ESTIMATE OF WATER POLLUTION POTENTIAL

BASED ON CHARACTERISTICS OF DOMESTIC SEWAGE IN PUERTO RICO

Project A-043-PR.

By

Dr. Ning-Hsi Tang

Associate Professor of Civil Engineering
University of Puerto Rico
Mayaguez Campus

From

Water Resources Research Institute
Research Center
University of Puerto Rico
Mayaguez Campus

To

Office of Water Research and Technology
U.S. Department of the Interior
Washington, D. C.

" The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379" .

January 1975

ABSTRACT

Accurate measurements of BOD, COD, solids and nutrients in sewage are very important for water pollution control. Many of these per capita values used by engineers today were established decades ago. Re-evaluation of these values is necessary.

In this investigation, the sewage from a typical residential area with a population of 1,203 was sampled and measured. Altogether, sixteen 24-hour composite samples were collected and analyzed.

The average per capita sewage flow has been found to be 57.4 gal/day and the average BOD loading to be 0.088 lb/day/capita. Both of them are lower than the established values. Higher concentration of suspended solids (0.126 lb/day/capita) may have been caused by the fact that all houses in the survey area have garbage grinders.

Both nitrogen and phosphorus nutrients in the sewage have been found to be higher in per capita loading values when compared with the results of the recent Milwaukee study. The need for more washing and cleaning in the tropical climate and the large consumption of high protein foodstuff such as beans in Puerto Rico may be the causes of the difference.

ACKNOWLEDGMENTS

Gratitude is extended to Dr. Roberto Vázquez, Acting Director of the Water Resources Research Institute of Puerto Rico, for his help and cooperation throughout the entire period covered by the research project. Appreciation is also expressed to Mr. Gregorio S. Ayala, Mr. Francisco Rivera-García, and Mr. Manuel Martínez-Alvarez, who helped in the collection and analysis of the samples and the population survey. A special thanks to Mrs. Rosa Almodóvar de Gerena for her patience in typing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ESTIMATE OF WATER POLLUTION POTENTIAL
BASED ON CHARACTERISTICS OF DOMESTIC SEWAGE IN PUERTO RICO

Introduction

Domestic sewage is characterized by the measurements of its per capita loadings of BOD, COD, solids, and nutrients. These measurements are of importance in sewage treatment plant designing, operating, and in general pollution control programs. Many of these loading values were established several decades ago. Obviously, changes of life style in recent years result in changes of sewage characteristics. Renewed measurements of these values are needed to match the changes.

Puerto Rico is situated in a tropical area and has a fast growing economy. The cultural and living habits here are quite different from those in the States. Therefore, the values developed in the States may not be automatically applied to situations in Puerto Rico. The primary purpose of the study reported here is to establish the per capita BOD loading together with other important loadings for the domestic sewage in Puerto Rico.

Principle

Domestic sewage contains many pollutants. They are organics and inorganics in nature and appear in the forms of dissolved and suspended solids. However, pollutants in the domestic sewage can generally be classified into three categories which are organics, solids, and nutrients. Organic pollutant in sewage causes oxygen depletion in the receiving waters. Solids in suspenion form cause high turbidity, excessive bottom sediments, and objectionable floating matters on the receiving rivers. High nutrient concentration in sewage results in abundant growth of unpleasant algae which deprive the receiving lakes or reservoirs of their beneficial uses.

The measurements of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of a sewage sample determine, respectively, its biodegradable organic and total organic contents in terms of the oxygen demands. The measurements of solids in sewage include total solids, suspended solids, volatile solids, and fixed solids. Various forms of nitrogen and phosphorus in sewage are determined in order to characterize the pollution potential of the nutrient pollutants.

The sewage flow of a community can be measured and the number of people contributing to the sewage flow can be counted. Therefore, the per capita sewage flow can easily be determined. By using this value together with the values of parameters such as BOD, COD, solids, and nutrient concentrations in the sewage, the values of per capita loading can be established. For example, if the per capita sewage flow is 100 gal/day and the BOD concentration of the sewage is 200 mg/l, the per capita BOD loading of the sewage is $(100/10^6) \times 200 \times 8.34 = 0.17$ lb/day.

Literature Review

Most of the values of the per capita loading used by engineers today were established a long time ago. Zanoni and Rutkowski (1) recently summarized the values of the per capita loadings of BOD and suspended solids from the literature of the past 50 years as shown partially in Table 1. The problems of evaluating these values found in the literature as noted by the above mentioned authors are frequently those of lack of documentation for such items as source of sample, method of analysis, and extent of data involved. For example, it is not always clear whether the published per capita value of BOD loading is on a 5-day basis or on an ultimate basis. As far as the source

TABLE 1
SUMMARY OF LITERATURE FINDINGS ON PER CAPITA LOADING VALUES
(after Zanoni and Rutkowski)

Parameter	Publication Date	Loading lb/day/cap)	Source
	1927	0.132 to 0.324	Mohlman (2)
	1947	0.20	Tolman (3)
Suspended	1952	0.167	Simpson (4)
Solids	1952	0.21	Babbitt (5)
	1954	0.198	Fair and Geyer (6) (8)
	1960	0.20	Schroepfer (7)
	1968	0.198	Fair and Geyer (8) (6)
	1927	0.26*	Mohlman and Pearse (2)
	1927	0.25	Streeter and Phelps (2)
BOD	1927	0.17*	Wagenhals, et al. (2)
	1927	0.18	Minn. Dept. of Health (2)
	1927	0.24*	McGuire (2)
	1927	0.24*	Baltimore, Md., Study (2)
	1936	0.099 to 0.20	Carpenter et al. (9)
	1954-1968	0.119	Fair and Geyer (6) (8)

* Known to be on a total demand basis

of sewage is concerned, it is not always clear either, whether the sewage is from strictly domestic source or from the combination of domestic and storm water, or domestic and industrial wastewater sources. Sometimes the combinations are presented descriptively rather than quantitatively.

In 1967, Watson et al. (10) conducted an interesting study on the characteristics of sewage flowing just outside of the houses of three different sizes. The average values of numerous analyses of each parameter are summarized in Table 2. The study showed that the per capita loading values of different parameters varied widely from house to house.

In 1972, Zanoni et al. (1) re-evaluated the per capita loadings of strictly domestic sewage from 270 dwelling units of single-family homes and apartments with a population of 1,207 in the Milwaukee area. The results of the study are summarized in Table 3. This study demonstrates that the new per capita BOD loading of 0.1 lb/day/capita is considerably lower than the long time established value of 0.17 lb/day/capita .

Location of the Study

The area chosen for this study is a new urbanization, Alturas de Mayaguez, located just north of the city of Mayaguez. The urbanization was built on a small sloped hillside; its sanitary sewage is collected and treated at the lowest point of the area by a small activated sludge treatment plant. At the time of the survey, sewage from most houses flows by gravity to the treatment plant. However, the sewage from some urbanization houses on the other side of the hill have to be pumped to the treatment plant.

