PILOT PLANT STUDIES ON THE EFFECT OF HYDRAULIC SHOCK LOADS ON THE EXTENDED AERATION ACTIVATED SLUDGE TREATMENT PROCESS

by

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INTRODUCTION

In recent years, there have been two trends of particular interest to those concerned with the design and construction of sewage treatment plants. One trend has been that of increasing suburbanization and development of rural areas for recreation and domestic purposes. The other trend, sometimes in conflict with the first, has been a general increase in the number, scope, and stringency of state, regional, and federal stream quality and wastewater effluent quality standards brought on by an increased awareness of the possibility of further degradation of the nation's water resources. As a result of present requirements, and the probability of more restrictive laws yet to come, many rural communities, isolated motels, factories, schools, recreation areas, and so forth, have been forced to seek improved methods for handling their wastewater flows.

One solution that has been used with increasing frequency and that is well suited to the task is the extended aeration activated sludge package plant. The extended aeration activated sludge treatment system is a biological system utilizing an active, viable microbial mass for the oxidation of organic waste, and will be described further in the literature review. A package plant is one that is mass produced in component sections and can be erected on-site for a variety of flow rate ranges. The combination of these ideas has resulted in a system usually requiring a lower initial investment and lower maintenance costs than those of conventionally designed and constructed treatment facilities, a distinct advantage for a small sewerage district.

The extended aeration system has been in use in the United States since 1947 (1), and in the United Kingdom since 1961 (2). Usage had increased in the United States from three plants by 1950 to over 2,600 by 1962 (3). A major objection to the process has been a tendency to discharge excess suspended solids concentrations in the effluent (1, 2, 3, 4, 5, 6). These solids losses have been attributed to:

1. Storm drainage flush-out or wastewater flow variations (1, 2, 3, 5, 6),
2. Excessive or non-flocculent solids (1, 5),
3. Denitrified floating solids buoyed by nitrogen gas (1, 3, 5),
4. Variations in the zone settling rates at various mixed liquor suspended solids concentrations (2), and
5. High sludge ages (2).

Due to these solids losses, Nicoll (2) reports that effluent polishing is commonly adopted in Great Britain as a means of ensuring adequate wastewater effluent standards.

Common reasons given by Morris (3) for the wastewater flow, or hydraulic, variations are the:

1. Variation of activity in the facility served,
2. Entrance of stormwater into the sewers, and
3. Use of constant-speed raw-sewage pumps having capacities in excess of the normal flow rate.

Nicoll (2), in reporting on package plants in Great Britain, advocated awareness of the situations likely to produce extremes in hydraulic loadings, such as when the contributing population is small, where the pattern of activity of the inhabitants is similar, and when wastewater travel times are short, all situations likely to be encountered in units serving small numbers of houses, schools, industries, and so forth, which are often package plants.

This problem of solids unloading to the effluent during hydraulic overload or shock overload formed the basis for this research. A 3,000 gallon commercial extended aeration package plant was used in pilot-plant studies to observe and analyze the effect of various hydraulic shock loading rates on effluent quality. In addition, some of the system variables, specifically aeration tank loading rates and air requirements and sedimentation tank loading rates, were studied with respect to existing criteria governing the design of such plants for field usage to determine if it was possible to locate potential causual areas leading to the solids discharge.

LITERATURE REVIEW

EXTENDED AERATION PROCESS

The extended aeration sewage treatment process is a modification of the basic activated sludge process (3), whereby total oxidation is utilized to ensure the removal of the dissolved and colloidal biochemical oxygen demand of the sewage with stabilization of the solids (4). Biodegradable organic matter is converted to microbial cell material and removed from the wastewater effluent by bio-flocculation and sedimentation (7). This conversion or stabilization takes place in two stages (7, 8) and is represented in Figure 1.

These stages occur simultaneously and in the same tank. First, approximately one-third of the organic material is immediately oxidized to produce energy for the synthesis of the remaining two-thirds of the organic matter into new bacterial cells. Secondly, in endogenous respiration, the cell mass undergoes self-oxidation to the final end products of water, carbon dioxide, and a biologically inert residue. This process reduces biological residue to a minimum, but there is a limit to the decrease in sludge mass possible due to the gradual buildup of the inert solids.

The degree of auto-oxidation accomplished is dependent on the availability of food and the time available for metabolism. The basic mechanism is the same for all biological treatment processes, only the relationship between the amount of synthesis and endogenous respiration allowed differentiates between the

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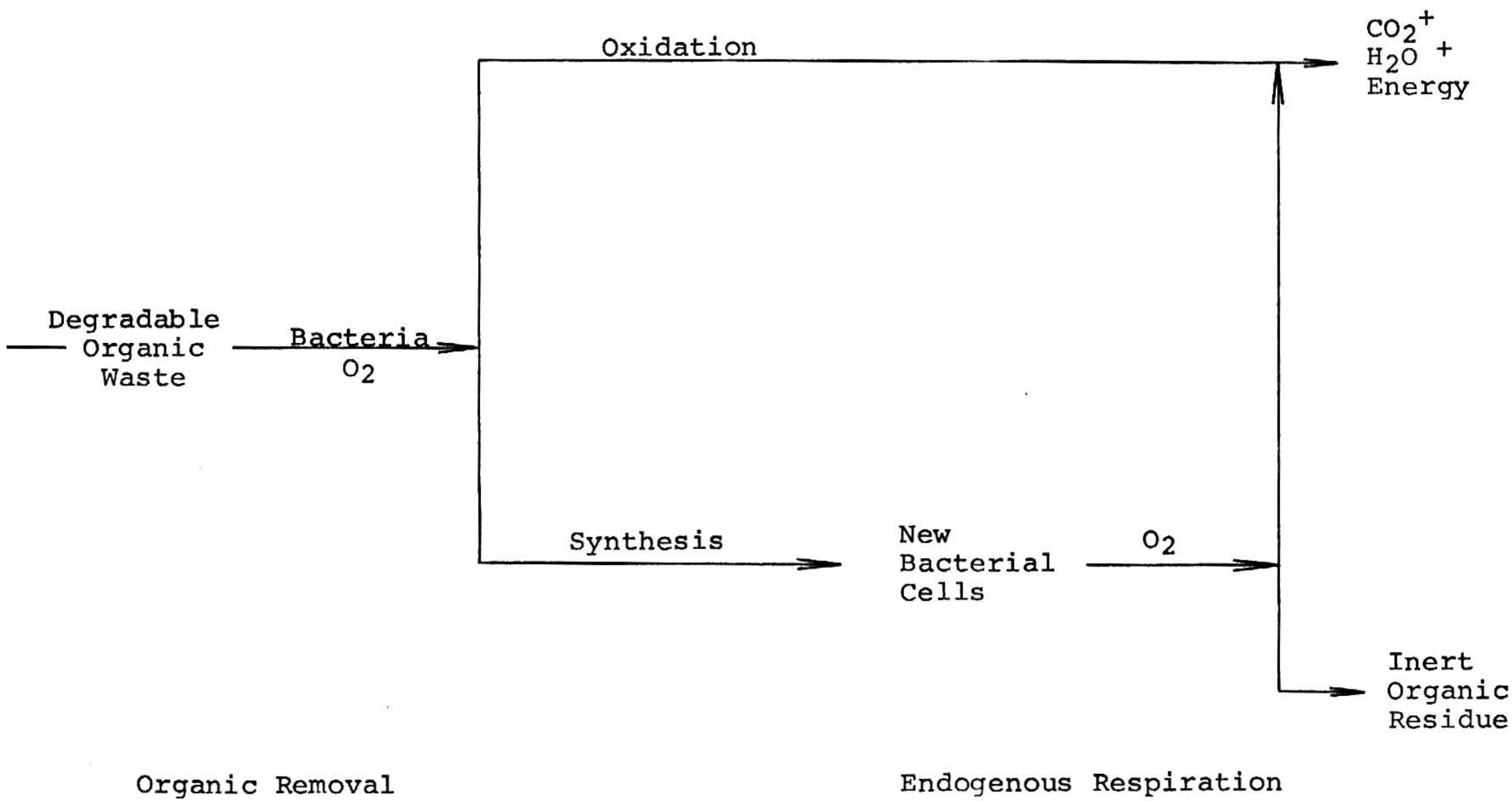

Figure 1. Conversion of Organic Wastes in Activated Sludge [from McCarty and Broderson (8)]

various systems. If food is limiting, that is, a low food to microorganism ratio (F/M) is present, the endogenous phase will predominate. Thus, extended aeration systems operate in the fifteen to thirty pounds biochemical oxygen demand (BOD) per day per thousand cubic feet of aeration tank volume range as opposed to the thirty-five to fifty pounds BOD per day per thousand cubic feet range of conventional activated sludge systems (7). This loading, combined with typically high mixed liquor concentrations and long aeration times, ensures a low F/M ratio and a system operating in the endogenous phase.

