DESIGN AND OPERATING CRITERIA
FOR RURAL WATER SYSTEMS

By

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INTRODUCTION

The Problem

During recent years the federal government has spent hundreds of millions of dollars on a rural development program to improve the rural environment and reverse the trend of rural to urban migration. The program's success depends largely on improving rural living conditions to approximate those available in urban areas.

One of the major aspects of satisfactory rural living conditions is a plentiful supply of high quality water. As many areas of the country do not have a groundwater supply of adequate quality, rural water districts have been developed to provide plentiful quantities of potable water.

A total of 308 rural water systems had been completed in Oklahoma serving 31,293 families as of June 30, 1973. The total value of loans closed, funded, under review, and applications pending was almost ninety million dollars for Oklahoma alone.

Most of the water districts in Oklahoma have been formed in the last seven years and much of the design information needed to accurately design these systems has not been developed. The design criteria presently being used have been derived from experience in municipal systems design. These rural water systems have different problems and design criteria than do city water systems. Typical rural systems may be designed for two to four services per mile (1.61 kilometers), while a city may have thousands in the same distance, and the water demand patterns of rural users may be quite different than those of city dwellers. Usually a rural system had many miles (kilometers) of pipe and at the extremes of lines, the water being used may require a travel time of an hour or more from the source, which would flatten the peak of the demand curves. The extremities of many rural water systems are served by booster pumps and standpipes, filled by off-peak pumping. The designer does not have available the expected time-demand curves to design economic pumping systems. In addition, some existing rural systems have been saturated soon after construction, and the capacity for satisfactory service is not available. It is because of such factors that research is needed to determine patterns of water demand for rural system users.

Scope of Investigation

The study described in this thesis was designed to evaluate the water use patterns of customers on a rural water district. The system observed had one primary storage tower and three main laterals, each designed to serve approximately forty-two miles (67.6 kilometers) of pipeline.

The data collected were in pairs of flow rate and the corresponding time. An attempt was made to correlate magnitudes of usage by various economic classes of consumers on the basis of the apparent economic value of the residence. No attempt was made to determine differences in time of demand for consumer classes. Data were gathered during the period from January to October to observe seasonal variations in usage patterns, if any.

Objectives

The objectives of this research were:

1. To determine values of monthly usage rate for contractural arrangements to purchase water.
2. To obtain patterns of use by different economic classes of consumers so that the present and anticipated mix of users will reveal the peak demand, the daily demand, and the monthly demand.
3. To obtain design values of daily demand for different classes of consumers in order to determine the storage requirements per customer.
4. To obtain design values of peak demand flow rate for different types of rural consumers in order to determine economic pipe sizes and the capacity of existing systems to add on new customers.
5. To obtain patterns of time distribution of demand for different times of the year in order to determine available pump operating periods for off peak pumping plants and the required pump and pipe capacities per customer.

CHAPTER II

REVIEW OF LITERATURE

Considerable literature has been written on residential water use requirements, mostly on municipal systems. The topics covered in this review are the design criteria used by the Farmer's Home Administration, water usage patterns of municipal residents, and water usage patterns of rural users with private and public water systems.

FHA Design Criteria

The Farmer's Home Administration (1) lists the following design values for peak demand to be used for sizing the distribution pipelines for systems serving low population density areas:

Type of Establishment	Peak Flow
Farm Family	2 gpm (7.57 lpm)
Motel	1 gpm (3.79 lpm)/unit
Restaurant	1.5 gpm (5.68 lpm)/unit
Launderette	5 gpm (18.93 lpm)/unit
Service Station	3 gpm (11.36 lpm)/unit
Churches	0.1 gpm (.379 lpm)/member
Other Establishments	0.25 gpm (.95 lpm)/member

The storage for rural water systems is designed on the basis of providing two day use requirements using a design value of 150 gallons (56.78 liters) per day per customer. The design value of four hours of off-peak pumping time is used in the design of off-peak pumping plants.

Municipal Usage Patterns

Wolff (2) states that hydrographs of systems serving predominantly residential communities have a pattern generally containing two peak rates of flow. One peak occurs between the hours of 7 a.m. and 1 p.m. and the other in the evening between the hours of 5 and 9 p.m. The time when those peaks occur depends on the season of the year. In the winter, the maximum hours occur during the periods of 7 to 9 a.m. and 5 to 7 p.m. During the spring, summer and early fall, when sprinkling demands are imposed, the times of peak occurrence shift to the later morning hours and to 6 to 9 p.m. in the evening.

The hydrographs of demands in residential areas were found to vary with the following factors:

(1) The number of services,

(2) Seasonal factors, such as preceding rainfall and humidity,

(3) Size and age of the residential lots,

(4) Number of people on each service,

(5) The number of water-consuming devices in the home.

Maximum usage days for four residential areas were found to range from 93 to 564 gallons (352 to 2135 liters) per capita per day.

Herman (3) states the pattern of water system demand has two important classifications:

(1) the average demand on the maximum use day

(2) the peak hourly demand

He notes trends of increasing per capita consumption and increasing peak day and peak hourly consumption. Hermann also notes that residential water demands are influenced by the total number of customers, the economic level of the user based on the market value of the residence, the average irrigable area of lawn, evapotranspiration, and effective precipitation. He states that when using historical data to project future peak system demands, the same conditions responsible for past data probably will not prevail.

Proudfit (4) in describing the systems of several cities presents the information needed for accurate design, namely the hourly demand for the peak use day. For Sedalia, Missouri, he lists a maximum hourly demand of 5.5 million gallons (20.8 million liters) per day and a peak day demand at 3.5 million gallons (13.2 million liters). His listing of design data for typical cities shows a ratio of total storage divided by use from storage varying from 1.7 to 29.0.

The committee on water works practice of the American Water Works Association (5) lists an average daily consumption ranging from 40 to 250 gallons (151 to 946 liters) per capita, and a value of 150 gallons (568 liters) per day per capita was listed for the maximum use day. The committee also recommended a value for the peak hourly use as 225 percent of the average for the maximum day.

Linaweaver (6) has demonstrated that water use is a function of the economic status or living standard of the consumer. He lists the empirical equation:

$$Q = [157 + 3.46\ V]K$$

where Q = expected average household use in gallons or liters per day

V = average market value in thousands of dollars

K = 1.0 or 3.79 for a demand in gallons or liters, respectively

Kiker (7) indicates the need for additional research by stating that the selection of arbitrary volumes based on percentages of old per capita consumption figures may be less accurate now than they were before: hence, data should be collected to determine the trends in different communities and should be properly evaluated to determine the system requirements.

Muldowney (8) indicates the importance of the consumer in the design of water systems. He states that how the consumer intends to operate is of great concern in the design of the systems to serve him. Quite often the billing record or the service application will contain the facts necessary to determine what the average consumption is or will be but does not have enough information to determine the maximum rates.

Rural Residence Usage Patterns

Yung (9) monitered eight farmsteads and one urban home in Nebraska and found that the maximum daily demand and maximum hourly demand were about the same. He reported annual water usage rates ranging from 66,000 to 237,000 gallons (249,837 to 897,143 liters). Yung listed the following design values:

		Number of Systems	Average	Maximum	Units
Total Systems Demand		9	1699 (6431)	2694 (10198)	gph (lph)
Pump Capacity		8	290 (1098)	570 (2158)	gph (lph)
Daily Peak Demand		9	458 (1734)	604 (2286)	gpm (lpm)
Maximum Hourly Demand		9	62 (235)	113 (428)	gph (lpm)
Design Factors:	R	8	4.2	6.0	
	K	8	9.0	15.6	
	C	8	5.2	10.8	

where R = water diversity ratio = total systems demand/daily peak

K = water demand ratio = daily peak demand/maximum hourly demand

C = pump capacity ratio = pump capacity/maximum hourly demand

Yung developed the following formula to determine pump capacity needed.

$$\text{Pump Capacity} = \text{Total System Demand} \left(\frac{C}{RK}\right)$$

The hydrology committee of the American Society of Agricultural Engineers (10) recommended the average daily requirement as 50 to 75 gallons (189 to 284 liters) per person depending on the number of water using appliances in the residence. The committee also reported the values listed below as the average daily requirement for various types of livestock:

Type of Livestock	Average Daily Requirement
Horses	12 gallons (45 liters)
Beef Animals	12 gallons (45 liters)
Milk Cows	15 gallons (57 liters)
Hogs	4 gallons (19 liters)
Sheep	2 gallons (8 liters)

Stotlenberg (11) made a study of the monthly billings of twenty rural community water systems in Illinois and reported an average monthly use of 2900 gallons (10978 liters) per service.

Johnson (12) made a survey of several rural water systems in Kansas and found an average monthly use of 3500 gallons (13249 liters) per service. He also reported that simultaneous peak usage rates for systems with 100 taps average 0.90 gallons (3.4 liters) per minute per tap and that the peak use rates per tap varied inversely with the number of customers on the system.

CHAPTER III

EXPERIMENTAL EQUIPMENT

The System

The data for this research project was collected on Rural Water District No. 3, Payne County. A schematic of the system is shown in Figure 1. The system consisted of three main laterals, each with approximately fourteen miles (22.5 kilometers) of pipe network and designed to serve approximately forty residences. A cylindrical tower, 12 feet (3.66 meters) in diameter and 85 (25.91 meters) high, was used to perform the dual functions of providing adequate pressure and storage. The northern two laterals had booster pumps with pressure tanks to provide service to the extremities of the system. The water supply was obtained from three wells, two miles (3.2 kilometers) from the storage tower.

The system was designed in accordance with guidelines given by the Farmer's Home Administration. A design peak flow of two gallons (7.57 liters) per minute per tap was used to size the pipes to maintain a minimum required pressure of 20 pounds per square inch (1.38 x 10^5 newtons per square meter). The storage tower was designed for two day storage of 150 gallons (567.8 liters) per tap per day.

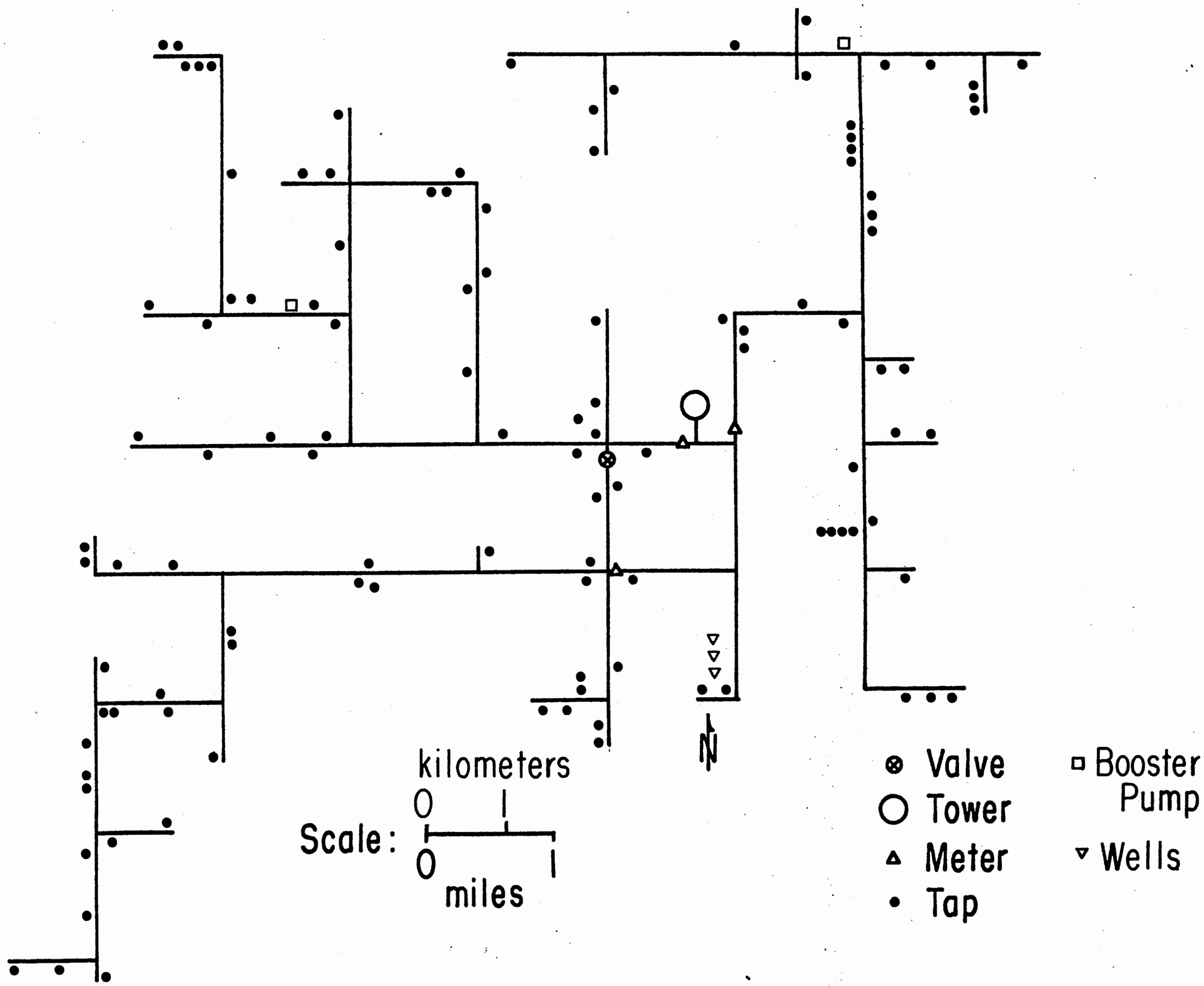


Figure 1. Payne County Rural Water District No. 3

Flow Measurement

The inflow into each main lateral was measured with a two-inch (5.08 cm.) Badger nutating disk water meter (Figure 2). Nutating disk water meters were chosen because of their relatively low pressure loss and high accuracy at flows in the range of 100 gallons (378.5 liters) per minute. The meters were calibrated in the Agricultural Engineering Laboratory at Oklahoma State University using a two inch (5.08 cm.) Trident meter that had been volumetrically calibrated. Regression equations were developed to predict actual flow rates from the observed values. Magnetic reed switches were placed in the meter heads to provide a contact closure for every 100 gallons (378.5 liters) of flow through the meter.

Data Recorders

Sodeco Printing Impulse Counters, Model PL104, recorded the contact closures of the water meter (Figure 3). The count solenoid of the counters was actuated by an impulse transmitter, Model KN651, which provided 3,600 uniform contact closures per hour. The zero reset solenoid of the counter was energized by a 24 hour time clock which provided a contact closure at midnight. The length of the print and zero reset pulses were limited to the design specifications of the PL104 by using solid state circuitry utilizing binary logic. The print circuitry was powered by a twelve volt direct current battery to provide a stable voltage supply,

Figure 2. Metering Station

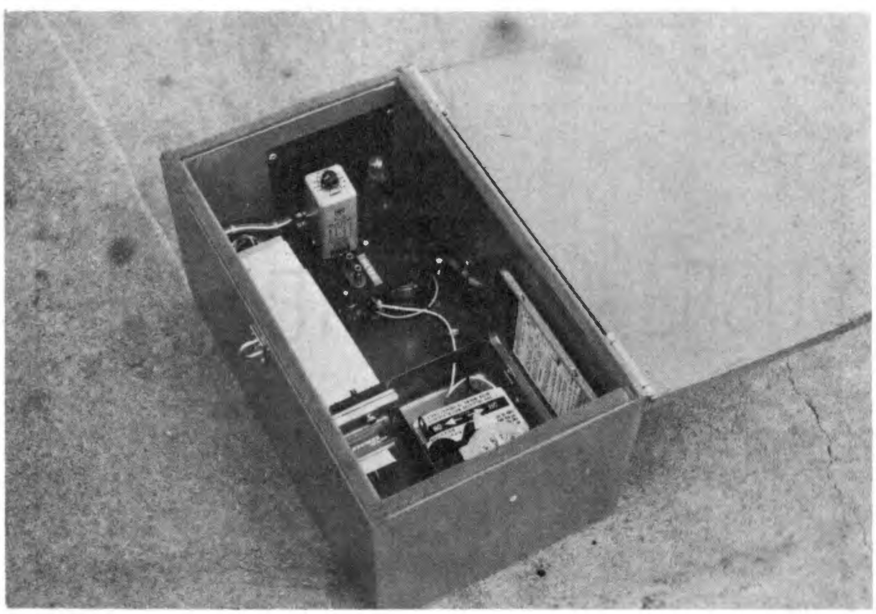


Figure 3. Instrument Setup

while the rest of the recording instruments were powered with one hundred twenty volt alternating current electricity. A circuit diagram for this instrumentation is shown in Figure 4.

