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LIME TREATMENT OF DOMESTIC WASTEWATER IN AN UPFLOW CLARIFIER

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Report to the Division of Water Pollution Control,
Massachusetts Water Resources Commission.
Contract Number 15-51450

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ENVIRONMENTAL ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF MASSACHUSETTS
AMHERST, MASSACHUSETTS

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ABSTRACT

A pilot plant scale upflow clarification unit, similar to those found in small water treatment plants, was used to chemically clarify raw wastewater. Good removals of both colloidal organics and phosphorus were achieved by the addition of 350 mg/l of lime. At the lowest overflow rate, 0.29 gpm/sq ft, total organic carbon (TOC) and phosphorus as P were reduced to 29 mg/l and 0.8 mg/l respectively.

The most significant operational finding from this study was that hydraulic shock loading, typical of diurnal flow variations, was detrimental to phosphorus removal efficiency. However, organic and phosphorus shock loadings, as provided for example by septic tank truck dumpings, did not upset system performance.

Although lime clarification of raw wastewater was demonstrated to be effective, low alkalinity wastewaters, exemplified by Amherst and typical of many areas of Massachusetts, will necessitate that subsequent pH reduction be an integral feature of the system if a biological treatment unit follows. Alternatively, it may be possible to supplement alkalinity in order to promote good lime clarification without increasing pH above about 10.5 and thus negating the need for further pH adjustment. Use of coagulant aids, such as synthetic organic polymers, also offers the potential of improving settleability of lime precipitates at reduced values of pH.

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INTRODUCTION

State and Federal regulations pertaining to the discharge of wastewater into streams and lakes are becoming increasingly stringent. A need has thus arisen for treatment techniques which are more efficient and reliable than the conventional processes used in the past.

A particular problem placing new demands on treatment technology is the high phosphorus content of wastewaters. Since the late 1940's use of synthetic detergents containing 12 to 13 percent phosphorus, or over 50 percent polyphosphates, has increased the inorganic phosphorus content of domestic sewage by a factor of two to three (9). Experience has shown that the phosphorus concentration of lake waters must be limited to about .01 mg/l to prevent the growth of algal blooms and associated nuisance conditions (9). Conventional treatment processes, however, will not remove phosphorus in quantities sufficient to maintain this level.

The addition of lime to wastewater is one method shown to be effective in promoting removal of phosphorus and other pollutants (e.g. 1,8,10). Several alternative means of introducing the chemical into the wastewater have been tried, including injection into the influent pipeline or preliminary treatment units, use of rapid mix and flocculation basins, and a direct addition to an upflow clarifier. The benefits and limitations of each of these systems need further investigation before their potential can be fully ascertained.

OBJECTIVES

This report describes the results of a pilot plant study in which raw sewage was treated with lime in an upflow (sludge blanket) clarification unit. Specifically, the objectives of this study were to determine:

1. the effectiveness of a pilot-scale upflow clarifier in removing phosphorus and total organic carbon from wastewater using lime as a coagulant,
2. the relationship between overflow rate and clarifier performance,
3. the effect of hydraulic shock loading on clarifier performance.

THEORY

Phosphorus Precipitation with Lime

Lime addition to wastewater causes several simultaneous reactions to occur. Calcium ions can combine in the alkaline pH range with inorganic phosphorus (in the orthophosphate form) to form a precipitate known as hydroxyapatite. Under certain conditions this precipitate forms at pH values as low as 8, negating the need for excessive elevation of pH. The second reaction accompanying addition of lime is that of $CaCO_3$ precipitation. This reaction results from the addition of OH^- ion which shift carbonate equilibria to CO_3^{2-} ions. The extent of this reaction depends upon the amount of carbonate present which in turn relates to the wastewater alkalinity.

Schmid and McKinney (10) showed that although only orthophosphate is involved in the hydroxyapatite precipitation, other phosphorus forms are removed through adsorption. Polyphosphates, for example, were found to adsorb onto hydroyapatite floc and possibly onto calcium carbonate precipitate.

The solubility of hydroxyapatite is very low. This property theoretically permits removal of large fractions of phosphorus, even at pH values as low as 8.0 as noted. However, practical considerations, involving removal of poorly-settling precipitates, often dictate that a higher operating pH be employed.

In lime precipitation, two treatment options are available, single-stage and two-stage. The choice of system depends primarily on the alkalinity of the water. In single stage treatment, lime is mixed with feed water to raise the pH in the range of 9.5 to 11.0. This process is well-suited to hard waters with alkalinities above 250 mg/l (1); in such waters a well-settling floc is more easily formed at lower pH. Two-stage lime treatment includes a primary stage with high pH, usually above 11.5, and subsequent recarbonation to remove excess calcium ions in the second stage. The high pH lime process should be used with waters of low alkalinity (200 mg/l as $CaCO_3$ or less) or the low fraction of $CaCO_3$ formed will result in a poorly settleable floc.

The lime dose required to achieve a given pH is dependent principally upon the wastewater alkalinity and is relatively independent of the influent phosphorus concentration. Only in waters of very low bicarbonate alkalinity would the phosphorus precipitation reaction consume a large fraction of the lime added. Raising the pH of wastewaters with low alkalinity will require less lime than wastewater with high alkalinity.

If the pH is raised above 9.5, magnesium hydroxide begins to precipitate:

$$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2\downarrow$$

This reaction is complete at pH 11. The precipitate is in a gelatinous form which removes colloidal solids as it settles, thus causing a partial reduction of TOC. However, the sludge generated does not thicken or dewater well.

Another reaction that is of major import, where lime is to be recovered by sludge recalcination, is as follows:

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

A pH above 10 is needed to obtain even measurable $CaCO_3$ production. Thus, recovery of lime by recalcining may not be practical with the single-stage precipitation process.

Upflow Clarification

Upflow clarifiers have been used effectively in water treatment for almost 80 years. Their usage has, however, been restricted primarily to softening and clarification where water characteristics are not variable and flow rates are uniform. The distinguishing feature of upflow clarification is that mixing, flocculation, and settling are all combined in one integrated unit; additionally, flow in the settling compartment proceeds in an upward direction and passes through a suspended blanket of floc particles. For this reason upflow clarifiers are often called sludge blanket clarifiers. The latter term is actually preferable since upflow (solids contact) clarifiers have come into use which do not operate with a sludge blanket.

Theoretically, the vertical flow floc blanket system requires a lower surface loading (overflow rate) to separate the same size of particle as a horizontal-flow settler. This is due to the lower settling velocity resulting from the interference of flocs in bulk (7). In addition, horizontal units are capable of removing a percentage of particles with settling velocity less than the overflow rate; all such particles theoretically escape in an upflow clarifier. In practice, however, the blanket in an upflow unit acts as a crude filter for small particles, and efficient separation can be achieved at rates considerably above the theoretic value. Moreover, the dense concentration of particles allows flocculation to be achieved more readily.

Because the majority of the particles that enter an upflow unit are removed, the sludge blanket volume progressively increases. Thus, it is necessary to remove solids from the sludge blanket at the same rate that they enter to maintain a sludge blanket volume. This is a practical operating problem which is greatly complicated by changes in flowrate such as diurnal fluctuations in municipal wastewater flow (2).

EXPERIMENTAL PROGRAM

Upflow Clarifier and Lime Feed System

The upflow clarifier installed at the University of Massachusetts pilot facility is a package unit manufactured by the Permutit Company of Paramus, New Jersey. The unit was originally intended to be used for water treatment with a design capacity of 785 gallons per hour (gph).

The upflow clarifier consists of a mixing-coagulation zone, a settling zone, and a treated effluent storage zone as shown in Figure 1. The detention time and overflow rate of the unit as a function of flow-rate are shown in Figures 2 and 3. Raw sewage and lime were mixed at the top of the mixing-coagulation compartment by means of an electrically driven paddle-type agitator; several drive ratios are available for paddle speed adjustments, although speed was maintained constant in these experiments. Flow was downward through this compartment and then upward through the settling compartment into a collector at the top which carries the water to the storage chamber. A sampling valve is located in the storage zone two inches beneath the water surface.

The lime feed system consists of a chemical storage tank of 190 gallon capacity and a Wallace and Tiernan adjustable flow positive displacement pump. The tank is equipped with an electrically driven

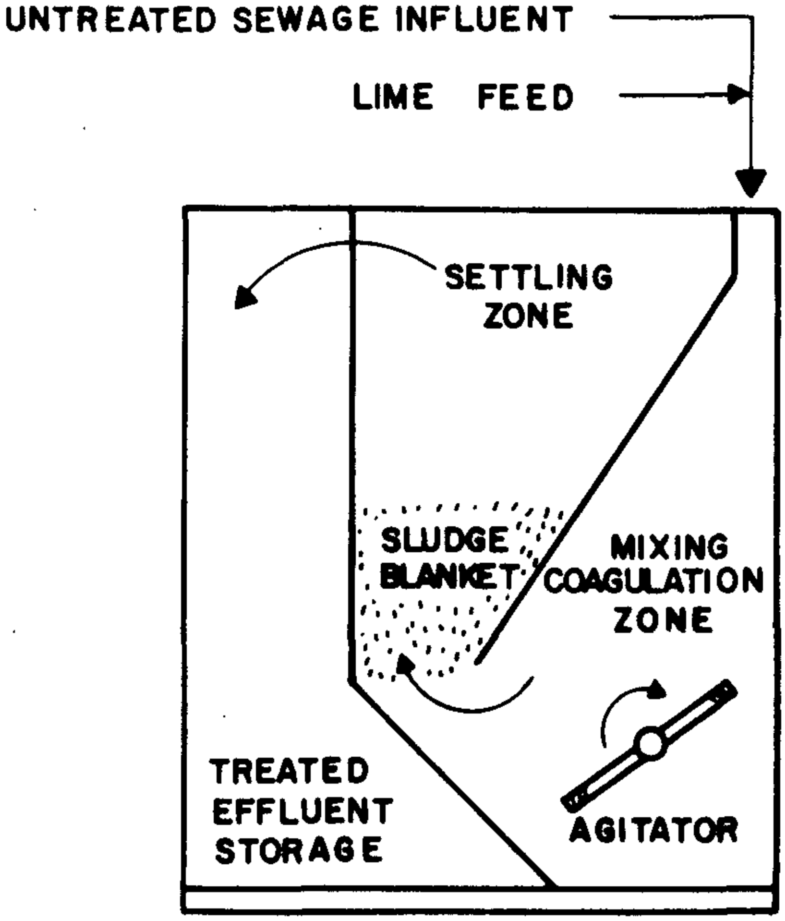

Figure 1. Sectional View of the Upflow Clarifier.