Separate sludge wasting of excess sludge is not always practiced. Ideally, only the biologically inert fraction of the oxidized cell mass remains in the system, but, due to time limitations, some of the viable cell mass is also residual. If sludge is allowed to accumulate, the mass will increase until the capacity of the system for solids retention is exceeded, resulting in a discharge of solids in the effluent, thus establishing an equilibrium mixed liquor suspended solids concentration. This concentration may range from 5,000 to 6,000 mg/l if sludge is manually wasted to 8,000 to 10,000 mg/l if not (7).

The efficiency of the extended aeration process with respect to BOD and suspended solids removal is dependent primarily on the BOD loading and the use of separate sludge wasting (7). Pfeffer (7) reported that with a loading of from ten to fifteen pounds BOD per day per thousand cubic feet and no sludge wasting, the BOD removal may be from ninety to ninety-five percent. The suspended solids removal will be less due to the high degree of oxidation of the sludge to an inert mass which has lost its flocculation properties and does not settle out of the effluent. However, these effluent solids are generally well stabilized. As the BOD loading increased, the removal percentage decreased (to eighty to eighty-five percent with a loading of twenty to twenty-five pounds BOD).

The quantity of sludge produced per unit BOD increases with an increase in load and a decrease in aeration time. Oxygen requirements increase as a result of a less stable sludge. As extended aeration systems age, there is a general buildup of inert sludge, silt, grit, and so forth, increasing the volume of sludge to be wasted.

The presence of suspended solids in the effluent increases the BOD of the effluent corresponding to a BOD loading increase. Morris, et al. (3), have reported that as most of the solids lost in the effluent consist of non-biodegradable matter, this effluent BOD is not as high as might be expected with a similar loss of solids from a conventional activated sludge plant. However, the BOD of the viable portion of the effluent solids does consititue nearly all of the carbonaceous effluent BOD. They considered the control of solids loss in the effluent to be a primary factor affecting the efficiency of extended aeration plants.

Structurally, the true extended aeration system is less complex than a conventional biological treatment system as it will consist of only an aeration tank and a final clarifier. These components may be modified or added to, however, to fit the situation.

DESIGN CRITERIA

Design criteria governing the construction of extended aeration treatment plants have been established by various state agencies, regional commissions, and engineering organizations. Table 1 presents some current design criteria.

Nicoll (2) reports that the British criteria formulation is based on the Royal Commission Standards of less than thirty milligrams per liter (mg/l) suspended solids and less than twenty milligrams per liter BOD in the treatment plant effluent. He states that British practice is to design a plant so that it is capable of handling up to three times the dry-weather flow (dwf).

In reporting on several package treatment plants of the Metropolitan Sewer District of Greater Cincinnati, Seymour (12) states that while the Ohio State Department of Health set minimums for wastewater detention times and maximums for surface and weir overflow rates, they did not include in these criteria the factor of the solids loading rate to the clarifier. ASCE Manual of Engineering Practice No. 36 (13) (WPCF Manual of Practice No. 8) states that, generally, for mixed liquor suspended solids concentrations of up to 3,000 mg/l, sludge volume indexes (SVI) of less than one hundred, and return sludge concentrations of less than one percent, the clarifier surface area as determined by

Table 1. Selected Extended Aeration Design Criteria

	State of Kansas (9) (tentative)	Ten State Standards (10)	from Eye, et al. (11)	British Standards [from Nicoll (2)]
Aeration Tank				
Plant flow	2,000 to 6,000 gpd	---	---	---
Detention	24 hr. at avg. design flow	24 hr.	24 hr. at avg. design flow not including recirculation	---
Organic loading	15 lb. BOD_5/1,000 ft^3 aeration tank vol.	12.5 lb. BOD_5/1,000 ft^3 aeration tank vol.	10 to 20 lb. BOD_5/ day/1,000 ft^3	240 mg/l aeration capacity/day
MLSS/BOD_5	---	10/1 to 20/1	---	0.05 to 0.15 gm. BOD_5/ day/gm. MLVSS
Air	1,500 ft^3 (STP)/day/ lb. BOD_5	2,000 ft^3/lb. BOD_5 aeration tank load Min. DO of 2.0 mg/l in aeration tank	2,100 ft^3/lb. BOD_5 entering tank	4,500 ft^3/lb. BOD_5 (6 ft. depth) 3,000 ft^3/lb. BOD_5 (9 ft. depth)
Clarifier				
Plant flow	---	less than 0.05 MGD	---	---
Detention	1 hr. min. at max. rate of flow	4 hr.	4 hr.	---
Overflow rate	1,200 gal./day/ft^2 at max. rate of flow	300 gal./day/ft^2	---	450 gal./day/ft^2
Nominal upflow velocity	---	---	---	3 ft./hr.
Recirculation	---	min.: 50% of avg. std.: 100% design max.: 200% flow	100% based on avg. flow	---

the surface overflow rate is adequate for solids removal. It goes on to say that if these limits are exceeded, as they most generally are with extended aeration package plants, the solids loading per unit area may be important.

In WPCF Manual of Practice No. 11 (14), it is stated that the settling rate in the clarifier is usually expressed in gallons of inflow per day per square foot of surface area, the wastewater influent rate being most commonly used. Therefore, as the inflow to the settling tank includes both the wastewater influent flow and the recycled sludge flow, there is a discrepancy as some criteria, manufacturers, and engineers disregard the recycle flow in calculating the surface overflow and solids loading rates.

Seymour (12) determined the recycle rates and surface overflow rates for three plants in the study using the raw influent flow alone, and using the raw influent flow plus the recycle flow. The state criteria of five hundred gallons per day per square foot (gpd/ft.^{2}) for overflow rate was adhered to in each case only if the raw influent flow alone was used in the calculation. All three cases became marginally acceptable if the recycle flow was included in the computation. If the maximum raw influent flow was used along with the recycle flow, two of the plants exceeded the state standard while the third remained marginal.

The solids loading rate was also computed for the three plants using the three combinations of flows as before. Again, the inclusion of the recycle flow had a great influence. While there does not seem to be any definitive criteria for smaller package plants, as reported, with the recycle flow included, the loading value increased by up to eight times the values obtained using only normal raw influent flow.

Seymour (12) concluded that solids overflow would be expected at package plants, especially during periods of peak flows, when viewed from a determination of surface overflow and solids loadings rates using recycle flow in the computation along with the normal raw influent wastewater flow. He suggested research in the area of determining proper limits for settling tank design.

EFFECT OF HYDRAULIC SHOCK LOADS

Ramanathan, et al. (15), conducted laboratory experiments using a scale model of an extended aeration treatment plant to determine the effects of shock loadings, primarily organic, on the system. A synthetic wastewater influent was used for both batch-fed and continuous operations. During shock loadings, increases in effluent chemical oxygen demands were observed along with solids unloading, but all solids lost in the effluent were collected by centrifuge and returned to the aeration tank. Their conclusions were that:

1. It was shown that the process could handle slug loads of organic material,

2. Generally, the batch-fed system yielded poorer results than the continuous system, and

3. Indications were that the continuous system could handle higher quantitative shock loads than had been applied.

Eye, et al. (11), reported on five extended aeration plants in various residential Ohio communities. Effluent BOD and suspended solids concentrations were generally observed to increase following hydraulic overloads at the plants. On one plant, the flow was adjusted to provide for average detention times of 1.4 and 2.2 days. Periodic discharges of solids to the effluent were observed throughout the study but were more pronounced for detention times of 1.4 days than for 2.2 days and were assumed to result from hydraulic overload. The BOD concentration of the effluent tended to increase with decreasing aeration time. The overall performance of this plant seemed to relate directly to the ability of the clarifier to retain suspended solids.

In another plant, high suspended solids concentrations in the effluent were observed:

1. When the hydraulic capacity of the clarifier was exceeded,

2. When the sludge return line became clogged, and

3. When the sludge scraper mechanism failed.

A couple of tests were run where the flow was increased over a period of hours and solids washout was observed. The mixed liquor concentration did not exceed the theoretical maximum, but the minimum recycle ratio as given by the manufacturer was not attained either. Additional tests incorporating sludge wastage gave better effluent results.

They felt that system performance could be enhanced by either enlarging the clarifier to provide lower overflow rates or by controlled sludge wastage.

Nicoll (2) indicated that many British package plants have been shown to be sensitive to fluctuations in the hydraulic loading. He states that is foolhardy to assume that these plants can cope satisfactorily with sustained flows greatly in excess of the design flow without the risk of solids loss to the effluent. Even if the settling basin is designed to keep nominal upflow rates acceptable, other factors arising from the consequential high retention times, as denitrification possibilities and the advisability of an increased sludge return rate to the aeration tank, would require consideration. He felt that efficient and preferably positive sludge recycle to the aeration tank was essential in order to prevent solids buildup in the clarifier and subsequent loss to the effluent.

