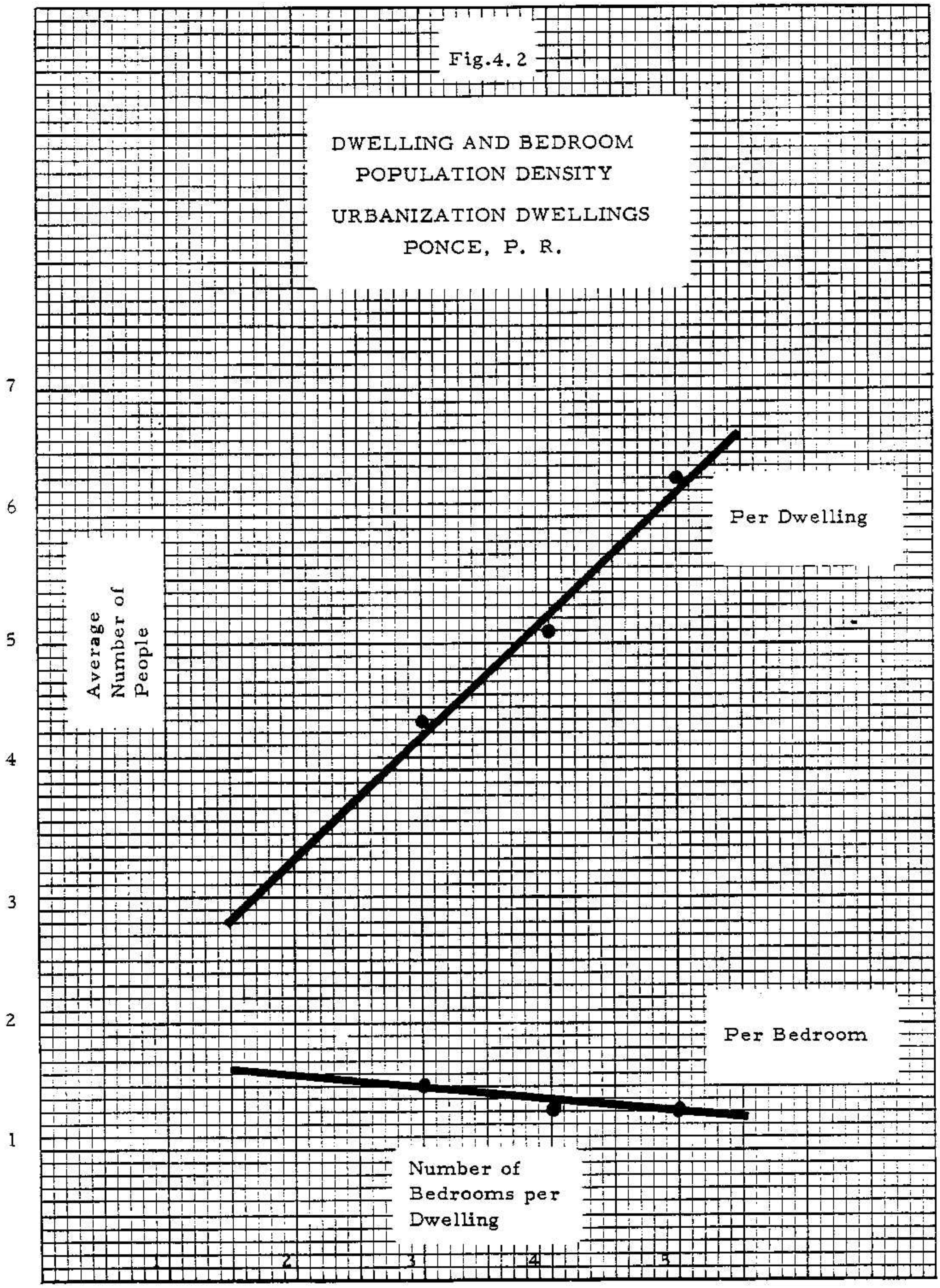
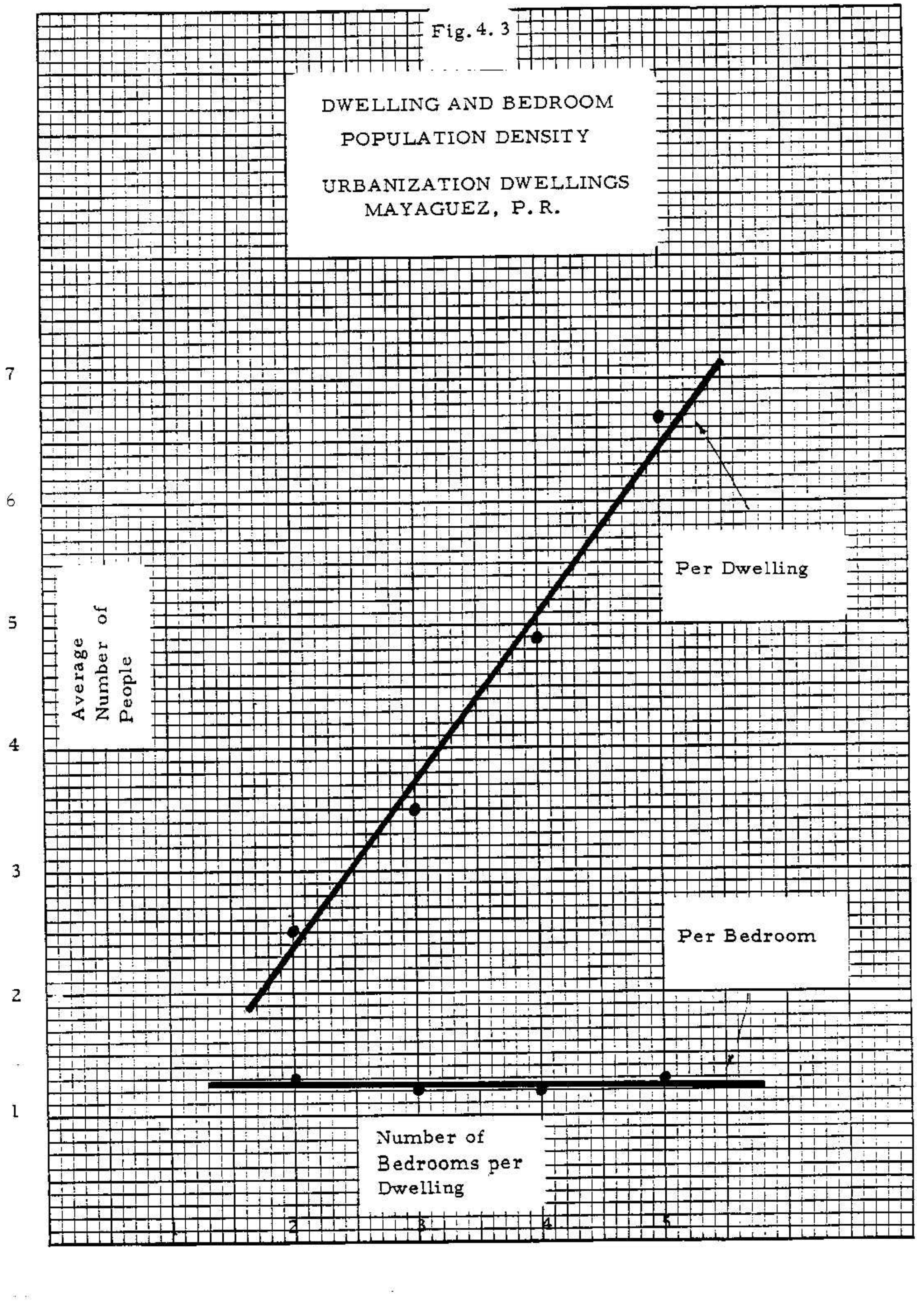


Fig.4.2

DWELLING AND BEDROOM POPULATION DENSITY
URBANIZATION DWELLINGS
PONCE, P. R.

Fig. 4.3


DWELLING AND BEDROOM
POPULATION DENSITY
URBANIZATION DWELLINGS
MAYAGUEZ, P.R.
Per Dwelling
Per Bedroom
Average Number of People
Number of Bedrooms per Dwelling
7
6
5
4
3
2
1
1
2
3
4
5

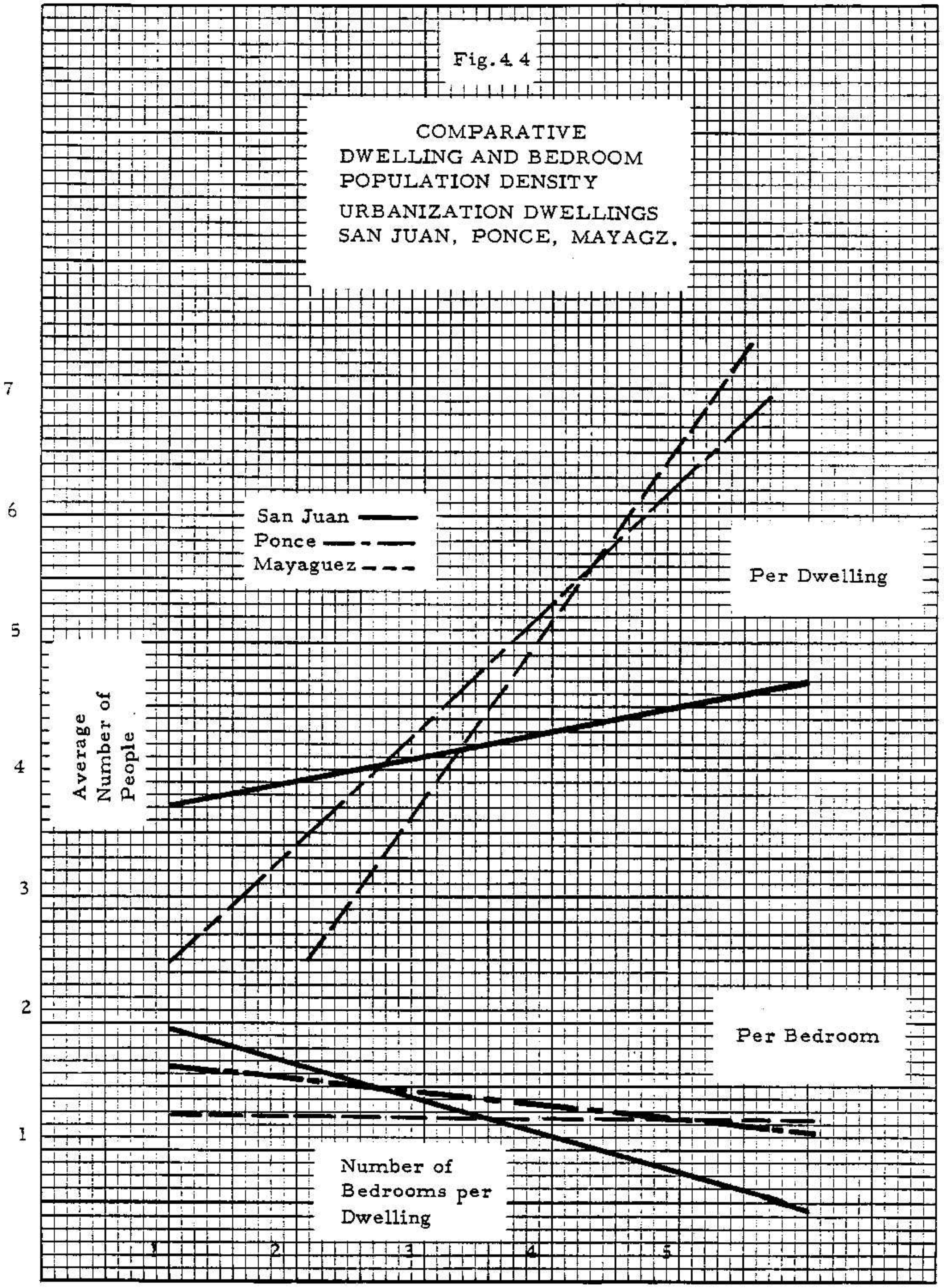


Fig. 4.4

COMPARATIVE DWELLING AND BEDROOM POPULATION DENSITY URBANIZATION DWELLINGS SAN JUAN, PONCE, MAYAGZ.

TABLE 4.1

Comparative Summary of Bedroom and Dwelling Density
San Juan, Ponce, and Mayaguez, Puerto Rico

Characteristic Density	City	Number of Bedrooms per Dwelling			
		2	3	4	5
Average Number of People per Bedroom	San Juan	-	1.4	1.1	-
	Ponce	-	1.5	1.3	1.3
	Mayaguez	1.3	1.2	1.2	1.3
Average Number of People per Dwelling	San Juan	-	4.1	4.3	-
	Ponce	-	4.4	5.1	6.3
	Mayaguez	2.5	3.5	4.9	6.7