Several reasons have led to the selection of this particular urbanization for the study. First, it is a recently built residential area. All the sewer lines are newly constructed, therefore, infiltration flow will be minimal. Second, since the sewer system

TABLE 2
SUMMARY OF DOMESTIC SEWAGE CHARACTERISTICS
(1967 Study)

Parameter	Home 1	Home 2	Home 3
Type of home	large restored home	3-bedroom ranch	3-bedroom Cape Cod
Lot size (acres)	3.6	2.8	5
Market value	$45,000	$25,000	$18,000
BOD_5:			
avg.conc.(mg/l)	475 (246)	325 (196)	475 (47)
lb/day/capita	0.26	0.12	0.10
COD:			
avg.conc. (mg/l)	800 (386)	550 (314)	900 (61)
lb/day/capita	0.43	0.21	0.19
Suspended Solids:			
avg.conc. (mg/l)	350 (392)	250 (316)	425 (62)
lb/day/capita	0.19	0.09	0.09
Orthophosphate:			
avg.conc. (mg/l)	25 (72)	25 (42)	45 (68)
lb/day/capita	0.014	0.009	0.009
Total nitrogen:			
avg.conc. (mg/l)	65 (-)	55 (-)	125 (64)
lb/day/capita	0.035	0.021	0.026

Values in parentheses represent number of samples analyzed

TABLE 3
SUMMARY OF PER CAPITA LOADINGS OF A STRICTLY DOMESTIC WASTEWATER

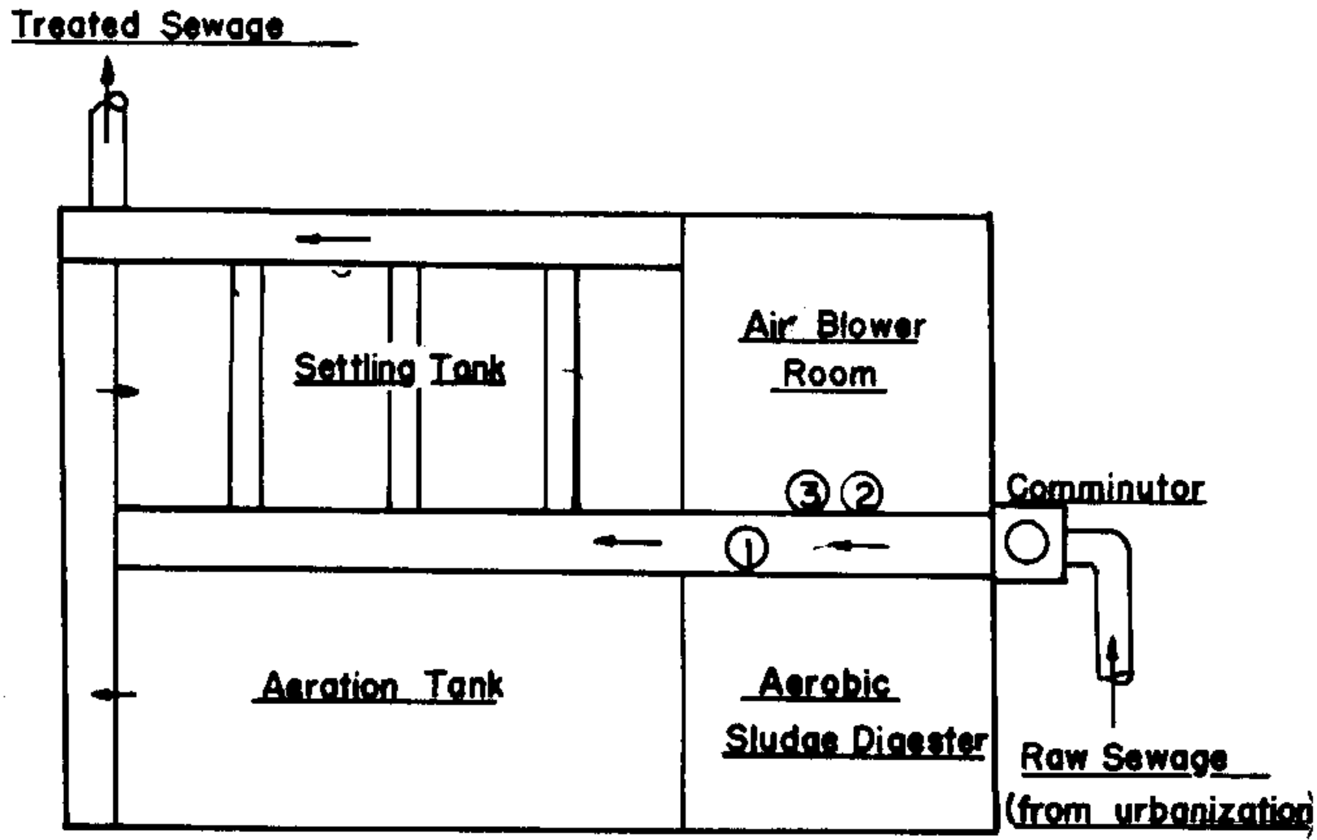
Parameter	Mean Value*, in lb/day/capita (except as noted)
Sewage flow (gpd/capita)	58
BOD_5	0.10
COD	0.20
Suspended solids	0.08
Total nitrogen (as N)	0.0145
Ammonia nitrogen (as N)	0.0057
Orthophosphate (as PO_4)	0.0119
Total phosphate (as PO_4)	0.0246

*Mean values of twenty two 24-hr. composite samples serves only the urbanization, all wastewaters collected are strictly domestic in nature. Last, the entire area has been developed by one company using lots of about the same size and having several house-models of approximately 100 square meters with one or two bathrooms. The area can be characterized as a typical middle-class neighborhood. With this environment, it is relatively easier to estimate the number of residents who contribute to the sewage flow in the entire area.

Flow Measurement

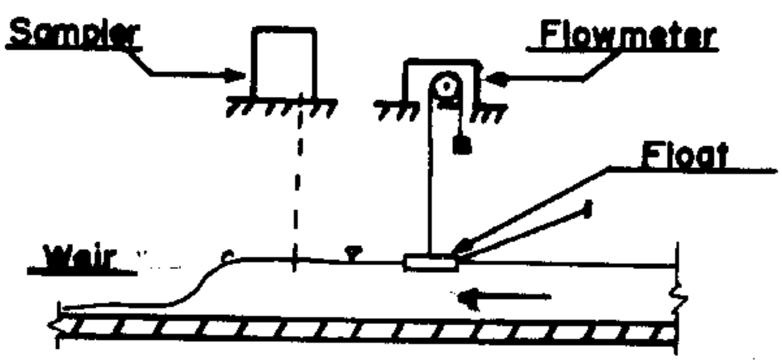
A V-notch weir as shown in Figure 1 was installed at the inlet channel of the sewage treatment plant. The depth of water over the weir was registered constantly through a float which transmitted the information to a flow recorder manufactured by Leupold & Stevens, Oregon. Each sampling day (24 hours), a new chart was installed on the recorder. The chart was adjusted to show exact water depth over the V-notch weir at any given time. Therefore, sewage flow rates were determined by either the standard V-notch weir formula or the calibrated flow scale on the chart. The actual installations of the V-notch weir, the float, and the recorder are shown in Figure 2 .

Since the water depth over the weir varied with time, a 30-minute average water depth was used to determine the flowrate within that 30-minute period. The volume of flow is equal to the flowrate multiplied by the time interval. The flow was measured between February 20, 1974 and May 7, 1974 during which time a total of sixteen 24-hour measurements were obtained. However, on account of a breakdown in the pumping station, the first 10 measurements taken within the period extending from February 20 to April 2, 1974 did not include the pumped sewage flow. In other words, the sewage flowing to the treatment plant during this period was solely from the district where sewage



PLAN

① V-notch Weir
② Flowmeter
③ Automatic Sampler



Arrangement of Flowmeter

Figure 1- Location of Flow Measurement and Sampling Point

flowed by gravity. Figure 3 shows the typical depth versus time curve of the first 10 flow measurements.

In the last 6 flow measurements, the sewage from the other side of the slope in the urbanization was pumped again into the sewage treatment plant. There were two pumps in the pumping station, each with a pumping rate of 290 gpm. The pumps were controlled by the water level in the pumping pit and operated alternately. The pit volume for each pumping was calculated to be 850 gallons. For each pumping cycle, a big surge of sewage flow appears at the sewage treatment plant. This is shown distinctly on the flow chart. In order to facilitate the flow estimation, those peaks are separated from the regular flow in the chart. The typical depth versus time curve of the last 6 flow measurements is shown in Figure 4. In the flow volume calculation, the peak flows resulted from the pumping are separated from the regular flow. Daily total flow resulted from pumping is equal to the number of peaks multiplied by 850 gallons.