With this instrumentation, a printout was obtained on paper tape, recording the cumulative number of seconds after midnight of each successive 100 gallons (378.5 liters) of water usage. The average flow rate for the 100 gallons usage interval could then be determined by the formula:

$$Q = \frac{60K}{\Delta t}$$

Q = Flow rate in gallons per minute or liters per minute

t = Time interval between any two successive prints

K = 100 for a flow in gallons per minute or 378.5 for a flow in liters per minute

Since the recorder measured to the nearest second, the error could then be expressed by

$$E = \frac{\pm Q}{K}$$

Q = Flow rate in gallons per minute or liters per minute

E = Error in percent

K = 60 for a flow in gallons per minute or 227.1 for a flow in liters per minute

At a flow of 60 gallons (227 liters) per minute, the maximum error is $\pm$ one percent and the error decreases for decreasing flows. The time clock indicated to the nearest fifteen minutes, giving a maximum error of seven and one-half minutes. The repeatability of the midnight contact closure was not determined, but the error should have been quite small.

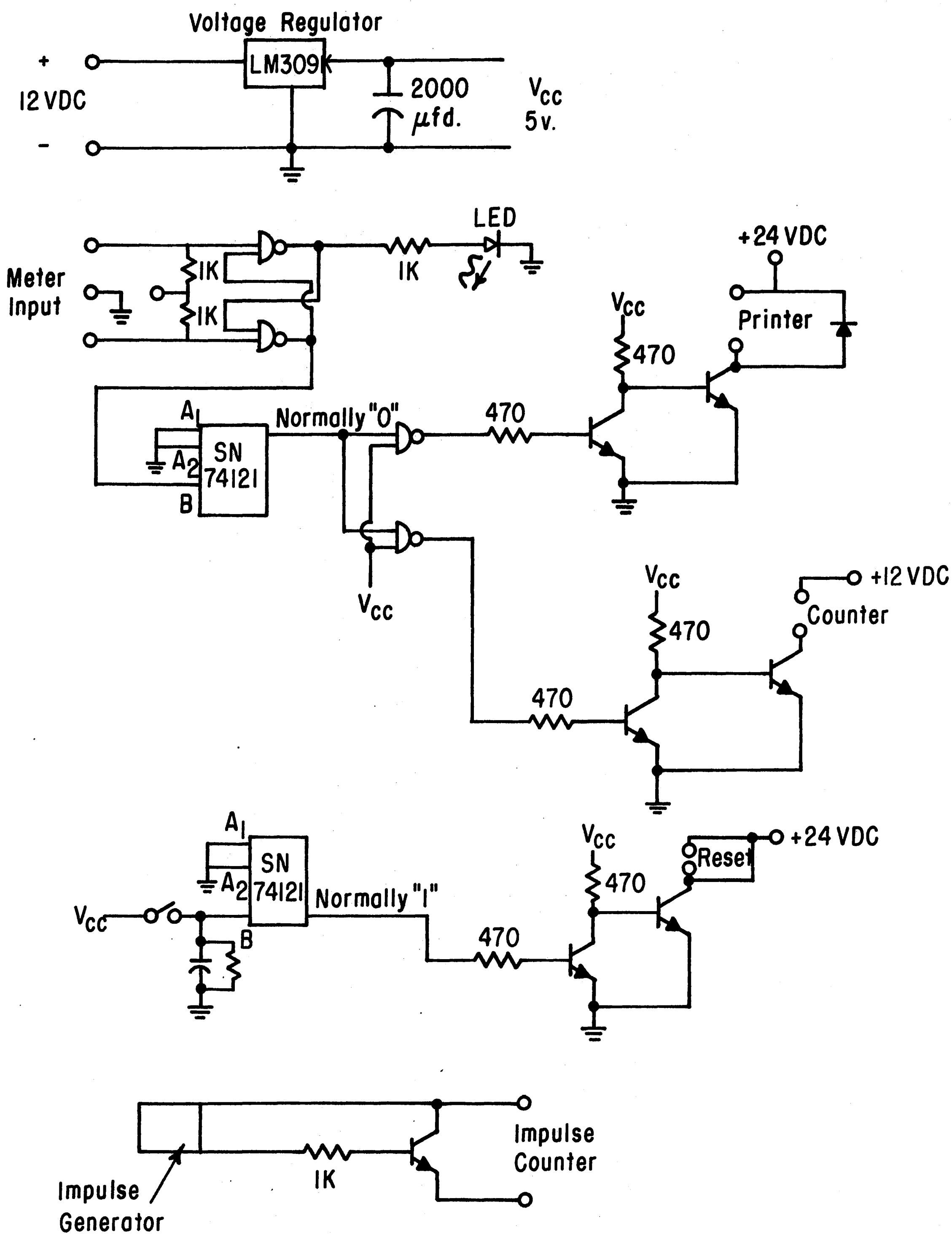


Figure 4. Diagram of Circuits used for Solid State Control of Instruments

CHAPTER IV

PROCEDURE

Flow Measurement

Metering stations (Figure 2) were installed in each of the laterals and a valve was closed in the only pipeline connecting two laterals together (Figure 1), so that the number of customers served through each metering station was known. The metering stations consisted of a two-inch (5.08 cm.) Badger nutating disk water meter with valving and piping, so that the six-inch (15.24 cm.) valve in the lateral could be closed and the flow channeled through the meter. The stations were designed for a pressure loss below five pounds per square inch (3.45 x 10^4 newtons per square meter) at a flow of 100 gallons (378.5 liters) per minute to minimize the monitoring effect on the system's operating pressures. Sodeco printing impulse counters were used in conjunction with the Badger meters to provide a record of the flow usage by the consumer.

Consumer Residence Classification

The consumer residences were classified on the basis of their apparent economic value. A windshield survey of the residences, an approach a design engineer might use, was made, ranking the residences in classes of I through V in descending order of value (Figures 5-9). A sixth class was included to represent dairies. The customers were: 22 percent Class I; 14 percent Class II; 23 percent Class III; 17 percent Class IV; 18 percent Class V; and six percent Dairy.

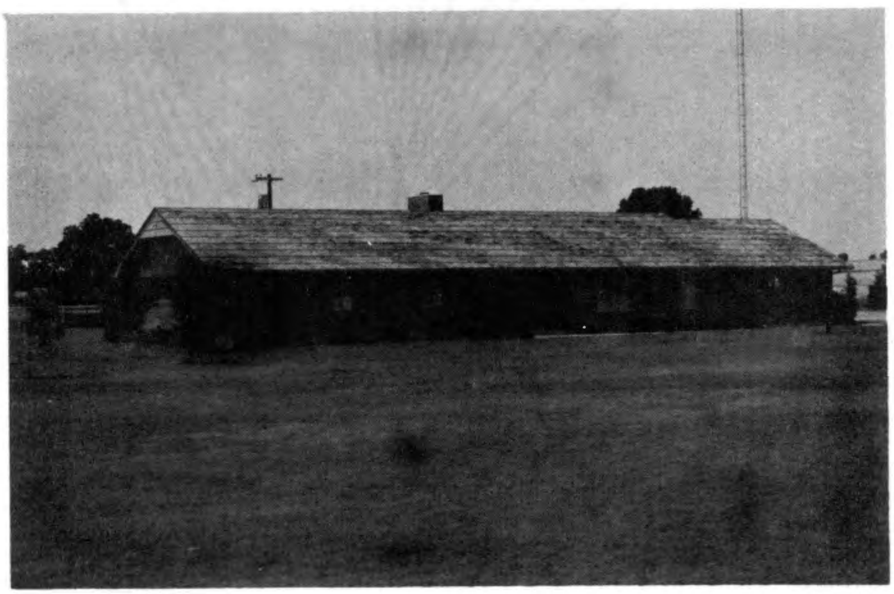


Figure 5. Class I Residence

Figure 6. Class II Residence

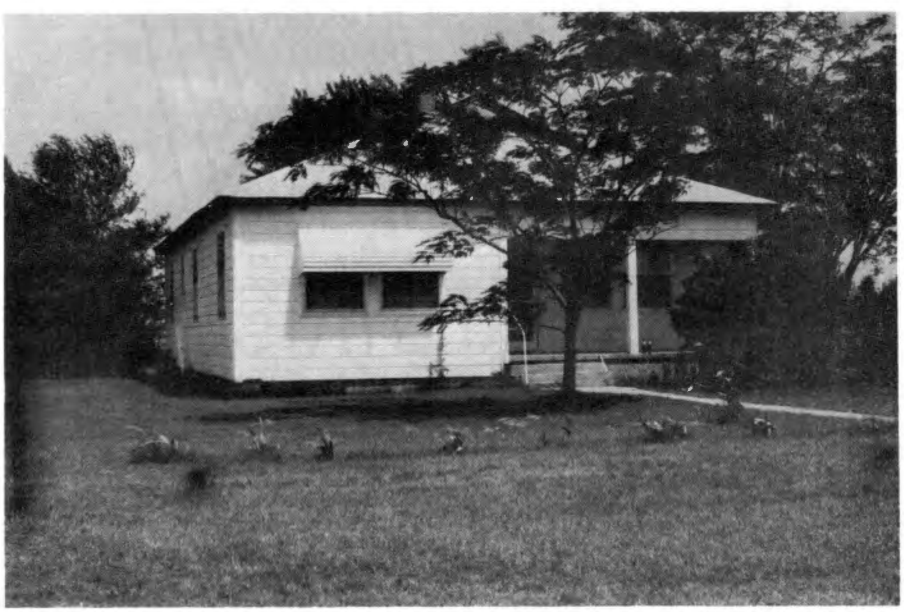


Figure 7. Class III Residence

Figure 8. Class IV Residence

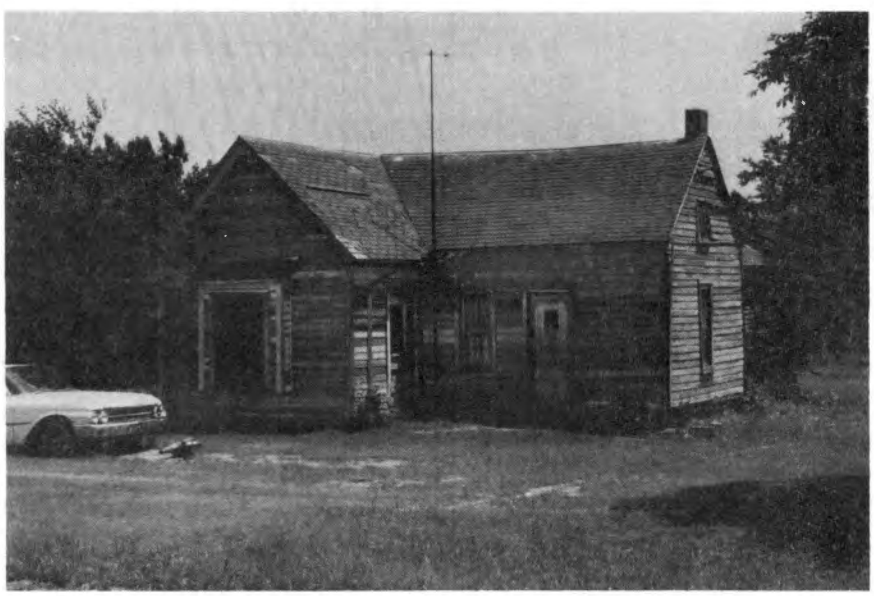


Figure 9. Class V Residence

Monthly Use

Monthly usage readings for the services on the system were furnished by the system maintenance technician. Since few services were connected to the system at the start of the research project the technician also furnished valuable information as to the date each service was installed, the intended use of the service, and the number of people being served in such residences.

CHAPTER V

ANALYSIS OF DATA AND PRESENTATION OF RESULTS

Monthly Usage

Monthly usage readings per tap were obtained from the water district maintenance technician during the period from February to September, 1974. The readings were separated under the economic class of the user, and a one-way classification analysis of variance was performed by month to determine any statistically significant difference among class means. The expected correlation of use magnitude with the apparent economic value of the consumer residences did not hold for classes I, II, III, and IV. Classes I through IV were merged to form Class A, and analysis of variance was performed for the three classes of Dairy, Class A and Class B (formerly Class V). The results of this analysis are shown in Table I. Although not all classes were significantly different for all months, the dairies were found to have the highest usage rates, while Class A and Class B followed the previously mentioned correlation for each month.

Population data were also furnished by the district technician and were used to determine monthly readings per person for each economic class. The one-way classification

TABLE I

AVERAGE MONTHLY USAGE PER TAP

Month	Dairy Gallons	Liters	Class A Gallons	Liters	Class B Gallons	Liters	Least Significant Difference 5% Level Gallons	Liters
February	9178	34743	5569	21081	2537	9604	5431	20559
March	8768	33190	4357	16493	2768	10478	1859	7037
April	12288	46515	6021	22792	3370	12757	2995	11337
May	12108	45834	7331	27751	3919	14835	4304	16292
June	15617	59117	6810	25779	2811	10641	3751	14199
July	19183	72616	11983	45361	4160	15747	6622	25067
August	17100	64731	9973	37752	3817	14449	5481	20748
September	15217	57603	7739	29295	3369	12753	4213	15948

analysis of variance was performed and, as before, the expected correlation of use with economic class did not hold. The data were then separated under two classes and the analysis of variance repeated. The results of this analysis are displayed in Table II. The average monthly usage per person (Class A tap) ranged from 1424 gallons (5390 liters) to 2821 gallons (10,677 liters) while the average monthly usage per person (Class B tap) ranged from 939 gallons (3743 liters) to 1664 gallons (6923 liters). There was a significant difference, at the five percent level, between classes for every month except February. Ratios of use per person (Class B to Class A) are presented in Table III, along with ratios of use per tap.

TABLE II

AVERAGE MONTHLY USAGE PER PERSON

Month	Class A Gallons	Liters	Class B Gallons	Liters	Least Significant Difference 5% Level Gallons	Liters
February	1662	6291	1087	4115	598	2264
March	1424	5390	989	3744	261	988
April	1907	7219	1211	4584	416	1575
May	2248	8510	1524	5769	578	2188
June	2065	7817	1054	3990	398	1507
July	2821	10679	1664	6299	535	2025
August	2643	10005	1459	5523	588	2226

TABLE III

MONTHLY USE RATIOS

	Per Tap		Per Person
Month	Dairy/Class A	Class B/Class A	Class B/Class A
February	1.65	0.45	0.65
March	2.02	0.64	0.69
April	2.04	0.56	0.64
May	1.69	0.53	0.68
June	2.30	0.41	0.51
July	1.60	0.35	0.59
August	1.72	0.38	0.55
September	1.97	0.44	0.54

Graphs were made of the average monthly use per tap and per person to represent the variation in usage patterns with time. Interaction between class of user and the time of year is noted (Figure 10) in the per tap graph as the lines are not parallel. A smaller amount of interaction between class of user and the time of year is noted in the per person graph (Figure 11), suggesting some of the interaction present in the preceding graph may have been due to population effect. Both graphs show a general periodic trend, as expected over time, decreasing during the cooler months and increasing during the warmer months.