Fig. 4.5

WATER USE IN RELATION
TO NUMBER OF BEDROOMS

URBANIZATION DWELLINGS
SAN JUAN, P. R.
AVEMO

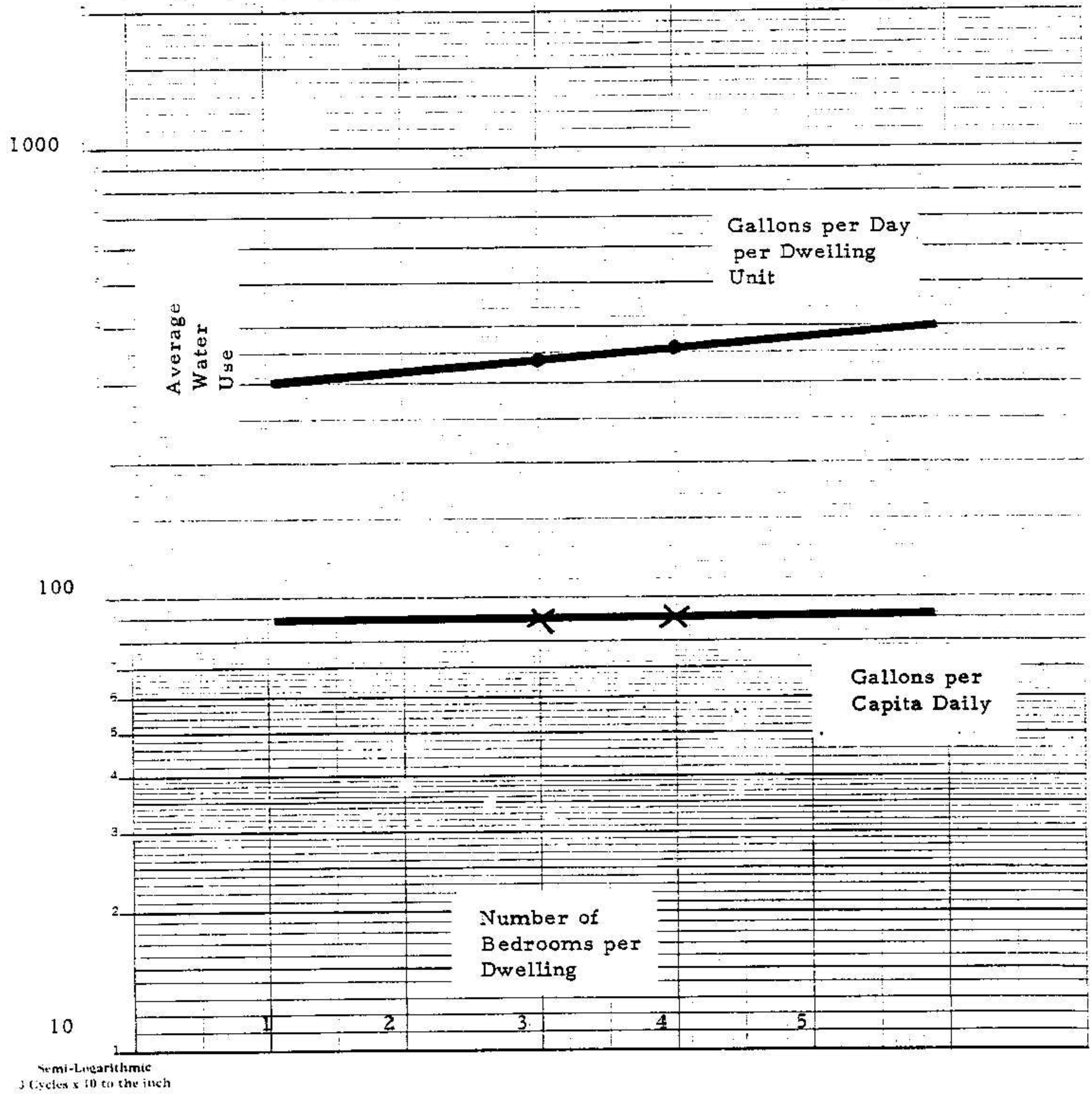


Fig. 4. 6

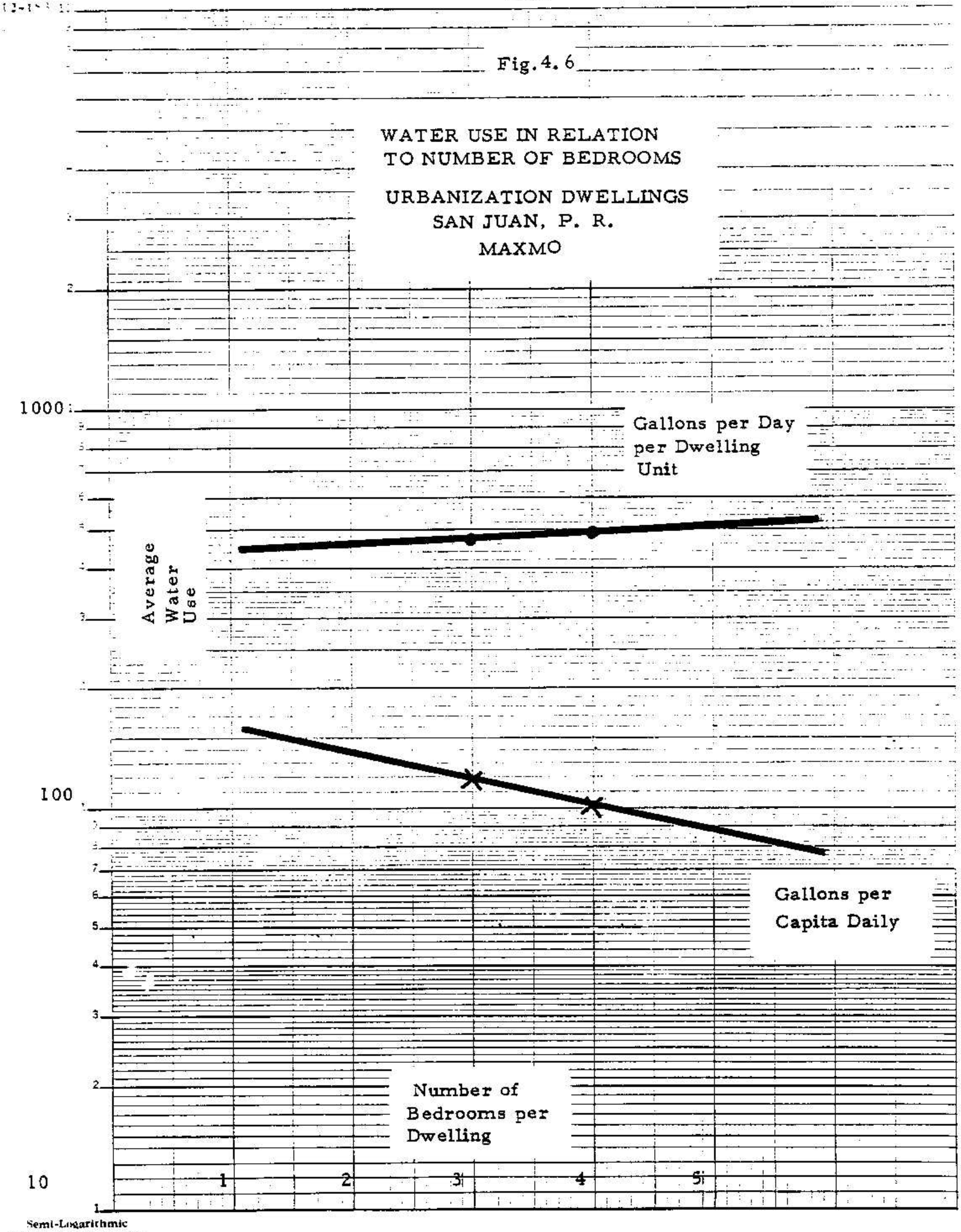

WATER USE IN RELATION TO NUMBER OF BEDROOMS
URBANIZATION DWELLINGS
SAN JUAN, P. R.
MAXMO
1000
100
10
Average Water Use
Gallons per Day per Dwelling Unit
Gallons per Capita Daily
Number of Bedrooms per Dwelling
1
2
3
4
5
Semi-Logarithmic
3 Cycles x 10 to the inch

TABLE 4.2

Summary of Some Results of the Analysis of a Sample of Urbanization Dwellings in San Juan, Puerto Rico

WATER USE IN GPD AND GPCD

Water System Design Index	Equivalent Month	NUMBER OF BEDROOMS PER DWELLING			
		2	3	4	5
gpd	AVEMO	-	338	360	-
	MAXMO	-	475	490	-
gpcd	AVEMO	-	90	91	-
	MAXMO	-	120	100	-

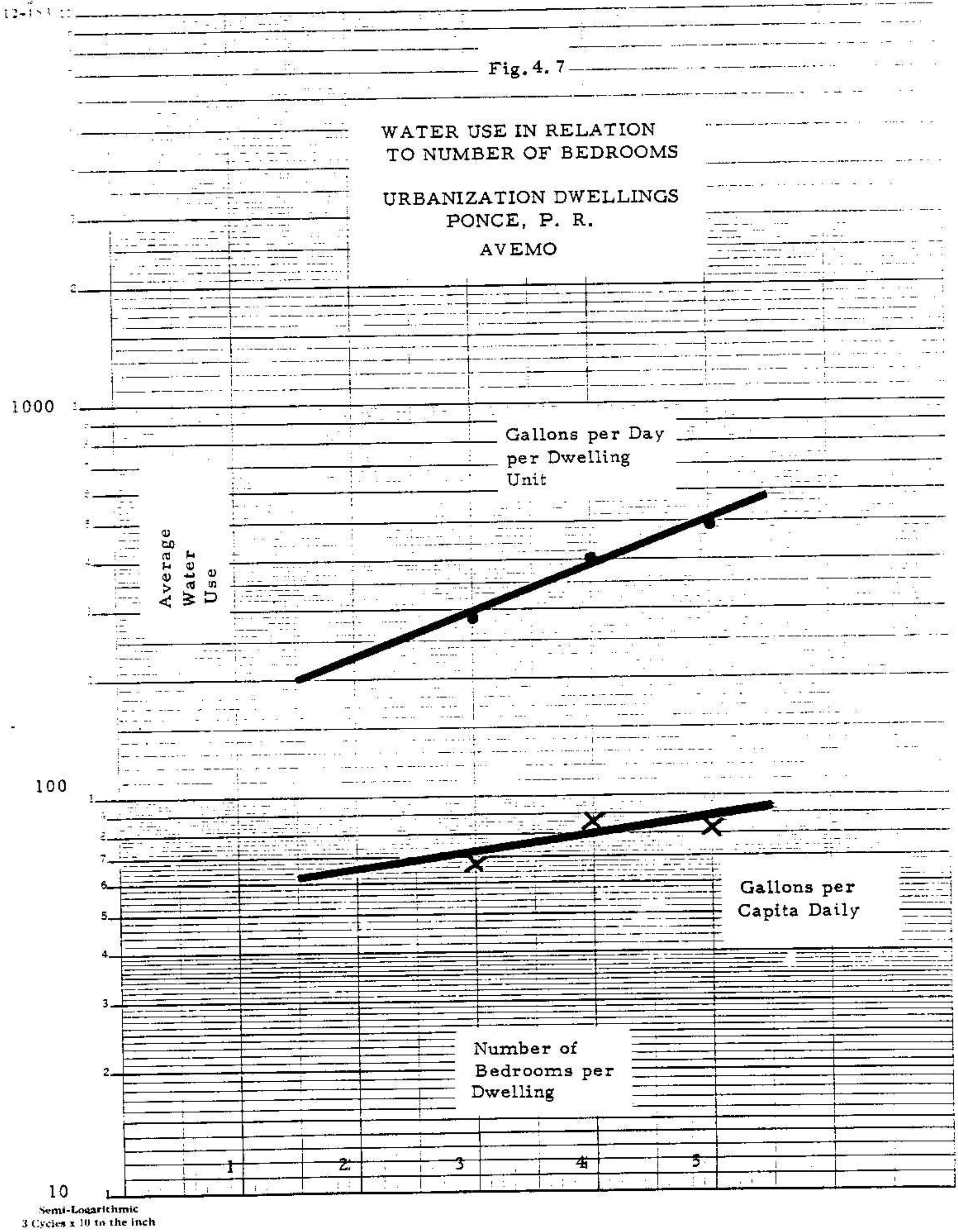


Fig. 4. 7

WATER USE IN RELATION TO NUMBER OF BEDROOMS

URBANIZATION DWELLINGS
PONCE, P. R.
AVEMO

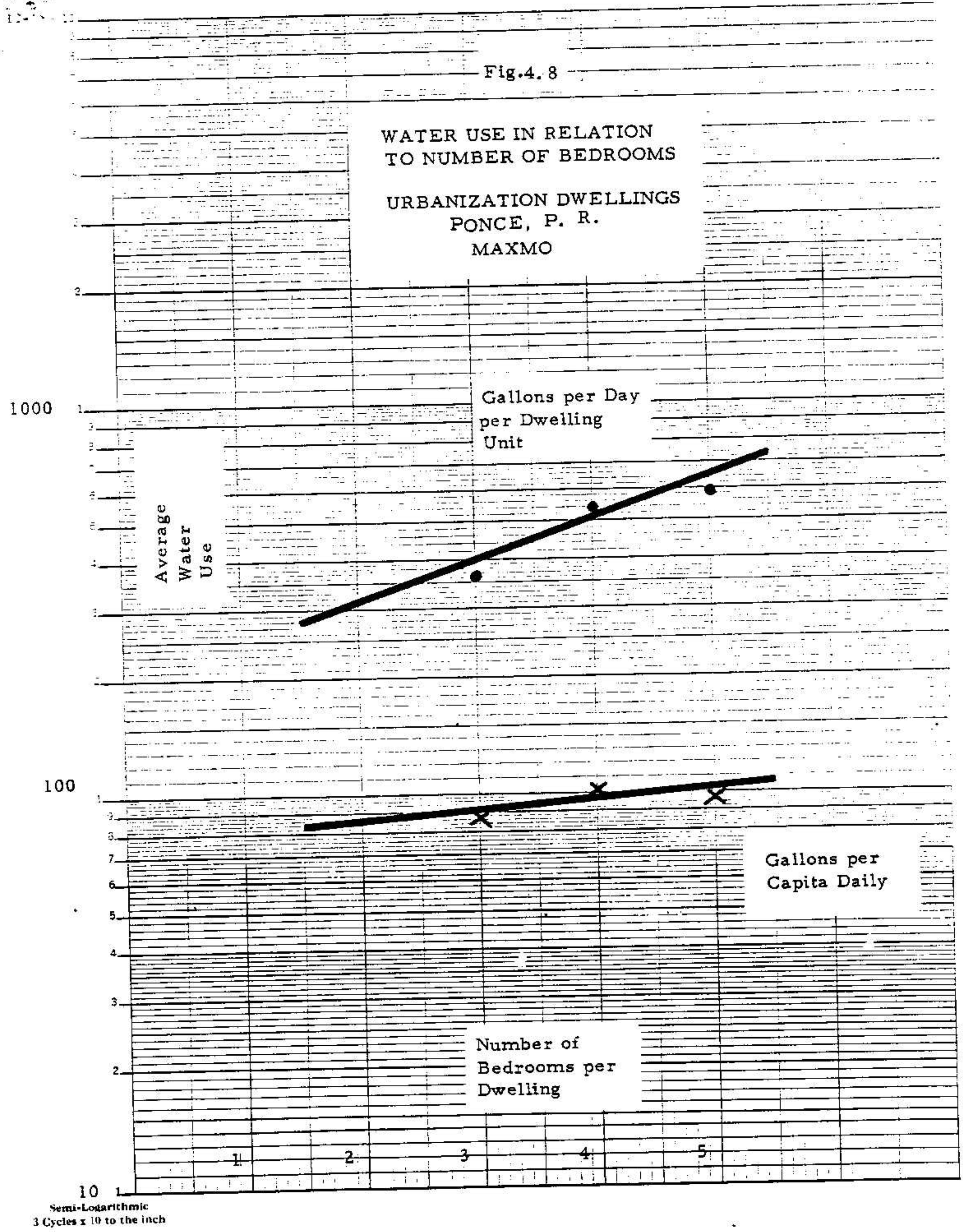


Fig.4.8

WATER USE IN RELATION TO NUMBER OF BEDROOMS

URBANIZATION DWELLINGS
PONCE, P. R.
MAXMO

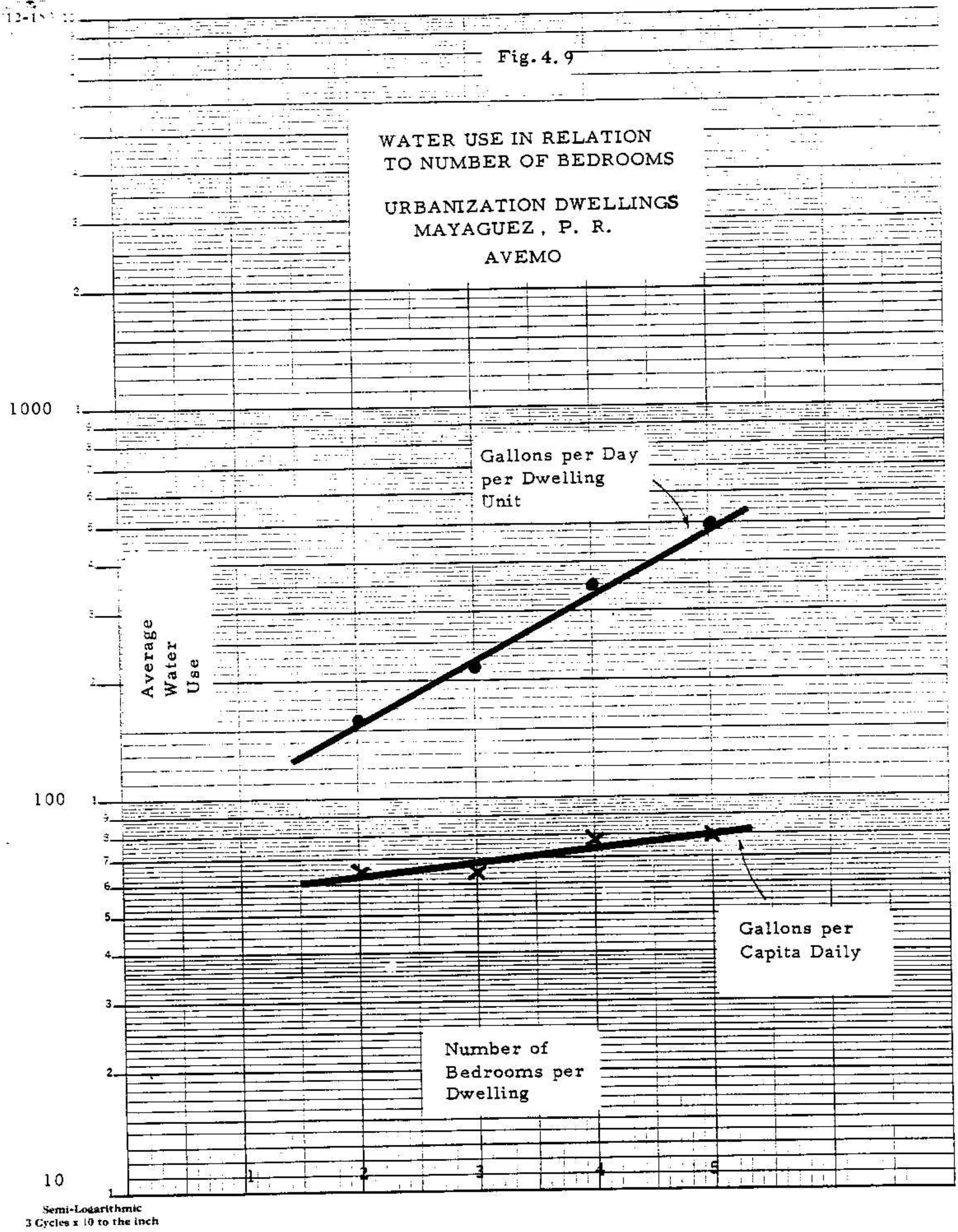
TABLE 4.3

Summary of Some Results of the Analysis of a Sample of Urbanization Dwellings in Ponce, Puerto Rico

WATER USE IN GPD AND GPCD

Water System Design Index	Equivalent Month	NUMBER OF BEDROOMS PER DWELLING			
		2	3	4	5
gpd	AVEMO	-	289	411	490
	MAXMO	-	364	542	580
gpcd	AVEMO	-	68	86	82
	MAXMO	-	87	101	96

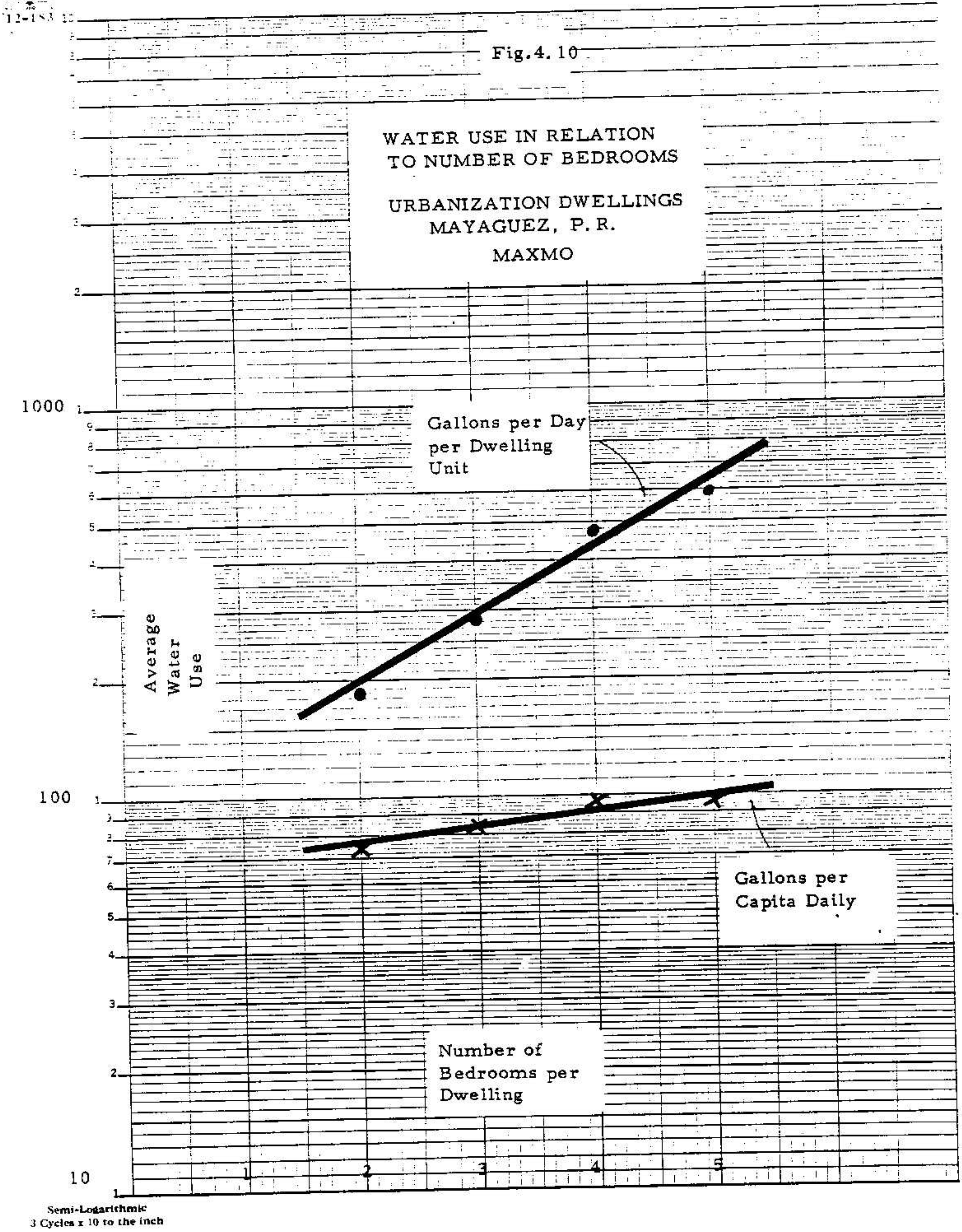
Fig. 4. 9



WATER USE IN RELATION TO NUMBER OF BEDROOMS

URBANIZATION DWELLINGS
MAYAGUEZ, P. R.
AVEMO

Fig.4. 10



WATER USE IN RELATION TO NUMBER OF BEDROOMS

URBANIZATION DWELLINGS
MAYAGUEZ, P. R.
MAXMO

TABLE 4.4

Summary of Some Results of the Analysis of a Sample of Urbanization Dwellings in Mayaguez, Puerto Rico