Skimming devices were found to have an effect on the nominal upflow velocities. For an average flow of 3,960 gpd and a skimmer returning 1.2 gpm, the rate of skimming would be equivalent to forty-five percent of the average flow, and if constant, would represent a fifteen percent increase in the upflow velocity under maximum flow conditions.

With respect to the volumes of flow that may be expected during the hydraulic overload of small package plants, Nicoll (2) found that a unit serving thirty-one persons in twelve houses achieved flow rates of seven to eight times the normal dry weather flow for significant periods of the day, even with no infiltration of subsoil water.

PROCEDURES

ANALYTICAL PROCEDURES AND EQUIPMENT

Biochemical Oxygen Demand

Five-day biochemical oxygen demand (BOD_5) determinations were run on the daily composite samples primarily according to the methods listed in Standard Methods (16). Influent samples were not aerated and their initial dissolved oxygen (DO) concentrations were assumed to be zero. This was accounted for in the computation of the BOD_5 values.

Carbonaceous BOD_5 examinations were run on the effluent samples by acidification to inhibit the nitrogenous BOD_5 as recommended by Sawyer and McCarty (17) and described by Hurwitz, et al. (18). Treated effluent samples were aerated using laboratory compressed air and porous diffuser stones for fifteen to thirty minutes in beakers of up to 1,000 ml capacity. The effluent sample DO concentrations were then assumed to be saturated and equal to that of the dilution water, which was added to provide the required dilution or to ensure a water seal in those cases where no dilution of the effluent sample was required.

Dilution water was prepared according to Standard Methods (16) and aerated with laboratory compressed air and porous diffuser stones for several hours and thus assumed to be saturated with dissolved oxygen. Initial DO determinations were not run for either dilution water, influent, or effluent samples. Results were reported as recommended by Standard Methods (16) except that if a given series of dilutions did not provide the required final DO range of at least one-half milligram per liter DO remaining but a depletion of at least two milligrams per liter, the value reported was listed as being less than the minimum obtainable given the dilutions used.

The equipment used consisted of three hundred milliliter BOD bottles and a Precision Scientific Model 805 incubator.

Chemical Oxygen Demand

Chemical oxygen demand (COD) determinations were run as described in Standard Methods (16) for ten milliliter samples, using 0.25 N potassium dichromate and 0.05 N ferrous ammonium sulfate. Tests were run on all individual samples and on daily composite samples. Some COD and soluble COD determinations for effluent samples were run using the alternate procedure for dilute samples. Soluble COD effluent samples were obtained by passing an effluent sample through a Millipore filter and using the filtrate in the COD test.

The equipment consisted of either two hundred or two hundred fifty milliliter erlenmyer flasks with ground-glass 24/40 necks, three hundred millimeter Pyrex condensers with 24/40 ground-glass joints, and either a Lindberg Hevi-Duty type H-5 or LabConCo heater.

Dissolved Oxygen

Dissolved oxygen measurements in the pilot plant aeration tank were obtained using a Delta Scientific Model 3410-01

Dissolved Oxygen Analyzer. The DO probe was immersed in the mixed liquor and, when the instrument was operational, a continuous strip chart recording of the DO could be obtained.

Final DO determinations for the BOD_5 examinations were run using the azide modification of the basic Winkler method as described in Standard Methods (16).

Flow Rate

A continuous recording of the pilot plant flow was obtained using a Stevens Model 61R Total Flow Meter with a 22.5 degree V-notch weir. The instrument was located at the effluent end of the plant and recorded in thousand gallons per day. During periods of shock loading, instantaneous flow measurements were obtained using a graduated bucket and a stopwatch.

pH

The pH determinations were obtained using a Fisher Accumet Model 320 Expanded Scale Research pH Meter. These values were used only in the effluent sample treatment for the BOD_5 test.

Solids

Total suspended solids determinations were made using the Millipore filter technique. For individual influent and effluent samples, and daily composite samples, Millipore 0.45 micron ashless filter papers were placed in aluminum dishes and then placed in either a Precision Scientific Model 17 Thelco oven or a Matheson Scientific oven at 103° C for at least three hours. At the end of this period, the filters and dishes were placed in dessicators, cooled to room temperature, and weighed on a Mettler Type H6 analytical balance. After weighing, the filters were placed on the ground-glass filter holder with funnel. Using a volumetric pipet, the sample was added and the vacuum was applied. Upon completion of the filtration, the papers were placed back in the dishes and returned to the oven to dry at 103° C for one hour. The cooling and weighing procedure was followed as above to obtain the suspended solids concentrations.

Total fixed solids determinations were found for the aeration tank mixed liquor suspended solids (MLSS) samples. The procedure listed above was followed for total suspended solids utilizing porcelain crucibles instead of aluminum dishes. Following the second weighing, the crucibles, ash-less filter papers, and dried solids were placed in a Thermolyne Model F-A1730 Muffle Furnace and burned at 600° C for fifteen to twenty minutes as prescribed by Standard Methods (16). The crucibles and ashes were then cooled to room temperature, first in air and then in dessicators, and weighed using the Mettler balance. Initial weights were determined on the crucibles while the sample was being filtered.

Sludge Density Index

The sludge density index (SDI) determinations were obtained as described in Standard Methods (16).

EXPERIMENTAL PROCEDURES

Pilot Plant

The pilot plant used for this research is a Smith & Loveless Model "V" factory-built, cylindrical "ADDigest" sewage treatment plant with a Model 8CA3 aeration tank and a Model 10C60 clarifier (19). The plant is located on the property of the Manhattan, Kansas, sewage treatment plant and is identical to those sold commercially for field usage. A photograph of the plant is shown in Figure 2, and a schematic diagram of the unit, as operated, is shown in Figure 3.

In the photograph, the building on the left housed the pump apparatus, the wastewater flow being from left to right. The clarifier on the left served as the primary sedimentation basin during prior research utilizing this plant but was by-passed by piping the flow over its top into the aeration tank, and not used for this study. The stock tanks in the foreground were used for volumetric measurement during sludge wastage. The effluent pipe, as shown on the right, carried the flow below ground and into the flow meter weir box below the water surface. This was modified as noted later in this discussion to allow for effluent sampling prior to the flow entering the weir box.

Raw sewage was obtained from the inflow to the Manhattan sewage treatment plant after comminutation but before any settling could occur in the clarifier. Utilizing two inch ABS pipe, the raw sewage was pumped to the influent end of the pilot

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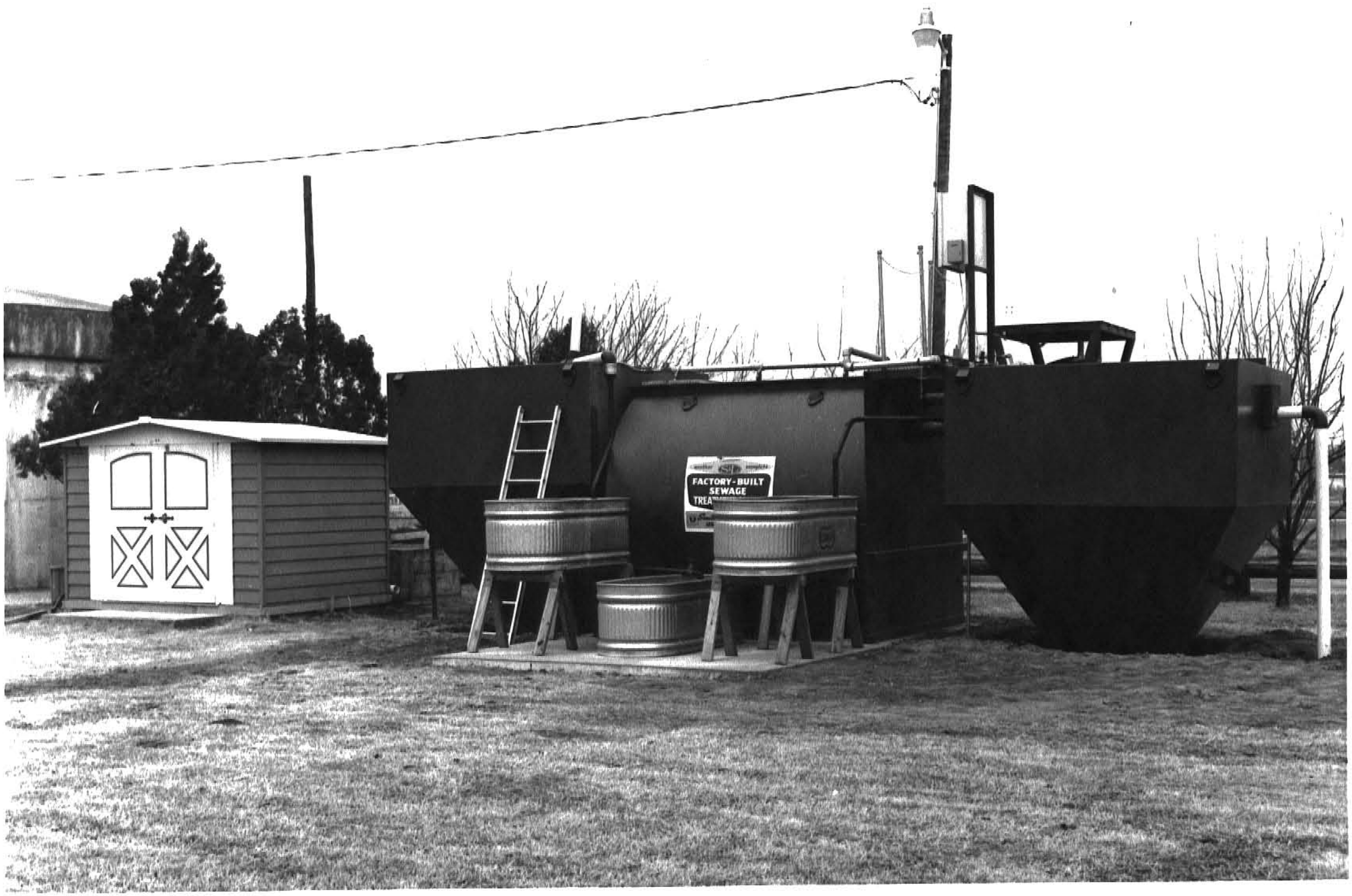