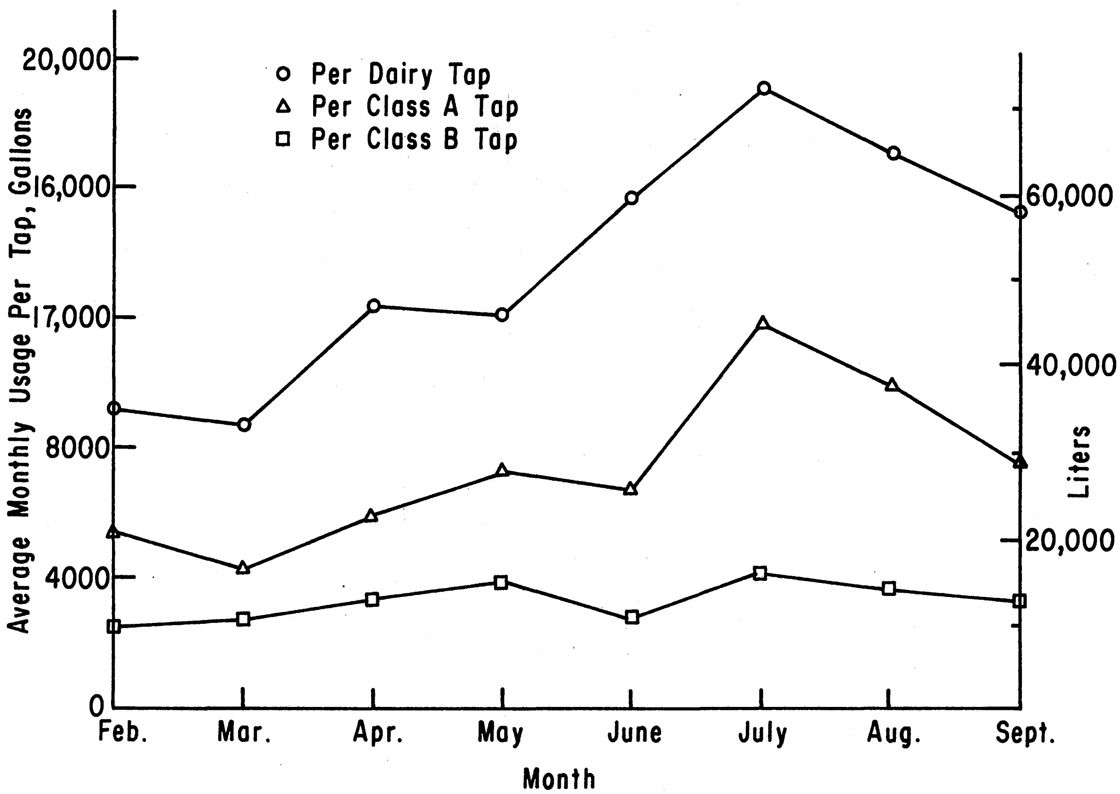


Figure 10. Monthly Usage Per Tap

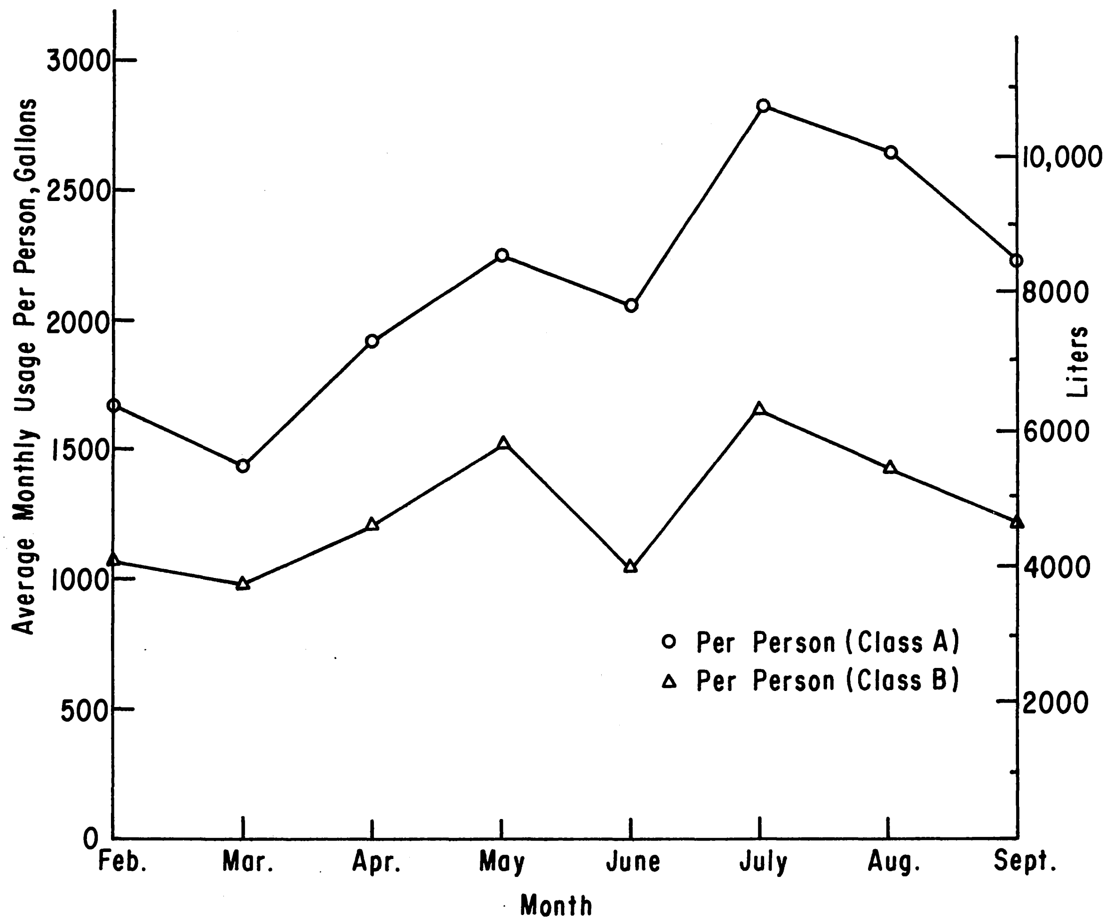


Figure 11. Monthly Usage Per Person

Daily Demand

The data obtained from the Sodeco print recorders were partitioned into 24 hour intervals from midnight. The number of prints were counted and the number of 100 gallons (378.5 liters) usage intervals were determined from the formula:

$$i = n-1 + \Sigma f$$

where i = number of 100 gallon (378.5 liter) intervals

n = number of prints

f = fractions of an interval that may have occurred between midnight the preceding day and the first print of the day and last print of the day and midnight

The daily demand per tap was then determined from the formula:

$$D = \frac{Ki}{T}$$

where D = daily demand in liters or gallons

i = number of intervals

T = number of taps using water

K = 378.5 or 100 for a demand in liters or gallons, respectively

On some occasions, the data were noted to contain extraneous prints. If the number of extraneous prints were less than five percent of the total number of prints, the data were used and the daily demand was determined by the formula:

$$D = D_o C$$

where D = actual daily demand

D_o = observed daily demand determined from the preceding formula

C = ratio of actual number of prints from the meter reading to the observed number of prints from the Sadeco counter

When the recorders were malfunctioning, readings were made from the meter over a 24 hour interval to obtain daily demand data. The demand values are shown in Table V, Appendix A.

A histogram was developed to represent the distribution of the daily demands per tap by finding the number of occurrences in 25 gallon (94.6 liters) intervals (See Figure 12). The average daily demand per tap was found to be 237 gallons (897 liters) with a standard deviation of 76 gallons (388 liters). The histogram was then integrated to form a cumulative frequency curve. From an analysis of the curve, 80 percent of the daily demand values were below 300 gallons (1136 liters) per day per tap and 90 percent of the daily demand values were below 350 gallons (1325 liters) per day per tap. Above 90 percent the curve begins to flatten and incremental increase in percent coverage becomes small for each incremental increase in volume of storage required.

Daily demand values per class of tap could then be determined by applying the monthly use ratios shown in Table III. The total volume of flow was corrected for usage due to any non-categorized tap by subtracting the average

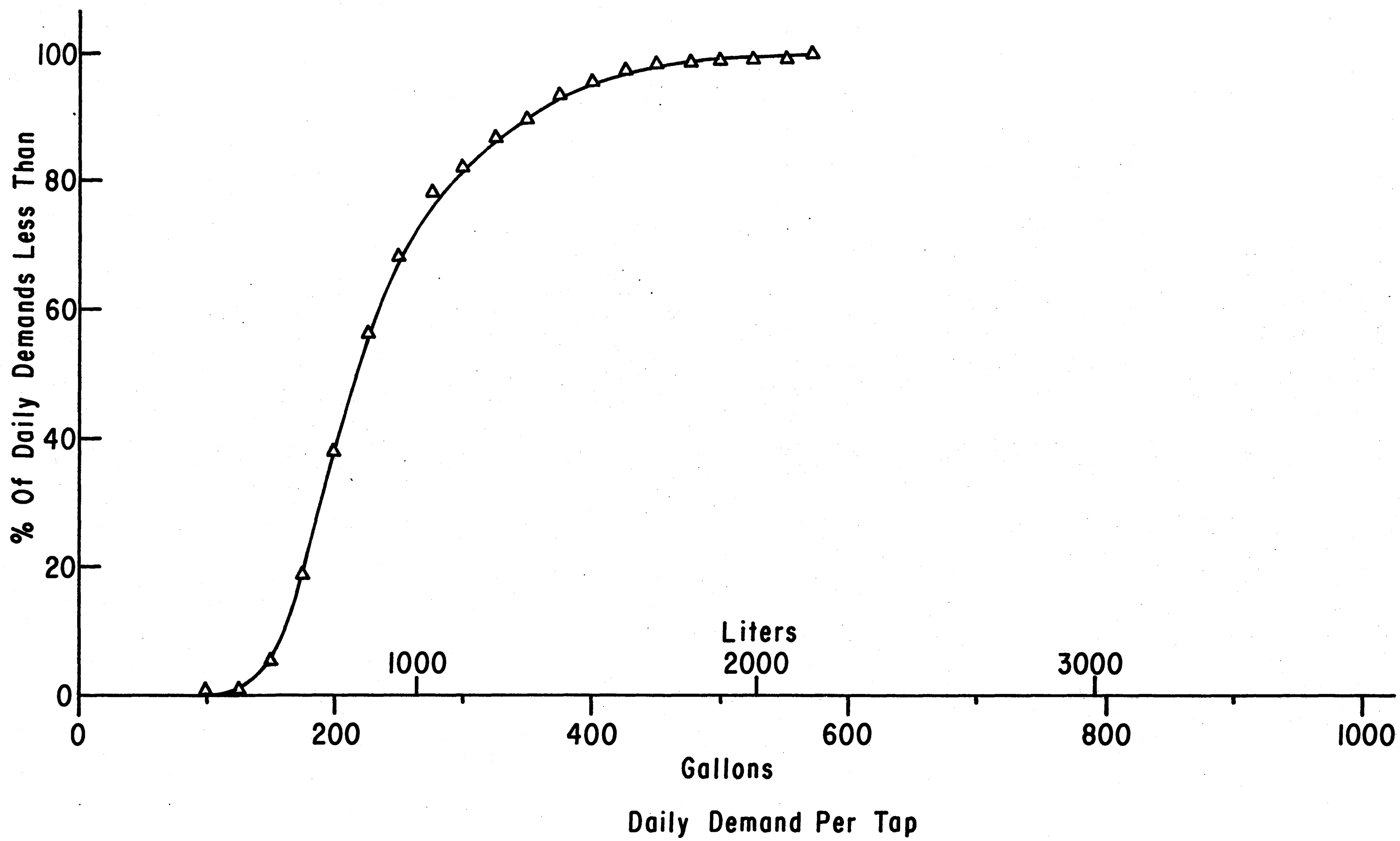


Figure 12. Cumulative Frequency of Daily Demand per Tap

daily use obtained from the monthly readings. No correction was made for the leakage in the system, except that days during which major line breaks occurred were excluded from the analysis. Monthly values for the amount of water pumped from the supply and the amount of water delivered are shown in Table IV.

TABLE IV

SYSTEM DELIVERY EFFICIENCY

Month	Liters Pumped	Liters Delivered	Percent Delivery
May	1,979,555	1,768,958	89
June	2,183,945	1,821,834	83
July	3,735,795	3,636,477	97
August	4,102,940	3,625,652	88
September	2,271,000	2,219,448	98

A system of three equations with three unknowns could be written as follows:

$$D_1 = R_1 \times D_2$$

$$D_3 = R_2 \times D_2$$

$$V = C + N_1 D_1 + N_2 D_2 + N_3 D_3$$

where D_1 = daily demand per Dairy tap

D_2 = daily demand per Class A tap

D_3 = daily demand per Class B tap

R_1 = ratio of Dairy to Class A monthly usage per tap

R_2 = ratio of Class B to Class A monthly usage per tap

V = total volume of flow

C = correction for usage by noncategorized taps, determined from monthly readings

N_1 = number of Dairy taps

N_2 = number of Class A taps

N_3 = number of Class B taps

Histograms for each category were developed as before and the data are shown in Appendix A. The histograms were then integrated resulting in the cumulative frequency curves of Figure 13. Recommended design values in the range of 200, 350, and 600 gallons (757, 1325 and 2271 liters) per day per Class B, Class A, and Dairy taps, respectively were obtained from a visual analysis of the curves.

Daily demand values per dairy cow being miled were then determined by using the following formula:

$$D = D_1 (N_1)/N_2$$

where D = daily demand per dairy cow milked

D_1 = daily demand per dairy tap

N_1 = number of dairy taps

N_2 = number of dairy cows milked

The values obtained are shown in Appendix A. A histogram was developed by finding the number of occurrences in two gallon (7.57 liter) intervals and integrated to give the

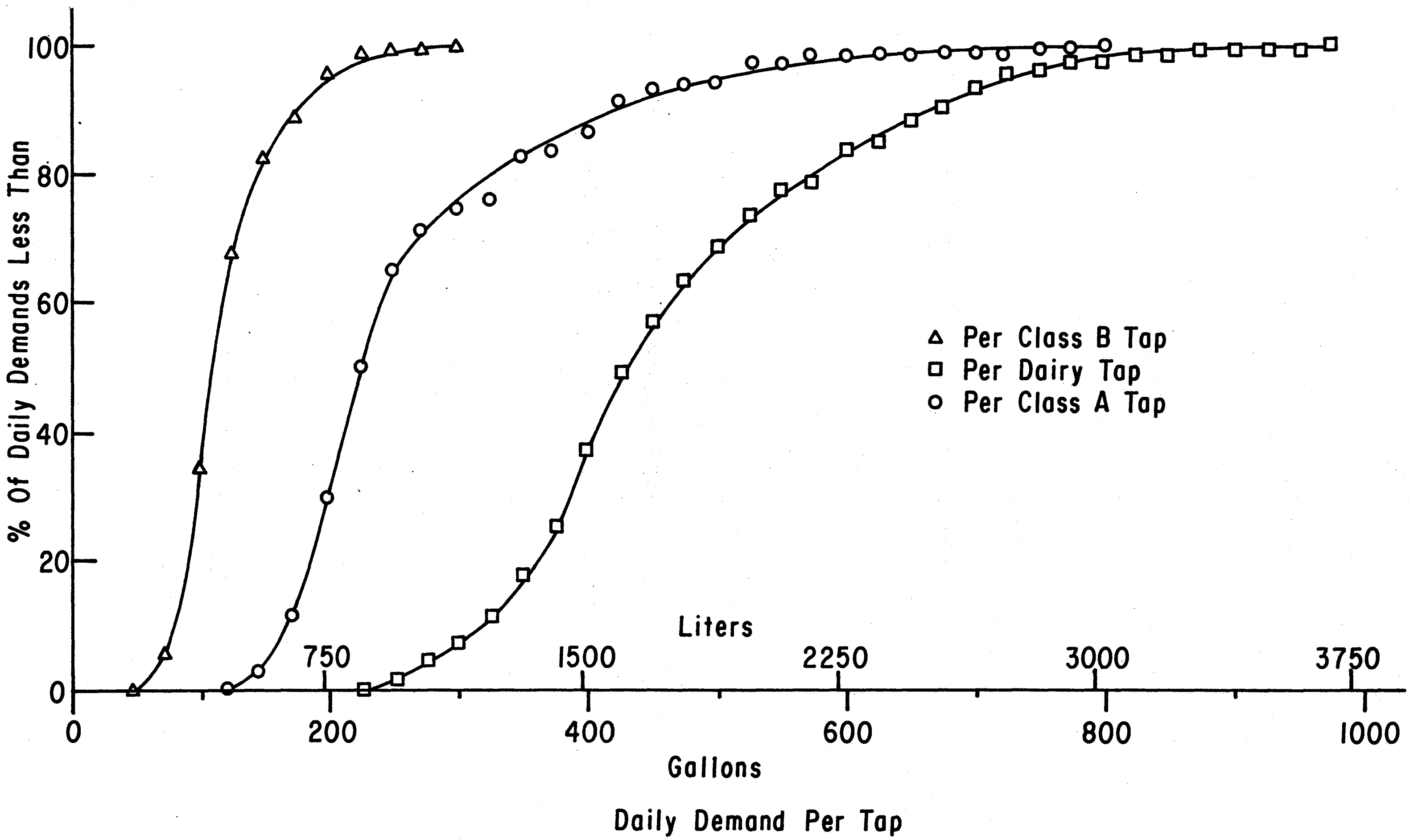


Figure 13. Cumulative Frequency Curves of Daily Demand per Dairy Tap, per Class A Tap, and per Class B Tap

cumulative frequency curve in Figure 14. Analysis of the curve shows that above the value of 12 gallons (45 liters) the incremental increase in percent coverage becomes small in relation to the incremental increase in storage volume required.