WATER USE IN GPD AND GPCD

Water System Design Index	Equivalent Month	NUMBER OF BEDROOMS PER DWELLING			
		2	3	4	5
gpd	AVEMO	162.5	218.0	352.0	500.0
	MAXMO	183.0	282.0	440.0	593.0
gpcd	AVEMO	66.5	64.0	77.0	79.0
	MAXMO	74.0	83.0	96.0	95.0

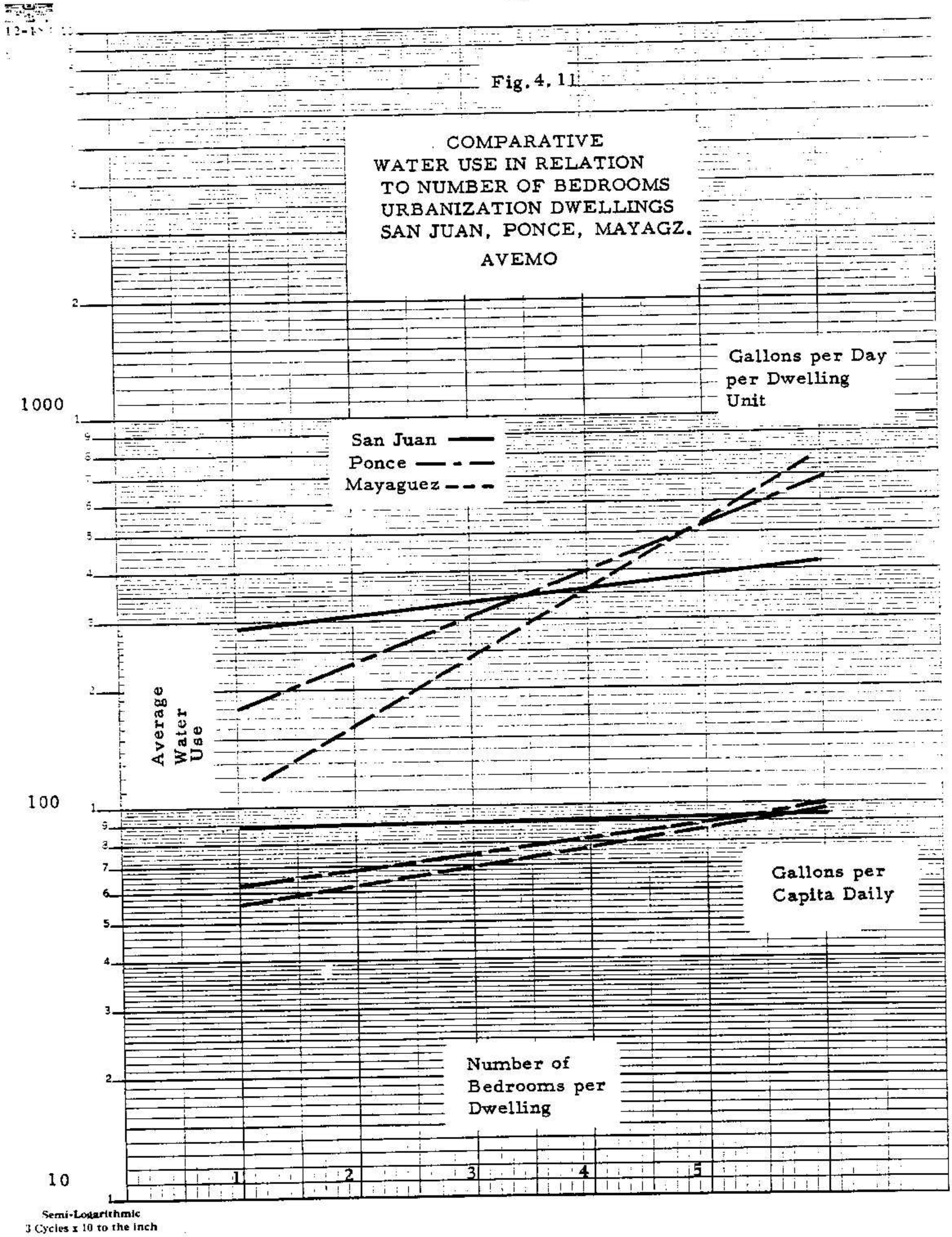


Fig. 4.11

COMPARATIVE WATER USE IN RELATION TO NUMBER OF BEDROOMS URBANIZATION DWELLINGS SAN JUAN, PONCE, MAYAGZ.

AVEMO

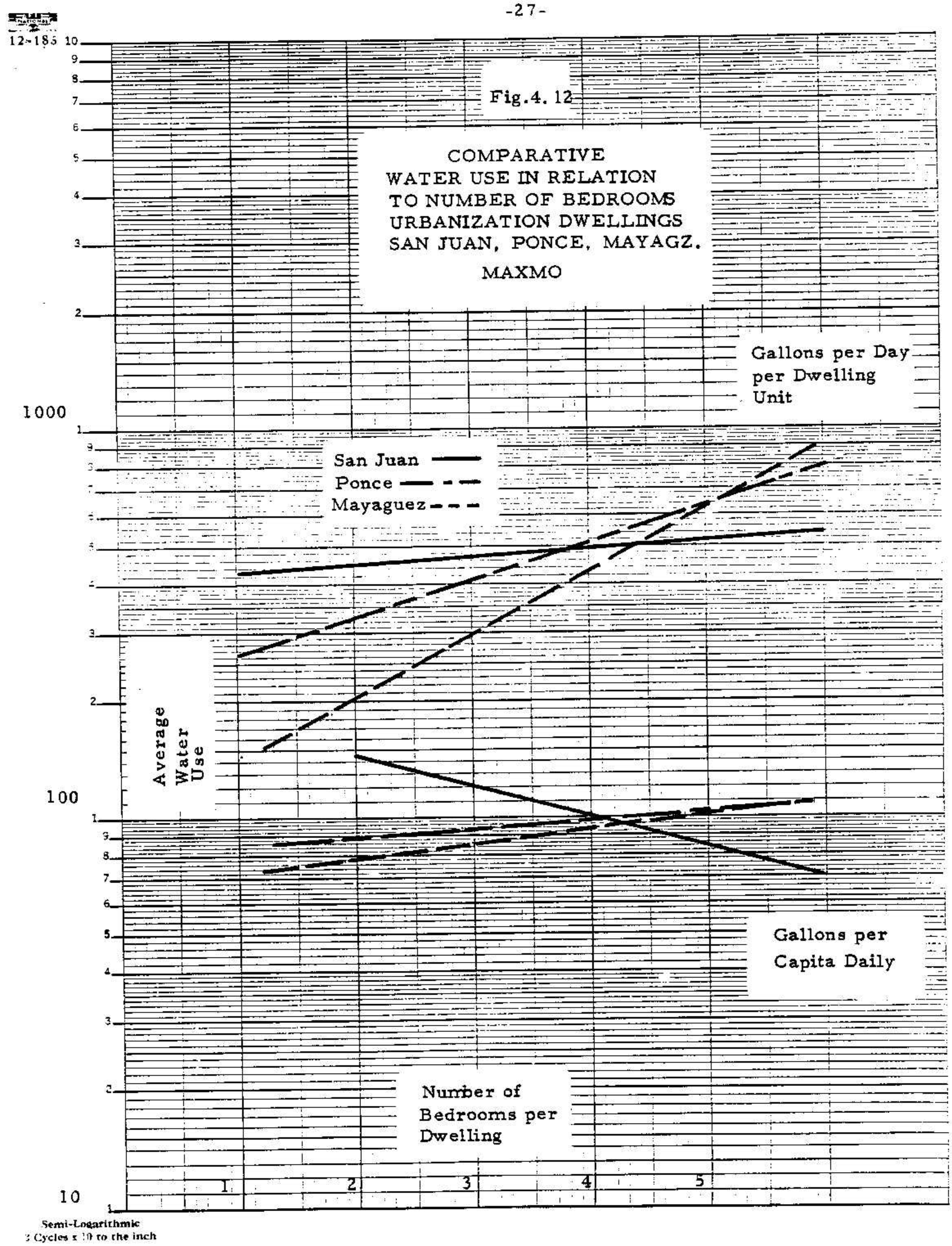


Fig.4. 12

COMPARATIVE
WATER USE IN RELATION
TO NUMBER OF BEDROOMS
URBANIZATION DWELLINGS
SAN JUAN, PONCE, MAYAGZ.
MAXMO

TABLE 4.5

Comparative Summary of The Results from the Analysis of Samples San Juan, Ponce and Mayaguez, P. R.

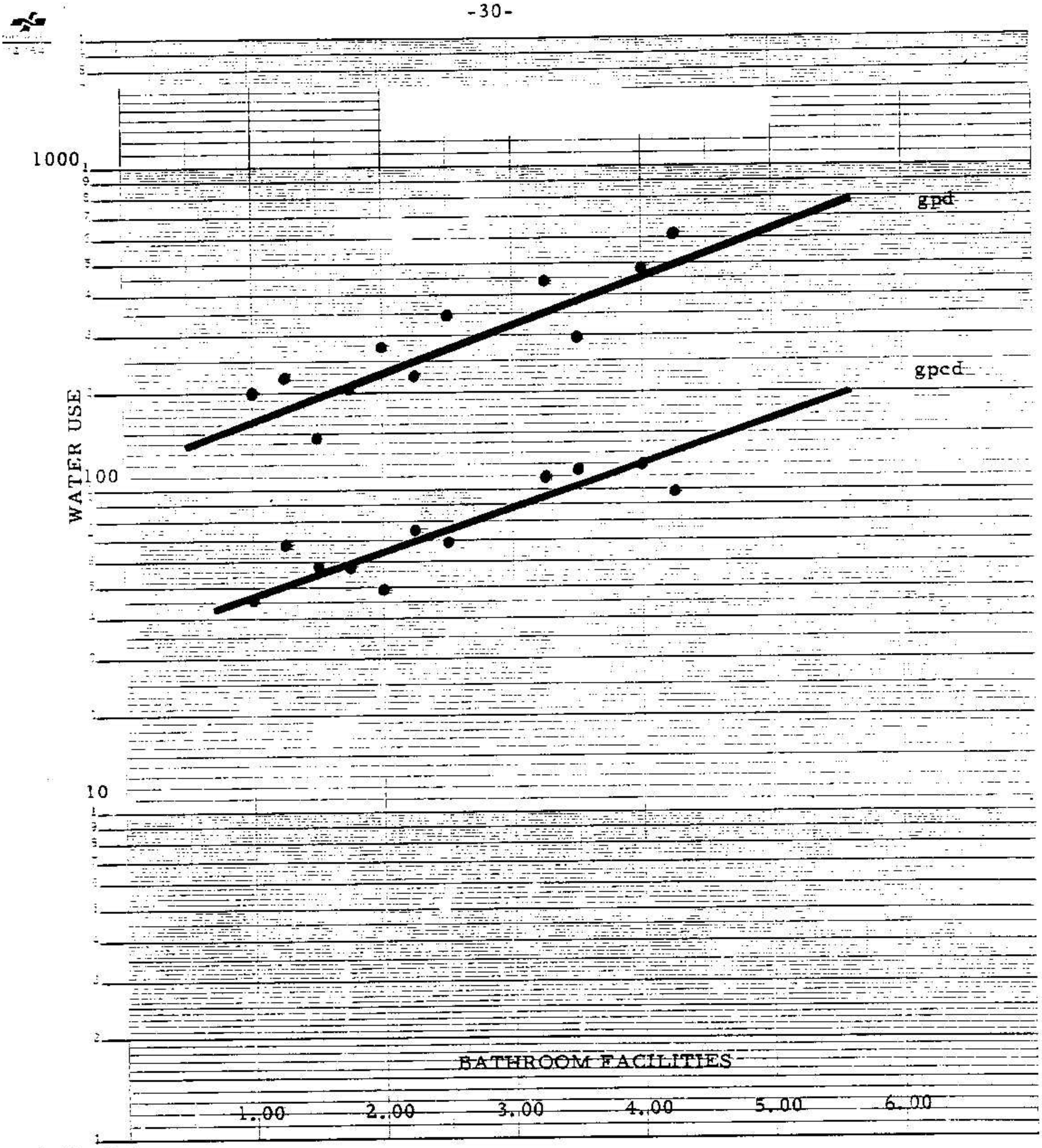
WATER USE IN GPD AND GPCD

Water System Design Index	Equivalent Month	City	NUMBER OF BEDROOMS PER DWELLING			
			2	3	4	5
gpd	AVEMO	San Juan	-	338	360	- -
		Ponce	-	289	411	490
		Mayaguez	163	218	352	500
	MAXMO	San Juan	-	475	490	-
		Ponce	-	364	542	580
		Mayaguez	183	282	440	593
gpcd	AVEMO	San Juan	-	90	91	-
		Ponce	-	68	86	82
		Mayaguez	67	64	77	79
	MAXMO	San Juan	-	120	100	-
		Ponce	-	87	101	96
		Mayaguez	74	83	96	95

TABLE 4.6

Water Use and Bathroom Water-Using Facilities
Mayaguez, P. R.

Equivalent Bathroom Facilities	gpd		gpcd	
	AVEMO	MAXMO	AVEMO	MAXMO
1.00	201	256	46	62
1.25	226	302	68	88
1.50	147	200	58	82
1.75	203	248	57	70
2.00	274	342	49	60
2.25	224	308	76	103
2.50	349	422	69	84
3.25	445	573	110	145
3.50	297	343	116	135
4.00	481	575	120	143
4.25	618	706	99	116



Semi-Logarithmic
4 Cycles x 10 to the Inch

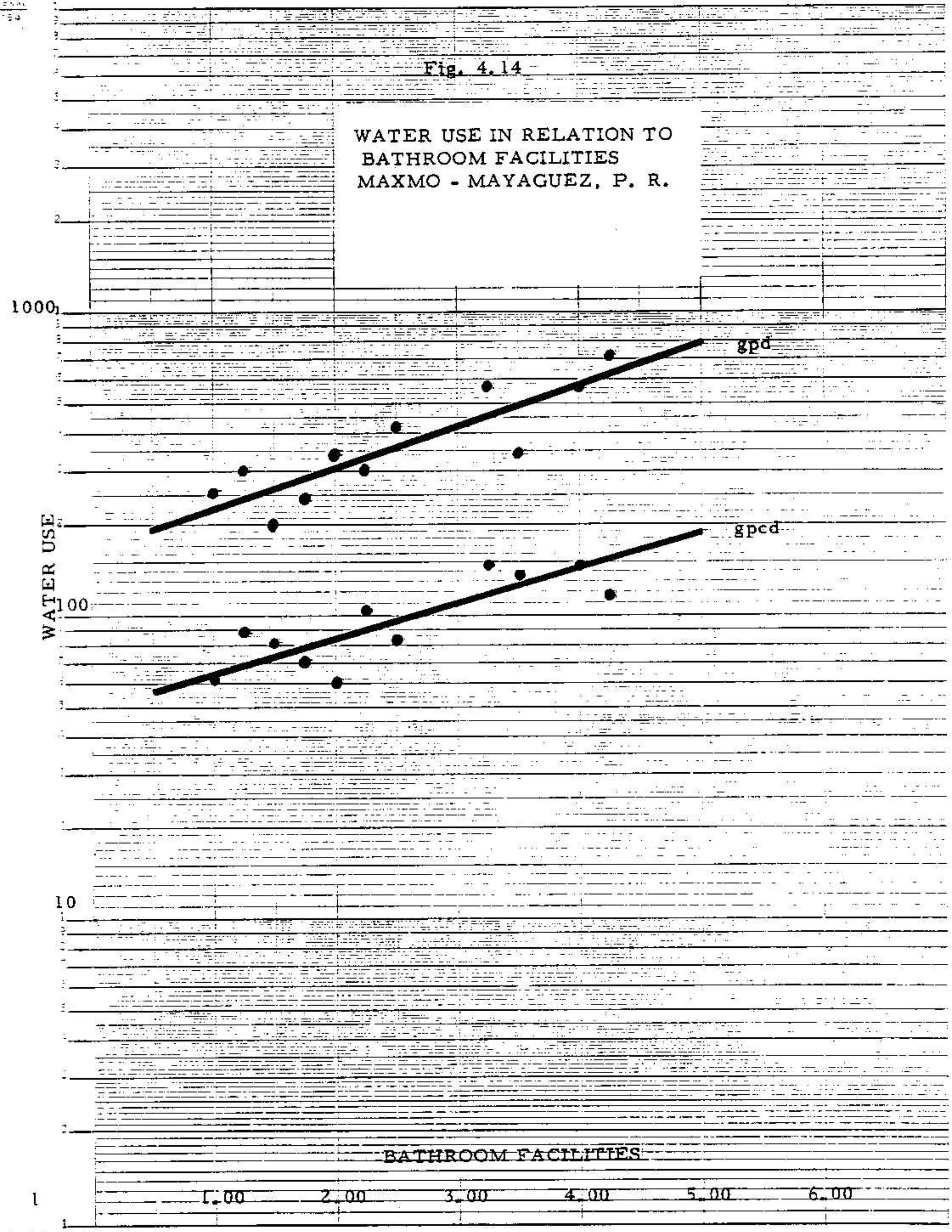


Fig. 4.14

WATER USE IN RELATION TO
BATHROOM FACILITIES
MAXMO - MAYAGUEZ, P. R.