Figure 2. Photograph of Pilot Plant

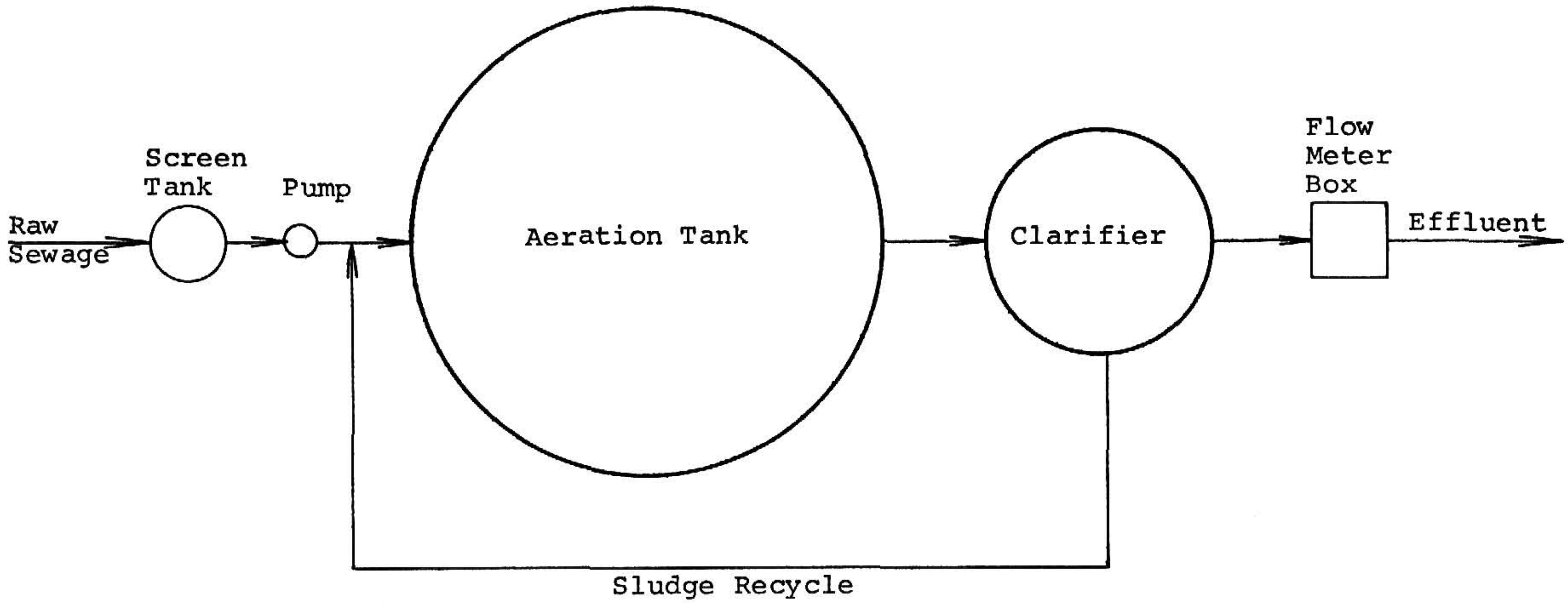

Figure 3. Schematic of Pilot Plant Operation

plant aeration tank by a variable speed rubber impellered, positive displacement pump. A screen tank was inserted on-line prior to the pump to remove those substances that would not pass through the pump. This tank also served to provide a constant head to the pump as it was air-sealed and evacuated by a vacuum pump actuated by a mercury switch-float mechanism contained within the tank.

The aeration tank is rated at 3,000 gallons capacity. Diffused aeration is provided through diffusers mounted on the lower end of each of three vertical drop pipes suspended from a horizontal header. Each drop pipe is equipped with a hand operated air throttling valve and two rubber diffuser boots having two rows each of one-sixteenth inch diameter orifices through which the air discharges.

The clarification tank, rated at 60.3 square feet of surface area, is equipped with both an air lift sludge return pump and an air lift surface skimmer to remove floating solids and scum. Both the return sludge and the surface skimmings are returned to the influent end of the aeration tank through a six inch diameter pipe. Mixed liquor from the aeration tank enters the clarifier below the water surface level and is directed against the wall nearest to the aeration tank. A slotted baffle was suspended across the clarifier tank perpendicular to the flow to help eliminate short-circuiting. The final effluent passes over a V-notch weir panel located against the wall farthest from the influent. Effluent flow passes through the flow meter and is then piped to join the effluent flow from the Manhattan treatment plant.

Air was provided by one fifty-five cubic feet per minute (cfm) (79,200 cubic feet per day) blower, which provided air for the sludge return air lift pump, the air lift surface skimmer, and the aeration tank diffusers. Individual adjustments could not be made for regulating the air to any of the mechanisms without affecting the others.

The pilot plant had been used for previous research at Kansas State University and contained a viable mixed liquor. This advantage was offset when the entire plant, including the aeration tank, froze during January, 1972, for a period of nearly two weeks as a result of the exposed influent piping freezing during the night low flow. When the aeration tank thawed, the mixed liquor suspended solids concentration was over 9,000 mg/l. This was lowered by sludge wastage to 2,000 to 3,000 mg/l. Extreme foaming problems in the aeration tank and denitrification in the clarifier were encountered until the mixed liquor population became established following the winter upset. By the week of 26 June 1972, the mixed liquor had stabilized and shock loading tests were begun. Twelve tests were run over the fourteen week period covering 26 June to 26 September 1972.

Test Procedures

The plant was operated using the extended aeration process by applying approximately 3,000 gallons per day of raw wastewater flow to the aeration tank, providing an aeration detention time of twenty-four hours. This flow was provided with a diurnal fluctuation to simulate normal field operation of such a treatment plant by regulating the pump with a Seco Electronics Corporation Model 850H rheostat operating off of a cam. This resulted in low flows during the late night and morning hours, rising through the afternoon to reach peak flow around seven P.M., then dropping off rapidly to repeat the cycle. Hydraulic shock loads were applied one day a week, on Monday afternoon, and then the plant was returned to the normal diurnal cycle and monitored for recovery.

During the first series of tests, covering the first five weeks, the shock load was applied over a five hour period utilizing an arm attached to the cam. This provided a gradual increase from the normal to the peak flow and a slightly less gradual decrease to the normal diurnal flow cycle. The shock loadings for the next two series of tests, covering periods of three and four weeks respectively, were applied by manually accelerating the flow to the peak over a thirty minute period. The flow was left at the peak for three hours and then decreased to the normal cycle, again over a thirty minute period. This provided for rapid increases and decreases in flow with a period of time at constant peak flow.

Due to the nature of the plant piping, whenever the flow exceeded approximately 8,000 gpd, the lines were flushed of settled matter. This provided a short-lived organic shock load to the aeration tank in addition to the applied hydraulic shock load.

Grab samples of both influent and effluent wastewater were collected on the day before, the day of, and the day following the application of the shock load at three and nine P.M. and at three and nine A.M. by the personnel of the Manhattan sewage treatment plant. These samples were refrigerated at the Manhattan plant until transported to the laboratory. Influent and effluent samples were taken hourly during the application of the shock load and during the half-hour period of flow increase and decrease when the pump was being operated manually. Influent samples were taken from the flow as it entered the aeration tank. Effluent samples were taken from the flow after it passed over the effluent weir but prior to its passing to the flow metering box. This was initiated after the third week of testing after it was noticed that the flow meter box was acting as a polishing pond and removing effluent solids. Grab samples of the mixed liquor were periodically taken from an area prior to the head of the connecting pipe between the aeration tank and the clarifier. Samples were collected in either five hundred or one thousand milliliter Nalgene bottles.