Daily demand values per person were calculated by an approach similar to that used for daily demands per tap, the difference being a correction factor included to represent usage by dairies. The equation used was:

$$V-C-(D_1N_1) = D_2N_2$$

where V = total volume of flow

C = correction for usage due to noncategorized taps

D_1 = daily demand per dairy tap

N_1 = number of dairy taps

D_2 = daily demand per person

N_2 = number of people using water

The values obtained are listed in Appendix A. A histogram was determined by finding the number of occurrences in 10 gallon (37.8 liters) intervals and was integrated to give a cumulative frequency curve (Figure 15). The curve shows that approximately 80 percent of the values were less than 100 gallons (378.5 liters) per person per day.

Values were then determined for daily demand per person for Class A and Class B residences, respectively, by using the ratios of per person monthly usage of a Class B residence to a Class A residence. Two simultaneous equations, with two unknowns, could then be written as follows:

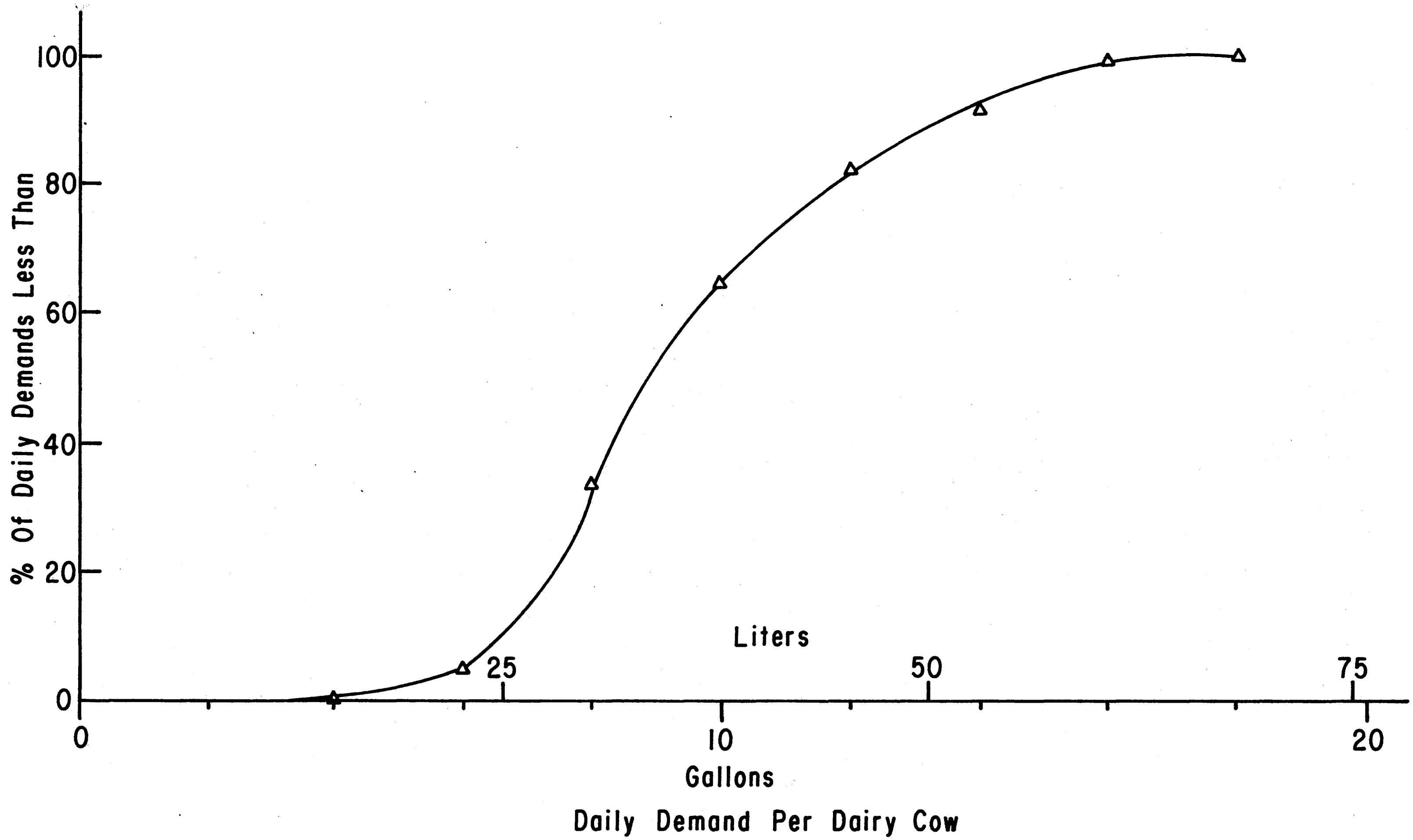


Figure 14. Cumulative Frequency of Daily Demand per Dairy Cow Milked

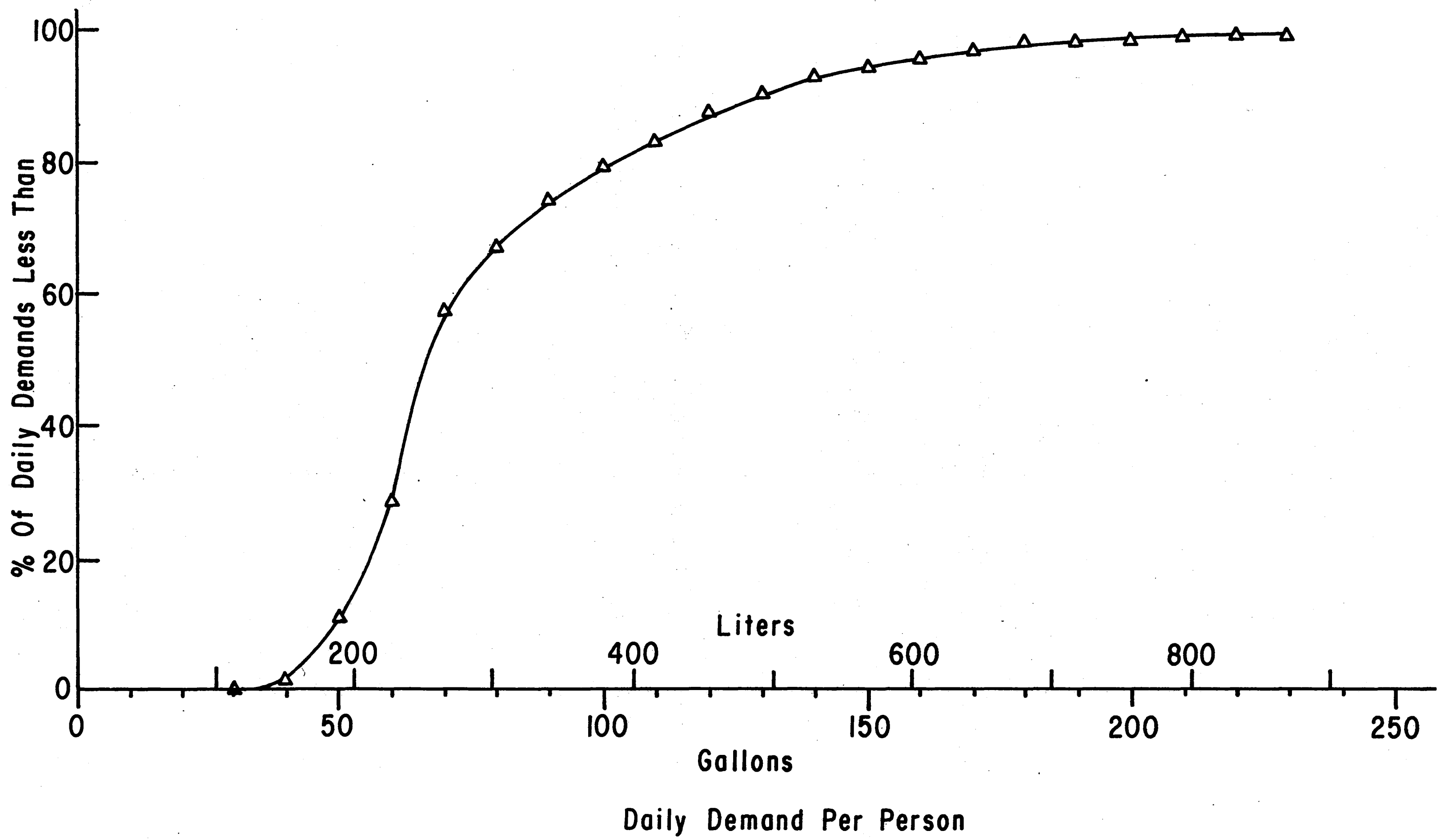


Figure 15. Cumulative Frequency of Daily Demand per Person

$$D_2 = D_1 R$$

$$V - C - (N\ D) = N_2 D_2 + N_1 D_1$$

where V = total volume of flow

C = correction for usage due to noncategorized taps

D_2 = daily demand per person at a Class B residence

D_1 = daily demand per person at a Class A residence

R = ratio of the monthly usage per person at a Class A residence to the monthly usage per person at a Class B residence

N = number of dairy taps

N_2 = number of people living in Class B residences

N_1 = number of people living at a Class A residence

D = daily demand per dairy tap

The results are listed in Appendix A. Histograms for each category were developed and integrated as before, resulting in the curves in Figure 16. The curve for Class B begins to flatten in the range of 90 gallons (341 liters) per person, while the curve for Class A begins to flatten in the range of 150 gallons (568 liters) per person.

An analysis of variance of the daily usage per day of the week showed no significant differences in the pattern of usage during the week at the five percent level.

Peak Demand

The flow rate into the system could be calculated by the formula:

$$Q = 60K/\Delta T$$

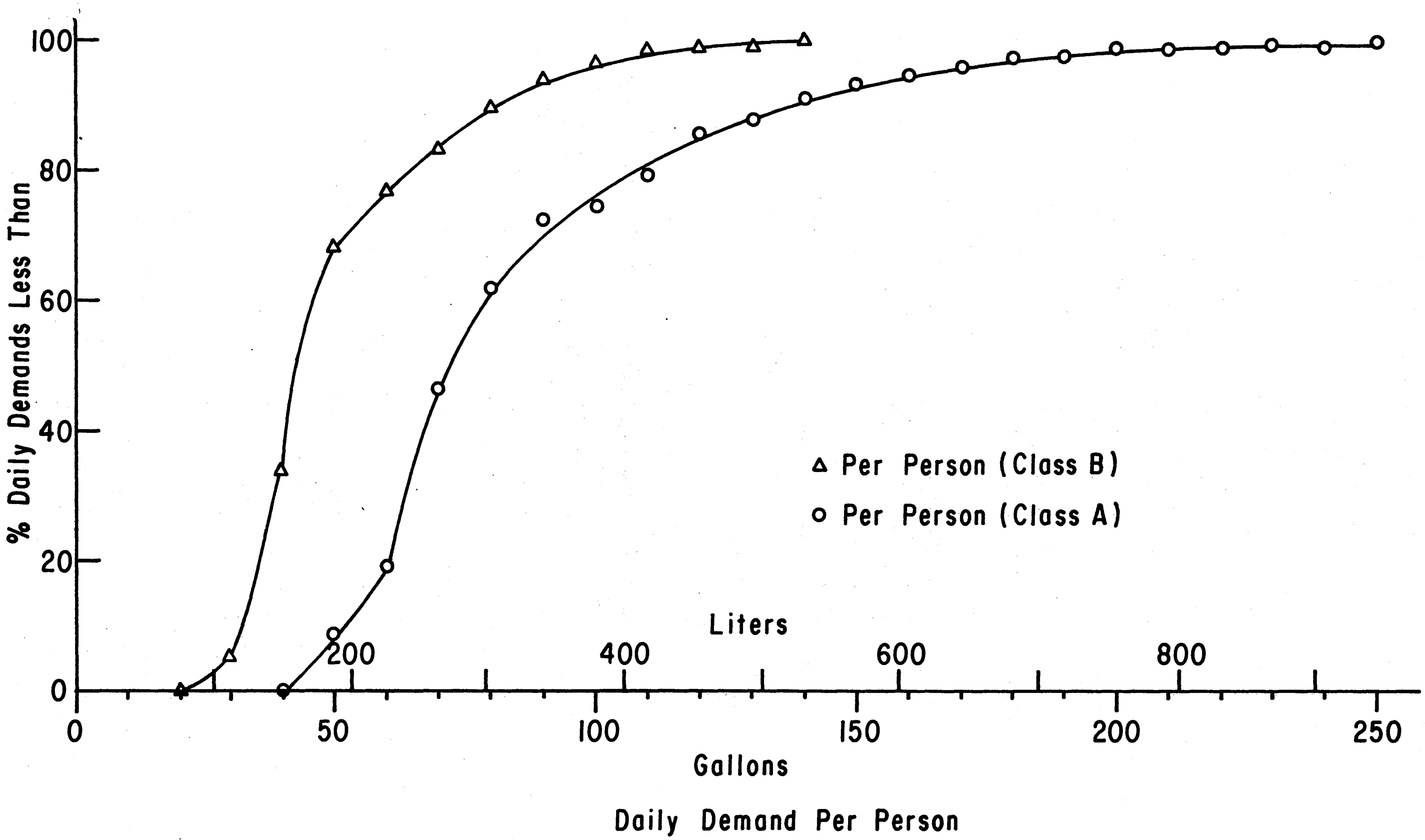


Figure 16. Cumulative Frequency Curves of Daily Demand per Person (Class A Residence), and per Person (Class B Residence)

where Q = flow rate

K = 100 for a flow rate in gallons per minute or 378.5 for a flow rate in liters per minute

ΔT = time difference between any two consecutive prints

The peak demand per tap was taken as the peak flow rate in a 24 hour interval, from midnight to midnight with no extraneous prints, divided by the number of taps using water. The peak demands were then determined over larger flow volumes of up to 500 gallons (1892 liters) to investigate the effect of expanding the time base of the peak flow. The values obtained are listed in Appendix B. Histograms were formed by finding the number of occurrences in 0.1 gallon (.38 liters) per minute intervals. The histograms were integrated to give the cumulative frequency curves of Figure 17. The curves begin to flatten in the range from 1.0 to 1.5 gallons (3.78 to 5.68 liters) per minute indicating optimal design values.