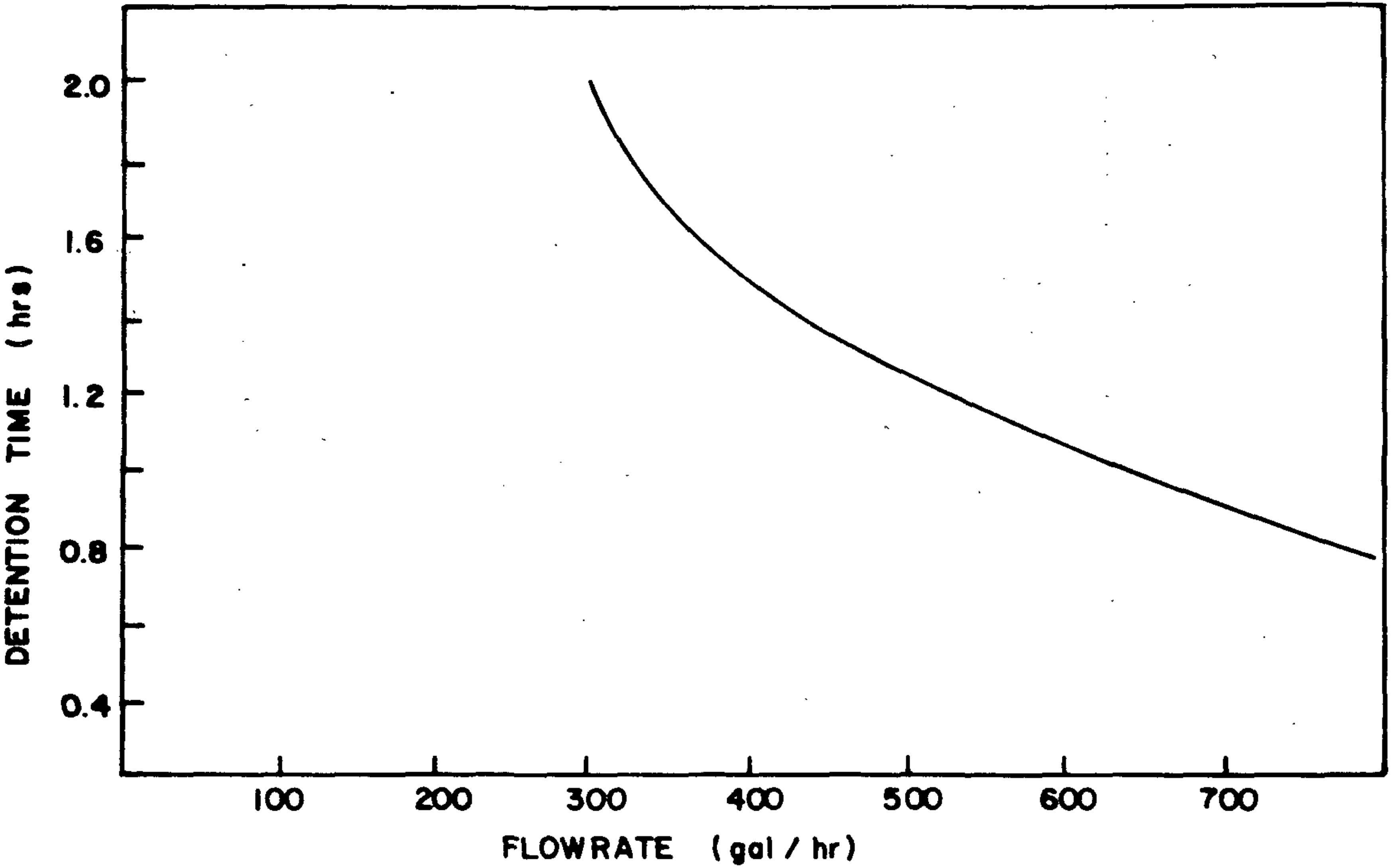

Figure 2. Detention Time Versus Flow Rate for the Settling Zone of the Upflow Clarifier.

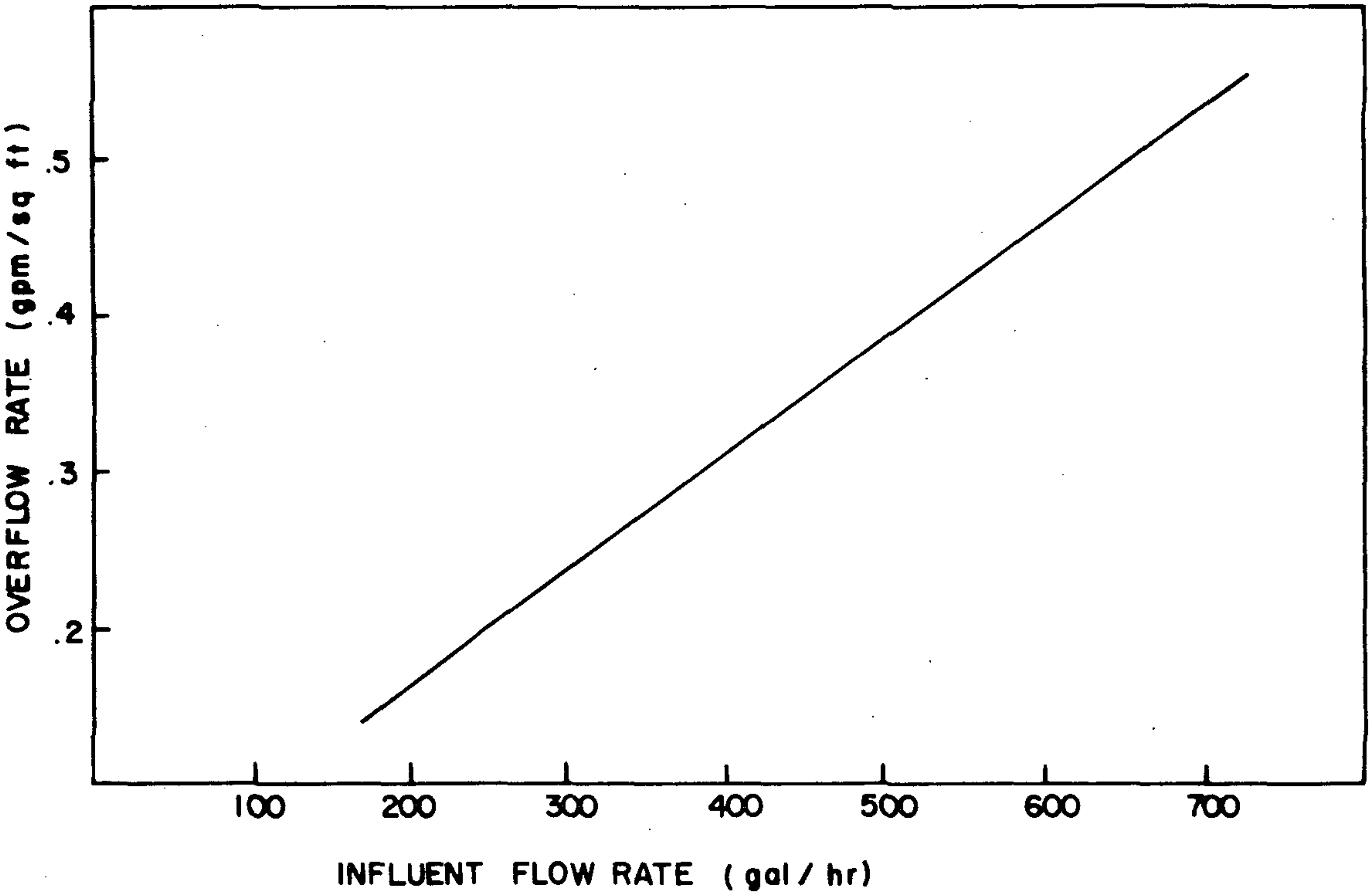

Figure 3. Overflow Rate of the Settling Zone Versus Influent Flow Rate.

"Lightnin" portable mixer manufactured by the Mixing Equipment Company, Incorporated of Rochester, New York.

Operating Procedure

For testing purposes, operation at a wide range of flowrates was desired. Preliminary testing indicated that the range from 380 to 760 gallons per hour (gph) would be suitable for study. Flowrate variation was achieved intially by an orifice and valve adjustment and later by a V-notch weir box. Through these procedures steady state flowrates of 380 gph, 550 gph, and 760 gph were attained. These flowrates correspond to surface overflow rates of 0.29, 0.42, and 0.59 gallons per minute per square foot (gpm/sq ft), respectively. Higher overflow rates are normally used in practice, but pilot settling units are always less efficient than their full-scale counterports.

To test the effect hydraulic shock loadings, flowrate step functions were imposed by abruptly changing the flowrate from 380 gph to 530 gph and from 380 gph to 730 gph. Each step function began at 11:30 a.m. and the unit was returned to the original flowrate at 5:30 p.m. This type of step was chosen because it was similar to diurnal flow variations, and provided four and one-half hours of operating data in the morning prior to the flow increase.

The chemical feed pump was adjusted to deliver the appropriate flow for the influent flowrate and a lime dose of 350 mg/l as $Ca(OH)_2$.

This dose was found to raise the pH of the feed water above 11. Selection of 350 mg/l was based on jar tests which indicated that pH values greater than 11 were necessary to obtain a good settling floc in the low-alkalinity Amherst wastewater. This finding substantiates results reported by others (1,3,6) and discussed previously.

Lime was purchased in 50 lb bags. The contents of each bag was weighed and an appropriate amount of water added. Slurry concentration was maintained at 138.4 mg/l $Ca(OH)_2$ and any desired changes in the lime dose made by changing the speed of the chemical pump. The concentration of 138.4 mg/l was selected somewhat arbitrarily as one which was compatible with the pump capacity and anticipated lime dosages.

Lime and water were added each day to maintain the slurry height as nearly constant as possible since it was found that the chemical pump delivery varied somewhat with height in the slurry tank. The slurry was completely discarded and replaced between runs to minimize the effects of evaporation on the slurry concentration.

Sludge was wasted from the clarifier once each day by operating the sludge run-down valve. It was necessary to waste sludge in this manner for about five minutes each day. At the lowest flow rates sludge was wasted every other day. Height of the sludge blanket was not a reliable indicator of the necessity to waste sludge since the height remained nearly constant regardless of sludge build-up or wastage. Sludge was wasted when floc began to carryover into the storage zone.

Between runs the influent was shut off and accumulated floc was cleared from the collector. The storage chamber was completely drained and settled sludge, which in some cases was considerable, was flushed out. The mixing-coagulation zone and settline zone were not completely drained in order to prevent loss of the sludge blanket, which took several days to develop.

Sampling Procedure

Originally, it was hoped to run analyses on a daily composited sample. After the compositing system proved unsuccessful, a periodic grab sampling technique was substituted. Grab samples were taken from 6:00 a.m. to 6:00 p.m. on an hourly basis and analyzed immediately. After several days it was observed that there was little or no variation between the 6:00 a.m. and 7:00 a.m. samples. Because the method used for phosphate determination took 45 minutes and transit time from laboratory to pilot plant and back was greater than 15 minutes, the schedule was modified to run from 7:00 a.m. to 5:30 p.m. with samples taken each 90 minutes. Lime slurry height was measured at 7:00 a.m. and again at 5:30 and flowrate checked by bucket and stopwatch each 90 minutes. Actual lime dose was calculated for the day using these figures.

Total Organic Carbon (TOC), total unfiltered phosphorus, alkalinity, and pH were measured routinely. Sludge concentration was checked a minimum of once each day using a sludge sampler and taking the sludge sample from the middle of the blanket.

Analytic Techniques

Total Organic Carbon. TOC was determined on a Beckman Model 915 A organic carbon analyser using 20 micro-liter samples and an appropriate calibration curve. All samples analysed were unfiltered. Analysis was performed within 20 minutes of collection.