After transportation to the laboratory, all samples were refrigerated at two to four degrees centigrade until examinations were made. Daily composite samples were made proportional to flow from the three P.M., nine P.M., three A.M., and nine A.M. individual samples. Single determinations of total suspended solids and COD were made for each individual and composite sample. Single soluble COD determinations were run on each composite effluent sample and on those individual samples of the last five weeks generally having a total COD of greater than forty milligrams per liter. Dual determinations were made of the aeration tank solids and an average taken for the value. Some of the mixed liquor samples were tested for their sludge density index. BOD_5 determinations were made only on the daily composite samples.

The laboratory glassware and the sample bottles were cleaned in hot detergent water and rinsed completely in hot tap water. The glassware was rinsed two or three times with distilled water prior to use. The glassware was also cleaned in chromic acid solution as necessary. All pipets were cleaned in chromic acid solution and rinsed completely with cold tap water, and again rinsed two or three times with distilled water prior to use. Standard chemical solutions were made up as specified in Standard Methods (16).

RESULTS

This study was conducted in three parts as has been noted. Data collected for each individual week in one series were averaged to obtain the results for each run. Data for the individual weeks are summarized in the Appendix.

RUN I

The data for this run are summarized in Table 2 and Figure 4. The column headings are those that will be used throughout in the presentation of run and weekly data.

Day 1 is the twenty-four hour period, 1200 to 1200 hours, immediately preceeding the day of the shock load application. Day 2 is the twenty-four hour period covering the day of the application, and Day 3 is the day following the day of the test. The time indicated is the time, on a twenty-four hour clock, that a sample of some variable was taken during any of the weeks comprising a run. Flow and dissolved oxygen measurements were obtained continuously except when:

1. The DO meter was inoperative,
2. The flow timer clock mechanism was wound down, or
3. The flow was off or excessive due to pump malfunction.

Those values listed under the influent and effluent headings, in milligrams per liter, are for the chemical oxygen demand (COD), suspended solids concentrations (SS), and five day biochemical oxygen demand (BOD_5) determinations. The influent BOD_5 values were also converted from milligrams per liter to pounds for

Table 2. Summary of Data for Run I

Day	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l (lb)	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
1	1100												(1) 4760	(1) 65	
	1300												(1) 4600	(1) 76	
	1500	(4) 4375	(3) 2.7	(4) 470	(4) 139		(4) 51	(3) 12		89					
	2100	(4) 3625	(3) 2.9	(4) 535	(3) 385		(4) 40	(3) 11		93					
	0300	(5) 1550	(3) 4.4	(5) 385	(4) 125		(5) 58	(4) 12		85					
	0900	(4) 1810	(2) 4.7	(3) 475	(3) 125		(4) 25	(3) 12		95					
	Composite	(4) 2980		(4) 460	(4) 260	(4) 180 (4.5)	(4) 24	(4) 10	(4) <12	95	93	(4) 20			
2	1200	(5) 2950	(4) 3.4	(5) 480	(5) 195		(5) 26	(4) 16		95			(5) 4330	(3) 70	(1) 0.844
	1300	(5) 5500	(4) 2.9	(5) 370	(5) 265		(5) 29	(4) 14		92					
	1400	(5) 8000	(4) 1.9	(5) 545	(5) 340		(5) 43	(5) 13		92					
	1500	(5) 9900	(4) 1.4	(5) 590	(5) 280		(5) 218	(5) 178		62			(5) 3660	(3) 67	(3) 0.885
	1600	(5) 9700	(4) 1.2	(5) 500	(5) 225		(5) 191	(5) 179		62					
	1700	(5) 6120	(4) 1.8	(5) 465	(5) 165		(5) 39	(5) 22		92					
	1800	(5) 5500	(4) 2.4	(5) 470	(5) 150		(5) 40	(5) 12		92			(5) 3900	(3) 72	(2) 0.501
	2100	(5) 3700	(4) 3.5	(5) 420	(5) 155		(5) 31	(5) 13		93					
	0300	(5) 1800	(4) 5.0	(5) 340	(5) 140		(5) 31	(4) 8		91					
	0900	(3) 2000	(2) 4.6	(3) 290	(3) 115		(3) 30	(3) 12		90					
	Composite	(4) 3775		(4) 390	(4) 190	(4) 205 (6.5)	(4) 88	(3) 61	(5) <12	78	94	(4) 13			
3	1200												(2) 3480		(1) 0.371
	1300												(3) 4560	(3) 72	(2) 0.795
	1500	(5) 4600	(4) 3.2	(5) 580	(4) 195		(5) 39	(4) 14		93					
	2100	(5) 3600	(4) 3.8	(5) 370	(4) 185		(5) 36	(4) 16		90					
	0300	(5) 1150	(3) 5.4	(2) 380	(1) 290		(5) 33	(4) 19		91					
	0900	(4) 2125	(2) 5.4	(3) 260	(4) 125		(4) 36	(3) 19		86					
	Composite	(5) 2850		(5) 410	(5) 160	(6) 165 (3.9)	(5) 28	(4) 12	(5) <12	93	92	(5) 18			

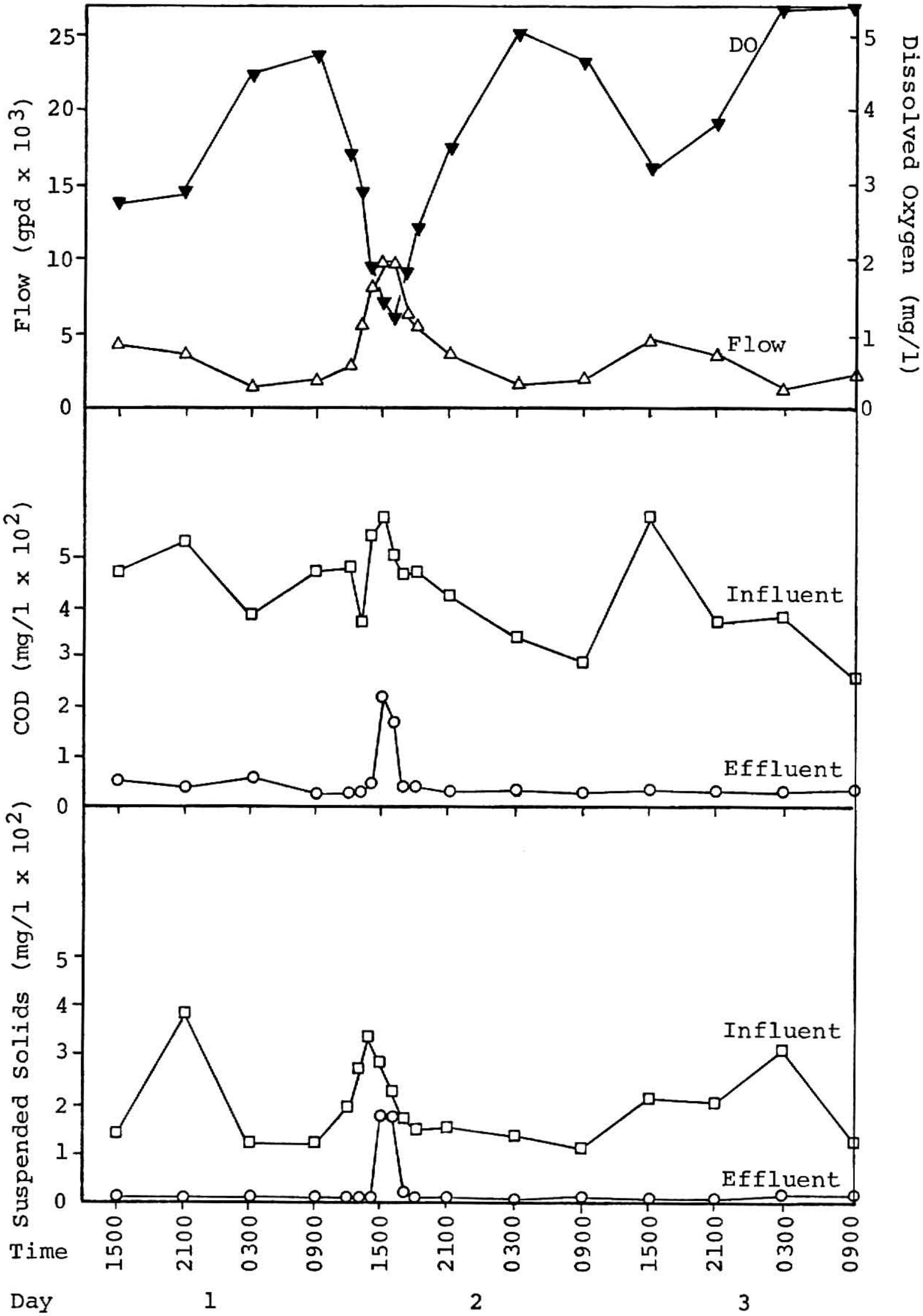

Figure 4. Summary of Data for Run I

later usage and listed below the mg/l values. The values for the percentage removal (% Rem.) for both COD and BOD_5 are, for Tables 2, 3, and 4, those obtained using the data presented and not an average of the data of the corresponding weeks. The soluble effluent (Sol Eff) values and values for the aeration tank mixed liquor suspended solids concentration (MLSS), percentage volatile (% Vol.), and sludge density index (SDI) are also presented.