Peak demand values per category of residential tap were then determined by applying the monthly usage ratios of Class B taps to Class A taps. No correction was made for the peak usage by dairies, noncategorized taps, or non-metered deliveries, so the demand values tabulated are over-estimated. Two simultaneous equations with two unknowns could then be written as follows:

$$Q_2 = Q_1 R$$

$$Q = Q_2 N_2 + Q_1 N_1$$

where Q = peak flow

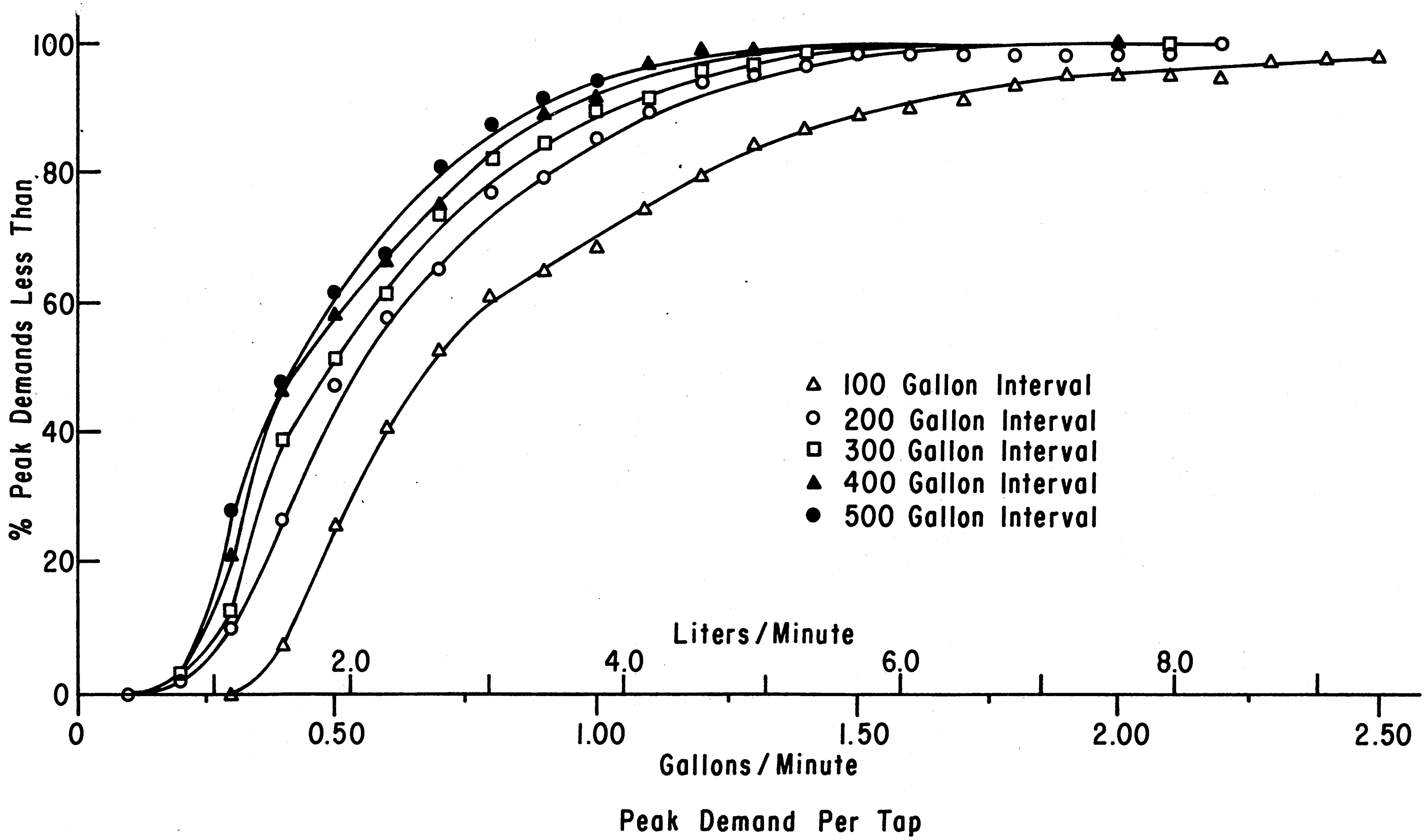


Figure 17. Cumulative Frequency Curves of Peak Demands per Tap

Q_1 = peak flow per Class A tap

Q_2 = number of Class B taps

N_1 = number of Class A taps

R = ratio of the monthly use of Class A tap to Class B tap

The values obtained are tabulated in Appendix B. Histograms were developed and integrated, as before, and the curves developed are shown in Figures 18 and 19. The curves for Class A taps begin to flatten in the range of 1.3 to 1.8 gallons (4.9 to 6.8 liters) per minute. The curves for Class B taps begin to flatten in the range of 0.6 to 0.9 gallons (2.3 to 3.4 liters) per minute.

Peak demand values per person were determined using the formula:

$$Q_1 = Q/N$$

Q_1 = peak flow per person

Q = peak flow

N = number of people using water

Peak demand values per person of Class A and Class B residences were then determined using the equations:

$$Q_2 = Q_1R$$

$$Q = Q_2N_2 + Q_1N_1$$

where Q = peak flow

Q_1 = peak flow per person of Class A taps

Q_2 = peak flow per person of Class B taps

N_1 = number of people of Class A taps

N_2 = number of people of Class B taps

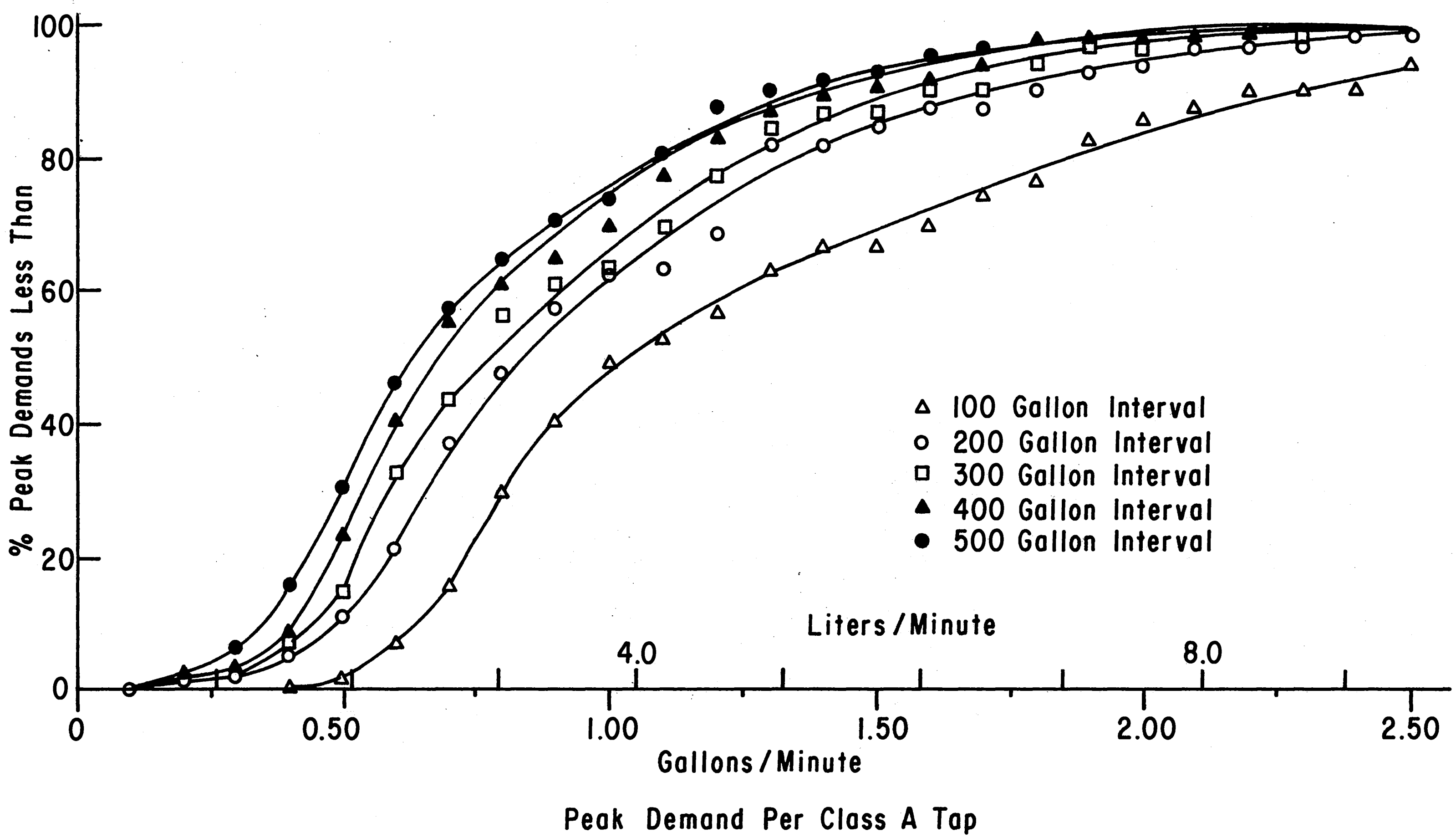
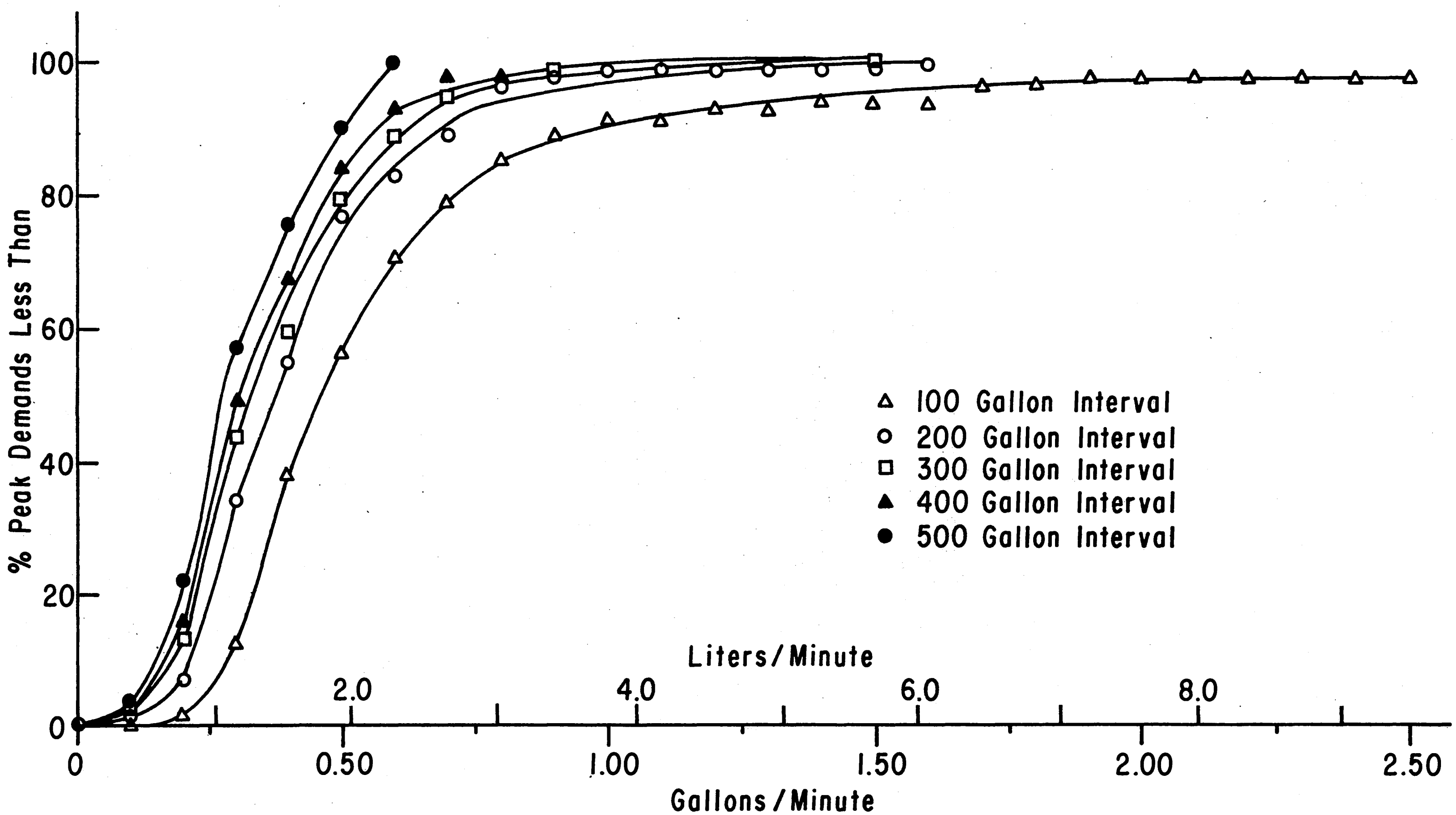


Figure 18. Cumulative Frequency Curves of Peak Demands per Class A Tap



Peak Demand Per Class B Tap

Figure 19. Cumulative Frequency Curves of Peak Demands per Class B Tap

R = ratio of monthly usage per person of Class B taps to Class A taps

Histograms were developed and integrated as before, resulting in the curves shown in Figures 20 to 22. The curves for peak demand per person begin to flatten in the range of 0.6 to 0.8 gallons (2.3 to 3.0 liters) per minute. Optimal design values are in the range of 0.5 to 0.7 gallons (1.9 to 2.6 liters) and 0.30 to 0.60 gallons (1.1 to 2.3 liters) per minute per person at Class A and Class B taps, respectively.

Flow rates over 10 minute intervals were obtained for a dairy during the milking period. The peak flow rate observed was 5.40 gallons (20.44 liters) per minute and occurred during the period when the barn was being washed.

Time Distribution of Demand

Time of occurrence of the interval flow rates was taken as the endpoint of the interval. Plots were made of the per customer demand per tap and clock time of occurrence data pairs. A tendency toward two peaks, in the morning and evening, was noted. Typical plots are shown in Appendix C. During the summer, the latter peak extended to 10 p.m. In the event that water is pumped from the supply to storage through a distribution lateral, it would be preferable to pump during periods of low demand, as the peak flow plus the pumping flow may cause excessive pressure loss. In order to determine periods of allowable off-peak pumping time an analysis was made of the percent of time that the level of