Semi-Logarithmic
4 Cycles x 10 to the inch

4.5 Model Form as Inferred from the Preceeding Graphical Analyses

The preceeding graphs show both significant alternate water-use factors in relation to water usage plotted in a semi-logarithmic background. The corresponding trend curve appears as (approximately) a straight line. Whenever a behavior like this is observed between two variables, it could be concluded that the corresponding functional relationships belongs to a family of exponential functions, whose general form is

$$W = \alpha e^{KB} \tag{4.1}$$

and

$$W = \alpha e^{KF} \tag{4.2}$$

respectively, where W stands for water use, α and e^K are two model parameters, e is the base of the natural logarithms system, K is a model parameter constant, B is the number of bedrooms per dwelling unit and F is the equivalent number of bathroom water-using facilities.

CHAPTER V - FACTORIAL ANALYSIS

In order to investigate the possible effect of alternate factors on water use in the areas under study, a factorial experiment was conducted.

Succeeding sections describe in detail the analyses conducted and the results obtained.

5.1 Factors Studied

Four alternate water use factors were considered: number of bedrooms per dwelling, equivalent index of bathroom water-using fixtures, equivalent home density (people per dwelling unit) and equivalent room density (number of people per bedroom). Each of these factors was studied at two levels.

5.2 Levels of Factors

For the purposes of this study, dwellings with two or three bedrooms were taken as pertaining to the low or "zero" level of the number of bedrooms per dwelling factor. Those with four or five bedrooms were allocated at the high or "one" level.

Similarly, dwellings with an equivalent index of bathroom water-using fixtures of 1.00 to 2.00 belong to the "zero" level and those with an index of 3.00 to 4.25 are part of the "one" level.

In the home density factor, 2 to 3 people per dwelling define level "zero" and 4, 5 or more pertain to level "one".

Equivalent room densities of 0.67 to 1.00 and 1.33 to 2.25 form levels "zero" and "one", respectively, in the number of people per bedroom factor.

5.3 "Treatment" Combinations

Sixteen treatment combinations were studied. These are depicted in Table 5.1, where B is bedrooms per dwelling unit, F is the equivalent index of bathroom water-using fixtures, H is the equivalent home density and R is the equivalent bedroom density. In all cases the subscripts 0 and 1 represent the factor levels studied. Capital letters represent factors and small letters are treatment combinations when the corresponding factors are treated at the "one" level. The "(1)" is that treatment combination where all factors are at the "zero" level.

TABLE 5.1

Treatment Combinations Four Factors each at Two Levels

Factors ↓	Treatment Combinations	B_0		B_1	
		F_0	F_1	F_0	F_1
H_0	R_0	(1)	f	b	bf
	R_1	r	fr	br	bfr
H_1	R_0	h	fh	bh	bfh
	R_1	hr	fhr	bhr	bfhr

5.4 "Response" to Treatment

The response to treatments was obtained by selecting, from within the sample of dwellings considered in this study, those with the required combination of factors at the stated levels. For each case, the gallons per day per dwelling unit and the gallons per capita daily at the equivalent months of average and maximum water use (gpd and gpcd in AVEMO and MAXMO), were determined.

TABLE 5.2

Response to Treatments

Treatment Combination	gpd		gpcd	
	AVEMO	MAXMO	AVEMO	MAXMO
(1)	145	200	48	66
b	292	392	97	130
f	207	252	103	126
bf	368	445	184	222
h	160	201	40	50
bh	219	270	54	67
fh	408	462	102	116
bfh	252	270	50	54
r	177	209	59	69
br	264	348	88	116
fr	222	235	74	78
bfr	411	453	103	113
hr	324	392	81	98
bhr	217	252	72	84
fhr	527	584	131	146
bfhr	549	802	91	133

5.5 Estimation of Main Effects and Interactions

Yate's method was used to obtain estimates of main effects and interactions. The method was applied to each column of responses in Table 5.2 so as to obtain an estimate of eight times the value of each main effect and interaction. These estimates are then used in the tests of significance presented in next section.

5.6 Testing for Significance of Main Effects and Interactions

The critical value w for the testing of main effects and interactions was determined from

$$w = (2^{n})^{1/2} \; t_{(1-\alpha/2)} \, S \qquad (5.1)$$

where n is the number of factors, t is the t- Distribution factor for an α level of significance and five degrees of freedom (corresponding to the five interactions of third or higher order that are present among four factors), and S is the square root of the estimate of variation due to experimental error, obtained from

$$S^2 = \frac{\sum g^2_{*}}{2^{n} \, \nu} \qquad (5.2)$$

where $\sum g^2_{*}$ is the sum of the squares of third or higher order interaction and ν degrees of freedom.

If the absolute value of a given main effect or interaction g_x was greater than the critical value w, g_x was considered a "significant effect or interaction", otherwise it was deemed "not significant", that is:

$$\text{If} \quad |g_x| > w \quad \therefore \quad \text{Significant} \qquad (5.3)$$

$$\text{If} \quad |g_x| \leq w \quad \therefore \quad \text{Not Significant} \qquad (5.4)$$

Table 5.3 summarize the results of testing for significance of main effects and interactions at the significance levels of 1% and 5% respectively.

TABLE 5.3

Results of Testing for Significance of Main Effects and Interactions**

Significance Levels = 1% and 5%

Treatment Combinations	gpd				gpcd			
	AVEMO		MAXMO		AVEMO		MAXMO	
	1%	5%	1%	5%	1%	5%	1%	5%
(1)								
b								
f	S	S		S		S		S
bf								
h								
bh		S				S		S
fh								
bfh								
r								
br								
fr								
bfr								
hr						S		S
bhr								
fhr								
bfhr								

** S means "Significant"

** Blank entries mean "Not Significant"

CHAPTER VI - GENERATION OF ALTERNATE WATER USE MODELS AND THE APPLICATION OF PEAK RATIOS

The preceeding chapters analyzed the collected data in order to disclose any significant relationship between the factors under study. The factorial analysis of Chapter V and the previous graphical studies of Chapter IV show that the only two significant alternate water-use factors were the number of bedrooms per dwelling unit and the equivalent number of bathroom water-using facilities. This chapter deals with the construction of the corresponding water-use models for residential dwelling units. Since the present study is a complement of a previous main study, reference should be made to it for more details on tests conducted (5,7).

6.1 Alternate Model Generation Analyses

A computer program was prepared to conduct the required analysis to generate alternate water-use models (5). This program uses as input master data cards punched with the collected data on dwelling characteristics and water use; one card per dwelling unit in the sample collected in each city. The output of this program is composed of dwelling characteristics in table format, with property value, water usage, regression computational elements, model parameter estimates, alternate models, a regression plotback table, an analysis of variance table, variance estimates confidence limits for model parameters, and the computed test-of-hypothesis values for Students t and Fisher's F distributions. To simplify the required calculations, equations 4.1 and 4.2 were changed to their reduced form:

$$\ln W = \ln \alpha + KB \qquad (6.1)$$

and

$$\ln W = \ln \alpha + KF \qquad (6.2)$$

where ln stands for the natural logarithm. By redefining $\ln W$ and $\ln \alpha$ as W_L and α_L, the new model parameters are α_L and K, which are identified in computer output as LNA and LNB respectively, for each alternate model generated.

Exhibit 6.1 presents a sample of the analysis conducted and the results obtained. They contain certain abbreviations which have the following meaning:

KSELEC - an indicator of the water-use index for a given month of water usage, that is being used for model development purposes. For example KSELEC = 5 refers to the employment of the number of gallons per capita daily of water usage in an equivalent month of average use.

MINMO - equivalent, month of minimum water usage.

AVEMO - equivalent month of average water usage.

MAXMO - equivalent month of maximum water usage.

W - estimated equivalent monthly water use, when obtained from the developed model.

V - property assessed value. Includes both the house and its lot.

A, B - main model parameters.

LNA, LNB - the natural logarithms of the evaluated model parameters.

LNW - the natural logarithm of the observed water-use value.

LNWH - the natural log. of the estimated water use value (from water-use model).

DLNWH - the difference between the observed and estimated natural logs. of water-use values.

DLWH2 - the square of DLNWH.

SDLWH - the sum of all DLNWH values (algebraic sum).

SDLWH2 - the sum of all DLWH2 values.

TPRDF - t-distribution percent confidence levels (80, 90, 95 and 99% respectively).

T, F - test-of-hypotheses parameters for comparison with Student's -t and Fisher's -F distribution critical values respectively.

EXHIBIT 6.1
SAMPLE OF THE ANALYSIS

```
UNIVERSITY OF PUERTO RICO
WATER RESOURCES RESEARCH INSTITUTE
MAYAGUEZ, PUERTO RICO


       OUTPUT OF EXPONENTIAL REGRESSION-MODEL ANALYSIS PROGRAM


EXPONENTIAL REGRESSION-MODEL ANALYSIS FOR SOME SELECTED DWELLING CHARACTE-
RISTICS WITH, ANALYSIS OF VARIANCE, REGRESSION PLOTBACK, VARIANCE ESTI-
MATES FOR MODEL PARAMETERS CONFIDENCE INTERVALS, AND TESTS OF HYPOTHESES.
PROFESSOR A. GUILBE, INDUSTRIAL ENGINEERING DEPARTMENT/WATER RESOURCES
RESEARCH INSTITUTE.


RESIDENTIAL WATER-USE PROJECT
PILOT        MAYAGUEZ       URBANIZATION DWELLINGS
SOME SELECTED DWELLING CHARACTERISTICS

INDIVIDUAL  NUMBER OF   PER DWELLING DAILY USE     PER CAPITA DAILY USE
 DWELLING   BEDROOMS       IN GALLONS FOR             IN GALLONS FOR
   I. D.    PER DWG.    MINMO    AVEMO    MAXMO     MINMO    AVEMO    MAXMO
 -41  -9        3.        96.     131.     157.       32.      44.      52.
 -41-10         3.       105.     144.     218.       21.      29.      44.
 -51-37         4.       166.     219.     270.       41.      55.      68.
 -51-35         5.       218.     264.     366.       31.      38.      52.
 -51-36         3.       122.     163.     192.       41.      54.      64.
 -42  -2        3.        87.     116.     192.       44.      58.      96.
 -42  -5        3.       122.     263.     602.       31.      66.     150.
 -42  -4        3.       218.     256.     296.       54.      64.      74.
 -41  -7        3.       131.     163.     201.       33.      41.      50.
 -41  -5        3.       192.     247.     296.       32.      41.      49.
 -41  -4        3.       209.     212.     218.       52.      53.      54.
 -51-34         3.        70.      90.      96.       23.      30.      32.
 -51-30         3.       148.     199.     235.       37.      50.      59.
 -42  -7        3.       131.     166.     201.       33.      41.      50.
   -3  -8       3.       105.     166.     209.       35.      55.      70.
 -51-21         3.       227.     278.     305.       45.      56.      61.
   -3  -6       2.       157.     177.     209.       52.      59.      70.
 -51-28         4.       305.     321.     349.       34.      36.      39.
 -13  -9        3.        87.     145.     201.       29.      48.      67.
 -13  -8        3.       148.     178.     209.       49.      59.      70.
   -3  -5       3.        96.     138.     183.       32.      46.      61.
 -51-27         3.       279.     324.     392.       70.      81.      98.
   -3  -7       3.       122.     169.     192.       31.      42.      48.
 -51-29         4.       340.     398.     471.       49.      57.      67.
 -13  -4        4.       174.     292.     392.       58.      97.     131.
   -3  -4       3.       227.     227.     244.       45.      45.      49.
   -3-10        3.        87.     150.     201.       44.      75.     100.
 -51-16         3.       148.     326.     610.       25.      54.     102.
 -51-19         3.       227.     257.     340.       76.      86.     113.
 -51-14         3.       157.     244.     410.       39.      61.     102.
 -51-13         3.       192.     235.     270.       48.      59.      68.
 -51-11         4.       227.     253.     270.       45.      51.      54.
 -39  -5        4.       357.     549.     802.       60.      92.     134.
 -51-10         3.       201.     235.     296.       50.      59.      74.
```

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-51-26        3.     131.    173.    227.      65.     86.    113.
-13 -7        2.     140.    148.    157.      70.     74.     78.
-13 -2        3.     140.    173.    201.      47.     58.     67.
-51-20        4.     166.    218.    253.      55.     73.     84.
-51-12        4.     174.    264.    349.      58.     88.    116.
-51-15        4.     296.    446.    575.      59.     89.    115.
-51 -1        5.     331.    443.    549.      83.    111.    137.
-39 -2        3.     140.    208.    253.      70.    104.    126.
-51-17        4.     314.    435.    497.      63.     87.     99.
-51 -2        3.     462.    528.    584.     116.    132.    146.
-51 -7        5.     724.    793.    863.      80.     88.     96.
-51 -6        4.     296.    481.    575.      74.    120.    144.
-39 -1        3.     166.    387.    436.      55.    129.    145.
-51 -5        3.     262.    270.    410.     131.    135.    205.


                         KSELEC= 2


REGRESSION COMPUTATIONAL ELEMENTS


N-   48.
V-        159. 00000000 SLNW-        262. 56836300
VEV-        3. 31250000 AVELNW-        5. 47017425
V2=       547. 00000000 SLNW2=      1445. 80606000 SVTLNW-     878. 20684100
SMV-      526. 68750000 SSMLNW=     1436. 29469000 SSMVLW=     869. 75769800
SSV-       20. 31250000 CSSLNW=        9. 51136780 CSSVLW-       8. 44914246


        LNA=          4. 09231412          LNB-          0. 41595778


                 THE CORRESPONDING REGRESSION MODEL IS

     LNW=     4. 09231412   +     0. 41595778* V    IN REDUCED FORM

  W =    59. 87829640   *     1. 51582186   ** V    IN EXPONENTIAL FORM



                       REGRESSION PLOTBACK

    V            LNW            LNWH           DLWH           DLWH2

  3. 000     4. 87360883    5. 34018749    -0. 46657866    0. 21769565
  3. 000     4. 96891904    5. 34018749    -0. 37126845    0. 13784026
  4. 000     5. 39107901    5. 75614524    -0. 36506623    0. 13327335
  5. 000     5. 57780576    6. 17210305    -0. 59429729    0. 35318927
  3. 000     5. 09229803    5. 34018749    -0. 24788946    0. 06144918
  3. 000     4. 75582576    5. 34018749    -0. 58436173    0. 34147863
  3. 000     5. 57229614    5. 34018749     0. 23210865    0. 05387443
  3. 000     5. 54428315    5. 34018749     0. 20409566    0. 04165504
  3. 000     5. 09229803    5. 34018749    -0. 24788946    0. 06144918
  3. 000     5. 50959760    5. 34018749     0. 16941011    0. 02869979
  3. 000     5. 35740578    5. 34018749     0. 01721829    0. 00029647
  3. 000     4. 50093353    5. 34018749    -0. 83925396    0. 70434722
  3. 000     5. 29378009    5. 34018749    -0. 04640740    0. 00215365
  3. 000     5. 10999757    5. 34018749    -0. 23018992    0. 05298740
```

```
3. 000      5. 10999757     5. 34018749     -0. 23018992     0. 05298740
3. 000      5. 62607253     5. 34018749      0. 28538504     0. 08173025
2. 000      5. 17782021     4. 92422968      0. 25359052     0. 06430815
4. 000      5. 77196187     5. 75614524      0. 01581663     0. 00025017
3. 000      4. 97896940     5. 34018749     -0. 36121809     0. 13047851
3. 000      5. 18191016     5. 34018749     -0. 15827733     0. 02505171
3. 000      4. 92767608     5. 34018749     -0. 41251141     0. 17016566
3. 000      5. 78097087     5. 34018749      0. 44078338     0. 19428999
3. 000      5. 12738931     5. 34018749     -0. 21279818     0. 04528306
4. 000      5. 98692727     5. 75614524      0. 23078203     0. 05326035
4. 000      5. 67710406     5. 75614524     -0. 07904118     0. 00624751
3. 000      5. 42365515     5. 34018749      0. 08346766     0. 00696685
3. 000      5. 00852817     5. 34018749     -0. 33165932     0. 10999790
3. 000      5. 78544515     5. 34018749      0. 44525766     0. 19825439
3. 000      5. 54994887     5. 34018749      0. 20976138     0. 04399984
3. 000      5. 49776316     5. 34018749      0. 15757567     0. 02483009
3. 000      5. 46139550     5. 34018749      0. 12120801     0. 01469138
4. 000      5. 53285444     5. 75614524     -0. 22329080     0. 04985878
4. 000      6. 30869335     5. 75614524      0. 55254811     0. 30530941
3. 000      5. 46139550     5. 34018749      0. 12120801     0. 01469138
3. 000      5. 15292263     5. 34018749     -0. 18726486     0. 03506813
2. 000      4. 99877203     4. 92422968      0. 07454234     0. 00555656
3. 000      5. 15292263     5. 34018749     -0. 18726486     0. 03506813
4. 000      5. 38443440     5. 75614524     -0. 37171084     0. 13816895
4. 000      5. 57780576     5. 75614524     -0. 17833948     0. 03180497
4. 000      6. 10064685     5. 75614524      0. 34450161     0. 11868136
5. 000      6. 09411085     6. 17210305     -0. 07799220     0. 00608278
3. 000      5. 33664382     5. 34018749     -0. 00354367     0. 00001256
4. 000      6. 07424265     5. 75614524      0. 31809741     0. 10118596
3. 000      6. 26820201     5. 34018749      0. 92801452     0. 86121094
5. 000      6. 67641813     6. 17210305      0. 50431508     0. 25433370
4. 000      6. 17591757     5. 75614524      0. 41977233     0. 17620881
3. 000      5. 95917338     5. 34018749      0. 61898589     0. 38314353
3. 000      5. 59954578     5. 34018749      0. 25935829     0. 06726672