The hourly sewage volumes of each of the sixteen 24-hour flow measurements are shown in Appendix A. The peak flows resulted from the pumping in each of the last 6 flow measurements are shown in Appendix B. The total daily flow of each flow measurement is given in Table 4.

Sampling Program

The sampling of sewage was carried out during the period of time when the sewage flow was being measured. Sixteen 24-hour composites were obtained. On each sampling day, from 6 A.M. to 10 P.M., two grab samples of equal volume were taken manually each hour at 30-minute intervals and placed in a plastic bottle; from 10 P.M. to 6 A.M. an automatic sampler (N-con model) was used to take samples and to put them into a large

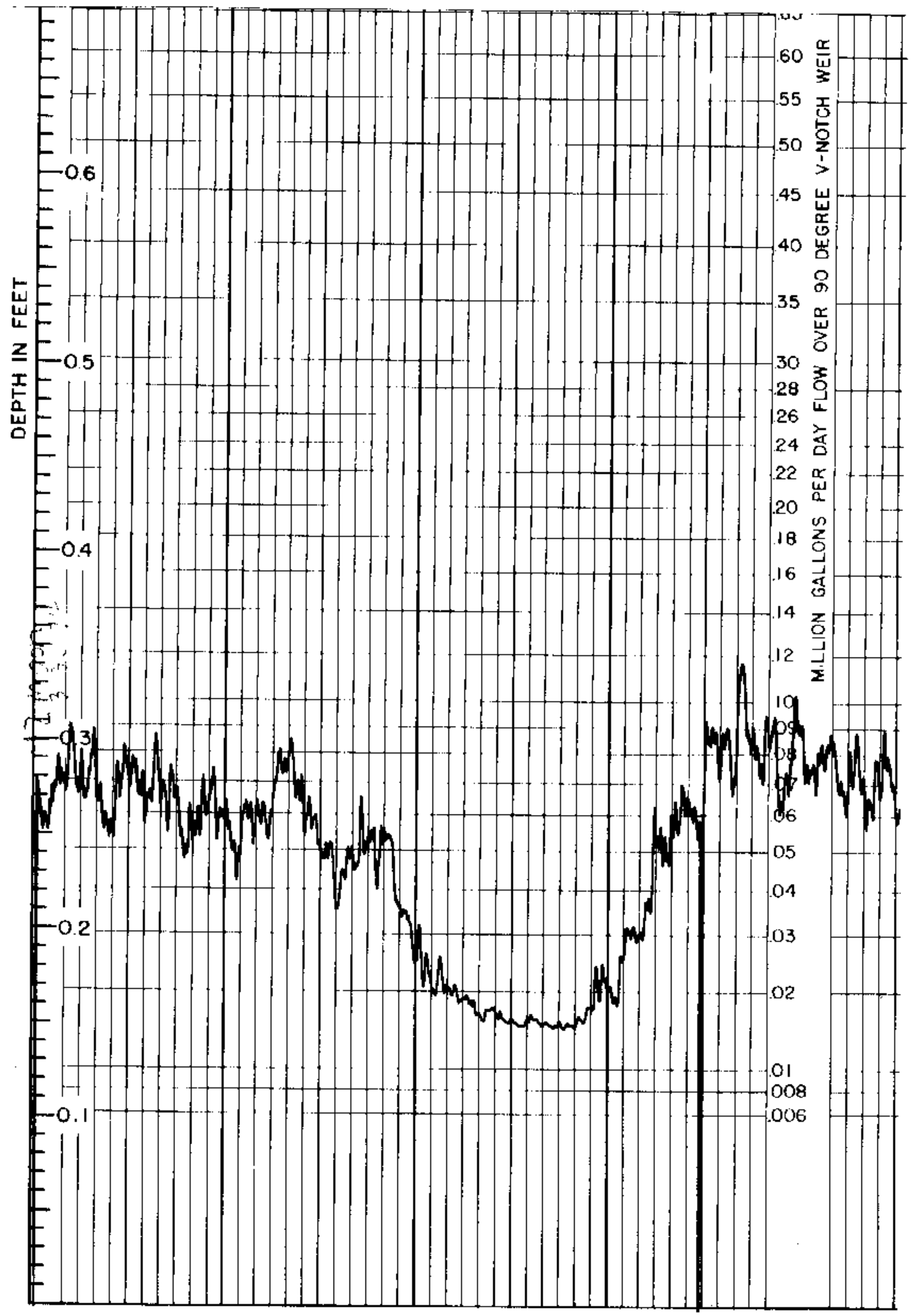


Fig. 3- Typical Water Depth Over the V-notch Weir Versus Time Curve

(Without Pumped Sewage Flow)

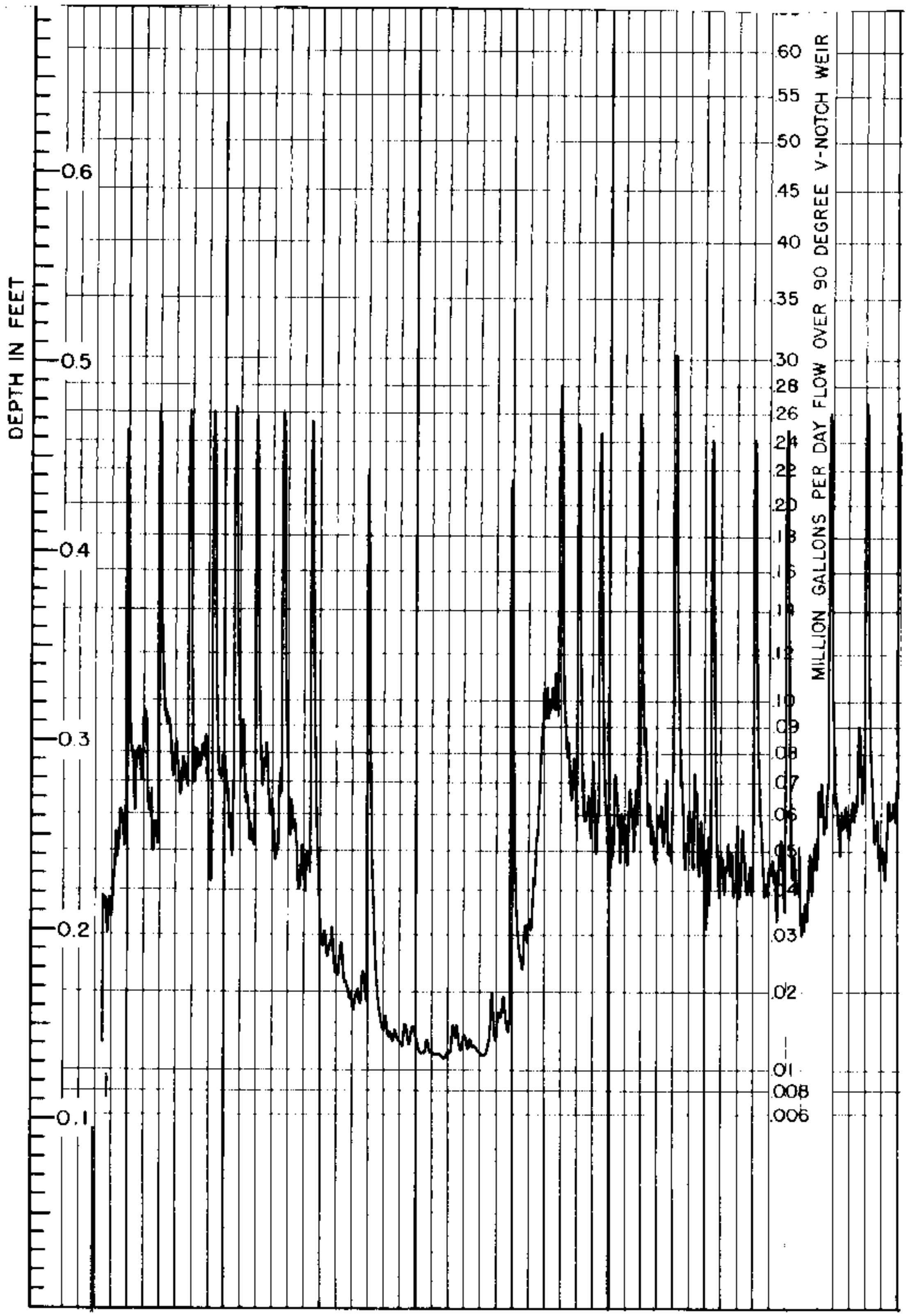


Fig. 4- Typical Water Depth Over the V-notch Weir Versus Time Curve

(Pumped Sewage Flow Included)

plastic bottle at 30-minute intervals. All bottles were covered with ice to minimize sample degradation.