Phosphorus. Phosphorus was determined using the single reagent method of the Federal Water Pollution Control Administration (6). Total phosphorus was measured by the persulfate digestion procedure. Since the range of this test is .01 mg/l to .5 mg/l as P, dilutions of 25:1 were necessary for influent samples and of 10:1 for effluent samples. A Bausch and Lomb Spectronic 20 spectrophotometer was used at 880 mμ for color measurements.

Glassware used throughout the test was initially acid washed with hot HCL. This glassware was used strictly for phosphorus determinations during the testing period.

Alkalinity. Alkalinity was determined by titration with .02 N H_2SO_4 in accordance with Standard Methods 13th edition (11). The indicator used was methyl orange. Results were expressed in terms of equivalent $CaCO_3$.

pH. Determinations of pH were made by glass electrode and meter in accordance with Standard Methods 13th edition (11).

Sludge Concentration. Suspended solids in the sludge blanket filter were determined in accordance with Standard Methods 13th edition (11). Sample size used was 10 ml.

RESULTS AND DISCUSSION

Effect of Overflow Rate Variations

Operating data for the pilot plant upflow clarifier was reasonably consistent from day to day. Variations in the influent parameters can be attributed to normal fluctuations and to weather conditions. The percentage occurrence of various concentrations of TOC and phosphorus in the process influent and effluent are shown in Figures 4 through 9. These figures are plotted for the three overflow rates tested of 0.59, 0.42, and 0.29 gpm/sq ft. Data points were derived by averaging samples taken from 7:00 a.m. to 5:30 p.m. at 90 minute intervals for each day of operation at a particular overflow rate. The effect of overflow rate on chemical clarifier performance was examined by comparing removals of phosphorus and TOC at 80% occurrence values as shown in Table 1.

From Table 1 it can be seen that effluent quality increased as overflow rate decreased. Effluent phosphorus concentration decreased markedly in the step from .59 gpm/ sq ft to .42 gpm/sq ft and to a lesser degree from .42 gpm/sq ft to .29 gpm/sq ft. Effluent TOC decrease was approximately equal in both steps.

Percentage removal is sometimes used as a performance indicator. Efficiencies of removal expressed as a percentage are illustrated in Figure 10. In compiling the data for this figure, non-representative

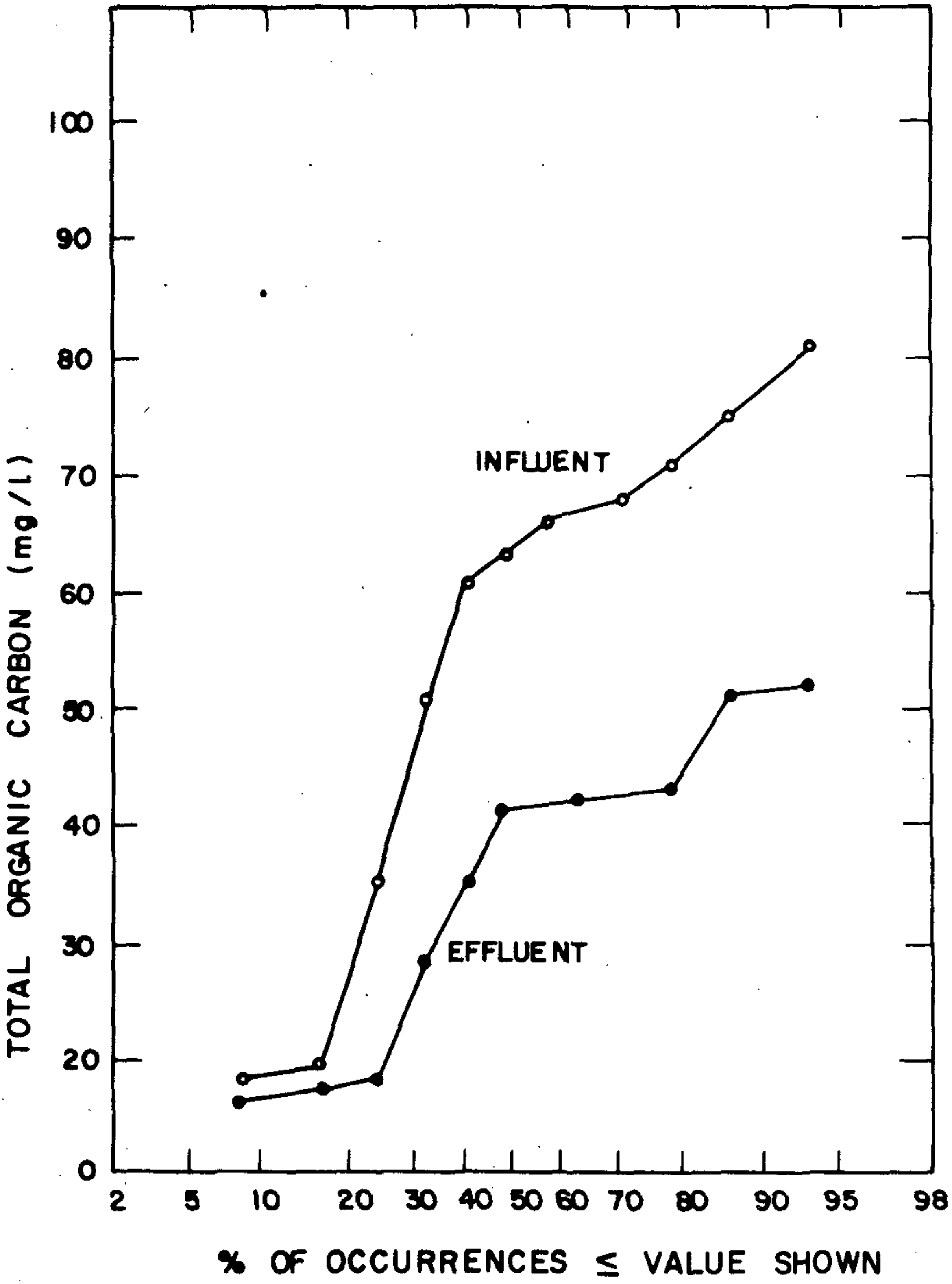

Figure 4. Influent and Effluent TOC Concentration at 0.59 gpm/sq ft Overflow Rate.

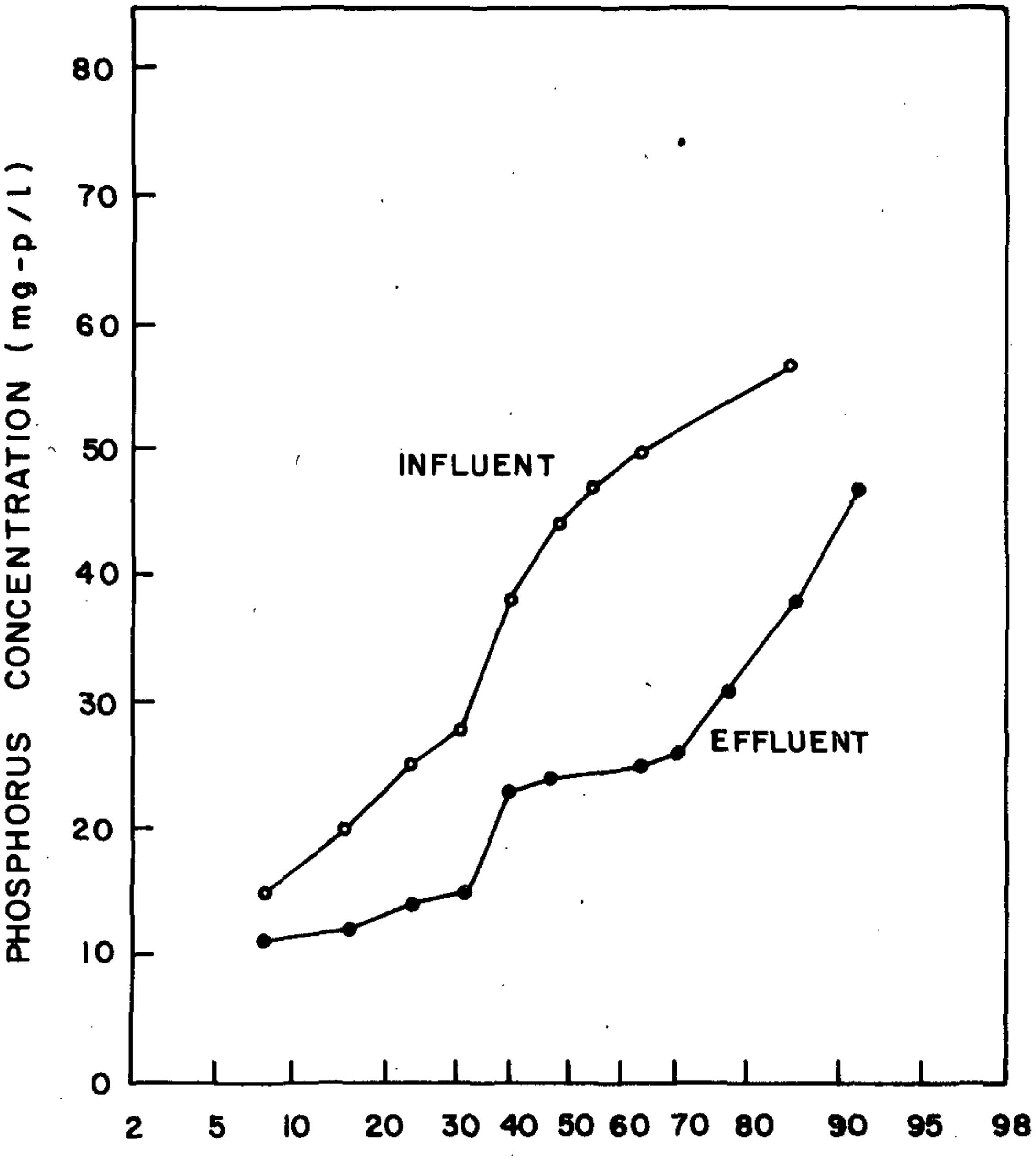

Figure 5. Influent and Effluent Phosphorus Concentration at 0.59 gpm/sq ft Overflow Rate.