            SDLWH=   -0. 00000042      SDLWH2=     5. 99683541


                         ANALYSIS OF VARIANCE TABLE


SOURCE OF       DEGREES OF          SUM OF                MEAN
VARIATION       FREEDOM             SQUARES               SQUARE


DUE TO LNA           1.          1436. 29469000         1436. 29469000
DUE TO LNB/LNA       1.             3. 51448655            3. 51448655
RESIDUAL            46.             5. 99683541            0. 13036599


                             VARIANCE ESTIMATES


VAR OF ERRORS OF ESTIMATE   VARIANCE FOR LNA    VARIANCE FOR LNB

          0. 13036599              0. 07313866            0. 00641802
```

```
                                      CONFIDENCE LIMITS

                          FOR LNA                                    FOR LNB


80909599
TPRDF           LOWER               UPPER               LOWER               UPPER

1. 301          3. 74046961         4. 44415867         0. 31173138         0. 52018419
1. 680          3. 63797224         4. 54665601         0. 28136873         0. 55054683
2. 014          3. 54764473         4. 63698351         0. 25461115         0. 57730442
2. 690          3. 36482623         4. 81980205         0. 20045508         0. 63146049



                     TEST-OF-HYPOTHESES PARAMETERS FOR LNB
                       (WITH THE HYPOTHESIS THAT LNB=0)


           T =          5. 19216877        F =           26. 95861580
```

```
UNIVERSITY OF PUERTO RICO
WATER RESOURCES RESEARCH INSTITUTE
MAYAGUEZ, PUERTO RICO


          OUTPUT OF EXPONENTIAL REGRESSION-MODEL ANALYSIS PROGRAM


EXPONENTIAL REGRESSION-MODEL ANALYSIS FOR SOME SELECTED DWELLING CHARACTE-
RISTICS WITH, ANALYSIS OF VARIANCE, REGRESSION PLOTBACK, VARIANCE ESTI-
MATES FOR MODEL PARAMETERS CONFIDENCE INTERVALS, AND TESTS OF HYPOTHESES.
PROFESSOR A. GUILBE, INDUSTRIAL ENGINEERING DEPARTMENT/WATER RESOURCES
RESEARCH INSTITUTE.


RESIDENTIAL WATER-USE PROJECT
PILOT         MAYAGUEZ       URBANIZATION DWELLINGS
SOME SELECTED DWELLING CHARACTERISTICS

INDIVIDUAL   BATHROOM     PER DWELLING DAILY USE      PER CAPITA DAILY USE
 DWELLING    FIXTURE         IN GALLONS FOR               IN GALLONS FOR
   I. D.      UNITS       MINMO    AVEMO    MAXMO      MINMO    AVEMO    MAXMO
  -41 -9        1. 00       96.     131.     157.        32.      44.      52.
  -41-10        1. 00      105.     144.     218.        21.      29.      44.
  -51-37        1. 00      166.     219.     270.        41.      55.      68.
  -51-35        2. 00      218.     264.     366.        31.      38.      52.
  -51-36        2. 00      122.     163.     192.        41.      54.      64.
  -42 -2        1. 50       87.     116.     192.        44.      58.      96.
  -42 -5        1. 00      122.     263.     602.        31.      66.     150.
  -42 -4        1. 00      218.     256.     296.        54.      64.      74.
  -41 -7        1. 00      131.     163.     201.        33.      41.      50.
  -41 -5        1. 00      192.     247.     296.        32.      41.      49.
  -41 -4        1. 00      209.     212.     218.        52.      53.      54.
  -51-34        1. 00       70.      90.      96.        23.      30.      32.
  -51-30        1. 00      148.     199.     235.        37.      50.      59.
  -42 -7        1. 00      131.     166.     201.        33.      41.      50.
    -3 -8       1. 00      105.     166.     209.        35.      55.      70.
  -51-21        1. 00      227.     278.     305.        45.      56.      61.
    -3 -6       1. 25      157.     177.     209.        52.      59.      70.
  -51-28        1. 00      305.     321.     349.        34.      36.      39.
  -13 -9        1. 00       87.     145.     201.        29.      48.      67.
  -13 -8        1. 50      148.     178.     209.        49.      59.      70.
    -3 -5       1. 00       96.     138.     183.        32.      46.      61.
  -51-27        1. 00      279.     324.     392.        70.      81.      98.
    -3 -7       1. 00      122.     169.     192.        31.      42.      48.
  -51-29        2. 00      340.     398.     471.        49.      57.      67.
  -13 -4        1. 25      174.     292.     392.        58.      97.     131.
    -3 -4       1. 25      227.     227.     244.        45.      45.      49.
    -3-10       1. 25       87.     150.     201.        44.      75.     100.
  -51-16        1. 25      148.     326.     610.        25.      54.     102.
  -51-19        1. 25      227.     257.     340.        76.      86.     113.
  -51-14        2. 25      157.     244.     410.        39.      61.     102.
  -51-13        1. 25      192.     235.     270.        48.      59.      68.
  -51-11        2. 50      227.     253.     270.        45.      51.      54.
  -39 -5        3. 25      357.     549.     802.        60.      92.     134.
  -51-10        1. 75      201.     235.     296.        50.      59.      74.
```

```
-51-26          2.25       131.     173.     227.        65.      86.     113.
-13  -7         1.25       140.     148.     157.        70.      74.      78.
-13  -2         1.75       140.     173.     201.        47.      58.      67.
-51-20 .        2.25       166.     218.     253.        55.      73.      84.
-51-12          2.25       174.     264.     349.        58.      88.     116.
-51-15          2.50       296.     446.     575.        59.      89.   - 115.
-51  -1         4.25       331.     443.     549.        83.     111.     137.
-39  -2         3.50       140.     208.     253.        70.     104.     126.
-51-17          3.25       314.     435.     497.        63.      87.      99.
-51  -2         3.25       462.     528.     584.       116.     132.     146.
-51  -7         4.25       724.     793.     863.        80.      88.      96.
-51  -6         4.00       296.     481.     575.        74.     120.     144.
-39  -1         3.50       166.     387.     436.        55.     129.     145.
-51  -5         3.25       262.     270.     410.       131.     135.     205.


                              KSELEC= 2


REGRESSION COMPUTATIONAL ELEMENTS


N=   48.
V-          87.00000000 SLNW-         262.56836300
VEV-         1.81250000 AVELNW-         5.47017425
V2=        204.75000000 SLNW2-       1445.80606000 SVTLNW=       490.22764200
SMV=       157.68750000 SSMLNW=      1436.29469000 SSMVLW-       475.90515500
SSV-        47.06250000 CSSLNW=         9.51136780 CSSVLW-        14.32248690

         LNA-            4.91857779            LNB=             0.30432907

                  THE CORRESPONDING REGRESSION MODEL IS

       LNW-      4.91857779  +    0.30432907* V    IN REDUCED FORM

   W -   136.80790300   *     1.35571510   ** V    IN EXPONENTIAL FORM



                        REGRESSION PLOTBACK

   V            LNW              LNWH             DLWH             DLWH2

 1.000      4.87360883       5.22290689      -0.34929806       0.12200913
 1.000      4.96891904       5.22290689      -0.25398785       0.06450983
 1.000      5.39107901       5.22290689       0.16817212       0.02828186
 2.000      5.57780576       5.52723593       0.05056983       0.00255731
 2.000      5.09229803       5.52723593      -0.43493789       0.18917097
 1.500      4.75582576       5.37507141      -0.61924565       0.38346517
 1.000      5.57229614       5.22290689       0.34938926       0.12207285
 1.000      5.54428315       5.22290689       0.32137626       0.10328270
 1.000      5.09229803       5.22290689      -0.13060886       0.01705867
 1.000      5.50959760       5.22290689       0.28669071       0.08219156
 1.000      5.35740578       5.22290689       0.13449889       0.01808995
 1.000      4.50093353       5.22290689      -0.72197336       0.52124553
 1.000      5.29378009       5.22290689       0.07087320       0.00502301
 1.000      5.10999757       5.22290689      -0.11290932       0.01274851
```

```
1. 250     5. 42365515     5. 29898912      0. 12466604     0. 01554162
1. 250     5. 00852817     5. 29898912     -0. 29046094     0. 08436756
1. 250     5. 78544515     5. 29898912      0. 48645604     0. 23663948
1. 250     5. 54994887     5. 29898912      0. 25095975     0. 06298080
2. 250     5. 49776316     5. 60331821     -0. 10555506     0. 01114187
1. 250     5. 46139550     5. 29898912      0. 16240638     0. 02637583
2. 500     5. 53285444     5. 67940044     -0. 14654601     0. 02147573
3. 250     6. 30869335     5. 90764725      0. 40104610     0. 16083797
1. 750     5. 46139550     5. 45115370      0. 01024181     0. 00010489
2. 250     5. 15292263     5. 60331821     -0. 45039558     0. 20285618
1. 250     4. 99877203     5. 29898912     -0. 30021709     0. 09013030
1. 750     5. 15292263     5. 45115370     -0. 29823107     0. 08894177
2. 250     5. 38443440     5. 60331821     -0. 21888381     0. 04791012
2. 250     5. 57780576     5. 60331821     -0. 02551246     0. 00065089
2. 500     6. 10064685     5. 67940044      0. 42124641     0. 17744854
4. 250     6. 09411085     6. 21197635     -0. 11786550     0. 01389228
3. 500     5. 33664382     5. 98372954     -0. 64708573     0. 41871994
3. 250     6. 07424265     5. 90764725      0. 16659540     0. 02775403
3. 250     6. 26820201     5. 90764725      0. 36055475     0. 12999973
4. 250     6. 67641813     6. 21197635      0. 46444178     0. 21570616
4. 000     6. 17591757     6. 13589406      0. 04002351     0. 00160188
3. 500     5. 95917338     5. 98372954     -0. 02455616     0. 00060300
3. 250     5. 59954578     5. 90764725     -0. 30810148     0. 09492652

           SDLWH=     0. 00000191      SDLWH2=     5. 15257257


                         ANALYSIS OF VARIANCE TABLE


SOURCE OF         DEGREES OF          SUM OF                   MEAN
VARIATION         FREEDOM             SQUARES                  SQUARE


DUE TO LNA             1.         1436. 29469000          1436. 29469000
DUE TO LNB/LNA         1.            4. 35874915             4. 35874915
RESIDUAL              46.            5. 15257257             0. 11201245


                            VARIANCE ESTIMATES


VAR OF ERRORS OF ESTIMATE    VARIANCE FOR LNA     VARIANCE FOR LNB

        0. 11201245                0. 01015252          0. 00238008
```

```
                                          CONFIDENCE LIMITS

                            FOR LNA                                   FOR LNB


80909599
TPRDF                LOWER           UPPER            LOWER           UPPER

1. 301              4. 78748941     5. 04966617      0. 24085843     0. 36779972
1. 680              4. 74930143     5. 08785415      0. 22236852     0. 38628963
2. 014              4. 71564770     5. 12150788      0. 20607398     0. 40258417
2. 690              4. 64753413     5. 18962145      0. 17309461     0. 43556353



                    TEST-OF-HYPOTHESES PARAMETERS FOR LNB
                      (WITH THE HYPOTHESIS THAT LNB=0)