At the end of each sampling day, the samples were brought back to the laboratory. Immediately a composite sample proportional to the volume of flow recorded for that day was prepared and sample analyses followed. Analyses for solids, BOD, COD, Kjeldahl nitrogen, ammonia nitrogen, and orthophosphate were run on the composite samples according to the procedures recommended in "Standard Methods" (11). For the BOD determination, three different dilutions were set up in triplicate.

The automatic sampler is shown in Figure 5. In Figure 6, sample taking and storage are shown. Analyses of sewage samples and laboratory facility are shown in Figure 7.

A summary of the laboratory analyses conducted during the period of the investigation is presented in Tables 4 and 5. Table 4 shows the analyses for solids, BOD, COD, and sewage flow. Table 5 presents the analyses for pH and nutrients.

Population Survey

The Alturas de Mayaguez urbanization has undergone several stages of development. The houses belonging to the first stage of development were completed more than a year ago and have been occupied since then. The sewage discharged from the 204 houses in this section flows to the treatment plant by gravity. The second stage of construction was not completed yet at the time of the survey (May, 1974). However, some of the finished houses of this stage had been occupied for more than 6 months, and others for more than 3 months. All sewage from these houses has to be pumped to the treatment plant. After careful screening during the sampling time (April 21 to May 7, 1974),

Figure 7 - Analysis of Sewage Samples

TABLE 4
SUMMARY OF LABORATORY ANALYSES (BOD_5, COD, and SOLIDS)

Sampling Date and Day (1974)	Concentration of Parameter (mg/l)						BOD_5/COD	Flow (gal)
	SS	TS	VS	FS	BOD_5	COD		
Feb. 20-21 (W-Th)	162	572	460	112	-	533	-	45,620
Feb. 26-27 (T-W)	216	651	462	189	192	729	0.263	40,300
Mar. 5-6 (T-W)	730	1088	460	628	198	675	0.293	37,590
Mar. 10-11 (S-M)	228	650	275	375	171	559	0.306	46,800
Mar. 12-13 (T-W)	684	1326	770	556	186	701	0.265	37,990
Mar. 19-20 (T-W)	203	691	378	313	183	604	0.303	40,940
Mar. 24-25 (S-M)	114	605	380	225	168	543	0.309	49,490
Mar. 26-27 (T-W)	336	775	420	355	228	647	0.352	44,880
Mar. 31-Apr. 1 (S-M)	150	625	372	253	156	548	0.285	55,950
Apr. 2-3 (T-W)	228	703	544	159	222	664	0.334	45,690
Apr. 21-22 (S-M)	160	688	368	320	183	645	0.284	75,580
Apr. 23-24 (T-W)	-	-	-	-	156	600	0.260	83,680
Apr. 28-29 (S-M)	242	682	389	293	168	613	0.274	70,000
Apr. 30-May 1 (T-W)	224	650	330	320	183	608	0.301	62,610
May 5-6 (S-M)	272	832	367	465	174	576	0.302	84,370
May 7-8 (T-W)	238	700	554	146	222	659	0.337	66,960
Average	279	749	435	314	186	619	0.298	55,530

TABLE 5
SUMMARY OF LABORATORY ANALYSES (pH, NUTRIENTS)

Sampling Date and Day (1974)	pH	Kjeldahl Nitrogen (mg/l as N)	Ammonia Nitrogen (mg/l as N)	Orthophosphate (mg/l as PO_4)
Feb. 20-21 (W-Th)	7.4	38.4	23.0	44.4
Feb. 26-27 (T-W)	7.1	48.4	30.5	60.1
Mar. 5-6 (T-W)	7.2	47.6	28.7	55.2
Mar. 10-11 (S-M)	7.7	-	-	-
Mar. 12-13 (T-W)	6.9	45.9	26.6	26.0
Mar. 19-20 (T-W)	7.3	48.8	28.6	62.8
Mar. 24-25 (S-M)	7.4	-	-	-
Mar. 26-27 (T-W)	7.3	51.2	32.4	62.8
Mar. 31-Apr. 1 (S-M)	7.7	-	-	-
Apr. 2-3 (T-W)	7.5	44.8	26.9	53.3
Apr. 21-22 (S-M)	7.7	-	-	56.7
Apr. 23-24 (T-W)	7.6	38.1	20.2	52.7
Apr. 28-29 (S-W)	7.7	-	-	49.0
Apr. 30-May 1 (T-W)	7.7	41.1	25.2	49.0
May 5-6 (S-M)	7.5	-	-	44.4
May 7-8 (T-W)	7.6	45.7	27.0	53.6
Average	7.5	45.0	26.9	51.5

it was found out that 102 houses in this section had been discharging their sewage into the treatment plant via pumping station.

It was possible for the developer of the urbanization to provide a list containing the number of people in each house because this kind of information is required for the document of house separation. However, with the passage of time, much of the population information could have been altered especially information regarding the first section in which some of the houses were built more than three years ago. For this reason, a door-to-door survey was conducted in May, 1974. After one month of intensive work, 258 families were visited out of a total of 306 families covered by the surveyed area. For the remaining residences, the population information from the developer was used. A summary of the population data is shown in Table 6.

Together with the population survey, age-ranges of the occupants in each house were asked by the surveyors. The summary of results is shown in Table 7.

All the houses in the study area are equipped with automatic washing machines. Information regarding the average number of washes per week of each family unit was also gathered. Table 8 summarizes the information.

Per Capita Sewage Flow

The per capita basis was considered most suitable for expressing the sewage characteristics. The per capita daily sewage flow is equal to the total sewage flow from a district divided by the total population of the same district. Sewage flow of the first 10 measurements was taken from the district in the urbanization served by the gravity sewer system. Therefore, the per capita sewage flow for these measurements is equal to the daily sewage flow divided by the total population of 811 in the district. In the last

TABLE 6
SUMMARY OF POPULATION INFORMATION

Item	District Served by Gravity Sewer System	District Served by Pumped Sewer System	Total
No. of houses	204	102	306
No. of residents	811	392	1203
Density (No./house)	3.97	3.84	3.93

TABLE 7
AGE GROUP OF THE RESIDENTS

Age (years)	Number of Residents	Percentage
Babies	107	10.0
2-13	239	22.4
13-21	120	11.2
21-50	523	48.9
>50	80	7.5
Total	1069	100.0

TABLE 8
SUMMARY OF LAUNDRY INFORMATION

No. of Washes per Week	No. of Families	Percentage
1	58	22.5
2	69	26.7
3	54	20.9
4	21	8.1
5	18	7.0
6	6	2.3
7	29	11.3
>7	3	1.2
	Sum = 258	100.0

6 measurements, however, the sewage flow came from the districts served by both the gravity sewer system and the pump sewer system. The per capita sewage flow for the last 6 flow measurements is, therefore, equal to the total daily sewage flow divided by the combined total population of 1,203 in both districts. The per capita daily sewage flows for all 16 measurements are shown in Table 9.