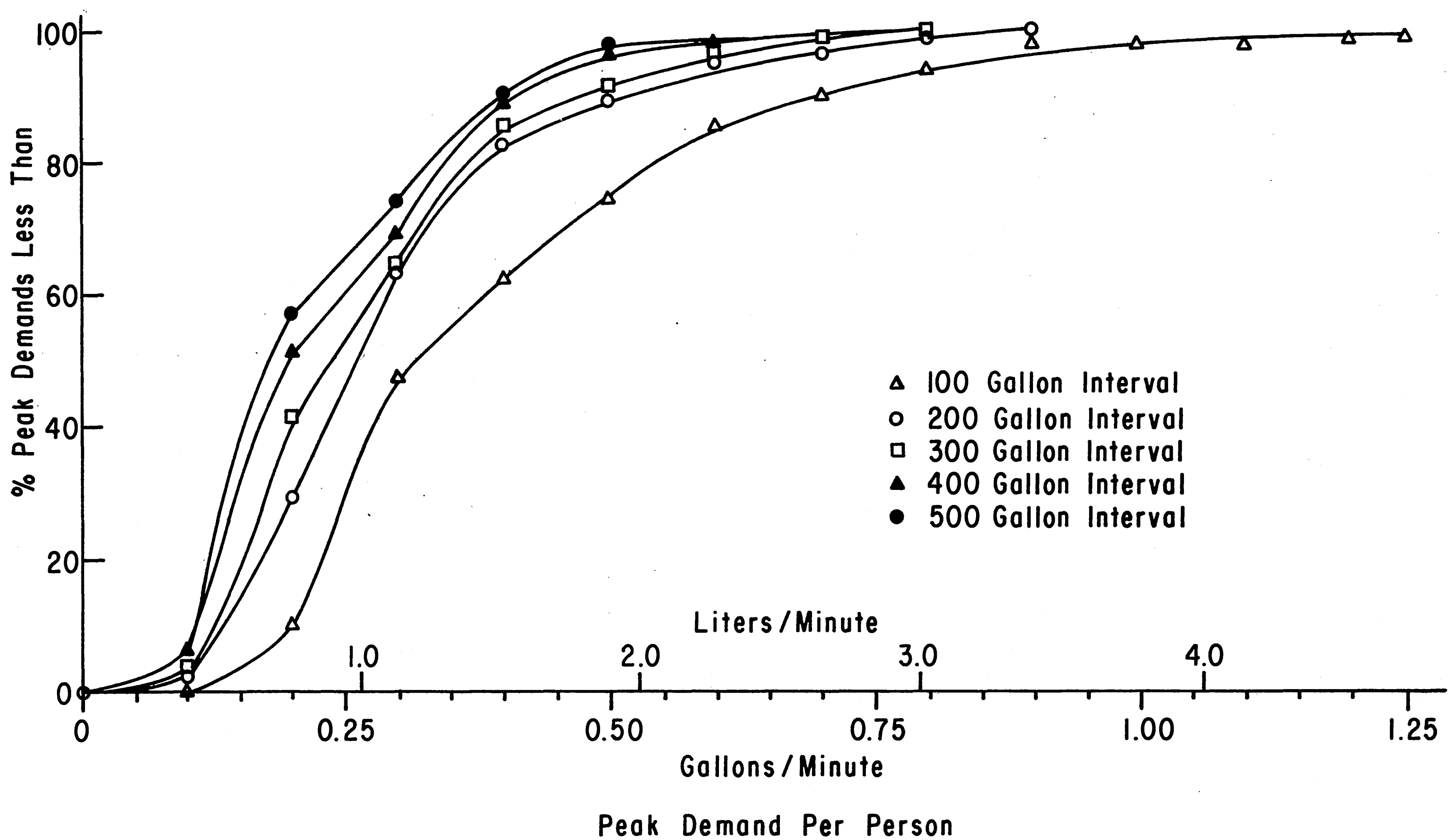


Figure 20. Cumulative Frequency Curves of Peak Demand per Person

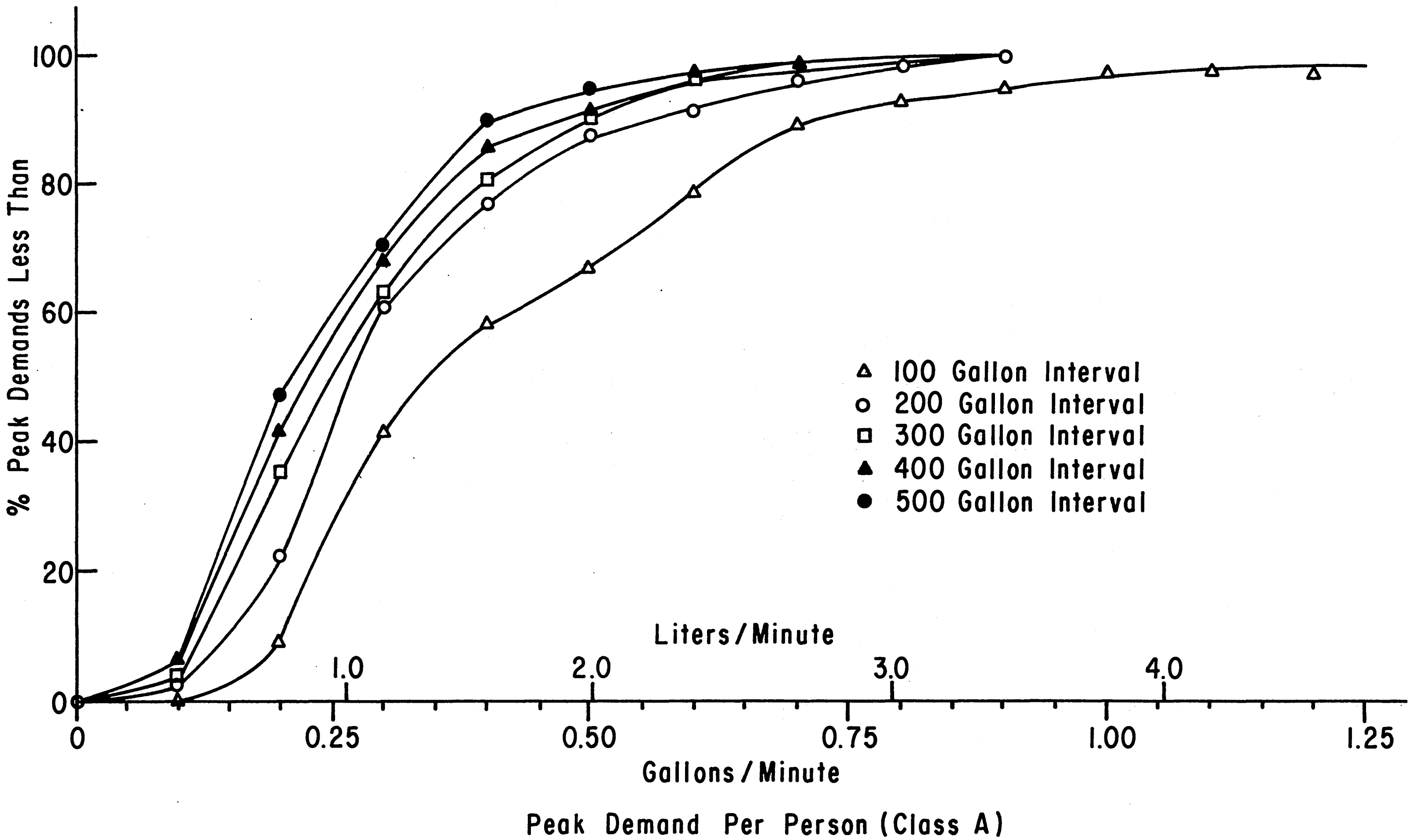


Figure 21. Cumulative Frequency Curves of Peak Demand per Person (Class A Residence)

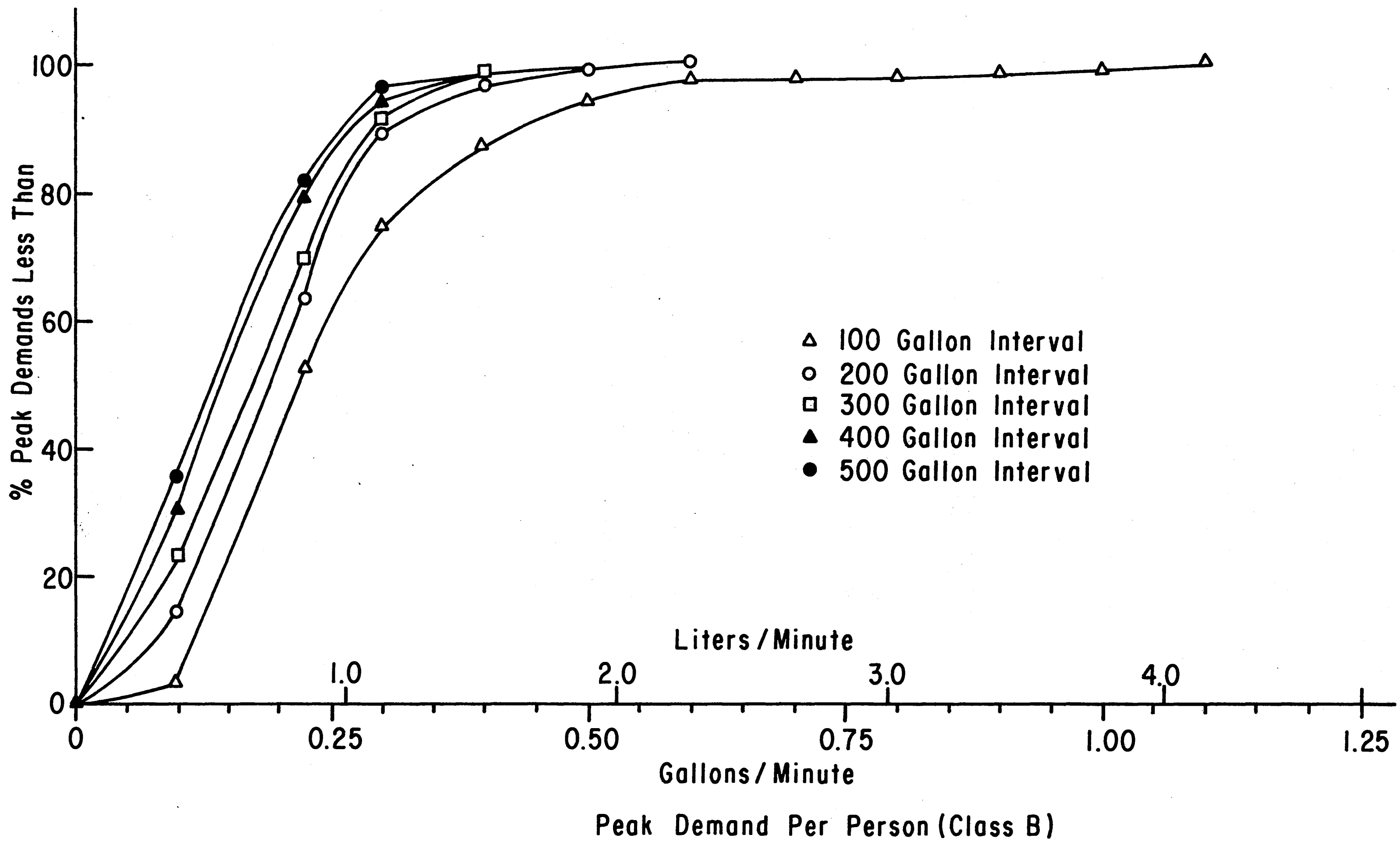


Figure 22. Cumulative Frequency Curves of Peak Demand per Person (Class B Residence)

usage exceeded 0.50 and 0.25 gallons (1.9 and .95 liters) per minute per tap.

For systems designed for two and one gallon (7.6 and 3.8 liters) per minute per tap use rates, the values of .50, and .25 gallons (1.9 and .95 liters) per minute represent flows below which the pressure loss is less than 1/16 of its design value. A visual analysis of the time-demand curves showed a dormant period between the hours from 10 p.m. to 7 a.m. and peak usage periods from 7 a.m. to 9 a.m. and from 5 p.m. to 10 p.m. The results of a further analysis of the amount of time the flow rate exceeded .50 and .25 gallons (1.9 and .95 liters) per minute are shown in Figures 23 through 26. For the interval from 10 p.m. to 7 a.m. there is a 97 percent chance of a usage rate below .5 gallons (1.9 liters) per minute for an 3 hour period. There is generally six to seven hours during this interval when the flow does not exceed .25 gallons (.95 liters) per minute. Figure 24 illustrates the fact that flows above the base levels of .5 and .25 gallons (1.9 and .95 liters) per minute occur more frequently. The curves in Figure 25 show the most frequent occurrences of peak usage. There is a 94 percent chance of a two hour duration of nonpeak usage, which is probably because the peak usage period during the cooler months generally ranged from 5 p.m. to 8 p.m. The curves of Figure 26 show some available off-peak pumping time during the interval from 9 a.m. to 5 p.m.

Data were gathered at a dairy to show a pattern of

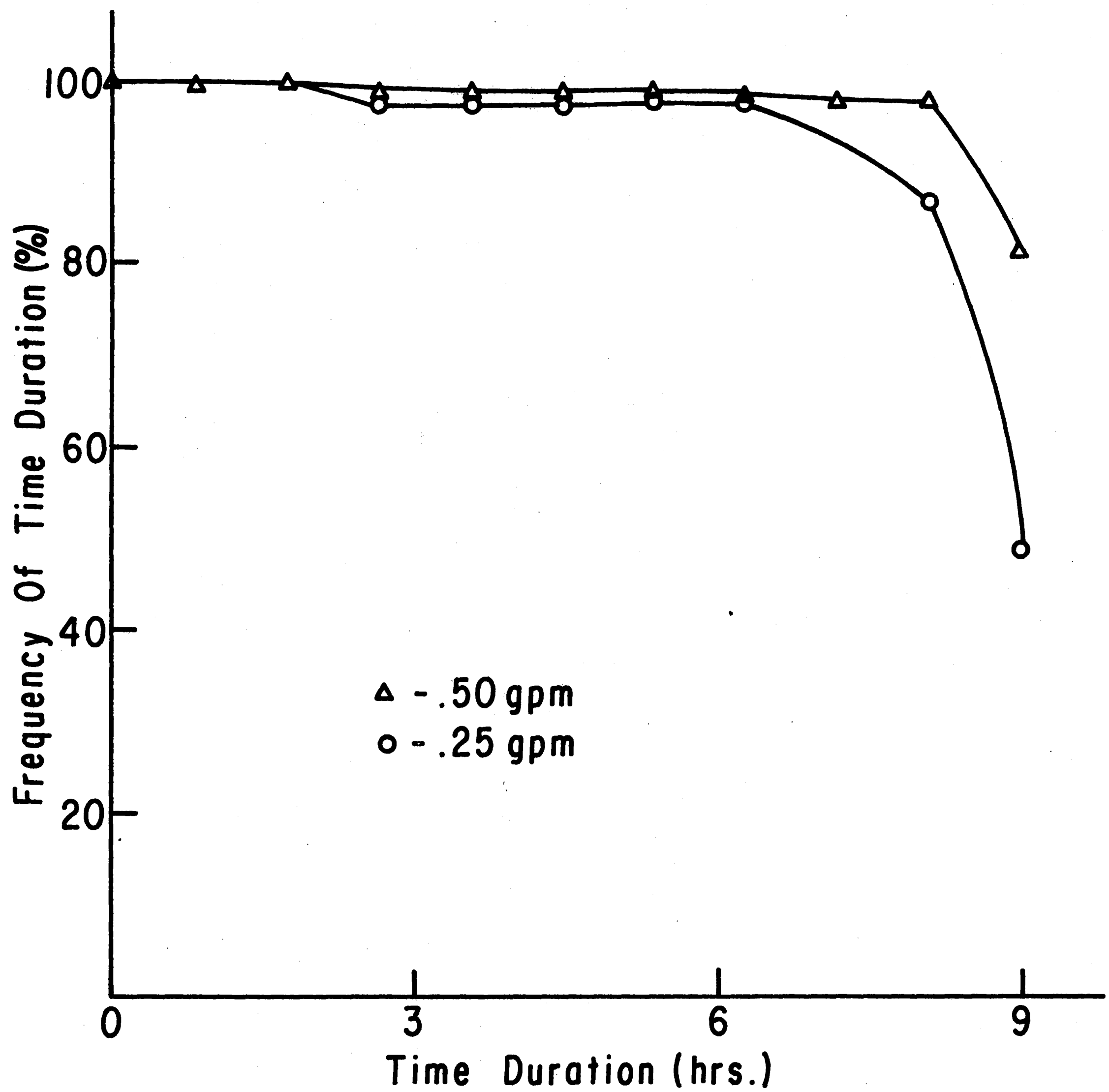


Figure 23. Probability of a Time Duration Below the Base Level for the Interval from 10 p.m. to 7 a.m.

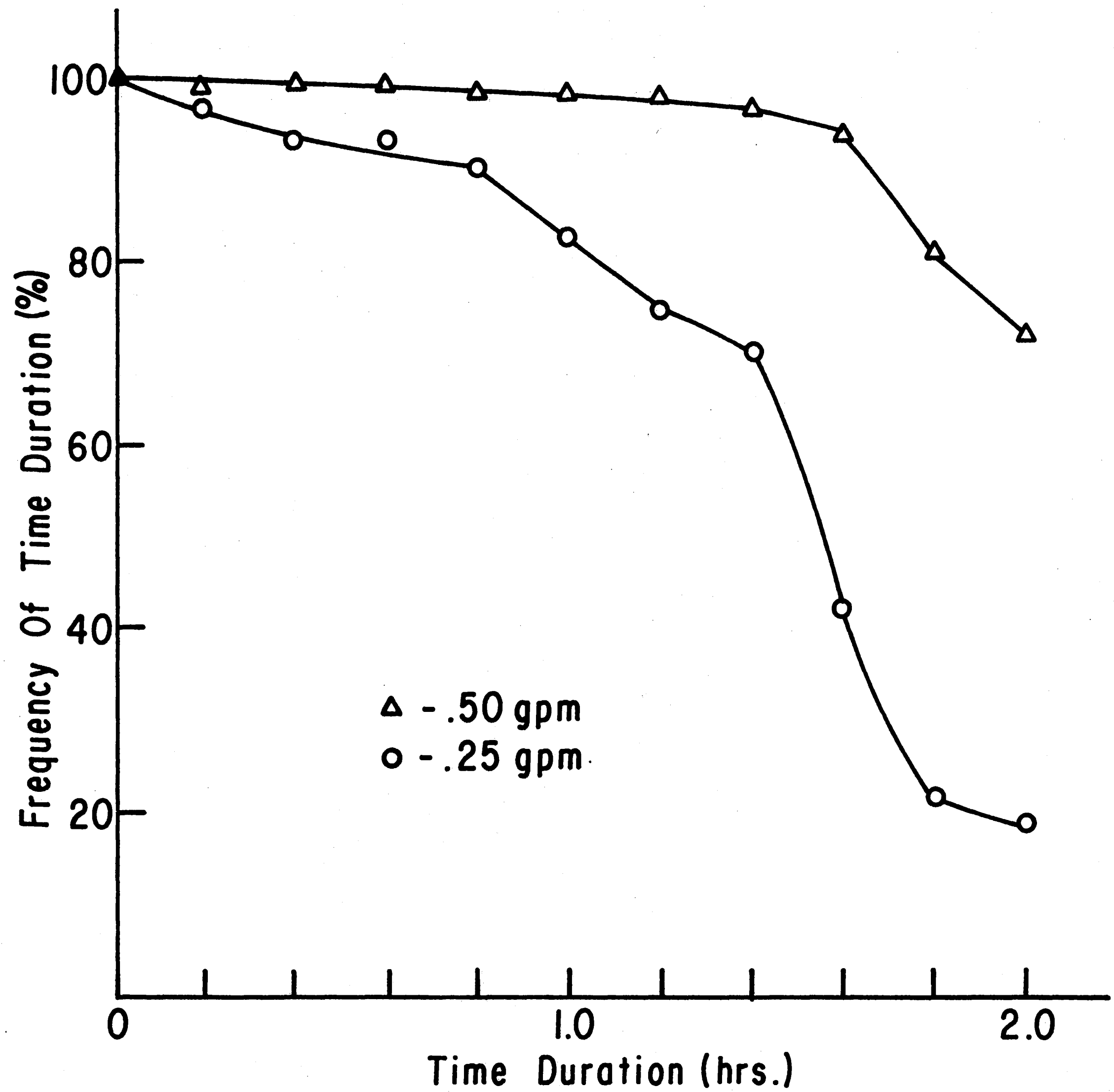


Figure 24. Probability of Usage Below the Base Level for a Time Duration During the Interval from 7 a.m. to 9 a.m.