      T =             6. 23803532         F =           38. 91307880
```

6.2 The Application of Peak Ratios

In order to use the average magnitudes of the estimates obtained by using the developed alternate models and those obtained in the main study (7), peak ratios should be applied to them.

Tables 6.1 and 6.2 present some of the estimates of these maximum -to-average multipliers for gallons per day per dwelling unit and gallons per capita daily in the various samples studied.

Figures 6.1 to 6.6 depict the pattern of variation (scattergram) of maximum-to-average ratios to be used with previously developed models (7). However, since these ratios are transparent to the relating water-use factor used, they serve as well for the newly developed alternate models. For design purposes, the maximum peak shown in each case in Tables 6.1 and 6.2 is recommended. As observed from these tables and the corresponding figures no significant differences are depicted between the samples studied in the three cities.

TABLE 6.2

Equivalent Daily Peak Ratios in Samples of Residences for San Juan, Ponce and Mayaguez, P. R.

(gpd)*

Peak	Peak Ratio in Sample for:		
	San Juan	Ponce	Mayaguez
Minimum	1.03	1.05	1.02
Average	1.33	1.25	1.21
Maximum	2.78	2.29	2.29

---

*gallons per day per dwelling unit

TABLE 6.3

Equivalent Daily Peak Ratios in Samples of Residences for San Juan, Ponce and Mayaguez, P. R.

(gpcd)*

Peak	Peak Ratio in Sample of:		
	San Juan	Ponce	Mayaguez
Minimum	1.01	1.05	1.02
Average	1.29	1.30	1.29
Maximum	2.76	2.27	2.31

---

*gallons per capita daily

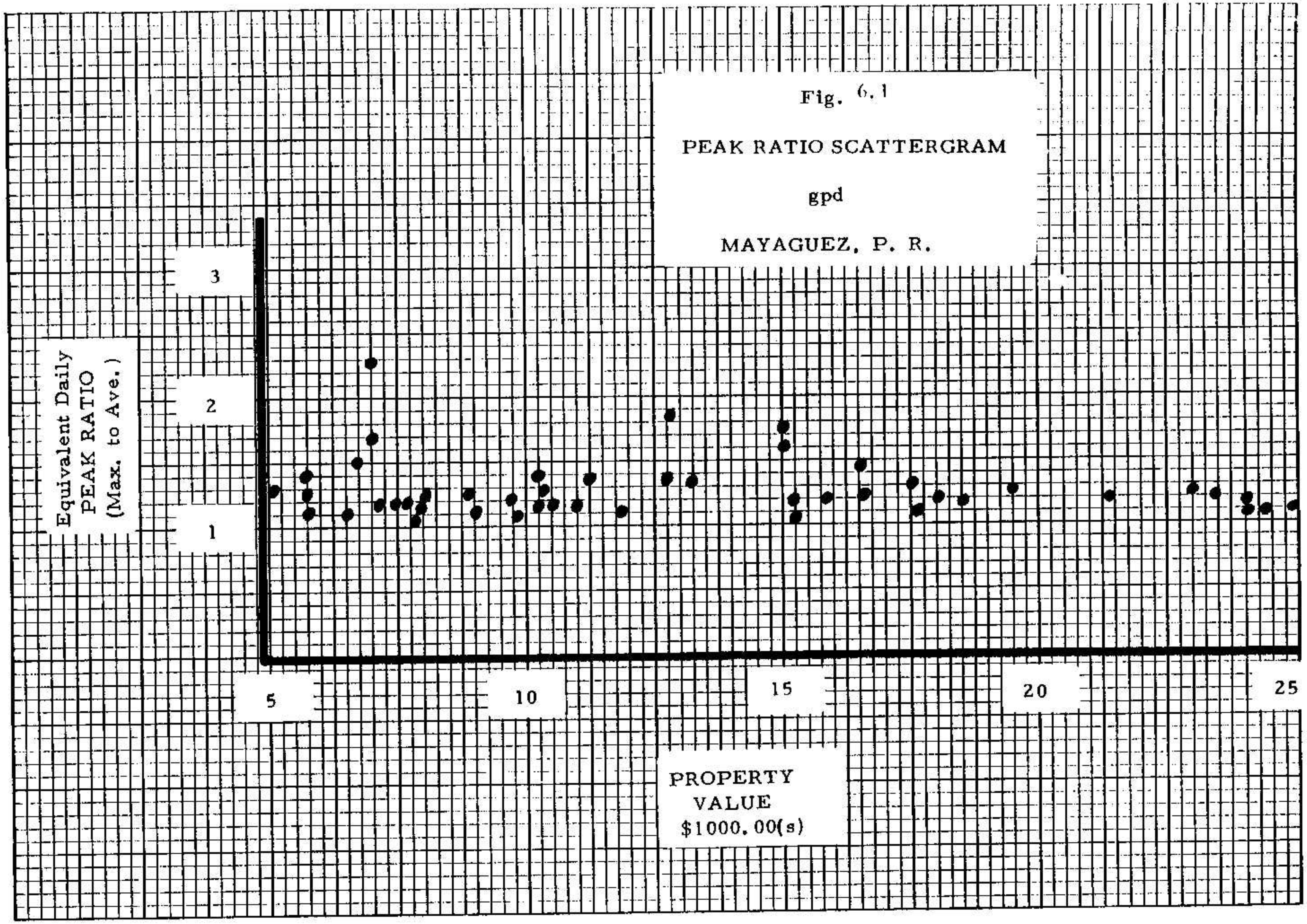

Fig. 6.1

PEAK RATIO SCATTERGRAM

gpd

MAYAGUEZ, P. R.

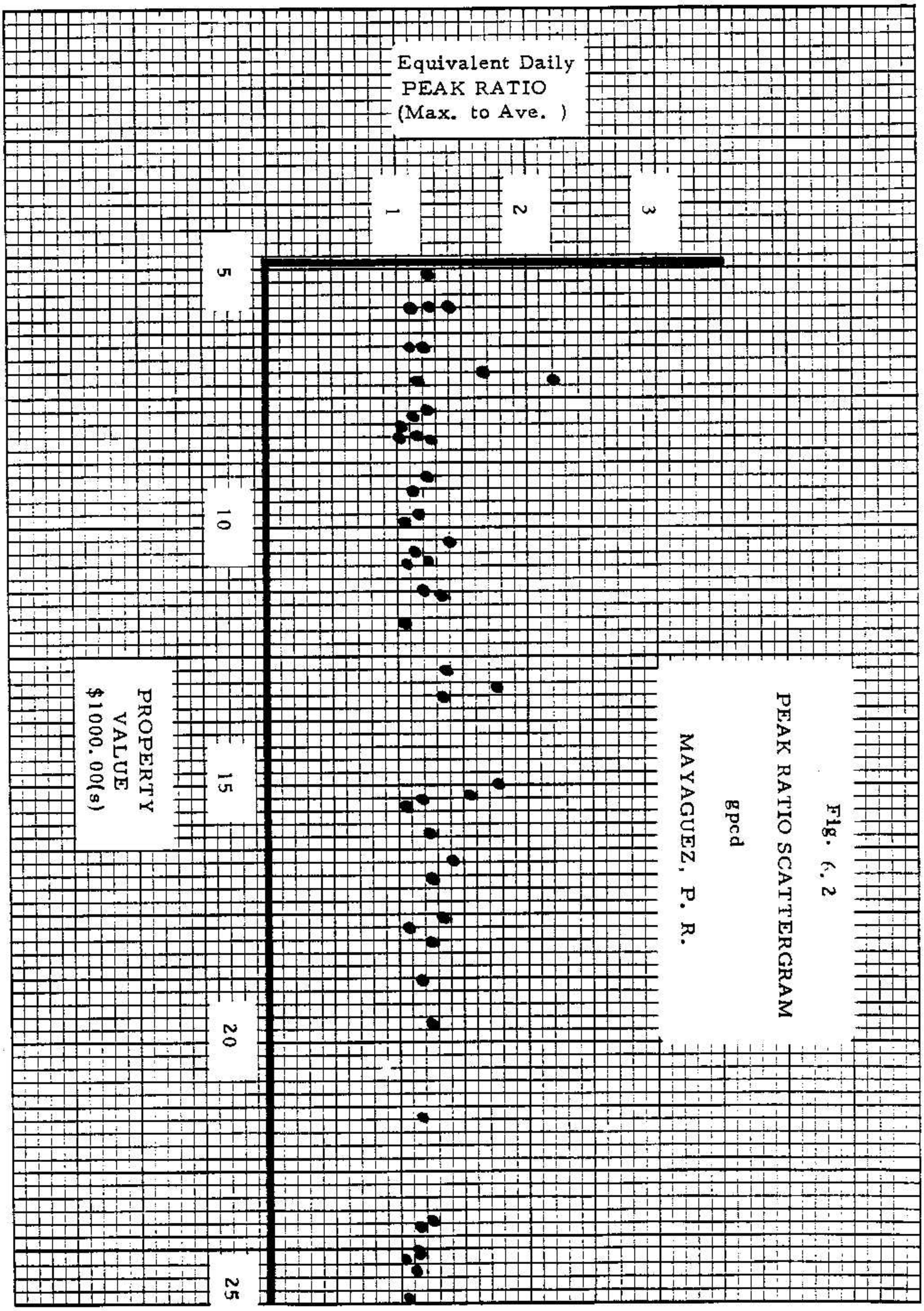

Fig. 6.2
PEAK RATIO SCATTERGRAM
gpcd
MAYAGUEZ, P. R.

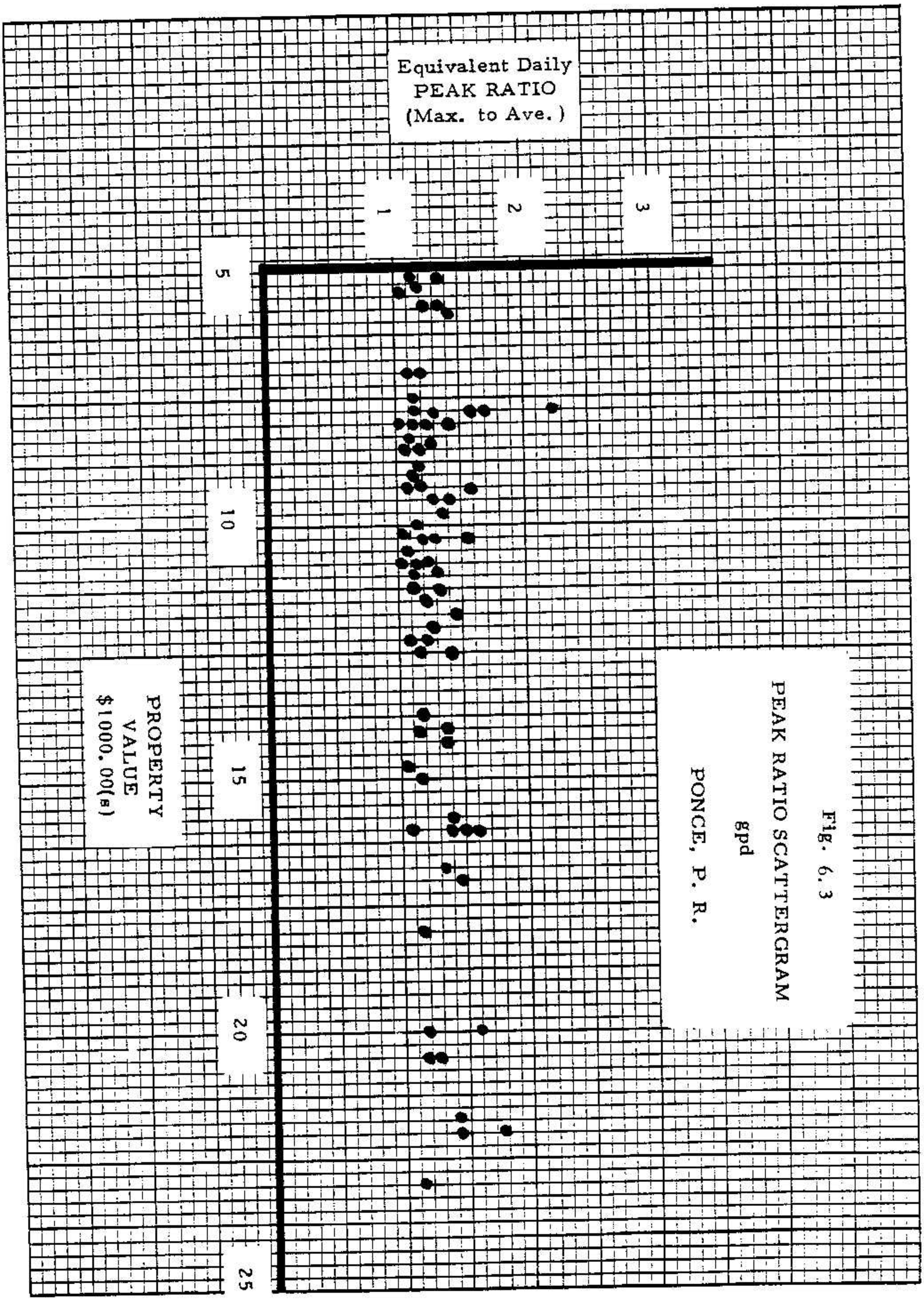

Fig. 6.3
PEAK RATIO SCATTERGRAM
gpd
PONCE, P. R.

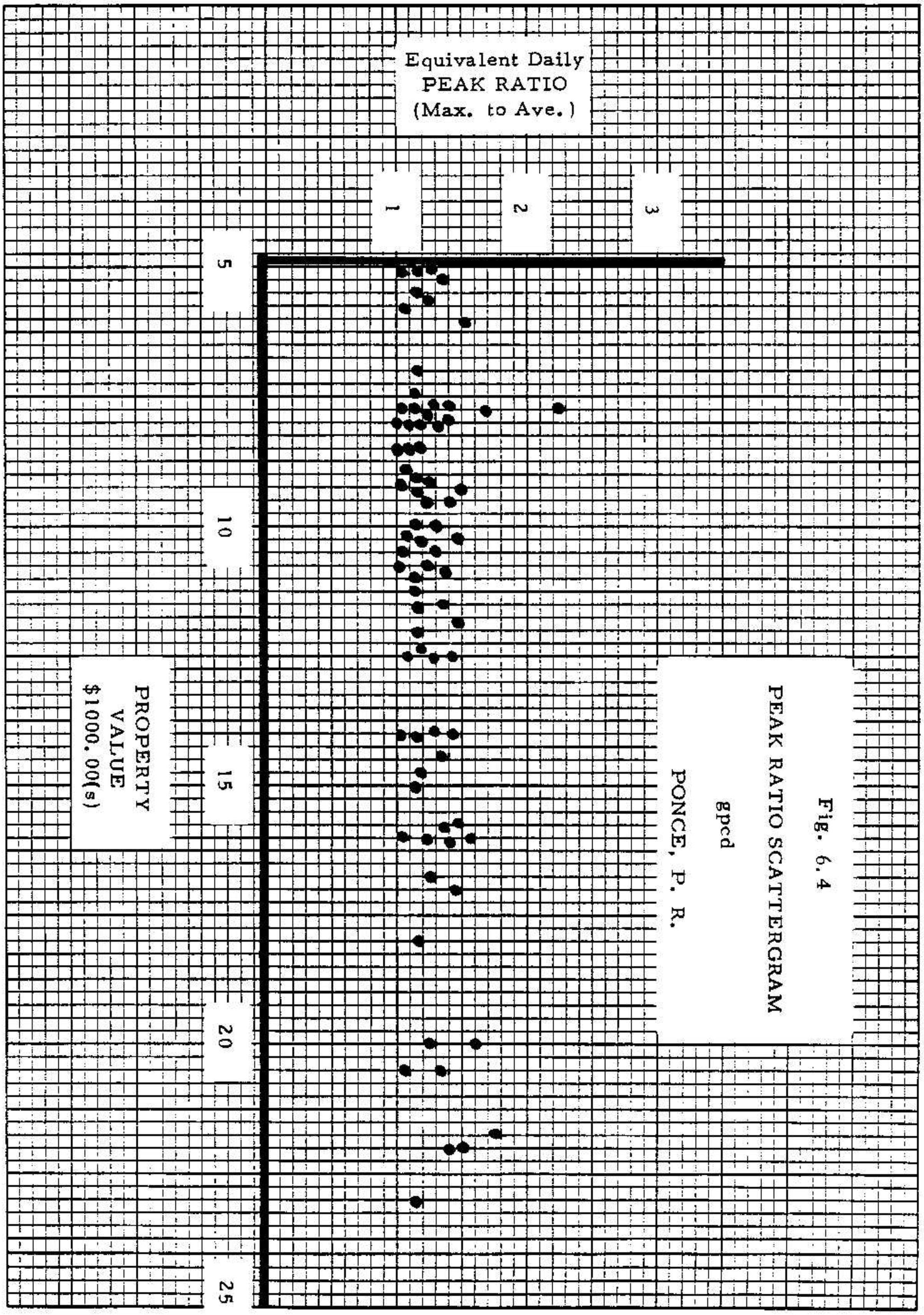

Fig. 6.4
PEAK RATIO SCATTERGRAM
gpcd
PONCE, P. R.

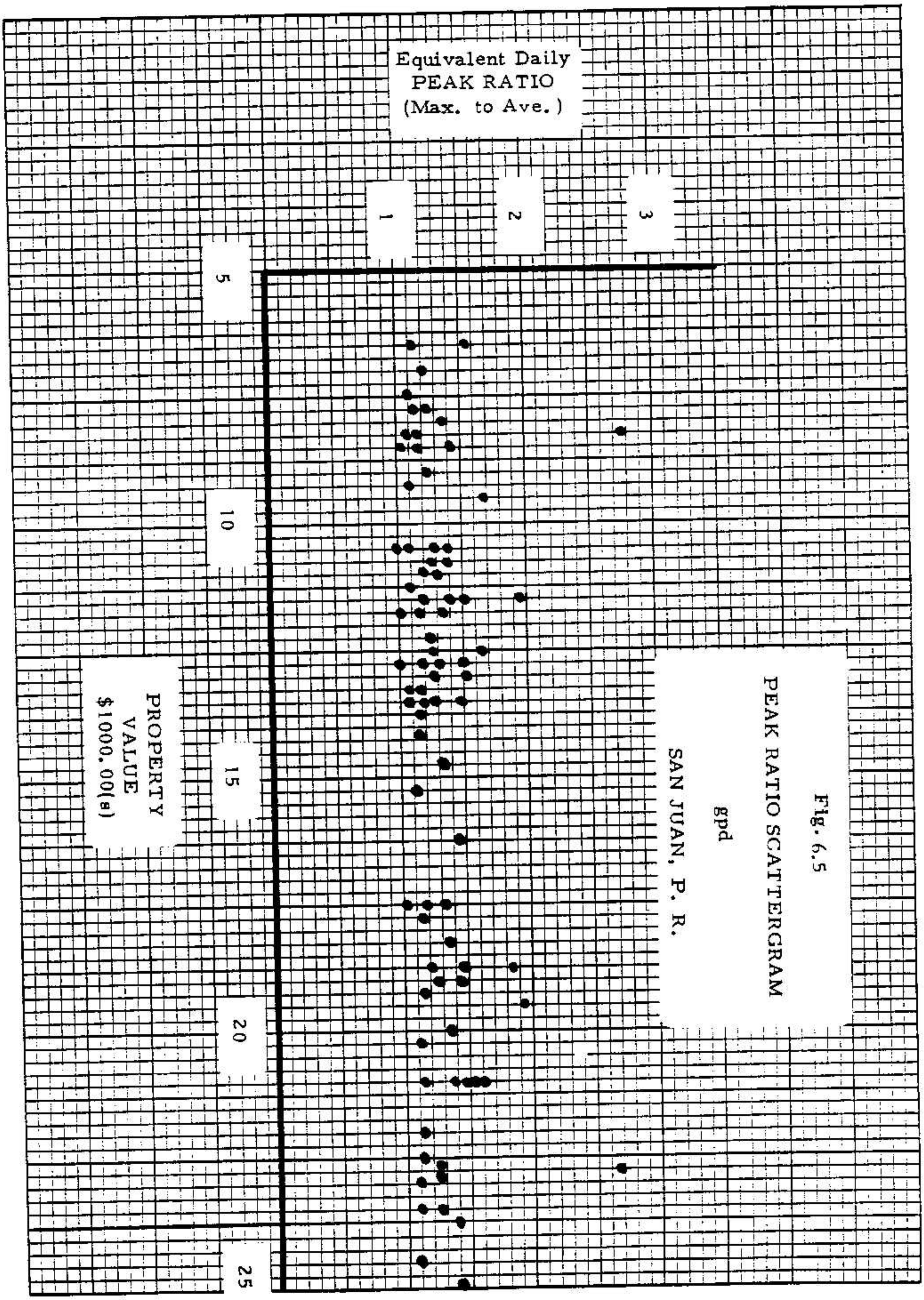
Fig. 6.5
PEAK RATIO SCATTERGRAM
gpd
SAN JUAN, P. R.

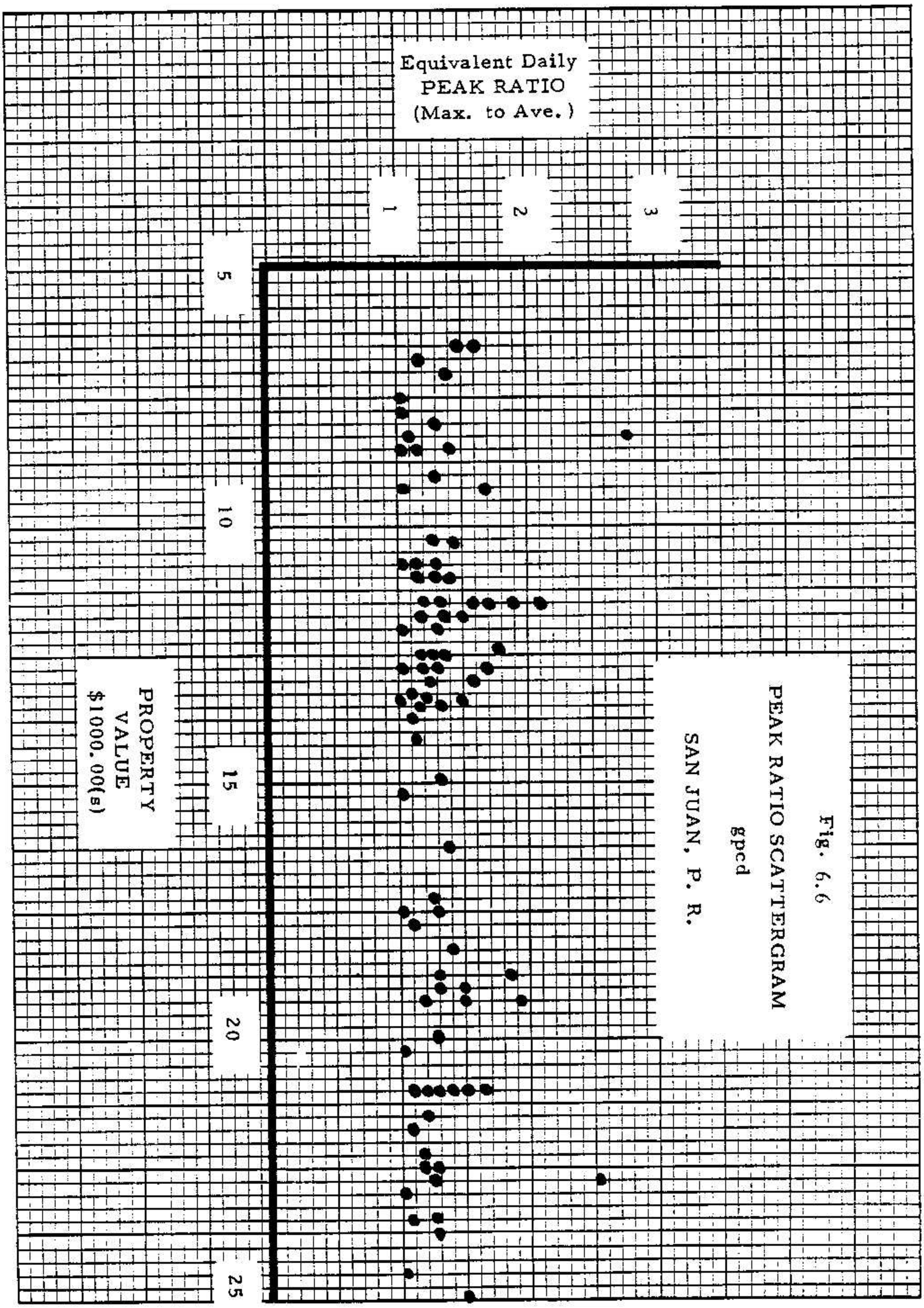

Fig. 6.6
PEAK RATIO SCATTERGRAM
gpcd
SAN JUAN, P. R.

CHAPTER VII - PUBLIC DWELLINGS

The previous main studies demonstrated that the number of bedrooms per dwelling unit correlated well with water use in this type of building (5, pp. 60-66; 7, pp. 75).

Since in this type of dwelling unit the family using it is allocated there on the basis of the family size and not its income, the property value of the dwelling does not reflect adequately their income status. Thus, the number of bedrooms per dwelling substitutes property value as a practical indirect indicator of the socio-economic factors influencing water use in these type of buildings.

As stated before (7, pp. 76), when subjecting the collected data to the same analysis presented in chapter VI, only the gallons per day per dwelling unit index (gpd) was found significant for residential water-use estimation purposes.

The corresponding water-use model in cases like this is represented by formula 6.1 or 6.2, but instead of those shown, the independent variable is the number of bedrooms in a public type dwelling unit (7, pp. 74).

Due to the essentially uniform bathroom water-using facilities in this type of buildings, no significant effect is expected from this alternate water-use factor.

CHAPTER VIII - MODEL USES AND LIMITATIONS

The developed alternate water-use models are intended mainly to serve as an alternative to the previously developed models (5,7) for residential water-use estimation.

The developed alternate water use models are not recommended for individual-residence water-use estimation, but for use with groups of relatively homogeneous residences, as classified in this study, and to estimate water in average magnitudes and corresponding expected peaks in AVEMO and MAXMO.

In order to make these estimates a procedure similar to that presented in reference 7 pp. 84 to 88 (procedure B) is suggested, making the corresponding substitution in the equivalent bathroom water-using facilities case.

A word of caution: Since any statistical population is dynamic, it is recommended to whoever uses these models, to conduct periodic cheks on model parameters (every several years) to see if their specific values still hold appropriate.[1]

---

[1] To do these checks, use the computer program of Reference 5, Appendix 2

to an improvement in decision making in water resources planning in the Island of Puerto Rico.

The developed regular and alternate water-use models will serve as tools to estimate the amounts of water required to adequately serve the demands of new private and public urbanization areas well in advance of the actual building of these types of residential projects, with the alternate water-use models serving the said objective when the assessed property valuation is not available, in the private housing case.

[redacted]

APPENDIX I - REFERENCES

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AN INVESTIGATION OF FACTORS AFFECTING THE INTENSITY OF WATER USE IN THE LAJAS VALLEY IRRIGATION PROJECT

Project A-036-PR

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To

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ABSTRACT

This study was conducted in the Irrigation District of Lajas Valley located in the southwestern part of Puerto Rico. Data used were obtained from the irrigation system during the fiscal years 1971-72, and 1972-73. A sample of ninety (90) farms with irrigation facilities encompassing a total area of 7,035 acres were selected for investigation. The primary productive activity of these farms is centered on the cultivation of sugar cane.

The fundamental objective of the study relates to an analysis of a series of socio-economic factors which were assumed to affect the intensity of irrigation water use in Lajas Valley. These factors are:

1- Size of farms
2- Ownership of farms
3- Available labor
4- Cost of irrigation
5- Employment of farmers in non-agricultural activities
6- Administration of irrigation services
7- Topography of the farms
8- Soil permeability

Other variables which appear to affect the use of irrigation water were the farmer's age and his level of education. Analysis revealed that although there is no definite relationship between the ownership of farms and intensity of irrigation water use, there is a tendency among farms of 100 acres or more to utilize water more intensively.

Data collected revealed that the majority of farms in the Lajas Valley are operated under rental contracts. Nevertheless, in the study the factor of ownership demonstrated that no significant relationship existed with the intensity of irrigation water use.

A factor of considerable influence on the intensity of water use was the availability of labor for the operation of irrigation systems. The data indicated that with increased labor availability the intensity of water used for irrigation was greater.

Irrigation costs are also a determining factor in the intensity of water use for irrigation. Analysis of data showed that a direct relationship exists between these two variables.

The employment of the farmer in non-agricultural tasks hold no significant relationship to the intensity of water use according to the results of the study. Nevertheless, one-third of the farmers studied pursued non-agricultural occupations in addition to farming. Within this group was noted that a higher index of water consumption on their farms was a common tendency.

The administration of irrigation services as a factor showed no relationship to the intensity of water use for irrigation. A large majority of the farmers found the services of the Water Resources Authority good or excellent.

Regarding the topography of farms, a significant relationship existed between this factor and the intensity of irrigation water use. The farms with a rolling topography showed a greater index of water consumption than those on the flat lands and the owners with both, flat and rolling topography.

Although the soil permeability of most farms is low, there was a significant relationship between this factor and the intensity of water use for irrigation in the farms of the valley.

The factors of age and education of the farmer had no significant relationship with the intensity of water use, despite, the fact that the majority of farmers of Lajas Valley were advanced in age and posessed a high level of education.

Data obtained in this study can serve as a basis for implementing a series of government measures and programs that may tend to stimulate the utilization of adequate quantities of irrigation water and as a result succeed in producing substantial increases in agricultural output.

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CHAPTER I

INTRODUCTION

The Irrigation Project of Lajas Valley is the most recent irrigation scheme among the three public irrigation projects which operate in Puerto Rico. In the second phase of the comprehensive Southwest Project being constructed by the Puerto Rico Water Resources Authority its primary objectives are to increase the electrical capacity of the island through the development of water resources for the production of energy, the provision of irrigation and drainage for a surface area of 20,000 acres of land in the Lajas Valley, the supply of water for domestic and industrial uses, and the flood control of the Añasco, Superior, Yauco, and Loco rivers.

The first phase of the southwest project was centered on the development of engineering works for the retention of water and the production of electricity. These engineering works include the Guayo, Yahuecas, Prieto and Toro dams in the northern slope of the Cordillera Central, the Lucchetti dam in the Yauco River in the southern slope and 13 miles of connecting tunnels. The hydroelectric aspect consists of "Centrals" No. 1 and No. 2 of Yauco which has a combined generation capacity of 35,000 kilowatts.

As was mentioned before, the second phase of the southwest project is composed of the irrigation and drainage system of Lajas Valley. This phase includes the dam of the Loco River which acts as a regulator reservoir, a main irrigation canal 23 miles long together with 43 miles of secondary lateral canals. The system also has 339 turn-out structures to allow the irrigation water into the farms. The drainage system is composed of 68 miles of principal and secondary canals that provides drainage to the farms. It also collects excess water of rainfall and surplus irrigation waters and conveys them to the sea through the Bays of Guánica and Boquerón. Table No. 1 shows the capacity of the reservoirs that supply water for irrigation in Lajas Valley.

Table No. 1

Capacity of the Reservoirs of the Irrigation System of Lajas Valley, May, 1973

Reservoir	Capacity in Acre-Feet
Prieto and Toro	97
Loco	639
Yahuecas	778
Lucchetti	11,875
Guayo	13,546
Total	26,935

The irrigation operations of Lajas Valley began in August of 1955, when for the first time deliveries of water were made to the farmers. Through legal provisions the Irrigation District of Lajas Valley should have been established permanently by July 1, 1971. However, for reasons mostly of an economic nature that face the system and the inability of the farms to generate sufficient incomes to recuperate the costs of services, the establishment of the permanent district was postponed until 1975.

Purchase and Distribution of Irrigation Water

The Irrigation District of Lajas Valley is controlled by the Water Resources Authority of Puerto Rico which stores, directs, delivers, measures, and bills water for irrigation to the properties authorized to receive it.

Water is generally delivered by gravity (the gravity system) in the higher elevations of the farms. In cases where the water cannot be supplied by gravity, the farmer resorts to pumping by the installation of his own pumps (pumping system). A 50 percent discount to compensate for the additional costs associated with pumping is generally conceded to the farmers.

The Department of Agriculture has assigned a water allotment of 3.0 acre-feet per acre per year, for every farm. An additional acre-feet of water is provided to those farms that exhaust their monthly allotment. Every farmer who consumed 0.25 acre-feet per acre during one month will receive 0.08 acre-feet of additional water for each acre, free of charge, provided that water is available. A farmer can receive, if he uses all of his allotment, a total of 6.0 acre-feet of water per acre per year providing that water is available and the ground water levels of the Valley are not affected. The price of the last two (2) acre feet is the same as the first three.

The direction and distribution of water within the farm is the responsibility of each farmer. The canals that the farmer constructs in a rudimentary form to distribute water within his farm affect the efficiency of irrigation. These canals are susceptible to overflows and filtrations which result in considerable losses of water occasionally. Construction of irrigation canals of adequate size and slope is required so that water can be moved uniformly to all lands of the farm without being lost or diverted from the planned course.

The Agricultural Pattern

In 1973 the number of plots receiving irrigation water was 249 covering a total area of 18,858 acres. Of this area, 14,403 acres were irrigated by the gravity system and 4,455 through the pumping system. In addition to the 2,000 acres of land reclaimed in the Guánica and Anegado area, some 700 acres have been developed to date.

The development work was made possible through the construction of a network of drainage canals, interception of ravines, and control of the irrigation which have contributed to the maintenance of land fertility of the Valley in the first 24 to 36 inches of soil.