The sampling days fell partly on weekdays (mostly Tuesdays) and partly on weekends (Sundays). The purpose of such a distinction is to see whether there was any difference between weekdays and weekends. The average value of 63.2 gpcd for weekend sewage flow measurements is significantly greater than that of 53.9 gpcd for weekday measurements. This can very well be the trend of modern living. In a small family in which both husband and wife are working on weekdays, house cleaning and laundry are usually done on weekends. With this trend, sewage treatment plants should be operated in accordance with the variations in order to attain maximum efficiency in each of the treatment processes.

On each day of the flow measurement, the percentage values of hourly flow in relation to the daily average flow were calculated, and the results for all 16 measurements are shown graphically in Figure 8. The patterns of the hourly flow variations for all weekday measurements are quite similar to each other. In general, each pattern exhibits two peaks daily, one in the morning from 6 A.M. to 8 A.M. and the other in the afternoon from 5 P.M. to 9 P.M. This demonstrates the typical pattern of sewage flow for a small community which is very much affected by the workday schedule of the residents. The variations of the hourly flow with two peaks for weekend measurements are not obvious. The pattern tends to be uniform throughout the daytime and evening hours. Late in the evening and early in the morning (around 12 midnight to 5 A.M.), the sewage flow was

TABLE 9
PER CAPITA DAILY SEWAGE FLOWS

Sampling Date (1974)	Day	Per Capita Flow (gal/day)
Feb. 20	Wednesday	56
Feb. 26	Tuesday	50
Mar. 5	Tuesday	46
Mar. 10	Sunday	58
Mar. 12	Tuesday	47
Mar. 19	Tuesday	51
Mar. 24	Sunday	61
Mar. 26	Tuesday	55
Mar. 31	Sunday	69
Apr. 2	Tuesday	56
Apr. 21	Sunday	63
Apr. 23	Tuesday	70
Apr. 28	Sunday	58
Apr. 30	Tuesday	52
May 5	Sunday	70
May 7	Tuesday	56
Average	Sunday only:	63.2
	Weekday only:	53.9
	Total:	57.4

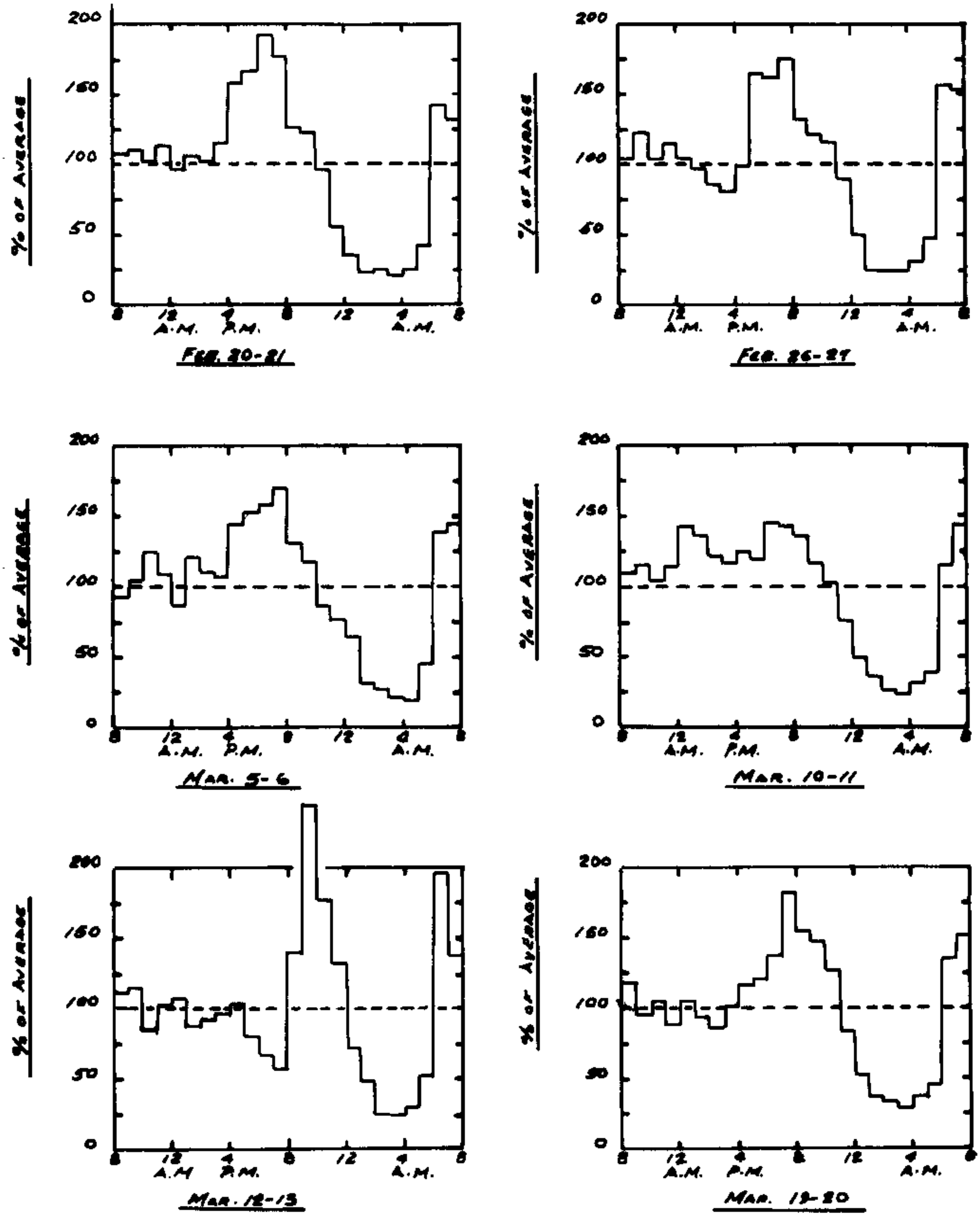


Fig. 8- Variations of the Percentage of Each Hourly Flow to the Avg. Hourly Flow for Each Measuring Day