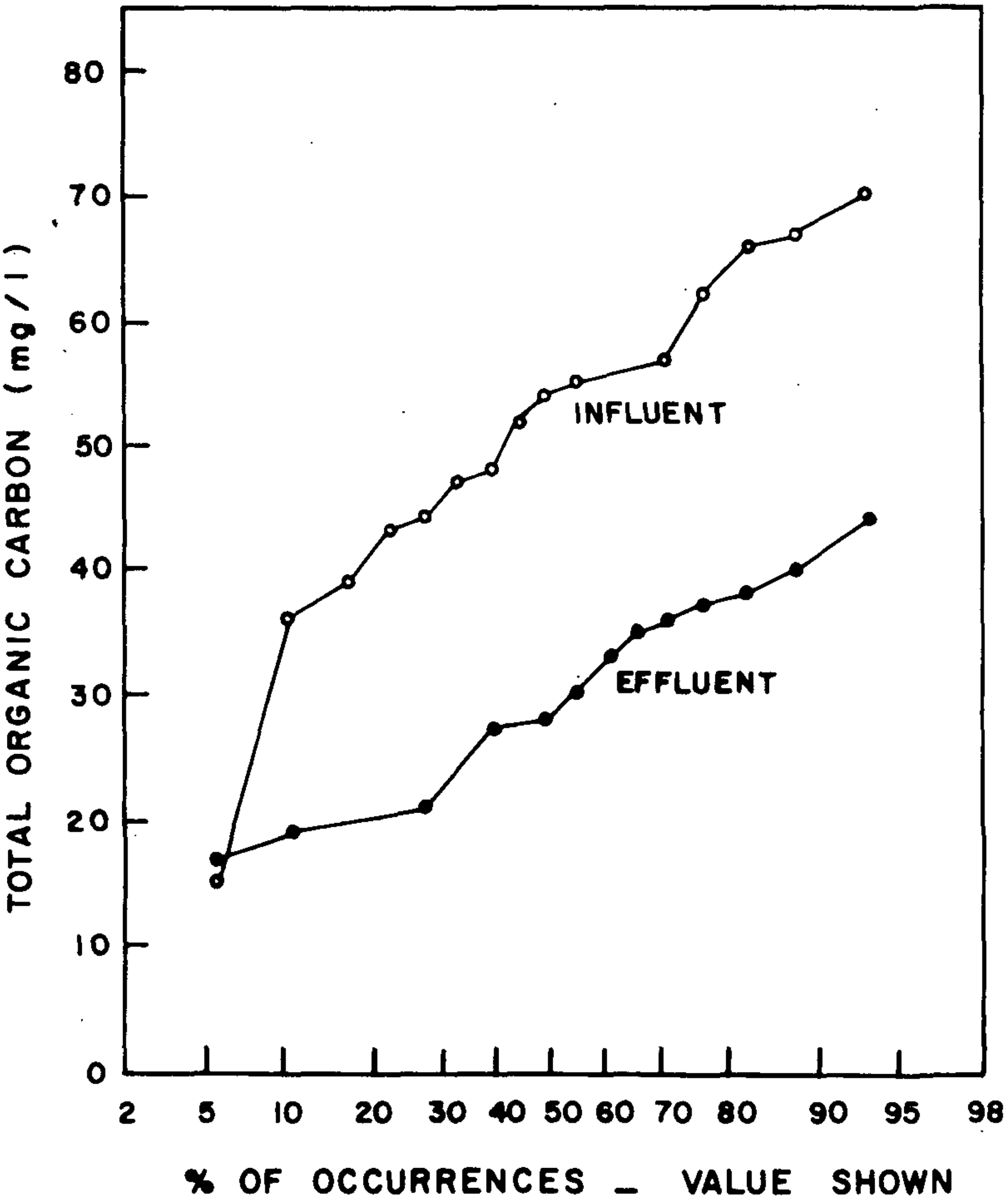

Figure 6. Influent and Effluent TOC Concentration at 0.45 gpm/sq ft Overflow Rate.

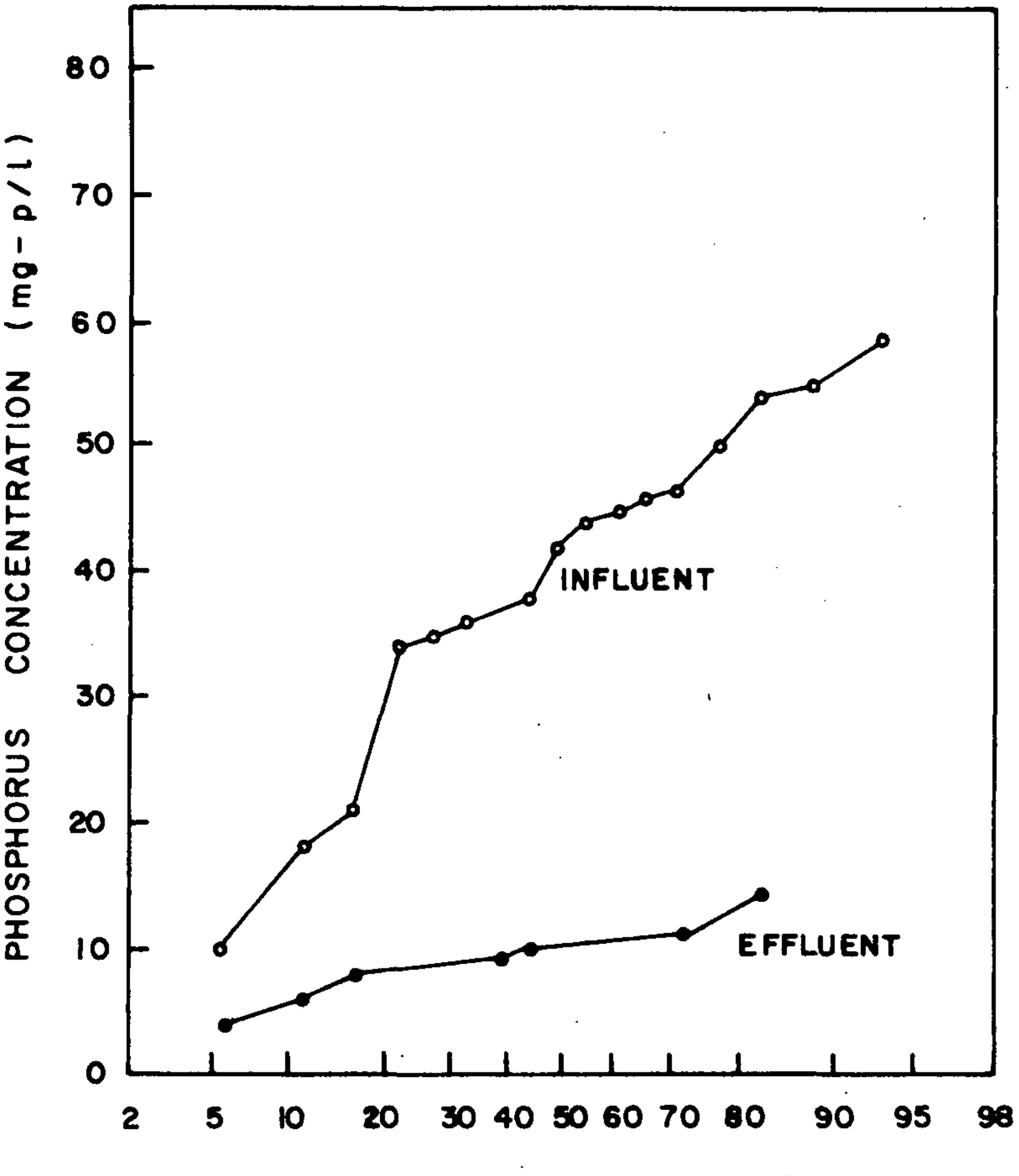

Figure 7. Influent and Effluent Phosphorus Concentration at 0.42 gpm/sq ft Overflow Rate.

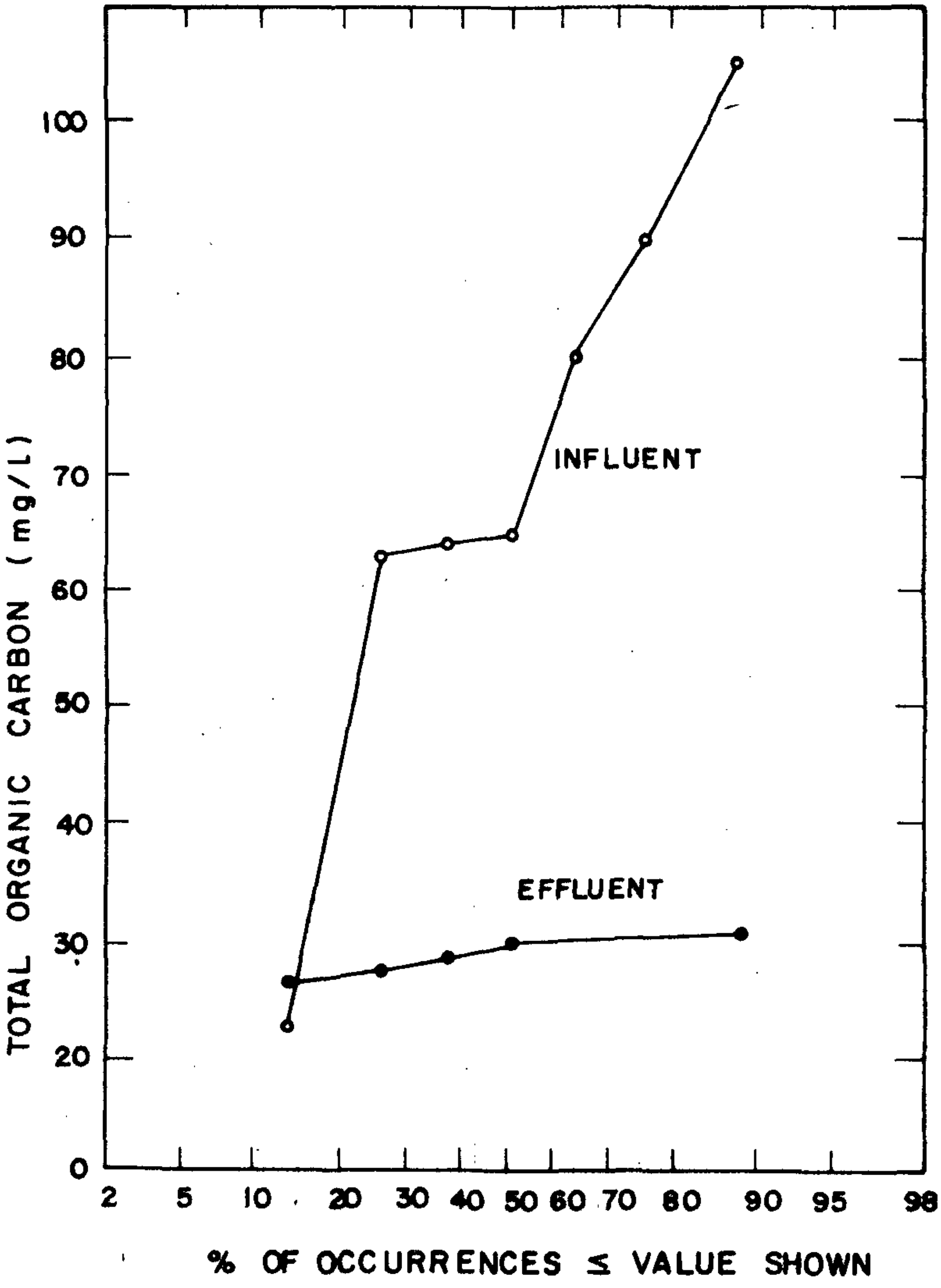

Figure 8. Influent and Effluent TOC Concentration at 0.29 gpm/sq ft Overflow Rate.