The numbers indicated in parentheses in front of the data values are the number of results from the individual weeks of the run used to determine the run average. In determining the average, only those sample values resulting from expected or normal flow rates, either diurnal or applied hydraulic shock load, were used. Values obtained during periods of no flow, due to pump malfunction, or excessive flow, due to erroneous pump settings following periods of plant upset or flow stoppage, were not considered to be consistent with the conduct of this study and were thus omitted. However, values obtained during periods of expected flow that seemed inconsistent with values obtained at the same flow rate for other weeks of the run were included in the determination of the run average. For other values, results for a given week may not have been obtained due to instrument malfunction (DO probe), erroneous sampling (COD, SS, and BOD_5), or the omission of a test.

Hydraulic shock loading rates for the first run, representing the maximum flows achieved, were approximately three times the normal average daily flow and two times the normal daily peak flow. Results from the weeks comprising the first run were consistent except for Weeks 1 and 2 which show high effluent suspended solids and COD values during the period of the hydraulic overload.

Values of the mixed liquor suspended solids concentrations (MLSS) were lower for this run than for the other two. During periods of major solids loss in the first two weeks, the solids in the clarifier could be seen to be bulking, the surface of the solids layer being only about six inches below the water surface when normally it was at a depth of several feet.

The relationship between the flow and the dissolved oxygen concentration in the aeration tank was of particular interest, their plots generally being mirror images of each other. Also shown by the data was the rapid recovery of the system, as represented by the effluent COD and suspended solids concentrations, from the period of upset, often occurring within one-half hour of the decrease of the flow rate from the maximum to the normal diurnal cycle. Both the flow-dissolved oxygen relationship and the rapid recovery were demonstrated throughout the study.

RUN II

The data for Run II are summarized in Table 3 and Figure 5. The maximum flows for this run represented rates of approximately five and three times the normal daily average and peak flows, respectively. The results of this run show COD removals

Table 3. Summary of Data for Run II

Day	Time	Flow	DO	Influent			Effluent			% Rem		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l (lb)	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
1	1100												(1) 4870	(1) 67	
	1500	(3) 4170	(1) 3.7	(3) 455	(3) 245		(3) 46	(3) 23		90					
	2100	(3) 3170	(1) 4.0	(3) 360	(3) 130		(3) 44	(3) 22		88					
	0300	(3) 1500	(1) 5.5	(3) 325	(3) 115		(3) 44	(3) 24		87					
	0900	(3) 2080	(1) 5.4	(1) 195	(1) 140		(3) 40	(3) 21		79		(1) 44			
Composite		(3) 2860		(3) 375	(3) 160	(3) 155 (3.7)	(3) 31	(3) 15	(3) <3	92	98	(3) 34			
2	1200	(3) 2760	(3) 3.4	(3) 530	(3) 175		(3) 40	(3) 23		92			(3) 4910	(3) 70	(1) 0.734
	1300	(3) 6600	(3) 2.6	(3) 2190	(3) 2160		(3) 45	(3) 24		98					
	1330	(3) 14300	(3) 1.0	(3) 710	(3) 415		(3) 43	(3) 27		94					
	1400	(3) 15100	(3) 0.4	(3) 535	(3) 245		(3) 55	(3) 35		90		(1) 23			
	1500	(3) 14900	(3) 0.4	(3) 610	(3) 245		(3) 60	(3) 40		90		(1) 23	(3) 4630	(3) 71	(3) 1.250
	1600	(3) 15100	(3) 0.3	(3) 555	(3) 255		(3) 56	(3) 40		90		(1) 23			
	1630	(3) 15100	(3) 0.3	(3) 445	(3) 155		(3) 64	(3) 44		86		(1) 37			
	1700	(3) 5140	(3) 0.5	(3) 435	(3) 145		(3) 58	(3) 43		87		(1) 35			
	1800	(3) 5070	(2) 0.7	(3) 385	(3) 140		(3) 55	(3) 36		86		(1) 28	(3) 4900	(3) 68	
	2100	(2) 3500	(1) 2.6	(3) 395	(3) 140		(3) 45	(3) 27		89		(1) 28			
	0300	(2) 1625	(1) 4.3	(3) 375	(3) 95		(3) 38	(3) 21		90					
	0900	(2) 2250	(1) 4.7	(3) 250	(3) 55		(3) 40	(3) 23		84					
Composite		(2) 4445		(2) 470	(2) 190	(2) 175 (6.5)	(2) 48	(2) 37	(2) 4	90	98	(2) 36			
3	1300												(3) 5110	(3) 70	(3) 0.733
	1500	(3) 4830	(1) 3.0	(3) 445	(3) 120		(3) 31	(3) 14		93					
	2100	(2) 3750	(1) 3.0	(2) 455	(2) 170		(2) 29	(2) 24		94					
	0300	(2) 1750	(1) 4.4	(1) 260	(1) 120		(2) 39	(2) 29		85					
	0900	(2) 2500	(1) 4.6	(2) 470	(2) 135		(2) 34	(2) 24		93		(1) 24			
Composite		(2) 3280		(2) 410	(2) 160	(2) 165 (4.5)	(2) 28	(2) 18	(2) 3	93	98	(2) 29			
4	1300												(1) 5725	(1) 66	(1) 1.396
	1400												(2) 5480	(2) 72	(2) 0.679