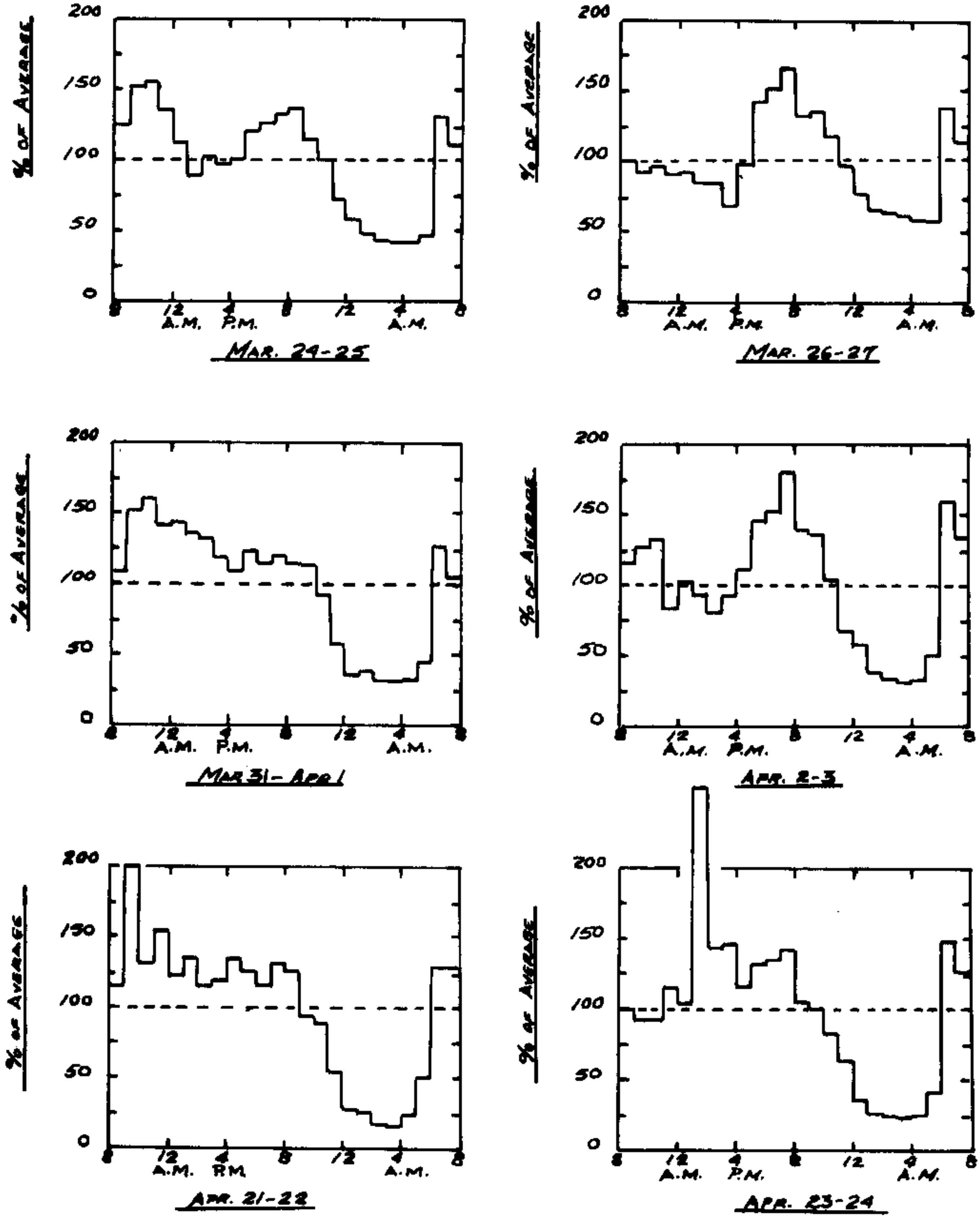


Fig. 8 - (Continued)

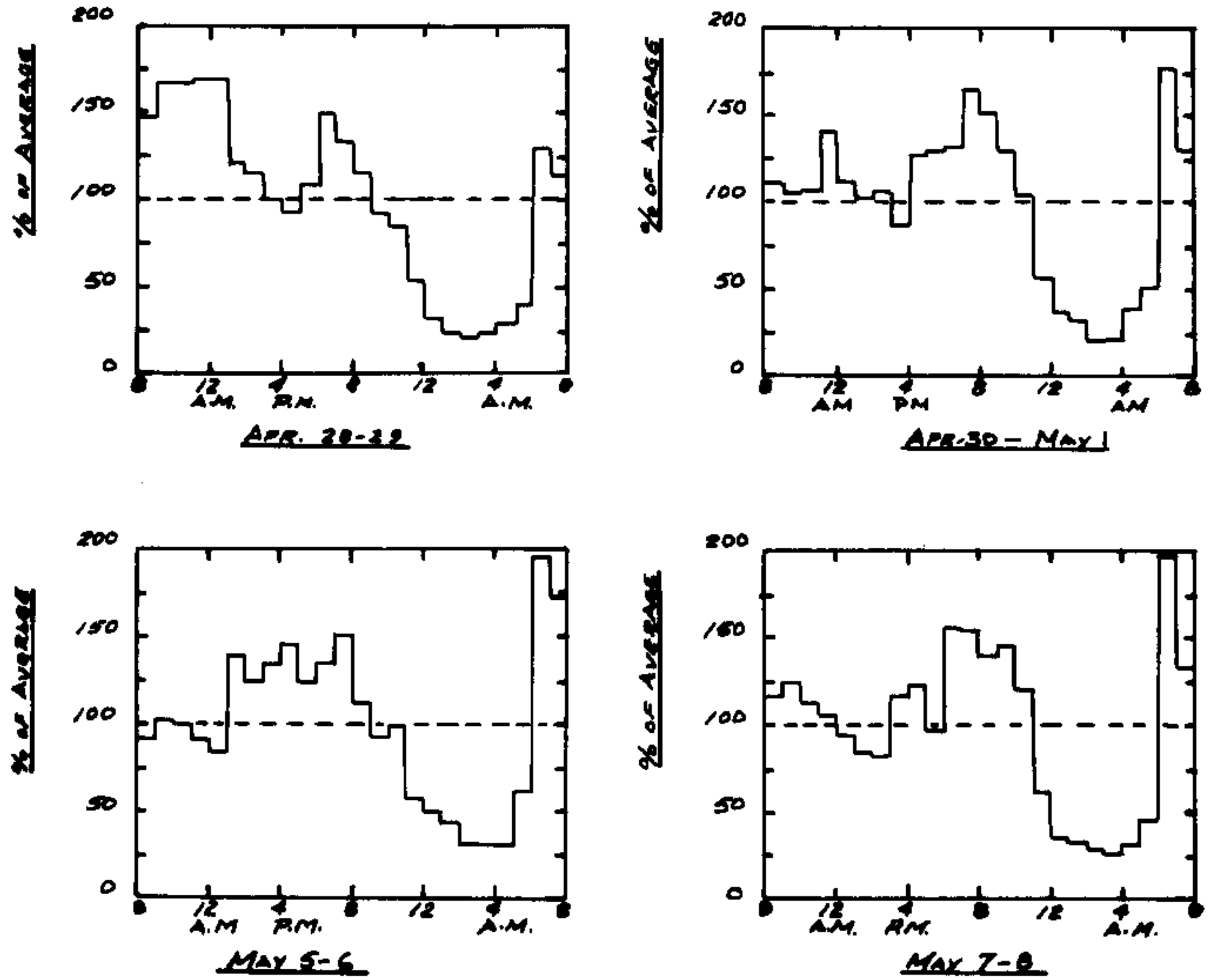


Fig. 8- (Continued)

very low for both weekday and weekend measurements. Indeed, there was very little activity during those hours for this residential community.

The maximum and the minimum sewage hourly flows expressed as percentage of the average for each flow measurement day were determined and the results are shown in Table 10. The average value of the maximum hourly sewage flow was 185.7 per cent of the average daily sewage flow with a range from 145.1% to 258.9%. The average value of the minimum hourly sewage flow was 29.3 per cent of the average daily sewage flow with a range from 18.8% to 59.9%. These wide ranges of variations are considered quite common for a residential district.

Per Capita Loading

By using the data in Table 4 and the population figures in Table 6, the results obtained are expressed in terms of pounds per day per capita. Table 11 shows the per capita loadings for BOD, COD, and suspended solids. Table 12 presents the per capita loadings for the nutrients.

The average per capita BOD loading of 0.088 lb/day is considerably lower than the long established value of 0.17 lb/day. However, the value of 0.17 lb/day/capita as the result of a survey conducted by Theriault in 1927 was based on the ultimate day. In general, 5-day BOD value for a domestic sewage is about 70 per cent of the value of ultimate BOD; the per capita loading of 5-day BOD of Theriault's survey would be approximately 0.12 lb/day/capita which would be much closer to the 5-day BOD value of 0.88 lb/day/capita obtained in this investigation. Traditionally, engineers adopt the 5-day per capita BOD loading from 0.12 to 0.17 lb/day which is rather high. The per capita 5-day BOD loading in the recent Milwaukee study is 0.10 lb/day/capita. Based

TABLE 10
MAX. OR MIN. SEWAGE HOURLY FLOWS AS PERCENTAGE
OF THE AVERAGE

Sample Date	Maximum Hourly	Minimum Hourly
Feb. 20-21	191.0	21.0
Feb. 26-27	176.3	25.0
Mar. 5-6	170.5	19.8
Mar. 10-11	145.1	25.6
Mar. 12-13	246.4	26.5
Mar. 19-20	182.9	29.3
Mar. 24-25	156.6	42.2
Mar. 26-27	166.8	59.9
Mar. 31-Apr. 1	160.9	32.2
Apr. 2-3	180.7	32.6
Apr. 21-22	200.9	18.8
Apr. 23-24	258.9	25.0
Apr. 28-29	168.4	21.5
Apr. 30-May 1	178.9	30.5
May 5-6	196.6	30.7
May 7-8	190.8	27.4
Average	185.7	29.3