Before 1955, cattle raising for milk as well as for meat was the chief industry of the Lajas Valley. Cane and edible fruits were cultivated in those areas where some water supplies could be obtained. With the advent of irrigation, the agricultural panorama changed completely. Table No. 2 shows the use of the lands by crops in the Lajas Valley.

Table No. 2

Distribution of the Area under Irrigation by Crop in Lajas Valley, May, 1973

Crop	Area (acres)	Percent of Total
Sugar cane	15,986.0	84.8
Pastures	2,778.0	14.7
Vegetables	58.0	.3
Others	36.0	.2
Total	18,858.0	100.0

As is shown in the above table sugar cane replaced cattle raising as the most important industry in the Lajas Valley. This crop occupies approximately 85 percent of the total area under irrigation.

Problems Confronted by the Project

In the past,development the Lajas Valley Irrigation Project was affected by different kinds of problems. Of major importance were the salinity and drainage problems and those relating to the high freatic levels and artesian pressures. A program of action was adopted to find an immediate solution to these problems.

Through research and studies at the Agricultural Experimental Station, the Water Resources Authority, and the Department of Agriculture of Puerto Rico and through the recommendations of local and foreign scientists and engineers, together with the experiences obtained, the corrective measures were realized.

In spite of the effort described above, the system faces at present functional and economic problems. These can be described as the high costs of maintenance and operation and the low water consumption by farmers. In recent years the system has been operating with deficits which are liquidated by government subsidies. Table No. 3 shows the outlays and incomes and the government contributions to the system in the last 14 years.

Table No. 3

Operational Expenditures, Income, and Government Contributions to the Irrigation System of the Lajas Valley, 1959-60 and 1972-73*.

Years	Income from water sales	Operational and Maintenance outlays	Government Contributions
1959-60	$ 64,719	$ 136,685	$ 92,398
1960-61	75,793	141,196	49,600
1961-62	74,708	184,782	85,700
1962-63	98,605	204,347	48,532
1963-64	109,224	251,278	112,024
1964-65	123,413	307,140	183,800
1965-66	128,629	262,955	134,600
1966-67	168,200	286,272	159,300
1967-68	148,754	371,162	211,375
1968-69	114,006	437,504	260,747
1969-70	78,312	523,514	409,868
1970-71	99,799	568,914	459,400
1971-72	105,880	558,070	506,400
1972-73	157,540	634,040	538,000
Totals	$1,547,582	$ 4,867,859	$3,251,744

As show in the above table the government contributions to keep the system operating have been increasing considerably in the last years.

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*Information provided by the Puerto Rico Water Resources Authority (PRWRA).

Importance and Objectives of the Study

The limited amount of rain, high temperatures, and winds that accelerate the evapotranspiration of plants are factors that make the use of irrigation imperative for the commercial development of farm crops in Lajas Valley. Nevertheless, the amount of irrigation water utilized by the landowners of the Valley at present averages 1.5 acre-foot per acre per year. This is considered very low if we note that the principal crop of the Valley is sugar cane. The water requirements of this crop are extremely high.

Table No. 4 presents in comparative form the average water use per year for a period of 10 years among the private landowners and the Land Authority of Puerto Rico. As noted, the Land Authority uses greater amounts of irrigation water than the private landowners. It should also be observed that water use has decreased considerably during recent years.

Table No. 4

Comparative Average Use of Irrigation Water Among Landowners and the Land Authority in the Lajas Valley 1962-63 to 1971-72*

Users of the System	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72
Landowners	** 1.30	1.40	1.25	1.24	1.65	1.46	1.02	0.64	0.78	0.74
Land Authority	4.20	4.43	2.58	5.22	5.20	4.66	3.18	2.28	2.33	3.90
Land Authority and Landowners	1.57	1.71	1.39	1.64	2.02	1.85	1.27	0.83	0.98	1.14

---

* Data provided by the Water Resources Authority of Puerto Rico.
Average use in acre-feet of water per acre per year.

The low use of water on the part of the farmers needs to be studied for the following reasons:

1- In Southwest Puerto Rico a continuous demand for water use for other purposes exists, apart from agriculture. The demand for domestic use as well as for industrial use has greatly increased.

2- Water resources for this zone are limited and the established irrigation system involves high costs of operation.

3- Maximum output in sugar cane is not being achieved in the region of Lajas Valley due chiefly to the fact that the amounts of irrigation water being used do not meet the normal requirements of this crop.

4- Not all the water that enters the main irrigation canal is used completely by the farmers; a great part is lost into the sea.

5- A maximum utilization of irrigation water is required so that maximum yields of the crops can be obtained. This would make the farms produce enough incomes so that taxes can be paid for the use of irrigation that will eventually be imposed on the users of the system. The farm lands of the Valley that will constitute the permanent district will be subject to the payment of a tax to cover the expenses of the operation of the system and of another tax classifield as a construction tax, for the amortization of the capital.

Originally the law that created the Irrigation and Drainage District of Lajas Valley provided that all capital invested in the system be collected, together with interest. The law, however, underwent an amendment eliminating the collection of interest and limiting the capital to be collected to the amount originally assigned, i.e $6,400,000 and not the total amount invested which was $10,000,000.

This study has as its main objective the provision of relevant information on the manner in which a series of factors are influencing the intensity with which irrigation water is utilized by the farmers. These factors are as follows:

1- Size of the farm
2- Ownership of the farm
3- Available labor
4- Irrigation costs
5- Non-agricultural economic activities that the farmer pursues on a part-time basis.
6- The administration of the system
7- The topography of the farms
8- The amount of water available
9- The permeability of the soil

In this study, an attempt is made to find the existing relationship among the above mentioned factors which leads to a low water consumption by the agricultural users of the system.

Another aim pursued is that of obtaining pertinent data regarding the irrigation and drainage practices carried out by farmers of the Valley in order to ascertain to what point it causes the inefficient use of irrigation water.

The data obtained can be used by the Department of Agriculture of Puerto Rico as well as by other agencies that are also struggling with the farm problem in the Lajas Valley. These data will also be of meaningful value in establishing the necessary measures to stimulate the intensity of use of irrigation water which would result in larger outputs and greater incomes for the farmer.

CHAPTER II

REVIEW OF THE LITERATURE

The problems encountered in the development of the Irrigation District of Lajas Valley relate to different areas which have been the object of study and analysis by local and foreign scientists and engineers. The studies reviewed below relate in one way or another to the main problem analyzed in the present study, i.e., the low intensity of water use for irrigation by farmers.

Miguel A. Quiñones in a study sponsored by the Water Resources Authority of Puerto Rico determined the amount of available water for irrigation based on an allocation of 3.0 acre-feet of water per acre per year. In this study, it was established that by controlling the operation of ~~reservoirs~~ in a systematic way, stored water would be enough to meet the needs of 20,000 acres. An analysis was made of the quantities of water stored in the reservoirs taking the period 1961-65 as a base. Table No. 5 presents the quantities of water available for irrigation in these years and the percent of allocation based on 3.0 acre-feet per acre per year for 20,000 acres. That is, in accordance with the data of this study, it was determined that the capacity of the system would be enough to serve 3.0 acre-feet of water annually when the 20,000 acres projected to be developed by the system had authorization to receive irrigation water.

Although at certain times the system has to limit the deliveries of water, it is noted on the other hand, that the system has in the majority of the years the quantities of water necessary to cover the farm needs.

Studies conducted in the cultivation of sugar cane in the zone of Lajas Valley, as well as other related studies, confirm the fact that the use of irrigation is indispensable to secure maximum yields of this crop.

Table No. 5

Comparative Summary of the Possible Annual Deliveries and Actual Sales of Irrigation Water, Lajas Valley, 1956 to 1961

Years	Available Allotment (percent)*	Available Water (acre-feet)	Sales (acre-feet)
1956	108	65,101	7,945
1957	92	55,334	10,334
1958	126	75,667	14,894
1959	94	56,167	16,999
1960	95	56,751	12,884
1961	115	69,068	18,121
Annual Average	105	63,015	13,530

Roberto Vázquez in a study conducted during the years or 1965-1968 at the Agricultural Experiment Substation in Lajas, found that sugar cane is a crop that consumes great quantities of water during its growing period. In this study the consumption of water was investigated with a plant cane and two ratoons. The tests made included plots that were frequently irrigated and plots that were less frequently irrigated during the entire period of plant growth (3). Treatments also included plots that were irrigated frequently up to three months prior to harvest and plots that were irrigated frequently up to five months before harvest. His data show that the highest consumption of water in both, the plant cane and the ratoons occurred in the period of August to October. During the first months of the growth period, cane uses smaller quantities of water.

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* 100 percent - 60,000 acre feet annually (20,000 acres x 3.00 acre feet).

The total consumptive use of water by a 13-month plant cane was 64.72, 57.18, 59.69, and 54.78 inches under the frequently irrigated and less frequently irrigated plots during the entire growth period and those that were irrigated frequently until 3 and 5 months prior to harvest without irrigation thereafter, respectively. The total water consumption by the first ratoon, 12 months old was 56.14, 47.90, 53.09, and 44.77 inches for each respective treatment. The respective total water consumption for a second 12-month ratoon was 55.97, 44.91, 50.36 and 43.70 inches.

The frequent application of irrigation during the growth period of the cane produces a positive effect on yields. In this study the largest yields of sugar cane were obtained under conditions of high soil moisture throughout the entire period of plant growth. On those plots that were frequently irrigated, yields up to 96.96 tons of cane per acre were obtained. In those lands where irrigation was suspended 5 months before the harvest, the yield fell to 64.3 tons of cane per acre.

The average yield per acre of a plant cane and two ratoons was 73.67 tons of cane and a yield of 7.80 tons of sugar per acre. This was obtained in the treatment that included frequent irrigation during the entire growing period of the plants.

On plots where irrigation was less frequent, the average yield of a plant cane and two ratoons was 59.37 tons of cane and 6.4 tons of sugar.

The results of this study demonstrate the need which exists in the Lajas Valley of increasing the use of irrigation water in order to increase the yields of the sugar cane fields.

Between 1966 to 1968 the Agricultural Experiment Station of Puerto Rico carried out an economic study of the sugar cane farms in the Irrigation District of Lajas Valley (4). The chief aim of this study was to obtain data on expenditures and incomes of cane farms with the hope of determining the economic factors which contributed mostly to the rate of payment of the farms under irrigation which could be charged when the Irrigation District begins to operate permanently.

In the above mentioned study it was found is that:

1- The farms under irrigation used an average of 1.24 acre-feet of water in 1966 and 1.76 acre-feet during 1967.

In Table 6 the distribution of the farms studied on the basis of the use of irrigation water is presented. The data of the table show that in the 1967 harvest, the yield of cane per acre varied from 15.30 tons in the group that did not use irrigation water to 28.36 tons in those which used 1.51 acre-feet or more. In the 1968 harvest, the variation ranges from 18.20 tons in the group that did not use water to 27.68 tons in those which consumed 0.75 acre-feet or less.

The data also revealed a highly significant difference on comparing the yield of cane per acre in the group of farms that were not irrigated with those that were irrigated in both years.

2- Economic analysis on non-irrigated farms showed incurred costs amounting to $219.49 against an income of $188.56, resulting in a loss of $30.93 per acre. On irrigated farms, however, income totalled $373.02 and costs $332.97 with a resulting profit of $40.05 per acre. Based on per unit output of cane, income generated on non-irrigated farms was $12.40 while costs incurred were $14.42. This resulted in a net loss of $2.02 per ton of cane produced. On irrigated farms a net income of $1.35 per ton was obtained since costs incurred were $11.29 and income generated $12.64.

3- The quantity of irrigation water used had a significant effect on the costs and incomes of the farms studied. Data for the 1967 harvest revealed that the income of one group of farms which used 0.75 acre-foot or less of