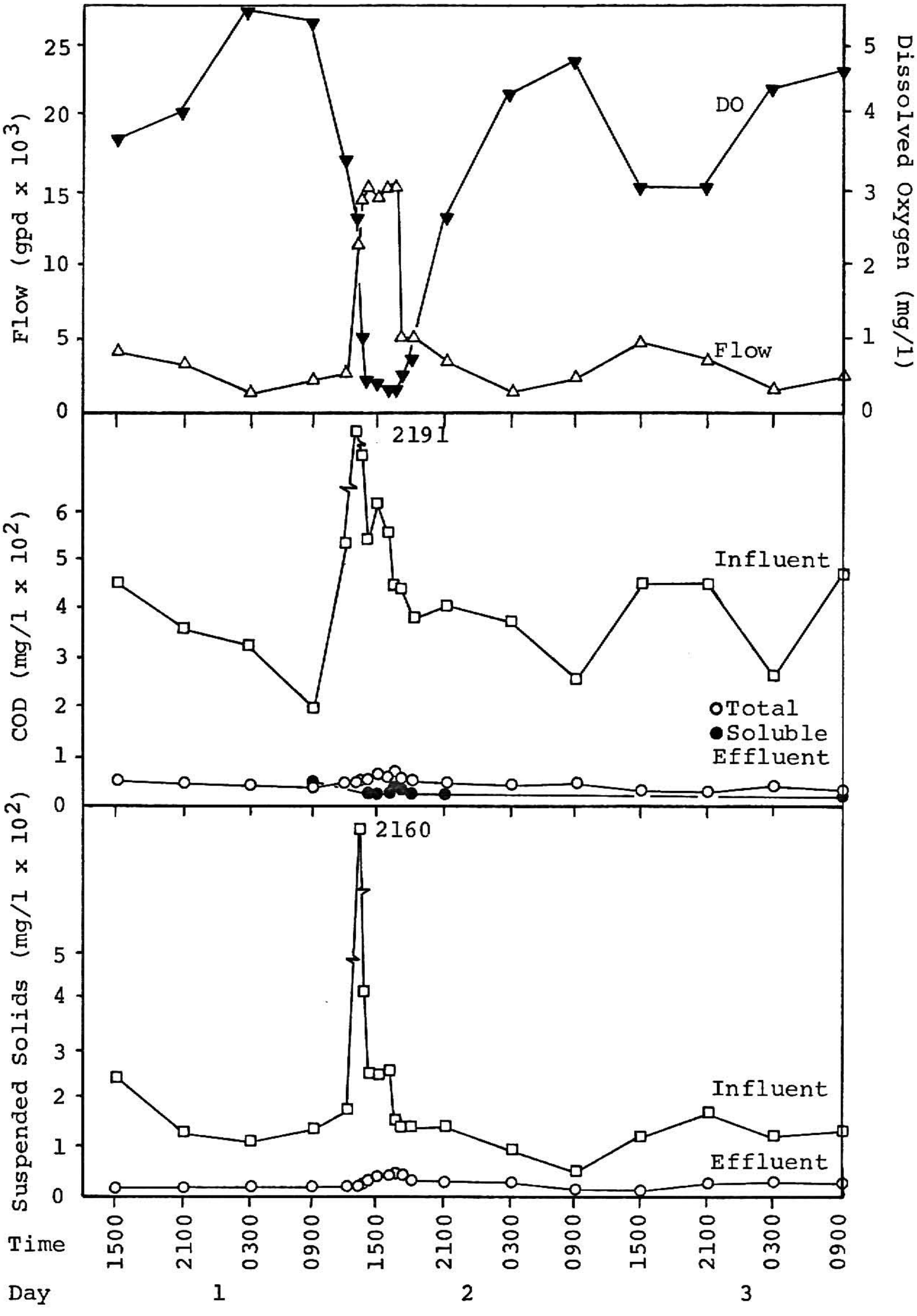

Figure 5. Summary of Data for Run II

consistently greater than eighty percent, even during the period of the hydraulic shock load. Minor sludge bulking in the clarifier was observed during the period of shock loading for the third week of the run but not to the extent of that of the first run.

RUN III

The data for Run III are summarized in Table 4 and Figure 6. The maximum flows for this run represented values of approximately eight and five times the normal daily average and peak flows, respectively. The results of these weeks showed a gradual decrease in the wastewater treatment efficiency, compared to those of the earlier weeks. Again, sludge bulking was observed in the clarifier, and major solids losses to the effluent occurred. During the second and third weeks of this run, an attempt was made to increase the amount of solids returned in the recycle without altering the recycle flow rate by increasing the sludge return while decreasing the surface skimmer flow midway through the period of hydraulic overload. Dissolved oxygen values are not shown after 1500 hours on Day 2 due to a malfunction in the DO probe that could not be corrected prior to the completion of the run.

DAILY COMPOSITES AND MLSS

The data for the daily composites and mixed liquor suspended solids concentrations covering the total period of the study are summarized in Figure 7.

Table 4. Summary of Data for Run III

Day	Time	Flow	DO	Influent			Effluent			% Rem		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l (lb)	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
1	1200												(1) 5600	(1) 63	
	1300												(1) 5875	(1) 63	
	1500	(3) 4750	(1) 1.8	(4) 550	(4) 285		(4) 45	(4) 27		92		(1) 29			
	2100	(3) 4080	(1) 2.6	(4) 340	(4) 140		(4) 51	(4) 20		85		(2) 35			
	0300	(3) 1830	(1) 4.1	(2) 330	(2) 115		(3) 34	(3) 18		90					
	0900	(3) 2330	(1) 4.2	(3) 185	(3) 75		(3) 34	(3) 15		82		(1) 41			
	Composite	(3) 3660		(3) 360	(3) 95	(3) 155 (4.3)	(3) 47	(3) 16	(3) 3	87	98	(3) 35			
2	1200	(1) 3170	(1) 2.9	(1) 585	(1) 170		(1) 47	(1) 19		92		(1) 39			
	1300	(4) 3950[a]		(3) 505	(3) 195		(4) 42	(4) 22		92		(3) 41	(4) 5785	(4) 65	(4) 1.103
	1330	(4) 12560	(2) 1.5	(4) 1940	(4) 4285		(4) 50	(4) 31		97		(3) 27			
	1400	(4) 25080	(1) 0.2	(4) 685	(4) 490		(4) 89	(4) 67		87		(4) 21			
	1500	(4) 24770	(1) 0.1	(4) 665	(4) 285		(4) 183	(4) 158		73		(4) 23	(4) 4895	(4) 66	(3) 1.045
	1600	(4) 24340		(4) 610	(4) 235		(4) 251	(4) 213		59		(4) 29	(2) 4835	(2) 68	(2) 1.186
	1700	(4) 24340		(4) 405	(4) 215		(4) 177	(4) 148		57		(4) 42			
	1730	(4) 5900		(4) 420	(4) 175		(4) 108	(4) 75		74		(4) 37			
	1800	(4) 5790		(4) 375	(4) 160		(4) 111	(4) 78		70		(4) 31	(4) 5590	(4) 65	(1) 0.618
	2100	(3) 3750		(4) 490	(4) 205		(4) 66	(4) 41		86		(3) 34			
	0300	(3) 1910		(2) 355	(2) 125		(4) 43	(4) 19		88		(2) 31			
	0900	(2) 2250		(3) 205	(3) 80		(3) 41	(4) 18		80		(1) 29			
	Composite	(3) 6535		(3) 530	(3) 125	(3) 220 (12.0)	(3) 146	(3) 90	(3) 9	73	96	(3) 47			
3	1300												(4) 5690	(4) 67	(2) 0.678
	1500			(1) 430	(1) 170		(1) 41	(1) 50		90					
	2100	(1) 3500		(2) 635	(2) 275		(2) 39	(2) 16		94		(1) 25			
	0300	(1) 1500		(2) 330	(2) 125		(2) 39	(2) 18		88					
	0900	(1) 2250		(2) 260	(2) 130		(2) 56	(2) 18		79		(1) 24			
	Composite	(1) 3070		(1) 515	(1) 190	(1) 235 (6.0)	(1) 35	(1) 4	(1) 3	99	99	(1) 26			
4	1300												(2) 6020	(2) 67	(2) 1.063

Notes: a. Flow times of Week 9, Run III, were shifted to match shock loading times of other three weeks of run.