TABLE 11
PER CAPITA LOADINGS FOR BOD, COD, AND SUSPENDED SOLIDS

Sampling Date (1974)	Loading (lb/day/capita)		
	BOD	COD	SS
Feb. 20-21	-	0.2500	0.0760
Feb. 26-27	0.0796	0.3021	0.0895
Mar. 5-6	0.0766	0.2609	0.2821
Mar. 10-11*	0.0823	0.2691	0.1098
Mar. 12-13	0.0727	0.2738	0.2671
Mar. 19-20	0.0772	0.2544	0.0855
Mar. 24-25*	0.0855	0.2765	0.0581
Mar. 26-27	0.1053	0.2989	0.1552
Mar. 31-Apr. 1*	0.0897	0.3152	0.0863
Apr. 2-3	0.1043	0.3120	0.1071
Apr. 21-22*	0.0959	0.3379	0.0838
Apr. 23-24	0.0905	0.3481	-
Apr. 28-29*	0.0815	0.2975	0.1175
Apr. 30-May 1	0.0794	0.2640	0.0973
May 5-6*	0.1018	0.3370	0.1591
May 7-8	0.1031	0.3060	0.1105
Average	0.0884	0.2940	0.1257

*Sunday Measurement

TABLE 12
PER CAPITA LOADINGS OF NUTRIENTS

Sampling Date (1974)	Loading (lb/day/capita)		
	Kjeldahl Nitrogen	Ammonia Nitrogen	Orthophosphate
Feb. 20-21	0.0180	0.0108	0.0208
Feb. 26-27	0.0201	0.0126	0.0249
Mar. 5-6	0.0184	0.0111	0.0213
Mar. 10-11	-	-	-
Mar. 12-13	0.0179	0.0104	0.0102
Mar. 19-20	0.0206	0.0122	0.0265
Mar. 24-25	-	-	-
Mar. 26-27	0.0236	0.0150	0.0290
Mar. 31-Apr. 1	-	-	-
Apr. 2 - 3	0.0211	0.0126	0.0250
Apr. 21 - 22	-	-	0.0297
Apr. 23 - 24	0.0221	0.0117	0.0306
Apr. 28 - 29	-	-	0.0238
Apr. 30 -May 1	0.0178	0.0111	0.0213
May 5 - 6	-	-	0.0260
May 7 - 8	0.0212	0.0125	0.0249
Average	0.0201	0.0120	0.0242

on the result of this study, it seems that the per capita BOD loading for strictly domestic sewage should be modified to the lower range which is between 0.08 and 0.12 lb/day/capita.

One might attribute the low value of per capita BOD loading to the limited number of residents contributing to the sewage flow during the working hours of weekdays. Because these residents work or study away from the urbanization, their sewage will have to be discharged into places other than the sewer system in the urbanization. However, the results as shown in Table 11 indicate that the average value of all Sunday results (0.0895 lb/day/capita) is about the same as the average value of all weekday results (0.0876 lb/day/capita). Sunday results should cover the total sewage flow contributed by all residents within the sampling time of 24 hours. The closeness of the two averages suggests that the absence of sewage flow during the working hours of weekdays does not cause significant change in the per capita BOD loading of the sewage in this urbanization. This can be explained by the fact that most workers and students living in this urbanization go home for their lunch. However, the per capita sewage flow on Sundays is definitely greater than that on weekdays as indicated previously in the flow data. More washes and cleanings on Sundays contribute to the larger quantity of wastewater flow but relatively smaller amount of biodegradable organic matter.

The per capita loading of COD appears to be quite high with an average value of 0.294 lb/day/capita. However, if the traditional BOD/COD ratio is 0.6 and the BOD loading is 0.17 lb/day, the COD loading will be 0.28 lb/day which is quite close to the value obtained in this study. The lower value of BOD and the approximately equivalent value of COD in this study indicate that the sewage contains less soluble biodegradable matter and more non-biodegradable or slow-rate biodegradable suspended matter.

The wide-spread installation of garbage grinders may very well explain this phenomenon. In the study area, every home is equipped with a garbage grinder in the kitchen. Coffee granules, chicken bones, vegetables, and fruit peelings contribute to higher suspended solids in the sewage which will result in higher COD value but not necessarily in BOD value.

In this study, the average value of COD is 0.294 lb/day/capita which is higher than the COD value of 0.20 lb/day/capita in the recent Milwaukee study. Besides, the average value of suspended solids is 0.126 lb/day/capita in this study. Again, it is higher than the value of 0.08 lb/day/capita in the same Milwaukee study. A plausible explanation for the difference is the percentage of garbage grinder installations. Only around 30 per cent of the homes in the Milwaukee study area have garbage grinders. In the residential area studied in the present investigation, 100 per cent of the houses have garbage grinders. A great difference is seen in the comparison between these two percentages.

The per capita loadings of nutrients are also of higher values. The average values for Kjeldahl nitrogen, ammonia nitrogen, and orthophosphate are 0.0201, 0.0120, and 0.0242 (all expressed in lb/day/capita), respectively. These values appear to be higher than those of 0.0145, 0.0057, and 0.0119 (all expressed in lb/day/capita) found in the Milwaukee study. Exact reasons for the marked differences are difficult to spell out. Perhaps more washing of clothes in tropical Puerto Rico may lead to greater use of detergent which eventually results in higher phosphate concentration in sewage. Local diet including the large consumption of beans with high protein content may produce higher nitrogen nutrient in the sewage. More research work is needed to verify these assumptions.

Summaries of per capita loadings for BOD, COD, and flow are shown in Table 13 together with their statistical analyses. Similar summaries for solids and nutrients are given in Tables 14 and 15, respectively.

Summary

Accurate measurements of BOD, COD, solids, and nutrients in sewage are very important for water pollution control. In this investigation, the sewage from a typical residential area with a population of 1,203 was sampled and measured. A total of sixteen 24-hour composite samples was collected and analyzed. The conclusions of the investigation are as follows:

1. The average per capita sewage flow has been found to be 57.4 gal/day. Weekend sewage flow is about 15 per cent greater than weekday sewage flow. The greater sewage flow may be contributed to the practice of doing more washing and cleaning on weekends.
2. The average BOD loading of 0.088 lb/day/capita obtained in this study is a little below the 0.1 lb/day/capita found in the recent Milwaukee study and considerably lower than the commonly adopted value of 0.17 lb/day/capita. For strictly domestic sewage, it seems that the BOD loading needs to be changed to the range between 0.08 and 0.12 lb/day/capita.
3. There was no difference in the per capita BOD loading between the average weekday measurements and the average weekend measurements in spite of the fact that the average weekend sewage flow is about 15 per cent greater than the average weekday sewage flow. More washes and cleanings on weekends contribute to the larger quantity of wastewater flow but relatively smaller amount of biodegradable organic matter.
4. The average COD loading of 0.294 lb/day/capita obtained in this study is considerably greater than that of 0.12 lb/day/capita found in the recent Milwaukee study.

TABLE 13
SUMMARY OF PER CAPITA LOADINGS FOR BOD, COD, AND FLOW OF DOMESTIC SEWAGE

Characteristics	Loading		Percent Confidence
	Average	Interval	
BOD (5-day) (lb/day/capita)	0.088	0.066-0.110	95
		0.074-0.102	80
COD (lb/day/capita)	0.294	0.234-0.354	95
		0.256-0.332	80
Flow (gpd/capita)	57	37.3 -76.7	95
		44.4 -69.6	80

TABLE 14
SUMMARY OF PER CAPITA LOADINGS FOR VARIOUS TYPES OF SOLIDS IN DOMESTIC SEWAGE

Type of Solids	Loading (lb/day/capita)		
	Mean	Medium	Range
Total Solids	0.348	0.330	0.268 - 0.518
Total Volatile Solids	0.202	0.194	0.132 - 0.301
Total Fixed Solids	0.146	0.146	0.053 - 0.272
Total Suspended Solids	0.126	0.107	0.058 - 0.282

TABLE 15
SUMMARY OF PER CAPITA LOADINGS FOR VARIOUS NUTRIENTS IN DOMESTIC SEWAGE

Nutrient	Loading (lb/day/cap) × 10^2		Percent Confidence
	Average	Interval	
Kjeldahl nitrogen (as N)	2.01	1.63 - 2.39	95
		1.77 - 2.25	80
Ammonia nitrogen (as N)	1.20	0.94 - 1.46	95
		1.03 - 1.37	80
Orthophosphate (as PO_4)	2.42	1.41 - 3.43	95
		1.78 - 3.06	80

More installations of garbage grinders (all houses) in the present study area resulting in higher concentration of suspended solids in the sewage may be a plausible explanation for the higher average COD value.