Table No. 6

Distribution of the Farms by the Amount of Irrigation Water Used per Acre, Area Sown, and Cane Produced, Lajas Valley, Puerto Rico, 1966-67 and 1967-68.

Years of Harvest	Water Used per Acre (acre-feet)	Number of Farms	Acres of Cane Harvest	Water Used (acre-feet)	Water Used per Acre (acre-feet)	Cane Produced (Tons)	Cane Produced per Acre (Tons)
1966-67	None	11		---	---	9,568.26	15.20
	Less than 0.75	11	654.80	232.46	0.36	16,715.83	25.52
	0.76-1.50	16	1,877.95	2,132.85	1.14	52,329.16	27.86
	More than 1.51	9	689.25	1,693.23	2.45	19,547.15	28.36
1967-68	None	10	310.50	---	---	5,651.19	18.20
	Less than 0.75	10	531.95	162.28	.30	14,725.53	27.68
	0.76-1.50	6	399.84	394.57	.99	10,680.22	26.71
	More than 1.51	12	2,138.32	5,565.65	2.60	58,106.64	27.17

water were $330.98 and the costs incurred $288.18 with a net profit of $42.80 per acre. On the other hand, farms that used 1.51 acre-feet or more had incomes of $374.68 and incurred costs of $312.42 with a net profit of $62.26 per acre.

In the 1968 harvest, the first group of farms that used 0.75 acre-foot or less of water obtained $359.72 in income and incurred costs of $310.42 with a net profit of $49.30 per acre, while those that used 1.51 acre-feet or more had incomes of $353.58 and incurred costs of $304.52, with a net profit of $49.06 per acre. The data of the study revealed highly significant differences when net profit per acre is compared between irrigated and non-irrigated farms. These differences are obviously due to the use of irrigation during the years of study.

Hugo Irizarry, in an economic study of the factors that determine water use in Lajas Valley in 1968, found that the average yield of cane in plots that were irrigated was 29 tons per acre (5). He also found that farms that did not use irrigation the average yield was 23 tons per acre.

The study, apart from being made during a dry year, showed low intensity of use of irrigation water by the farmers of the Lajas Valley. Table No. 7 presents the annual water use and distribution of 51 farms studied during 1967-68. Based on this table 21 farms used an average of 0.64 acre-foot of water per acre per year and 17farms used 1.44 acre-feet per acre per year. Most of these farms, therefore, can be considered as having a low use of water since the average level of use was less than 2.0 acre-foot per acre per year.

This study further revealed that as the use of irrigation water per acre increases, the price per unit of water as well as labor, decrease.

Table No. 7

Annual Use and Distribution of Irrigation Water on 51 Farms of Lajas Valley, Puerto Rico, 1969-70. (5)

Distribution of Annual Use (Acre-feet/acre	Annual Use Acre-feet/acre	Distribution of Water			
		Number of Farms	Acres Irrigated	Percent	Total Acre-Feet
0.00 - 1.00	0.64	21	756.96	19	487
1.01 - 2.00	1.44	17	1908.97	47	2754
2.01 - 3.00	2.38	11	1003.04	25	2387
3.01 - 4.00	3.36	2	361.38	9	1215

The Water Resources Research Institute of the University of Puerto Rico made a study during the year 1969-70 of the costs and effects of irrigation in the planning and implementation of the Agricultural Development Program of the Lajas Valley (6). It was found that cane grown on farms under irrigation, the output was 27.14 tons per acre. This output was very low when compared with farms under irrigation in the District of the South Coast, where average output is about 40 tons per acre. Similar yields are obtained by irrigated farms administered by the Puerto Rico Land Authority in the Lajas Valley.

Based on this information it can be concluded that the greater tonnage obtained in these farms is mainly due to the greater amount of irrigation water used.

The study also showed that in those farms where irrigation was not used, lower yields, averaging 22.8 tons of cane per acre were obtained. These data are similar to those obtained by Hugo Irizarry in his study described previously. It is significant to point out that according to the data of this study, the farmers that used irrigation on their farms received $55.25 more per acre of cane cultivated than those who did no irrigation on their farms. The data presented in table No. 8 show that the income per acre of all the items is greater in farms that used irrigation. Consequently a higher total income per acre was obtained.

It is relevant to point out that the farmer's income in this enterprise depends to a great extent on the volume of cane produced and harvested. Lands under irrigation in the zone are in fact more productive and because of this, incomes are larger. Included in such study were some socio-economic factors related to the farmer. Among these were age, education, type of ownership,and size of farms.

In the group of farmers studied, it was found that 63 percent of them were 50 years of age or older. Sixty-seven percent of the farmers had nine years or more of schooling.

Table No. 8

Gross Income per Acre and per Ton of Sugar Cane With and Without Irrigation in Lajas Valley, 77 Farms, Lajas Valley, Puerto Rico, 1969-70.

	Cane Without Irrigation			Cane With Irrigation		
Source of Income	Total Income	Income per Acre	Income per Ton	Total Income	Income per Acre	Income per Ton
Sugar Sales	$224,877.29	$172.32	$ 7.55	$ 890,550.33	$204.86	$ 7.55
Molasses	14,889.00	11.40	.50	58,937.54	13.56	.50
Insular Government Incentives	21,463.38	16.44	.72	111,581.04	25.66	.95
Federal Compensation	38,169.53	29.24	1.28	149,207.21	34.32	1.26
Freight	32,457.94	24.87	1.09	124,596.99	28.66	1.06
Other Income	10,315.48	7.93	.35	45,397.09	10.44	.38
Total	$342,172.62	$262.25	$11.49	$1,380,270.20	$317.50	$11.70

Most of the farms were not operated by their own proprietors accounting for 71 percent being rented or administered. About half of those farms were 100 acres or less in size.

Jorge López Zapata, in a study of the factors that affect the technological level of the farmers of Lajas Valley obtained similar results regarding the factors mentioned above (7). López Zapata found the age of the farmers whose farms had irrigation facilities ranged from 28 to 86 years. Fifty-six percent of the age group were between 46-65 years. The average education among these farmers was 9.7 school-years.

CHAPTER III

METHODOLOGY

A total of 268 farms in the Lajas Valley with established facilities for irrigation constituted the universe of the study. A list of farms was obtained from the official register of farms with irrigation facilities in the Office of Development of Lajas Valley.

The farms pertaining to the Agricultural Experimental Station and the Land Authority were excluded from the study.

Farms operated under rental by the Land Authority and the Land Administration were included in the study as individual farms. These represent 23.13 percent of the total of farms and 53.07 percent of the total area. Farms studied were operated by 140 farmers.

The sample of the study constituted 33 percent of the selected sugar cane farms. In order to facilitate a representative sample, farms were classified in 12 groups according to size.

To choose a random sample a number from one to three was sorted. The number selected was one, which corresponded to the first farm selected for inclusion in the study. From thereon, one in every three farms were selected. On this basis the resulting sample was composed of 90 farms with irrigation facilities covering an area of 7,035 acres.

As an instrument for implementing the study a questionnaire was used that included the necessary and relevant questions to the study in relation to the objectives formulated. Initially a basic questionnaire was prepared for consultation with technitians and experts acquainted with the subject, in methodology as well as in technical matters. Consultations were arranged with professors of the Mayaguez Campus of the University of Puerto Rico, the technical staff of the Agricultural Experimental Station, the Commonwealth Department of

Agriculture, the Agricultural Extension Service, the Water Resources Authority, and the Federal Soil Conservation Service.

The suggestions received were incorporated into the questionnaire. Field tests were conducted among five selected farms of the population to be studied in order to make any necessary adjustments to the questionnaire. Based on these tests, modifications of a few questions were made to facilitate easier interpretation on the part of the farmers. An additional page was also prepared to permit tabulation of the information at the Computer Center of the University of Puerto Rico in the Mayaguez Campus.

The questionnaire was administered through personal interviews. The questionnaire sought information on specific questions relating to farm, agricultural conditions, and those factors affecting the intensity of the water used for irrigation.

During the study, visits were made to the irrigation structures and facilities established by farmers on their farms and those of the Water Resources Authority. Supplemental information about the farms and water consumption were provided by some of the government agencies outlined previously.

A series of tables were prepared to compile data and other information obtained from the questionnaires. The same was processed and analyzed at the Computer Center in order to facilitate the final interpretation.

Statistical measures employed in the analysis of data include measures of central tendency such as the arithmetic mean, median, mode and percentages. Chi-square was used to measure the degree of association among the different factors and the intensity of water used by irrigation.

Definition of Terms:

1- Permeability is a specific property of a soil ~~of~~ which is a measure of the readiness with which the soil transmits water; usually expressed in inches per hour or in centimeters per hour.

2- Acre-foot of water is a measure equivalent to one foot or 12 inches of water over a surface of one acre of land; it is equivalent to 325, 851 gallons of water.

3- An acre is a piece of land covering an area of 43, 560 square feet, or 4, 047 square meters, or 1.03 "cuerdas".

4- Evaluation of services rendered or structures of the irrigation systems:

   a) Excellent = when the system or service is perfect and needs no improvements.

   b) Good = when the system or the service is almost excellent but needs minor improvements.

   c) Regular = when the system or service meets the minimum requirements but needs many improvements.

   d) Deficient = when the system or the service is below the minimum requirements and needs great improvements.

5- The irrigation canal of the Puerto Rico Water Resources Authority (PRWRA) of their own property made of concrete to transport water to the individual farms.

6- Irrigation outlet is the structure used by the PRWRA to deliver and meter the water to the different farms.

7- Irrigation ponds of the farm used to receive and distribute the water

a) Owners = when a farmer runs his own farms.

b) Tenant = a farmer who operates a farm through a contract that meets certain conditions of use and payment to the owner of the farm.

c) Administrator = when the operator receives payment from the owner of the farm so that he may operate or exploit it.

9- Formulas:

a) Arithmetic mean = the sum total of all the items divided by the number of farmers or, $X = \frac{\sum_{i=1}^{n} X_i}{N}$

b) Median = is the middle position of all the items placed in order of magnitude.

c) Mode = is the class that occurs most frequently within the values.

d) Percent = $\frac{\text{Number of farmers in a class}}{\text{Total number of farmers}} \times 100$

e) Chi square = X^2 Fo = observed frequency

Fc = calculated frequency

$$Fc = \frac{\text{(total columns) (total rows)}}{\text{Number of cases}}$$

$$X^2 = \frac{(Fo-Fc)}{Fc}$$

10- Payment conveyance = a system through which the farmer binds himself to efectuate a payment for a service received for using the incentives and other government subsidies to be subsequently received.

[redacted]

CHAPTER IV

RESULTS

This chapter describes the results of the present study which seeks to determine the relationship of factors affecting the use of irrigation water by farmers in the Lajas Valley. First, the population is described based on the selected socio-economic factors studied. Secondly, the relationship between these factors and the use of irrigation water is analyzed. Finally, the observations of technicians with respect to the farmers efficiency in the application of irrigation and drainage practices are described.

Description of the Population

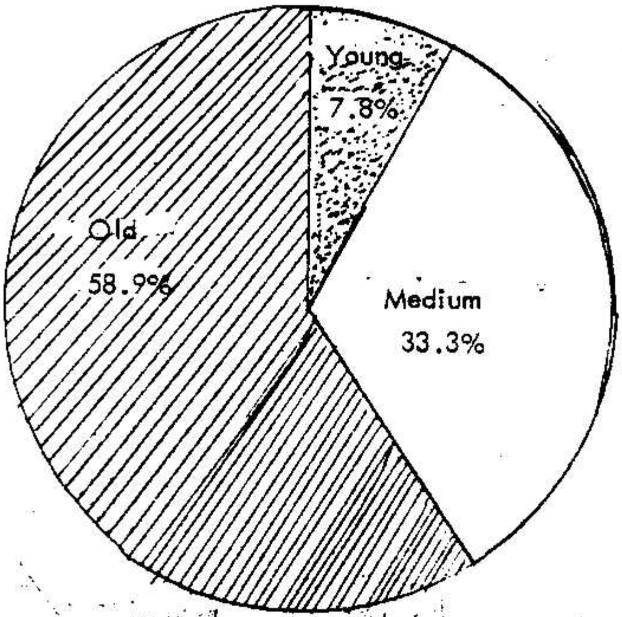
Age

The age of the farmers ranges from 30 to 84 years. Within this age span, 58.9 percent is 51 years or more of age, while only 7.8 percent is between the ages of 18 to 36. Most farmers are relatively advanced in age since the average is 57.7 years. The distribution of the farmers according to their ages is shown on figure No. 1.

The results of this study regarding age are similar to those reported by Busquests (8), Oliver Padilla (10), González Casillas (40), Collazo Collazo and Calero (15), López Zapata (7), Avilés Cordero (6), and the Commonwealth Department of Agriculture (13).

Figure No. 1

Distribution of Farmers of 90 Farms Studied in Lajas Valley According to Age
1971-72



The farmers' age is a point of great relevance for the agricultural development of the country. Traditionally, agriculture is of great economic importance in the Lajas Valley and in Puerto Rico. Knowledge regarding the relative high age of farmers is a cause for concern. Agriculture in the hands of people advanced in age may be an important reason why younger members has demonstrated little interest in it.

Education:

Figure 2 shows the education of the population studied. The level of education varied from fourth grade to professionals having 17 years of formal education. The average education was 11.7 years. Ten percent of the farmers had 6 or less years of schooling and 37.8 percent had completed one or more years at the college level.