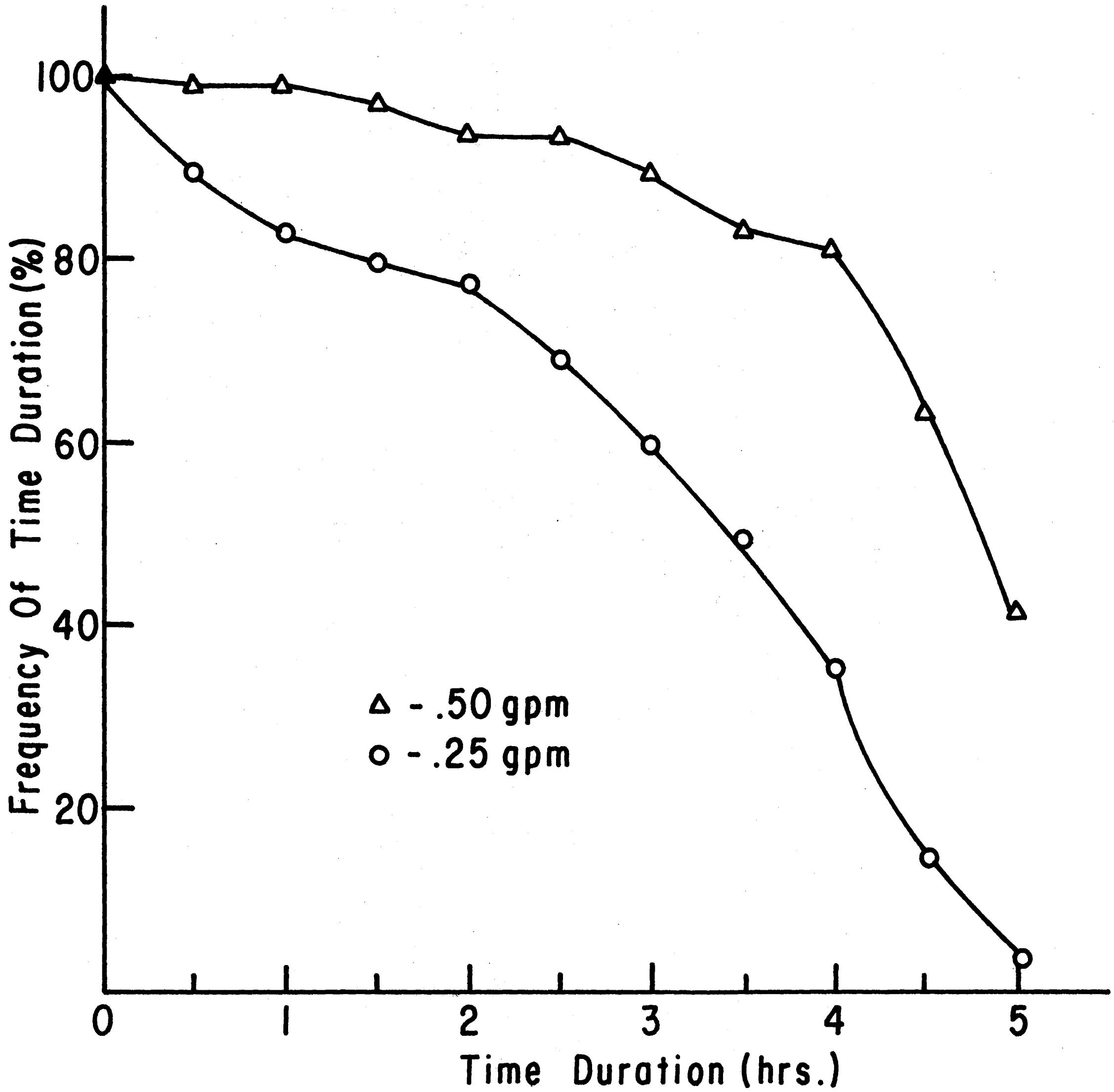


Figure 25. Probability of Usage Below the Base Level for a Length of Time During the Interval from 5 p.m. to 10 p.m.

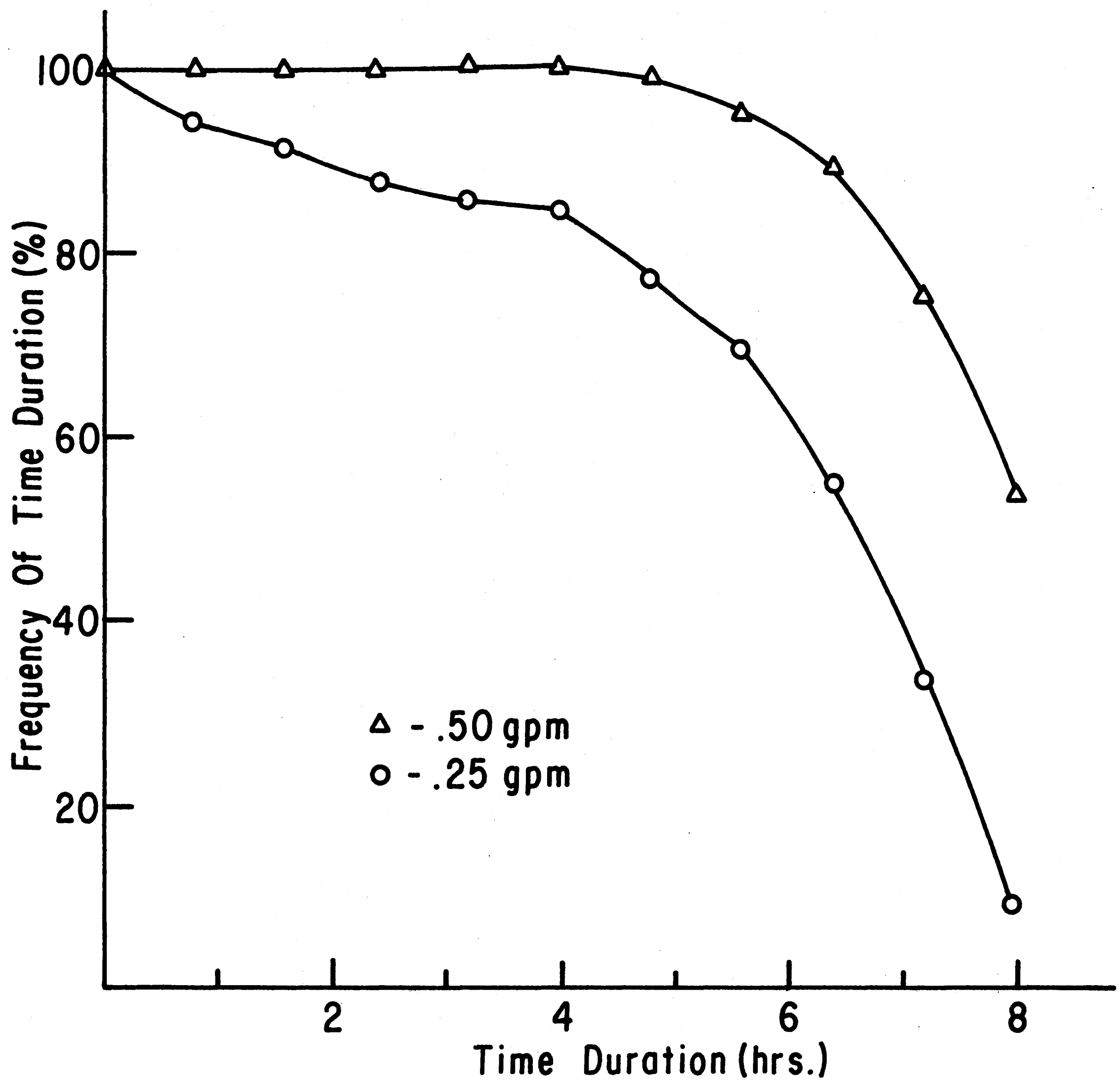


Figure 26. Probability of Usage Below the Base Level for a Length of During the Interval from 9 a.m. to 5 p.m.

usage. The data (Figure 27) show peak usage during the milking periods from 5 a.m. to 9 a.m. and 5 p.m. to 8 p.m.

The required pump and pipe capacities per customer to deliver water from the supply to the storage can be calculated by the formula:

$$Q = \frac{D}{T}$$

where D = daily demand

T = hours of off-peak pumping time

Q = flow rate to be transferred

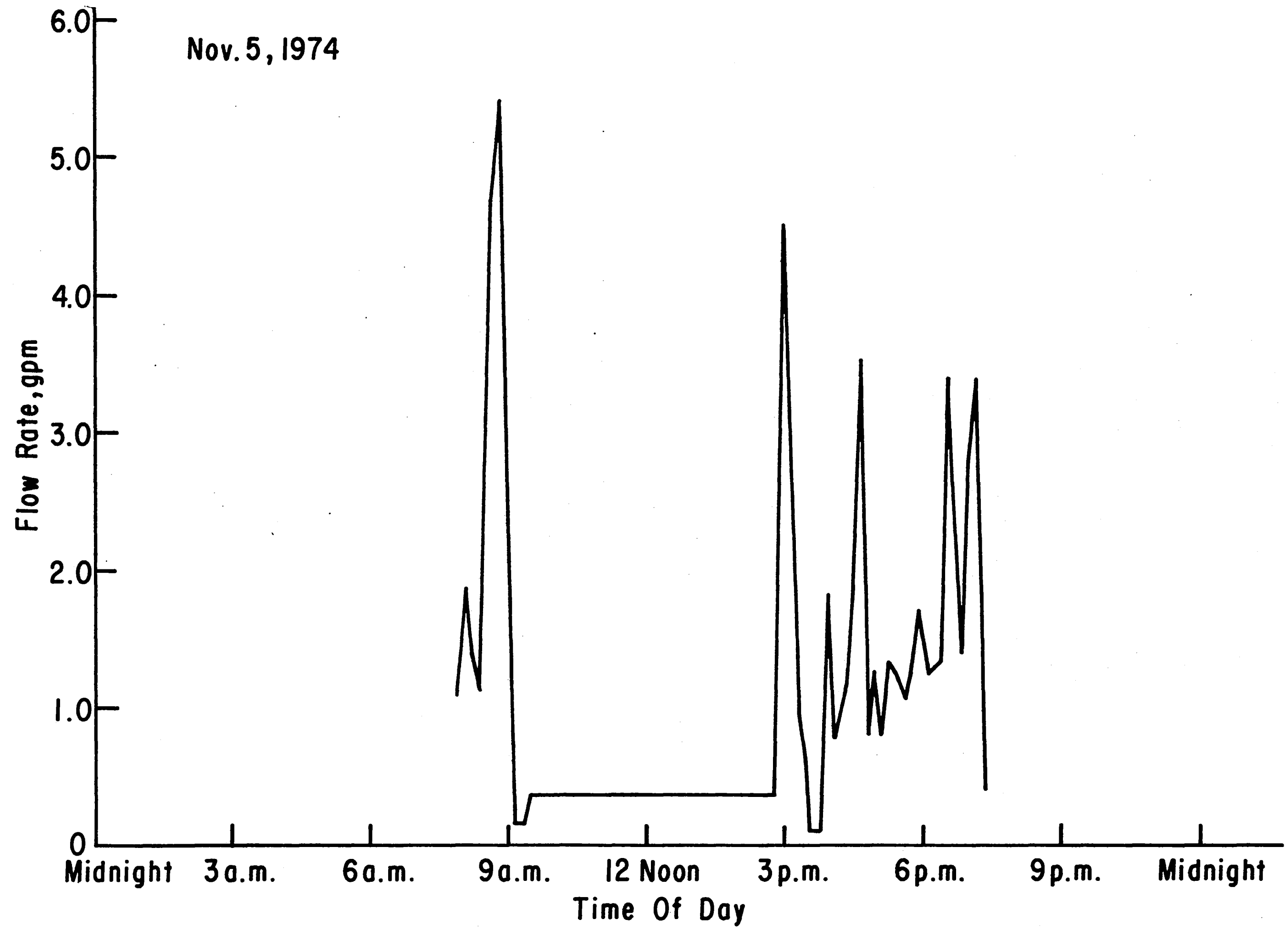


Figure 27. Hydrograph of Dairy Usage

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Monthly usage data were gathered on Rural Water District No. 3 from February to September, 1974. Monthly usage per tap was found to range from 8768 to 19,183 gallons (33,190 to 72,616 liters) for dairies, 4357 to 11983 gallons (16,498 to 45,361 liters) for Class A taps, and 2537 to 4160 gallons (9604 to 15,747 liters) for Class B taps. Monthly usage per person was found to range from 1424 to 2821 gallons (5390 to 10,679 liters) for Class A taps and 989 to 1664 gallons (3744 to 6299 liters) for Class B taps. The Farmer's Home Administration recommends an average monthly per tap usage of 3500 gallons (13248 liters) for typical rural systems in Oklahoma. Use ratios were calculated to be used in the daily demand and peak demand analysis.

Data were recorded via Badger water meters and Sodeco printing impulse counters on the usage patterns of the system customers. Values of daily demand were determined on a per person and per tap basis for various categories of customers. Design curves were developed and presented to allow the engineer to decide the amount of storage needed on the basis of the number and type of customers using the water.

On the per tap basis the optimal design value was in the range of 350 gallons (1325 liters) as compared to the design value of 150 gallons (568 liters) per day per tap recommended by the Farmer's Home Administration.

Values of peak demand were determined over flow volumes up to 500 gallons (1893 liters) to determine the effect of expanding the time base of the peak usage periods. Design curves were developed and presented as a basis for the engineer to design pipe sizes according to the number and type of users.

Hydrographs were drawn of the time distribution of demand in order to determine off-peak pumping time for off-peak pumping plants. The interval from 10 p.m. to 7 a.m., a period of 9 hours, was found to be ideal as off-peak pumping time. The intervals from 7 a.m. to 9 a.m. and 5 p.m. to 10 p.m. were found to be periods of peak usage, with occasional peak usage during the period from 9 a.m. to 4 p.m. An analysis showed there was some periods of off-peak pumping time available during the daylight hours. Optimal pump operating periods for two peak usage periods per day were from 10 p.m. to 7 a.m., from 9:30 a.m. to 11:30 a.m., and from 2 p.m. to 4 p.m. A possibility exists for the use of pressure control rather than time control for the pumping plants, but the pumping time may occur during a peak usage period. The pump and pipe capacity per customer may be determined from the formula:

$$Q = \frac{D}{T}$$

Q = flow rate to be pumped

D = daily demand

T = Pumping time

In the event the designer should choose to operate two or more pumps simultaneously, the pressure at services near the pumping station will be approximately equal to the elevation head required to deliver water from the supply to the storage plus the friction losses incurred in doing so. Pressure controlling valves may be needed at the services to prevent undesirably high pressures.

Conclusions

1. There was a significantly different pattern of usage for three classes of customers at the five percent level.
2. The average monthly usage per tap ranged from 8768 to 19183 gallons (33,190 to 72616 liters) for dairies, 4357 to 11983 gallons (16,493 to 45361 liters) for Class A taps, and 2537 to 4160 gallons (9604 to 15747 liters) for Class B taps.
3. The average monthly usage per person ranged from 1424 to 2821 gallons (5390 to 10679 liters) for Class A taps and from 989 to 1664 gallons (3744 to 6299 liters) for Class B taps.
4. Optimal design values for daily demand were in the range of: 350 gallons (1325 liters) per tap; 200 gallons (757 liters) per Class B tap; 350 gallons per Class A tap; 600 gallons (2271 liters) per Dairy tap; 12 gallons

(45 liters) per dairy cow milked; 100 gallons (379 liters) per person; 90 gallons (341 liters) per person, Class B tap; and 150 gallons (568 liters) per person, Class A tap.

5. Optimal design values for peak demand ranged from: 1.0 to 1.5 gallons (3.78 to 5.68 liters) per minute per tap; 1.3 to 1.8 gallons (4.9 to 6.8 liters) per minute per Class A tap; 0.6 to 0.9 gallons (2.3 to 3.4 liters) per minute per Class B tap; 0.6 to 0.8 gallons (2.3 to 3.0 liters) per minute per person; 0.5 to 0.7 gallons (1.9 to 2.6 liters) per minute per person, Class A tap; and 0.3 to 0.6 gallons (1.1 to 2.3 liters) per minute per person, Class B tap.
6. The optimal period off-peak pumping time is from 10 p.m. to 7 a.m., a period of 9 hours, with other periods a possibility.