5. Both nitrogen and phosphorus nutrients in the sewage have been found to be higher in per capita loading values when compared with the results of the recent Milwaukee study. The need for more washing and cleaning in the tropical climate and the large consumption of high protein foodstuff such as beans may be the causes of the difference.

REFERENCES

1. Zanoni, A. E., and Rutkowski, R.J., "Per Capita Loadings of Domestic Wastewater." Journal Water Pollution Control Federation, 44, 1756 (1972).

2. Theriault, E.J., "The Oxygen Demand of Polluted Waters." USPHS Bulletin No. 173 (1927).

3. Tolman, S. L., "Ground Garbage – Its Effect upon the Sewer System and Sewage Treatment Plant." Sewage Works Journal, 19, 441 (1947).

4. Simpson, R.W., "Effect of Ground Garbage on Sewers and Sewage Treatment." Wastes Engineering, 23, 33 (1952).

5. Babbitt, H. E., "Sewerage and Sewage Treatment." John Wiley & Sons, Inc., London, England (1952).

6. Fair, G. M., and Geyer, J. C., "Water Supply and Wastewater Disposal." John Wiley & Sons, Inc., New York, N. Y. (1954).

7. Schroepfer, G. J., et al., "Investigation of the Ratio of Population Equivalent to Actual Population for Nine Metropolitan Areas." Progress Report 134-S, Minneapolis – St. Paul Sanitary District, Minn. (1960).

8. Fair, G. M., et al., "Water and Wastewater Engineering." Vol. 2, John Wiley & Sons, Inc., New York, N. Y. (1968).

9. Carpenter, L. V., et al., "Disposal of Garbage in the Sewerage System." Sewage Works Journal, 8, 728 (1936).

10. Watson, K. S., et al., "The Contribution From the Individual Home to the Sewer System." Journal Water Pollution Control Federation, 39, 2039 (1967).

11. "Standard Methods for the Examination of Water and Wastewater." 13th. Ed., American Public Health Association, Washington, D. C. (1971).

Appendix A.

HOURLY SEWAGE FLOW VOLUME OF EACH SAMPLING DAYS IN GALLONS

Hour	2-20-74 to 2-21-74	2-26-74 to 2-27-74	3-5-74 to 3-6-74	3-10-74 to 3-11-74	3-12-74 to 3-13-74	3-19-74 to 3-20-74
8-9 A.M.	2040	1750	1460	2150	1770	2020
9-10	2080	2060	1650	2250	1830	1620
10-11	1920	1730	1960	2060	1330	1790
11-12	2150	1920	1710	2250	1620	1520
12-1 P.M.	1850	1750	1370	2770	1710	1770
1-2	2020	1650	1900	2650	1400	1600
2-3	1940	1460	1730	2370	1460	1500
3-4	2190	1370	1690	2290	1540	1730
4-5	3020	1670	2270	2420	1630	2020
5-6	3190	2770	2400	2330	1270	2080
6-7	3630	2750	2500	2830	1060	2370
7-8	3380	2960	2670	2790	920	3120
8-9	2400	2230	2060	2650	2230	2650
9-10	2350	2040	1850	2290	3900	2540
10-11	1830	1980	1370	2000	2830	2170
11-12	1100	1520	1210	1500	2100	1440
12-1 A.M.	710	850	1020	960	1150	920
1-2	440	420	500	730	790	650
2-3	480	420	440	540	420	580
3-4	400	420	330	500	400	500
4-5-	480	520	310	620	480	650
5-6	810	810	730	770	830	790
6-7	2710	2650	2190	2270	3130	2310
7-8	2500	2600	2270	2810	2190	2600
Total	45,620	40,300	37,590	46,800	37,990	40,940

Cont.

Hour	3-24-74 to 3-25-74	3-26-74 to 3-27-74	3-31-74 to 4-1-74	4-2-74 to 4-3-74
8-9 A.M.	2580	1870	2540	2210
9-10	3150	1730	3560	2420
10-11	3230	1830	3750	2520
11-12	2790	1710	3290	1580
12-1 P.M.	2310	1730	3350	1940
1-2	1850	1600	3190	1770
2-3	2120	1600	3080	1560
3-4	2000	1290	2780	1770
4-5	2080	1850	2540	2120
5-6	2480	2670	2870	2770
6-7	2600	2830	2710	2900
7-8	2730	3120	2810	3440
8-9	2810	2460	2710	2650
9-10	2350	2540	2690	2600
10-11	2080	2210	2150	1960
11-12	1500	1830	1370	1310
12-1 A.M.	1210	1440	850	940
1-2	1000	1250	920	750
2-3	920	1210	750	650
3-4	870	1170	750	620
4-5	870	1120	790	650
5-6	980	1120	1080	960
6-7	2710	2580	2980	3040
7-8	2270	2120	2440	2560
Total	49,490	44,880	55,950	45,690

Cont.

Hour	4-21-74 to 4-22-74	4-23-74 to 4-24-74	4-28-74 to 4-29-74	4-30-74 to 5- 1 -74	5-5-74 to 5-6-74	5-7-74 to 5-8-74
8-9 A.M.	2710	2330	3150	2100	2480	2500
9-10	4690	2150	3580	2000	2730	2620
10-11	3080	2150	3580	2020	2710	2400
11-12	3580	2710	3600	2670	2440	2250
12-1 P.M.	2870	2420	3600	2120	2270	2000
1-2	3170	6000	2580	1920	3770	1830
2-3	2710	3330	2440	2020	3350	1790
3-4	2790	3370	2150	1690	3620	2500
4-5	3150	2730	1980	2440	3920	2600
5-6	2960	3080	2330	2460	3350	2690
6-7	2710	3150	3190	2500	3670	3310
7-8	3080	3270	2830	3120	4060	3290
8-9	2920	2440	2440	2870	3020	2960
9-10	2210	2330	1980	2460	2500	3080
10-11	2080	1940	1850	1980	2690	2540
11-12	1310	1460	1150	1120	1560	1310
12-1 A.M.	690	900	690	730	1330	750
1-2	650	670	500	620	1210	710
2-3	460	620	460	580	830	620
3-4	440	580	500	580	830	580
4-5	540	620	620	750	830	650
5-6	1190	960	870	980	1670	980
6-7	3020	3440	2790	3400	5310	4040
7-8	3020	2980	2440	2480	4670	2810
Total	56,030	55,630	51,300	45,610	64,820	50,810

Appendix B.

TOTAL SEWAGE FLOW VOLUME OF EACH OF THE LAST SIX SAMPLING DAYS IN GALLONS

Sampling Date (1974)	Total Hourly Flow Volume	Peak Flow Volume			Total Flow Volume
		No. of Peaks	Volume Per Peak	Volume	
Apr. 21-22	56,030	23	850	19,550	75,580
Apr. 23-24	55,630	33	850	28,050	83,680
Apr. 28-29	51,300	22	850	18,700	70,000
Apr. 30-May 1	45,610	20	850	17,000	62,610
May 5-6	64,820	23	850	19,550	84,370
May 7-8	50,810	19	850	16,150	66,960