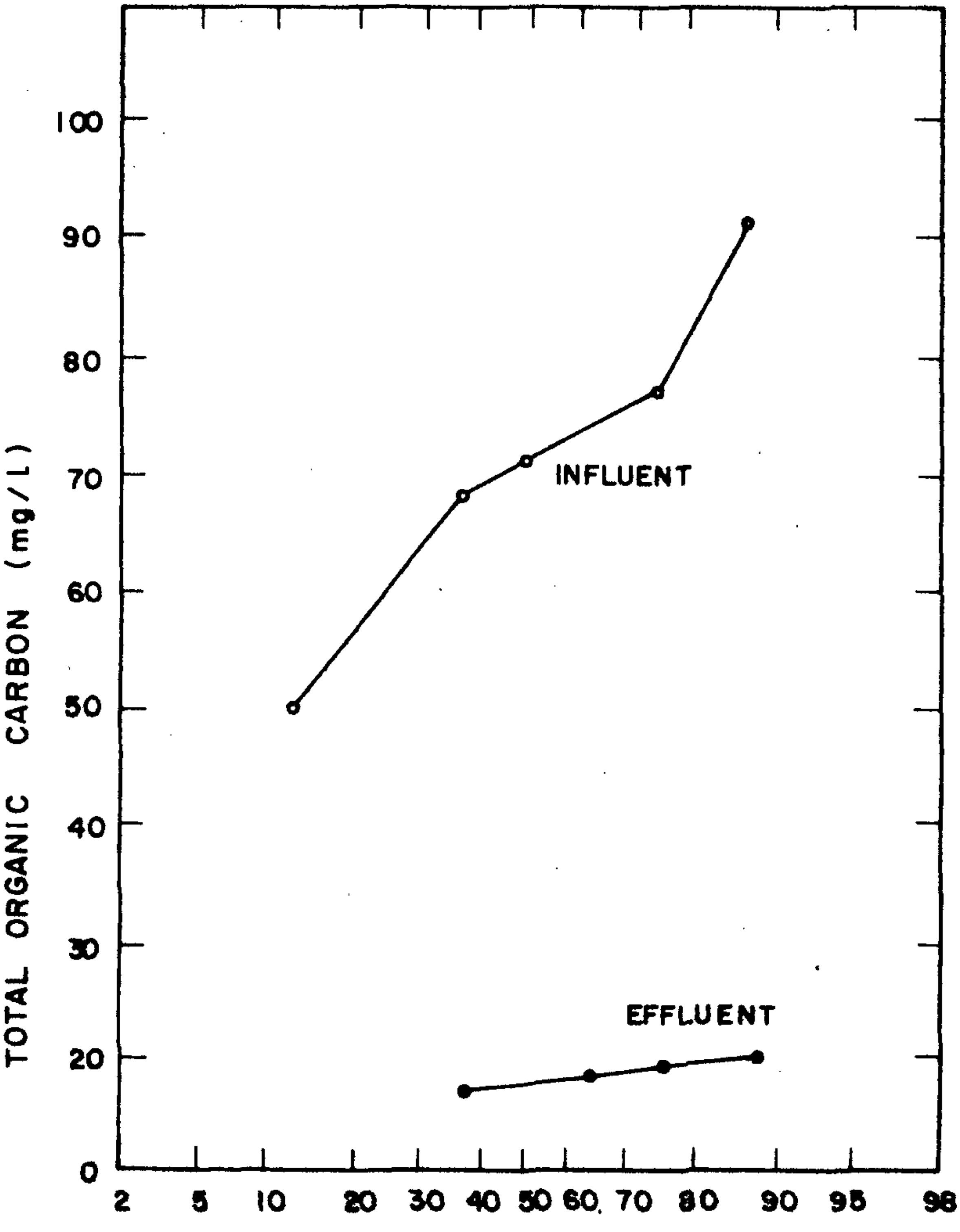

Figure 9. Influent and Effluent Phosphorus Concentration at 0.29 gpm/sq ft Overflow Rate.

TABLE I

Influent and Effluent Concentrations at 80% Occurrence for Given Overflow Rates

Overflow Rate (gpm/sq ft)	P (mg/l)		TOC (mg/l)	
	Influent	Effluent	Influent	Effluent
.59	5.5	3.2	73	46
.42	5.2	1.03	64	38
.29	7.2	.90	95	31

data points were discarded. For example, when a septic tank pumping truck dumped its load into the Amherst Sewage Treatment Plant from which the pilot plant draws its influent, an unusually high strength waste was encountered. This led to a temporary increase in TOC concentration of as much as 700 percent.

Inspection of Figure 10 reveals that percentage removal of TOC and phosphorus increased as overflow rates decreased. In the case of phosphorus, the removal approaches 100 percent asymptotically as overflow rate decreases, which seems reasonable. On the other hand, Figure 10 suggests that TOC removal approaches a minimum of around 30 percent regardless of overflow rate; however, additional data is needed to more fully ascertain the shape of this curve. An additional consideration is that percent removal is not an entirely satisfactory indicator of performance. That is, a given percent removal does not necessarily mean that a satisfactory effluent quality will be achieved. Also, variations in influent concentrations can make the percent removal fluctuate even though the actual effluent concentration may remain constant. In view of these factors it is not justified to draw any conclusions from Figure 10 other than that effluent quality at .29 gpm/sq ft is superior to that at higher overflow rates.

Table 2 presents a summarized tabulation of data for the three overflow rates studied. These results are in accordance with other studies (e.g. (3)). It is to be noted however, that previous

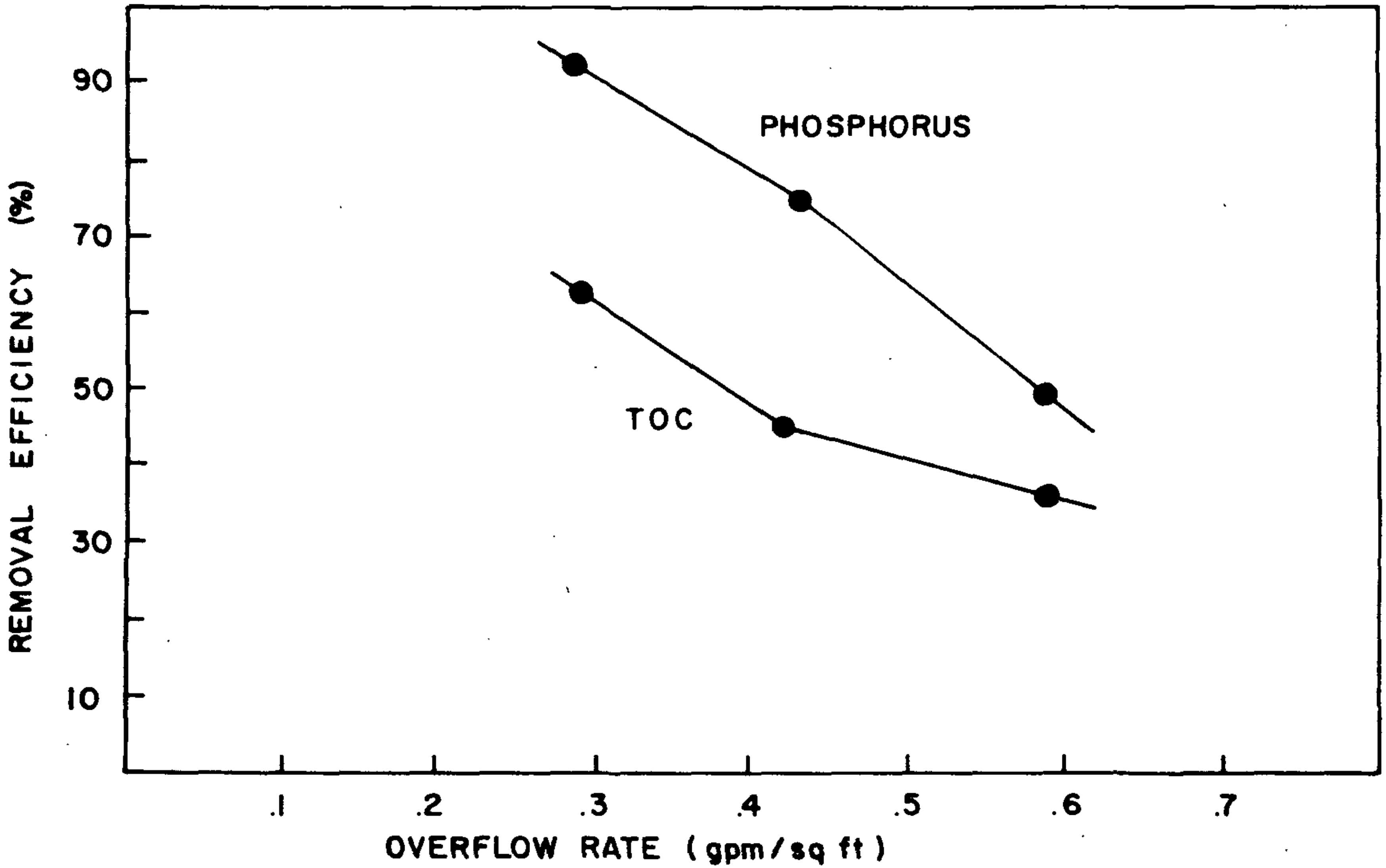

Figure 10. Percentage Removal of Phosphorus and TOC as a Function of Clarifier Overflow Rate.

TABLE II

Summary Tabulation of Data for Three Constant Flow Rates

	Run					
Operating Conditions	I		II		III	
Flow (gph)	760		550		380	
Overflow Rate (gpm/sq ft)	.59		.42		.29	
Length of run (days)	3		4		3	
Lime dosage (mg/l $Ca(OH)_2$)	353		352		354	
Total Detention Time	2.07		2.86		4.14	
Process Results	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Total Phosphorus mg/l as P	4.8	2.5	4.2	1.0	7.1	.8
TOC mg/l	57	37	54	31	76	29
pH units	6.8	11.0	7.3	11.2	6.9	11.3
Alkalinity mg/l as $CaCO_3$	86	346	87	292	93	376

investigations utilized high alkalinity wastewater. The high operating pH necessary to obtain adequate removal efficiency means that two-stage lime treatment (with intermediate recarbonation) would be necessary in Amherst.

Table 2 shows that the effluent TOC and phosphorus concentration decreased as the overflow rate decreased. Improved TOC and phosphorus removals are attributed to the entrapment of particles with lower settling velocity which escaped at higher flowrates. This entrapment also appeared to cause the sludge blanket concentration to increase. Accurate determinations of sludge production and concentration were not included as part of this study.

Effect of Waste Strength Shock Loads

Figures 11 and 12 illustrate response of the clarifier to organic and phosphorus shock loads at an overflow rate of .29 gpm/sq ft. The shock was induced by a septic tank pumping truck dumping into the Amherst Sewage Treatment Plant. Little or no effect on the effluent quality was noted. A similar occurrence in a biological treatment facility could cause serious upsets and consequent decreases in effluent quality.