Suggestions for Future Study

1. A study of the time distribution of demand for the different types of consumers.
2. Research on the cluster-well approach as opposed to the central well system.
3. Comparison of results with those of other research projects in different areas of the country.

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APPENDIX A

TYPICAL DAILY USAGE DATA

DAILY USAGE

DATE	PER TAP	PER PERSON	PER DAIRY TAP	PER DAIRY COW	PER CLASS A TAP	PER PERSON CLASS A	PER CLASS B TAP	PER PERSON CLASS B
JULY24	556.04	223.64	-----	-----	792.96	240.60	277.54	141.95
JULY25	318.64	119.78	-----	-----	424.71	128.86	148.65	76.03
JULY26	379.00	146.19	-----	-----	518.34	157.27	181.42	92.79
JULY27	406.82	158.36	-----	-----	561.50	170.36	196.52	100.52
JULY30	515.18	205.77	-----	-----	729.58	221.36	255.35	130.61
JULY31	327.16	125.69	675.06	11.91	421.91	134.00	147.67	79.05
AUG 1	279.47	113.90	657.28	11.60	382.14	121.92	145.21	67.06
AUG 2	306.63	125.51	724.32	12.78	421.11	134.36	160.02	73.90
AUG 3	376.50	155.39	896.73	15.82	521.35	166.34	198.11	91.49
AUG 4	315.73	129.40	746.77	13.18	434.17	138.53	164.98	76.19
AUG 5	405.28	167.70	967.76	17.08	562.65	179.52	213.81	98.74
AUG 6	251.25	101.83	587.65	10.37	341.65	109.01	129.83	59.95
AUG 7	344.63	141.76	818.09	14.44	475.63	151.76	180.74	83.47
AUG 8	358.55	176.40	852.43	15.04	495.60	191.45	188.33	105.30
AUG 13	292.67	119.54	689.85	12.17	401.08	127.97	152.41	70.38
AUG 14	276.23	121.83	-----	-----	429.82	132.04	163.33	72.62

APPENDIX B

TYPICAL PEAK USAGE DATA

PEAK USAGE

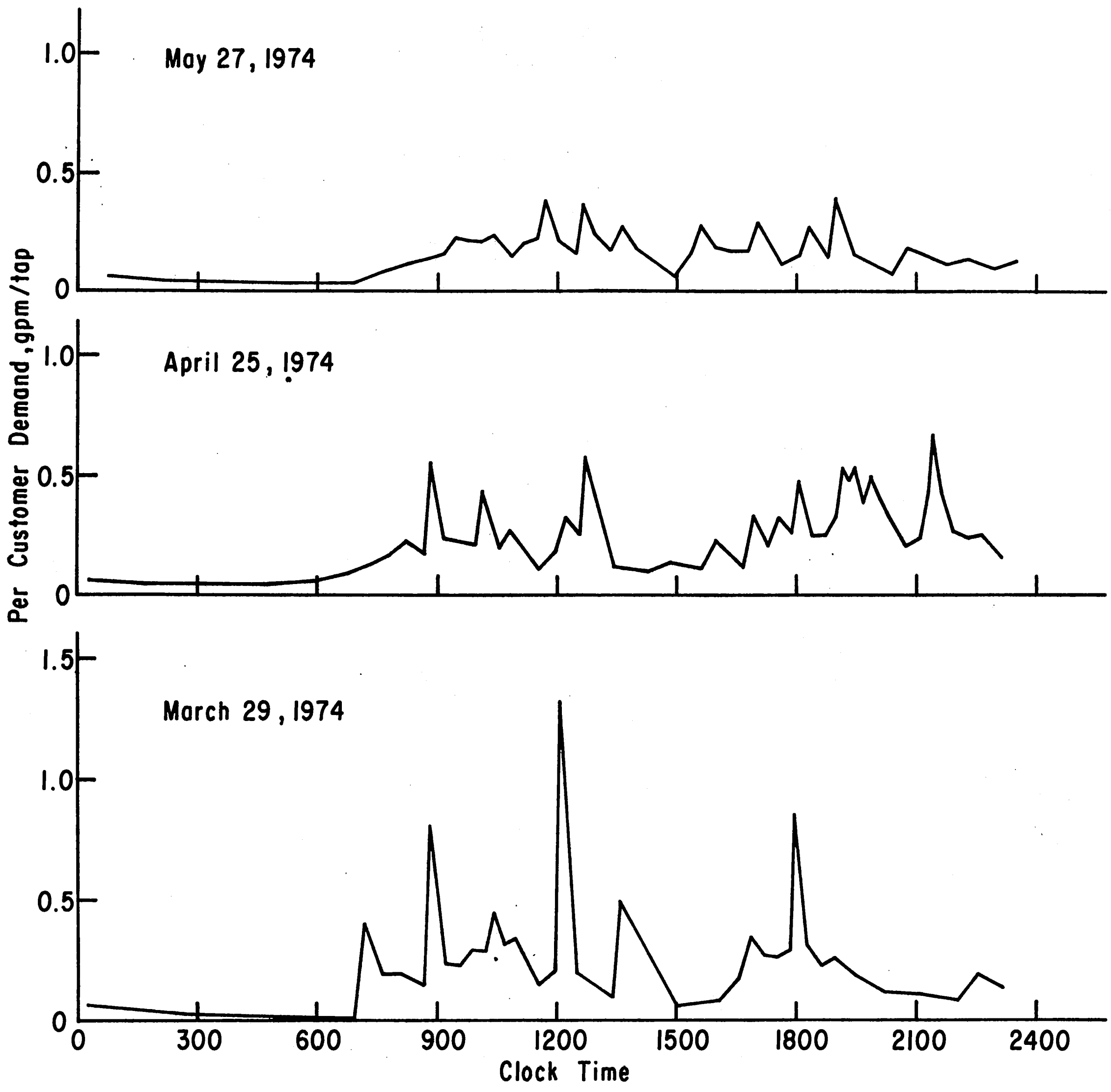
DATE	100 GALLON INTERVAL PER TAP	100 GALLON INTERVAL PER CLASS A TAP	100 GALLON INTERVAL PER CLASS B TAP	200 GALLON INTERVAL PER TAP	200 GALLON INTERVAL PER CLASS A TAP	200 GALLON INTERVAL PER CLASS B TAP	300 GALLON INTERVAL PER TAP	300 GALLON INTERVAL PER CLASS A TAP	300 GALLON INTERVAL PER CLASS B TAP	400 GALLON INTERVAL PER TAP	400 GALLON INTERVAL PER CLASS A TAP	400 GALLON INTERVAL PER CLASS B TAP	500 GALLON INTERVAL PER TAP	500 GALLON INTERVAL PER CLASS A TAP	500 GALLON INTERVAL PER CLASS B TAP
JULY24	1.33	2.06	0.72	1.14	1.77	0.62	0.98	1.52	0.53	0.87	1.35	0.47	0.81	1.26	0.44
JULY25	1.09	1.69	0.59	0.91	1.41	0.49	0.78	1.21	0.42	0.72	1.12	0.39	0.72	1.12	0.39
JULY26	1.00	1.55	0.54	0.65	1.01	0.35	0.65	1.01	0.35	0.60	0.93	0.33	0.53	0.82	0.29
JULY27	1.08	1.68	0.59	0.78	1.21	0.42	0.77	1.19	0.42	0.76	1.18	0.41	0.74	1.15	0.40
JULY30	1.22	1.89	0.66	1.18	1.83	0.64	1.14	1.77	0.62	1.10	1.71	0.60	1.09	1.69	0.59
JULY31	1.28	2.06	0.72	0.98	1.58	0.55	0.95	1.53	0.53	0.82	1.32	0.46	0.76	1.22	0.43
AUG 1	0.97	1.59	0.60	0.76	1.24	0.47	0.72	1.18	0.45	0.67	1.10	0.42	0.66	1.08	0.41
AUG 2	1.30	2.13	0.81	1.19	1.95	0.74	0.94	1.54	0.58	0.90	1.47	0.56	0.87	1.42	0.54
AUG 3	1.47	2.41	0.91	1.27	2.08	0.79	1.08	1.77	0.67	1.01	1.65	0.63	0.94	1.54	0.58
AUG 4	1.16	1.90	0.72	0.92	1.51	0.57	0.67	1.10	0.42	0.64	1.05	0.40	0.62	1.01	0.39
AUG 5	1.19	1.95	0.74	1.16	1.90	0.72	1.15	1.88	0.72	0.96	1.57	0.60	0.85	1.39	0.53
AUG 6	1.06	1.73	0.66	1.05	1.72	0.65	1.05	1.72	0.65	1.03	1.69	0.64	0.64	1.05	0.40
AUG 7	1.57	2.57	0.98	1.45	2.37	0.90	1.38	2.26	0.86	1.07	1.75	0.67	0.96	1.57	0.60
AUG 8	1.85	3.03	1.15	1.46	2.39	0.91	1.40	2.29	0.87	1.34	2.19	0.83	1.32	2.16	0.82

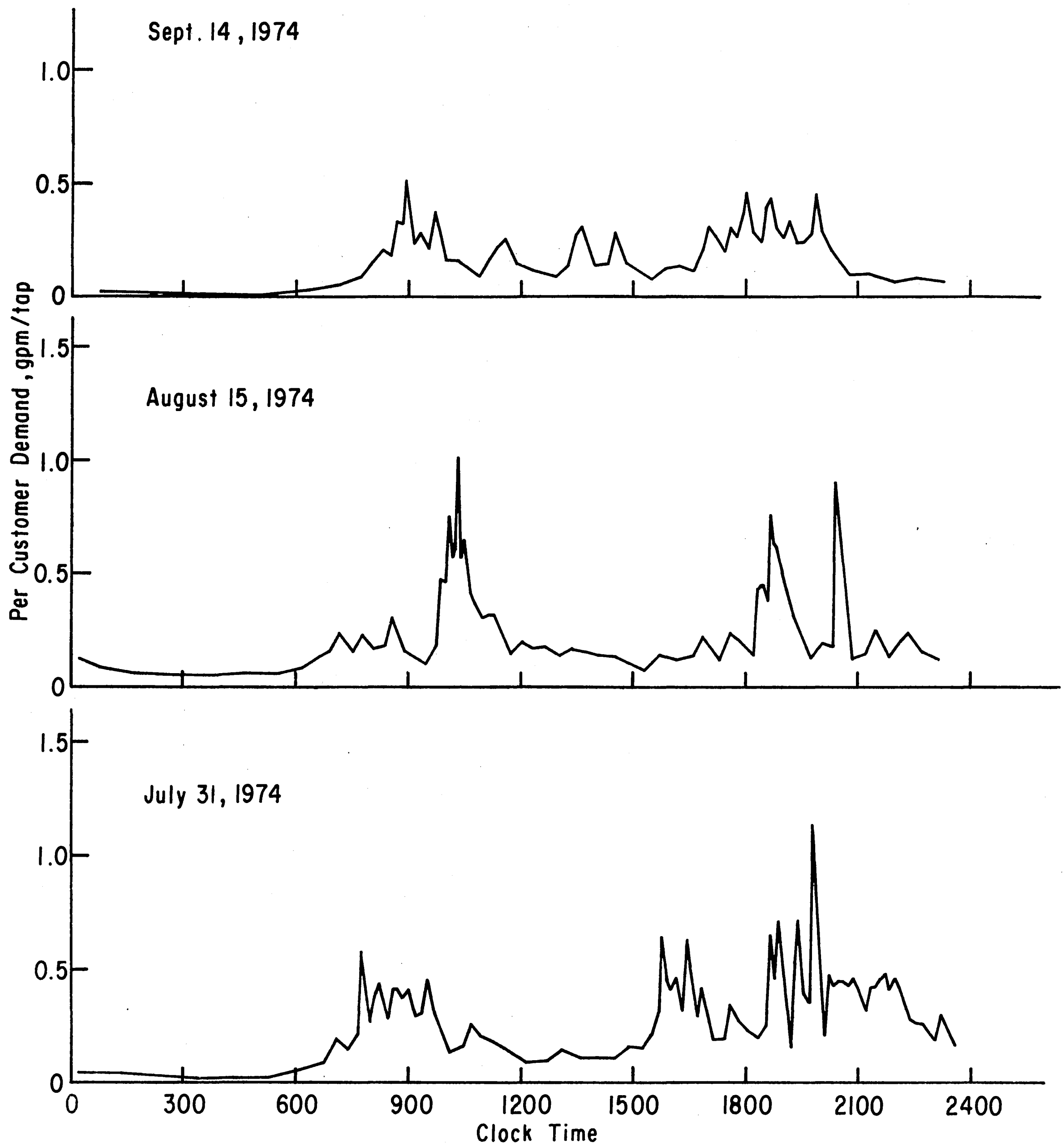
PEAK USAGE

DATE	100 GALLON INTERVAL PER PERSON	100 GALLON INTERVAL PER PERSON CLASS A	100 GALLON INTERVAL PER PERSON CLASS B	200 GALLON INTERVAL PER PERSON	200 GALLON INTERVAL PER PERSON CLASS A	200 GALLON INTERVAL PER PERSON CLASS B	300 GALLON INTERVAL PER PERSON	300 GALLON INTERVAL PER PERSON CLASS A	300 GALLON INTERVAL PER PERSON CLASS B	400 GALLON INTERVAL PER PERSON	400 GALLON INTERVAL PER PERSON CLASS A	400 GALLON INTERVAL PER PERSON CLASS B	500 GALLON INTERVAL PER PERSON	500 GALLON INTERVAL PER PERSON CLASS A	500 GALLON INTERVAL PER PERSON CLASS B
JULY24	0.58	0.63	0.37	0.50	0.54	0.32	0.43	0.46	0.27	0.38	0.41	0.24	0.35	0.38	0.22
JULY25	0.48	0.51	0.30	0.40	0.43	0.25	0.34	0.37	0.22	0.31	0.34	0.20	0.31	0.34	0.20
JULY26	0.44	0.47	0.28	0.28	0.31	0.18	0.28	0.31	0.18	0.26	0.28	0.17	0.23	0.25	0.15
JULY27	0.47	0.51	0.30	0.34	0.37	0.22	0.34	0.36	0.21	0.33	0.36	0.21	0.32	0.35	0.21
JULY30	0.53	0.57	0.34	0.52	0.56	0.33	0.50	0.54	0.32	0.48	0.52	0.31	0.48	0.51	0.30
JULY31	0.61	0.65	0.39	0.47	0.50	0.30	0.46	0.49	0.29	0.39	0.42	0.25	0.36	0.39	0.23
AUG 1	0.47	0.51	0.28	0.37	0.40	0.22	0.35	0.38	0.21	0.33	0.35	0.19	0.32	0.34	0.19
AUG 2	0.63	0.68	0.37	0.58	0.62	0.34	0.46	0.49	0.27	0.44	0.47	0.25	0.42	0.45	0.25
AUG 3	0.72	0.77	0.42	0.62	0.66	0.36	0.53	0.56	0.31	0.49	0.53	0.29	0.46	0.49	0.27
AUG 4	0.57	0.61	0.33	0.45	0.48	0.26	0.33	0.35	0.19	0.31	0.33	0.18	0.30	0.32	0.18
AUG 5	0.58	0.62	0.34	0.57	0.61	0.33	0.56	0.60	0.33	0.47	0.50	0.28	0.41	0.44	0.24
AUG 6	0.52	0.55	0.30	0.51	0.55	0.30	0.51	0.55	0.30	0.50	0.54	0.30	0.31	0.33	0.18
AUG 7	0.77	0.82	0.45	0.71	0.76	0.42	0.67	0.72	0.40	0.52	0.56	0.31	0.47	0.50	0.28
AUG 8	0.90	0.97	0.53	0.71	0.76	0.42	0.68	0.73	0.40	0.65	0.70	0.38	0.64	0.69	0.38

APPENDIX C

TYPICAL SYSTEM HYDROGRAPHS


May 27, 1974
April 25, 1974
March 29, 1974
Per Customer Demand, gpm/tap
1.0
0.5
0
1.5
0
300
600
900
1200
1500
1800
2100
2400
Clock Time


Sept. 14, 1974
August 15, 1974
July 31, 1974
Per Customer Demand, gpm/tap
1.0
0.5
0
1.5
1.0
0.5
0
1.5
1.0
0.5
0
0
300
600
900
1200
1500
1800
2100
2400
Clock Time

γ

VITA

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Professional Organizations: Student member of American Society of Agricultural Engineers; Registered Engineering-in-Training, State of Oklahoma.