Effect of Hydraulic Shock Loads

To test the effects of hydraulic shock loads, step increases of flowrates from 380 to 730 gph and from 380 to 530 gph were applied to the clarifier. Averaged data generated during this phase of the

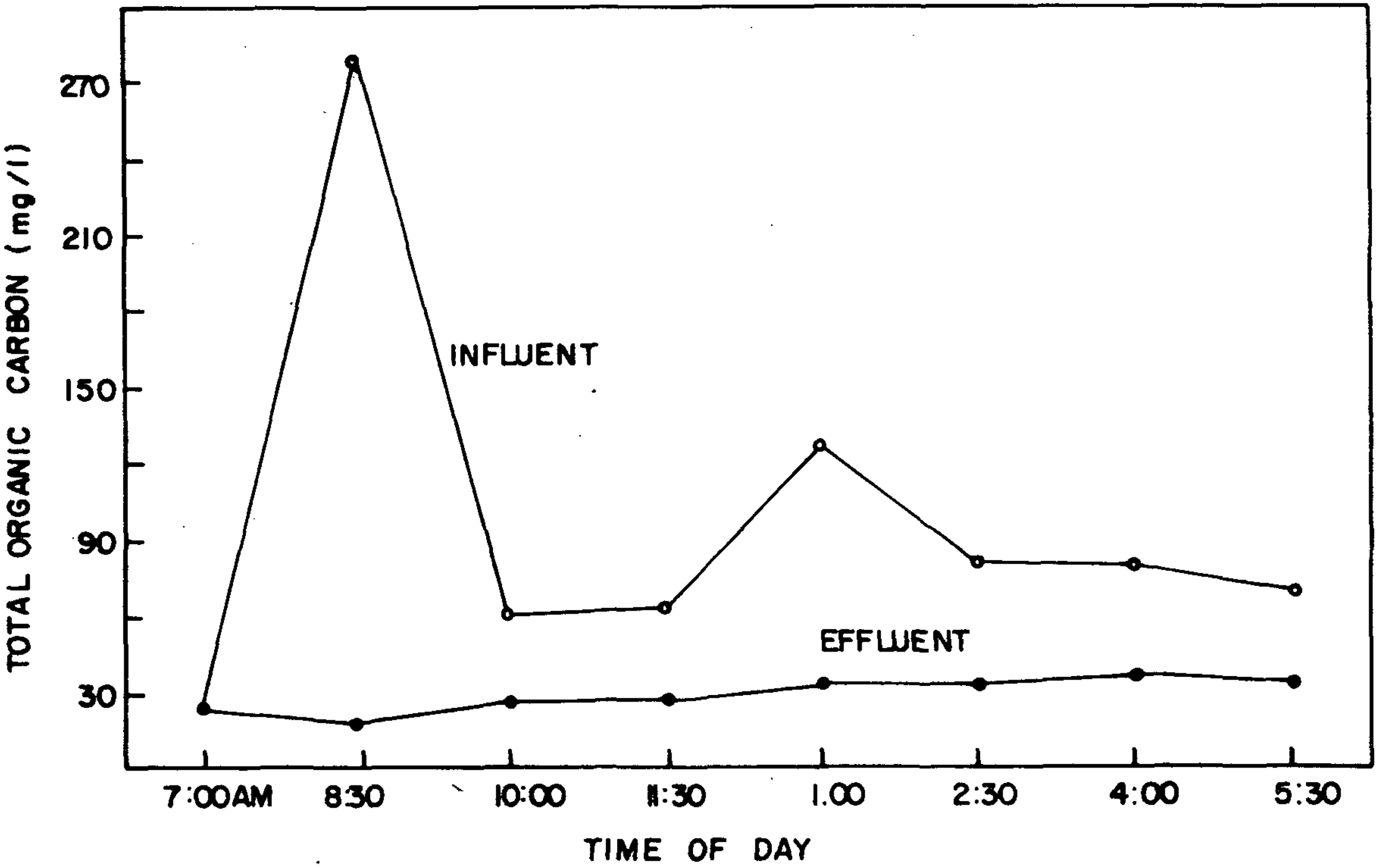

Figure 11. Response of Clarifier to Organic Shock Load at 0.29 gpm/sq ft Overflow Rate.

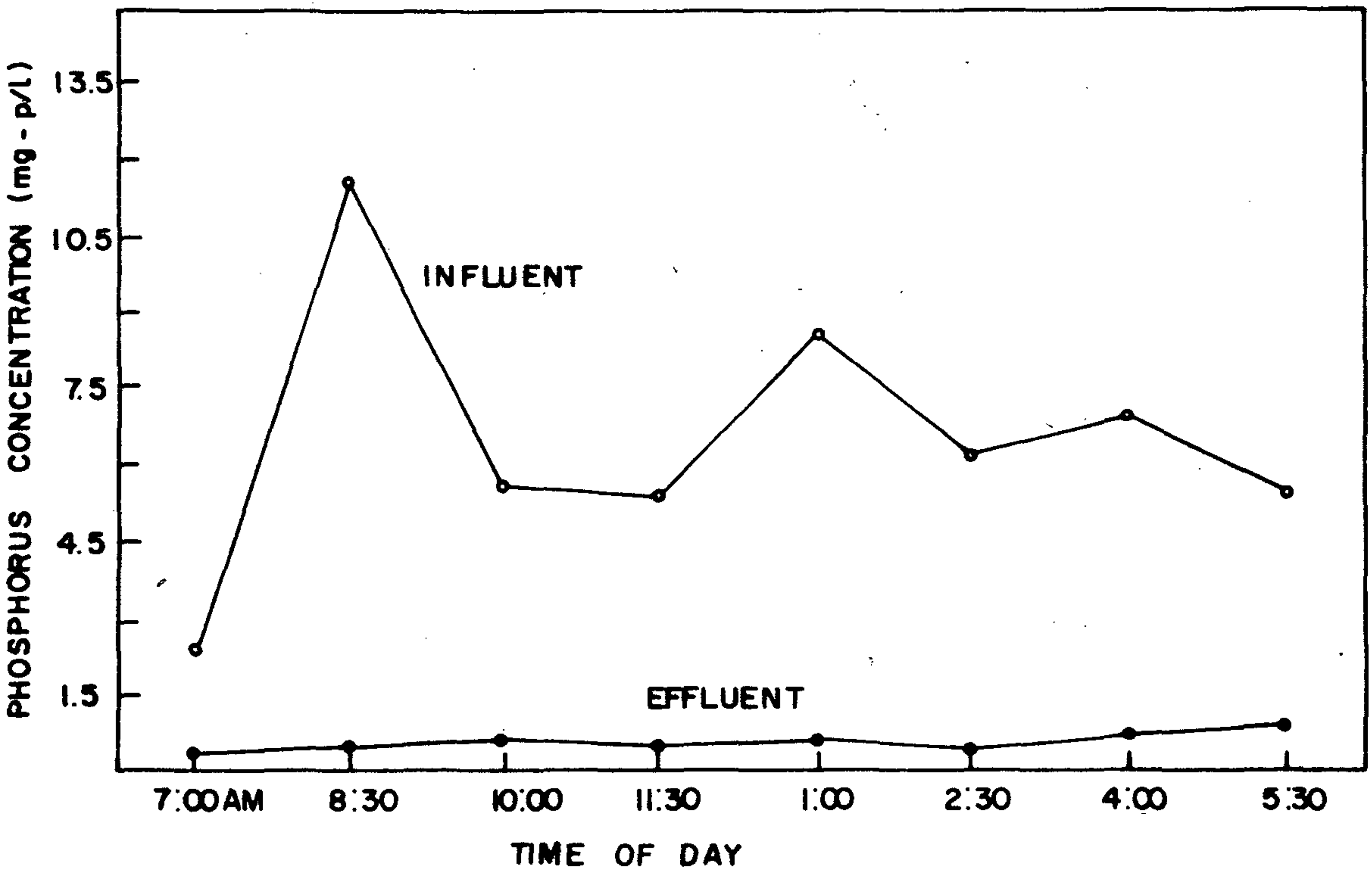

Figure 12. Response of Clarifier to Phosphorus Shock Load at 0.29 gpm/sq ft Overflow Rate.

testing is shown in Tables 4 and 5. Flowrates were increased at 11:30 a.m. and maintained at the higher rates until 5:30 p.m. at which time the unit was restored to the original flowrate. This procedure was intended to simulate diurnal flow fluctations, although the time-change in flowrate was obviously much more extreme than under natural conditions. Response was recorded each 90 minutes as before.

As can be seen in Figures 13 to 16, the effluent TOC and phosphorus concentrations increased rapidly during the first 1 1/2 hours after the flowrate increase. This is attributed to the fact that large quantities of floc were carried over initially in the effluent by the increased flow. The effluent TOC concentration resulting from the step of 380 gph to 730 gph leveled at around 60 mg/l in six hours. However, during steady state operation at the same flowrate (see Figures 4 and 5), the TOC was less than 52 mg/l on 90 percent of the recorded occurrences. Similarly, the effluent phosphorus concentration decreased to 11.5 mg/l while steady state operation under similar conditions yielded concentrations less than 4.5 mg/l on 90 percent of the recorded occurrences. The increases are attributed to disruption of the sludge blanket filter with consequent heavy carryover of floc.

Response of the clarifier to a shock load of 380 gph to 530 gph was more satisfactory. However, the effluent parameters observed in the shock-loaded unit still exceeded the average steady state values recorded previously at a similar flowrate (see Figures 6 and 7).

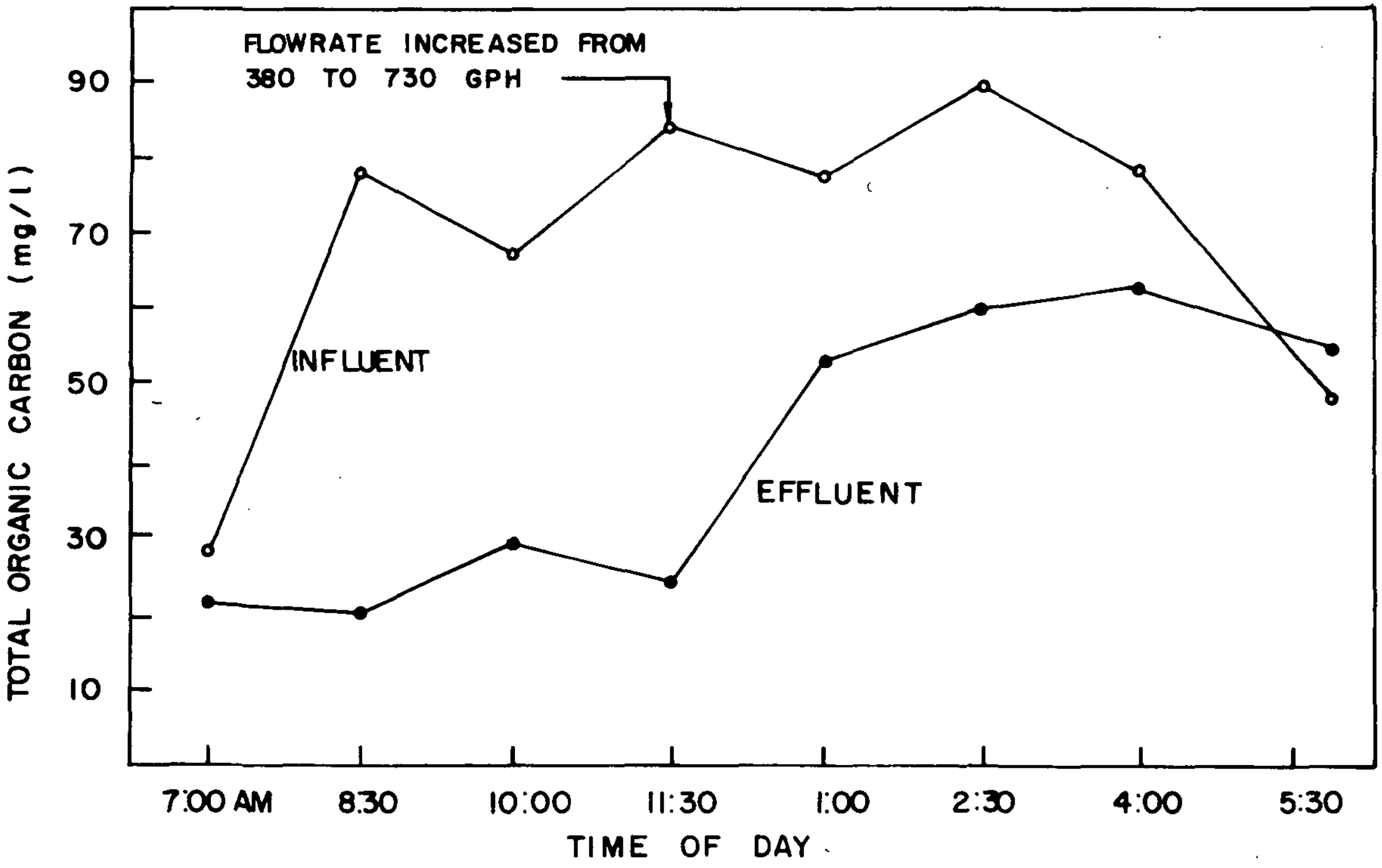

Figure 13. Response of Effluent TOC to Step Increase in Flowrate.

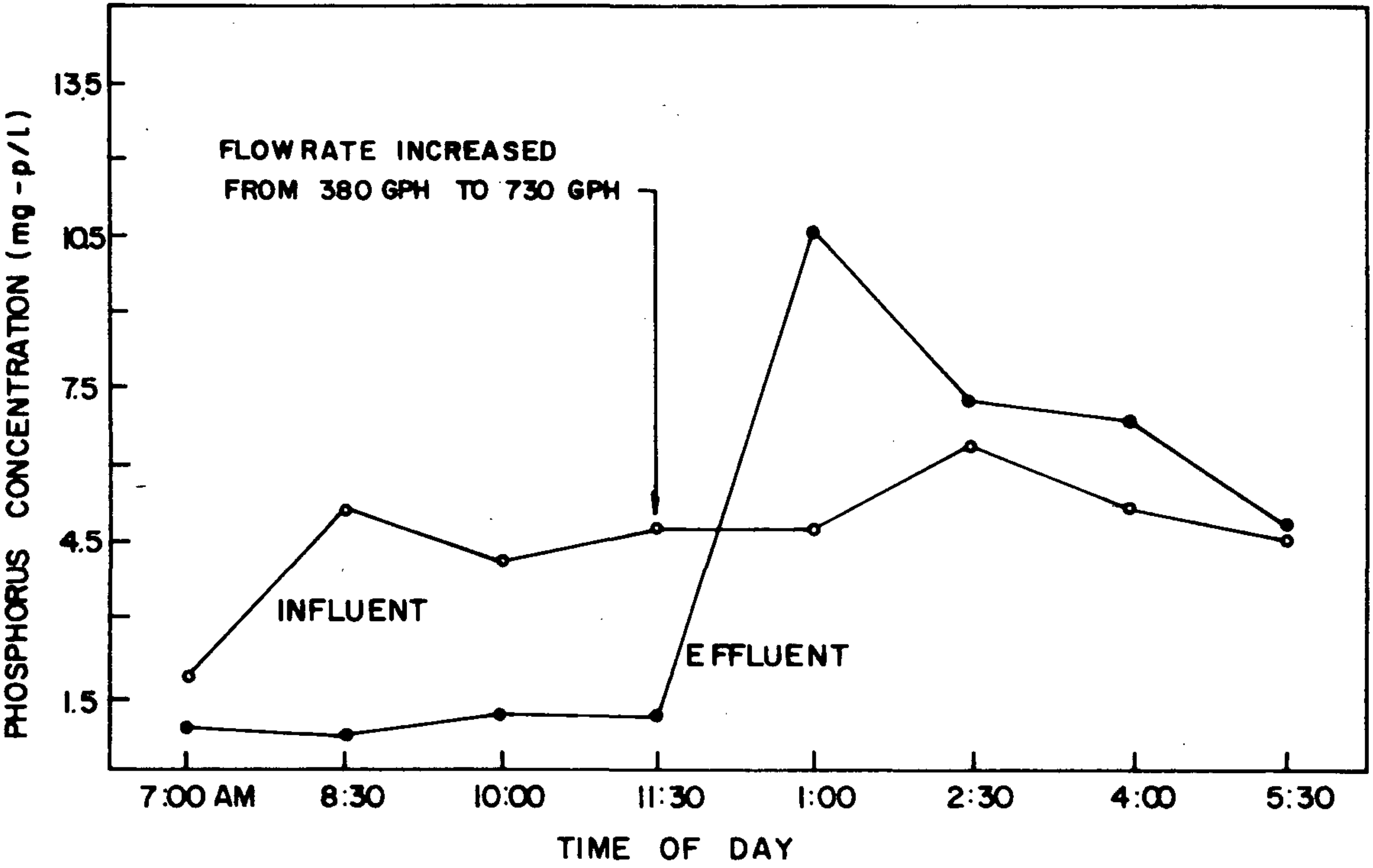

Figure 14. Response of Effluent Phosphorus Concentration to Step Increase in Flowrate.

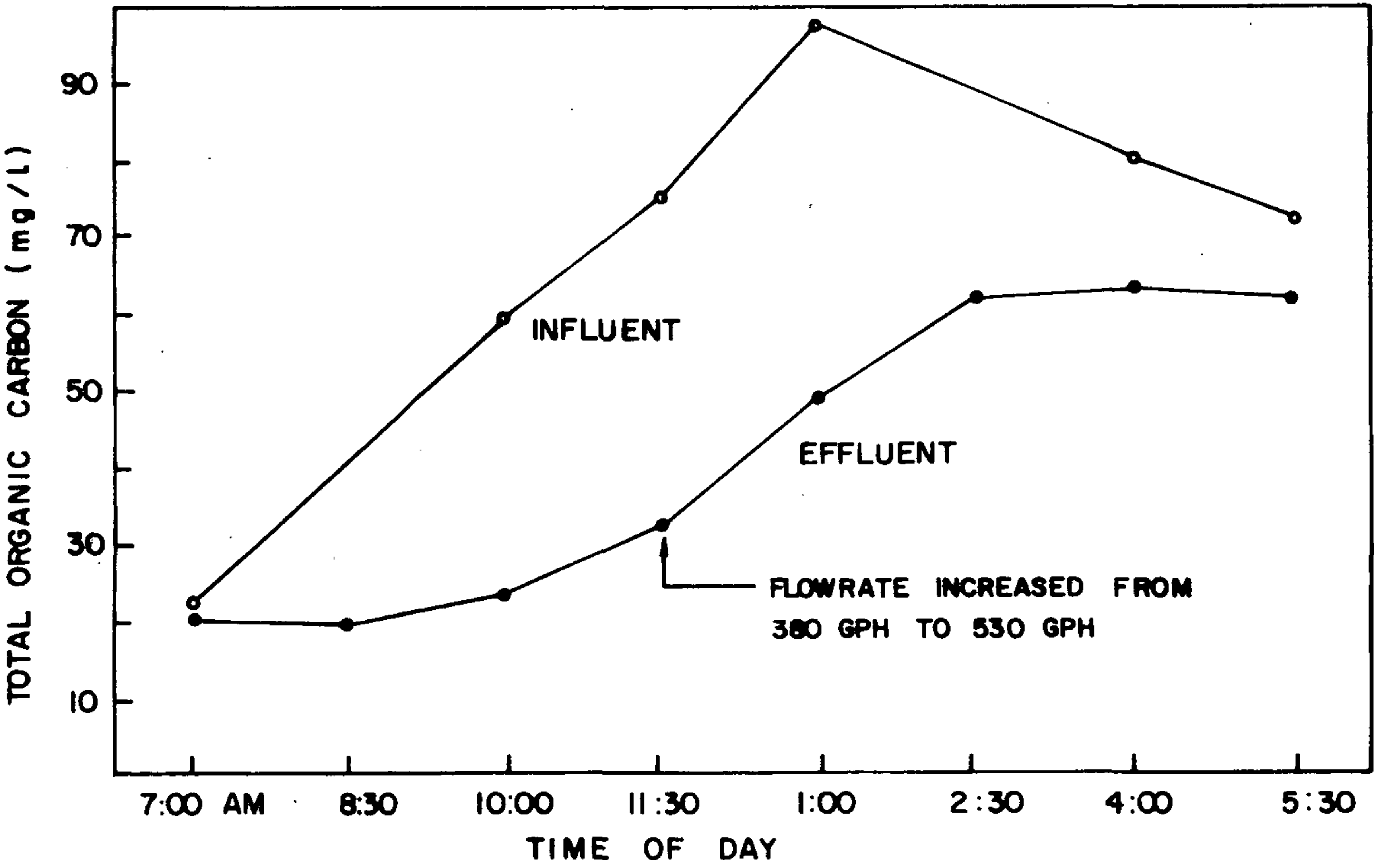

Figure 15. Response of Effluent TOC to Step Increase in Flowrate.

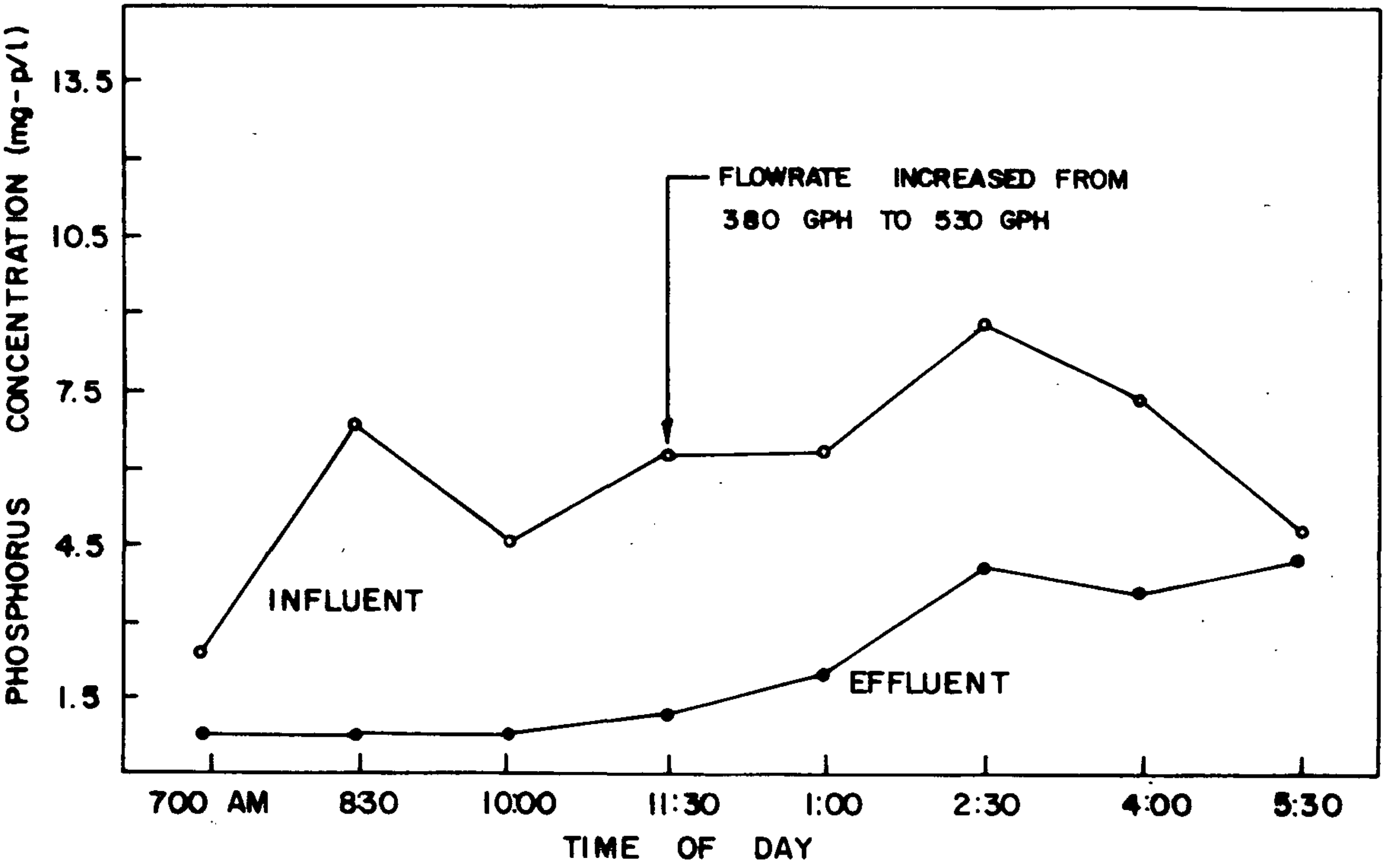

Figure 16. Response of Effluent Phosphorus Concentration to Step Increase in Flowrate.

Shock loaded, the clarifier effluent TOC increased to about 63 mg/l while at a steady flowrate of 550 gph, the effluent TOC was less than 44 mg/l for 90 percent of recorded occurrences. Likewise, the effluent phosphorus concentration in the shock loaded unit increased to about 4.0 mg/l while the steady state concentration for a similar flowrate of 560 gph was never higher than 1.4 mg/l for 90 percent of recorded occurrences.

Comparing the two shock loads applied, it can be noted that TOC response to the larger flowrate step (from 380 to 730 gph) was less severe than the smaller step (380-530 gph), when compared with steady state data. Effluent phosphorus response, however, was quite severe in both cases. Effluent phosphorus concentration after shock loading did decrease rapidly in the case of the 380 to 730 gph step. This was the only case in which a condition induced by shock loading showed indications of returning to normal. Further testing would be necessary to determine the cause of this isolated case.

Response to Start-Up

Figure 17 shows clarifier response to TOC and phosphorus loadings following start-up for a typical run. Effluent TOC decreased rapidly for three hours and was approximately constant thereafter. Effluent phosphorus concentration continued to decrease for eight hours. This observation indicates that if shutdown should

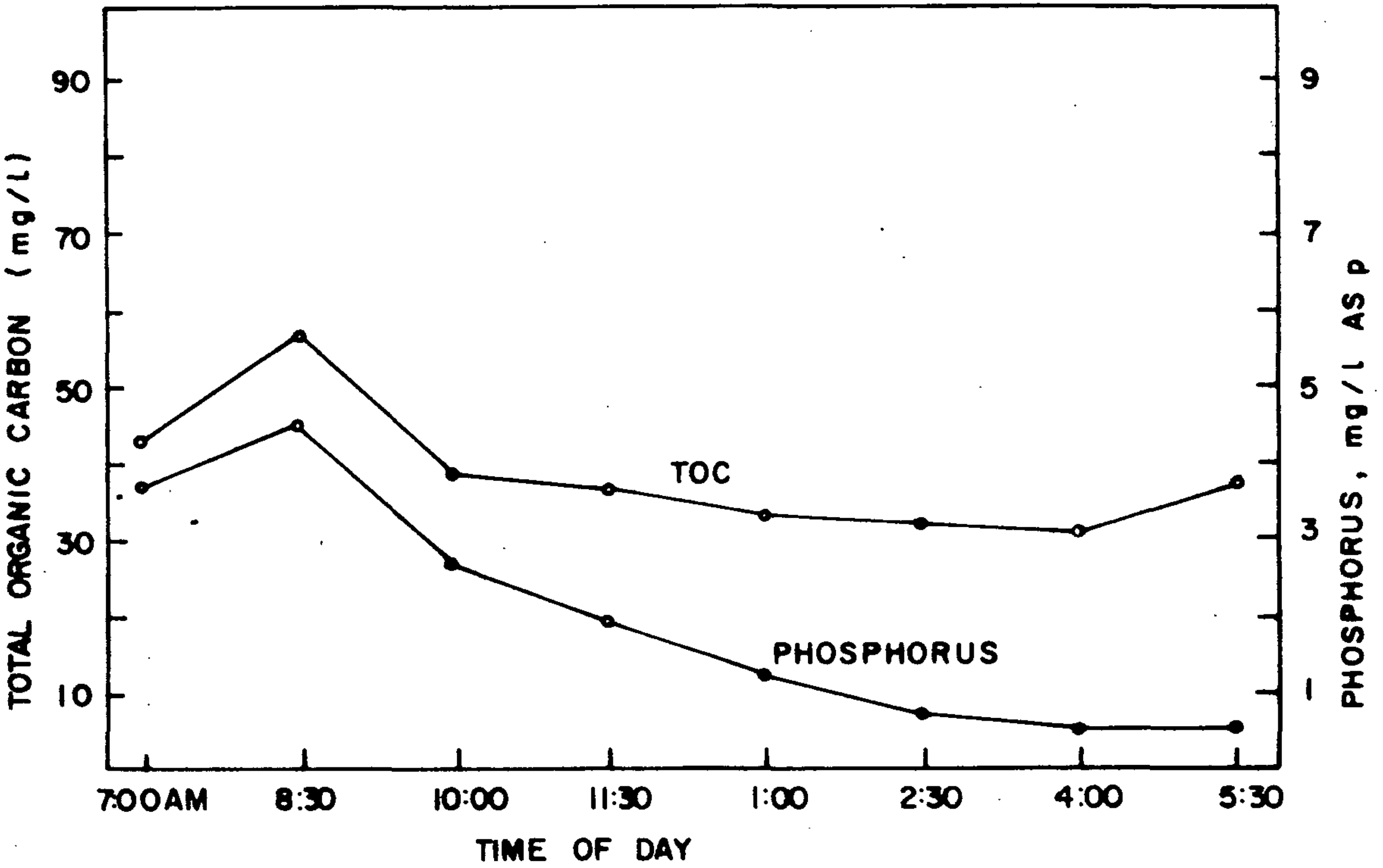

Figure 17. Effluent, TOC and Phosphorus Concentrations Following Unit Start-Up at 7:00 A.M.; Overflow Rate = 0.29 gpm/sq ft.

TABLE 4

Summary Tabulation of Data for Flowrate Step Function of 380 to 730 gph

Operating Conditions				
Flow gph	380 to 730			
Overflow Rate gpm/sq ft	.29 to .56			
Length of run (days)	2			
Lime dosage (as $Ca(OH)_2$) mg/l	350			
	(380 gph)		(730 gph)	
Process Results	Inf.	Eff.	Inf.	Eff.
Total Phosphorus mg/l as P	3.8	.9	5.4	6.5
TOC mg/l	60	25	55	63
pH units	6.9	11.3	7.0	11.3

TABLE 5

Summary Tabulation of Data for Flowrate Step Function of 380 to 530 gph

Operating Conditions				
Flow gph	380 to 530			
Overflow Rate gpm/sq ft	.29 to .40			
Length of Run (days)	1			
Lime Dosage (As $Ca(OH)_2$) mg/l	350			
	(380 gph)		(530 gph)	
Process Results	*Inf.*	Eff.	*Inf.*	Eff.
Total Phosphorus mg/l as P	5.0	.7	6.7	3.4
TOC mg/l	52	27	94	59
pH units	7.0	11.4	7.1	11.4
Alkalinity mg/l as $CaCO_3$	87	370	81	316

be necessary steady state operation after start-up could be achieved in a relatively short time if the sludge blanket has already been developed.

EXPERIMENTAL PROBLEMS

The following problems were encountered:

1. The lime mixing and feed system functioned well but mixing the lime slurry was a time consuming and unpleasant task. Although the slurry concentration was relatively low (138.4 g/l), the suction clogged occasionally.

2. Influent raw water flowrate regulation was difficult. Originally, orifices were used but they were prone to clog. A small constant head V-notch weir box was eventually installed and proved satisfactory.

3. On several occasions the influent line clogged at a point where it was reduced in diameter from 1 1/2" to 1" pipe. When this happened it was necessary to break the union at the reducer and clear the line manually.

4. Considerable floc carryover was encountered from time to time. This was not always a result of increased flowrates. For instance, it was noted that windy days had some effect on the sludge blanket filter zone and increased the amount of floc carryover.

5. The height of the sludge blanket was not easily regulated. It appeared to find its own height and was unresponsive to sludge wasting or other attempts to adjust it. This made wasting sludge a rather arbitrary procedure based on an estimate of the amount of sludge buildup.

6. Considerable sludge buildup was found in the clearwell. There is a drain valve for this compartment but clearing the sludge out proved difficult. The sludge is gelatinous in nature and does not move well even when a garden hose spray is directed on it.

7. Water evaporated in significant quantities from the slurry. In one-two week period the slurry concentration increased from 138.4 g/l to about 155 g/l. Much of this increase is attributed to evaporation.

CONCLUSIONS

The following conclusions regarding phosphorus and TOC removals can be drawn from this study:

1. The pilot upflow clarifier with lime coagulant proved satisfactory as a wastewater treatment process, providing effluent phosphorus and TOC concentrations of 0.8 mg/l and 29 mg/l, respectively, at the lowest flowrate tested.

2. An effective overflow rate for this particular upflow clarifier is .29 gpm/sq ft.

3. The pilot upflow clarifier is relatively stable when subjected to shock loads in organic concentration and phosphorus.

4. The pilot upflow clarifier is relatively unstable when subjected to hydraulic shock loads. Thus, the unit is impractical for treatment of wastes with diurnal flow variations unless flow equalization is employed.

5. The pilot upflow clarifier reaches steady state operation within eight hours, provided that there is a sufficient quantity of sludge blanket initially present.

6. The relatively high pH necessary to achieve good floc settleability in these experiments means that two-stage lime treatment with intermediate recarbonation is probably necessary to treat low alkalinity wastewaters as found in Amherst or in other regions of Massachusetts.

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