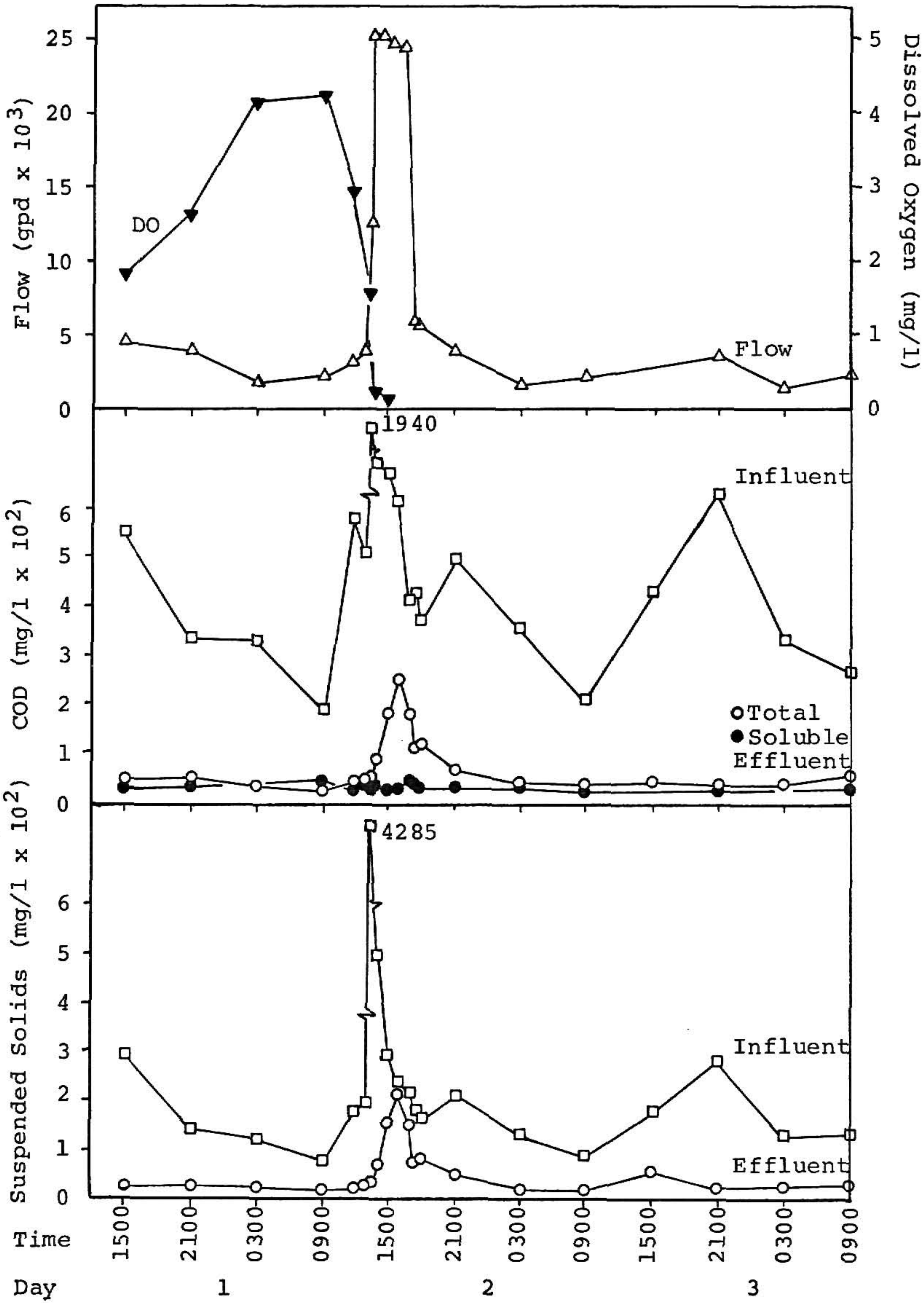

Figure 6. Summary of Data for Run III

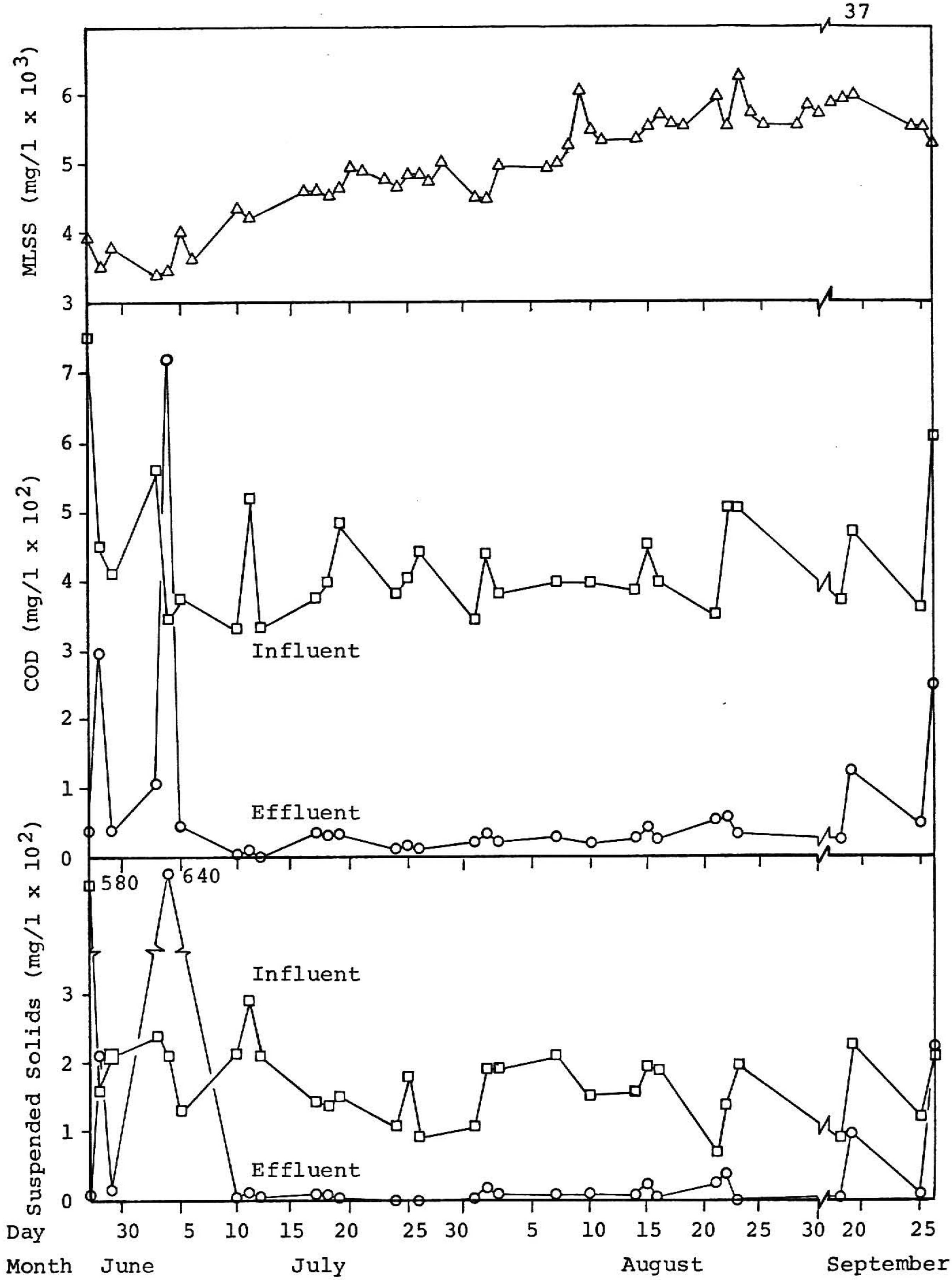

Figure 7. Summary of Data for Daily Composites and MLSS

Composite samples were proportioned for the twenty-four hour period 1200 to 1200 hours and recorded for the date of the last sample time of the period. Mixed liquor concentrations generally increased gradually over the period of the study from approximately 3,000 mg/l at the start of Week 1 to approximately 5,500 mg/l at the close of Week 12.

During each of the periods of shock loading, it was observed that the MLSS concentration in the aeration tank was lower than it was either before or after the application of the overload. This is shown in the data for the individual runs and weeks, and is a result of the sludge return pump operating at a constant flow rate while the increased flow into the clarifier caused a transfer of solids from the aeration tank to the clarifier. No sludge was wasted during the period of study except that which was lost to the effluent. The noon MLSS sample is recorded on Figure 7 as being the daily average concentration.

DISCUSSION OF RESULTS

For the purposes of this study, the items of interest are believed to be those relationships between design criteria and treatment practice that pertain to hydraulic shock loads as may be encountered in field situations. While effluent COD, BOD, and suspended solids concentrations are indicative of treatment plant efficiency, they are just that, indicators, and not causual relationships governing the performance of a system.

No BOD_5 values were obtained for individual samples. However, often the COD values determined for composite samples were similar to those obtained for many of the individual samples taken during periods of hydraulic shock loading. Thus, while no explicit relationship between COD and BOD_5 was established, it can be assumed that the BOD_5 values for samples having similar COD values would also be similar. In this manner, it is possible to obtain organic loadings and aeration loadings for the periods of high flow. Table 5 lists the Kansas and Ten State Standards design criteria for aeration tank organic loading, pounds BOD_5 per pounds MLSS, and air requirements along with values obtained from this study at the design flow and at the peak hourly and daily flows.

From this analysis, it would appear that periods of hydraulic shock loading tend to overload the system organically even when the individual waste strengths may be no greater than those at low periods of flow and when the daily average flow is used instead of just the hourly peak flow. Also, the air supplied

Table 5. Summary of Aeration Tank Loadings

Design Criteria							Organic Loading (lb BOD_5/1000 ft^3)	lb BOD_5/lb MLSS	Air Requirement (ft^3/lb BOD_5/day)		
State of Kansas (9)							15	---	1500		
Ten State Standards (10)							12.5	0.10 to 0.05	2000		
Flow Period	Run	Day	Flow		BOD_5	MLSS			Air Supplied (% blower Air to diffusers)		
			Day gpd	Hour gpd	lb	mg/l			100	50	25
Design	I	1	2980		4.5	4330	10.8	0.04	17600	8800	4400
Peak Day	I	2	3775		6.5	4128	16.1	0.05	12800	6400	3200
" "	II	2	4445		6.5	5110	16.1	0.03	12200	6100	3050
" "	III	2	6535		12.0	5690	30.0	0.04	6580	3290	1645
Peak Hour	I	2		9900	19	(est.)	47.4		4170	2085	1043
" "	II	2		15100	32	(est.)	72.2		2470	1370	685
" "	III	2		25080	50	(est.)	125.2		1580	790	395

during periods of hydraulic shock loading seems to be less than that called for by the standards.

As has been mentioned, the blower on this plant supplied air for all of the systems and there was no way to determine how much air was being furnished to the diffusers alone. As the resistance to air flow would be greater through the diffusers than through either the sludge return pump or surface skimmer, it can be assumed that perhaps half of the air was going to the aeration tank, at best, even if the pump and skimmer were valved down but not off. Using this portion of the table, it can be seen that aeration requirements were not being met when the flow exceeded approximately 10,000 gpd on an hourly basis. However, as shown for Runs I and II, even at flows less than this, the dissolved oxygen in the aeration tank was recorded as being less than the 2.0 mg/l minimum level as required by the Ten State Standards, at times even reaching essentially zero for periods during the application of the shock load. As aeration requirements are generally based on the average daily flows, this would indicate a too low aeration design requirement to handle the probable occurrence of hydraulic shock loads.

On the other hand, even during periods of high wastewater flow and low aeration tank dissolved oxygen concentrations, the soluble effluent COD values, or that part of the organic waste of the influent that was not stabilized and synthesized into a bacterial cell mass, remained consistently low, going over forty milligrams per liter only once other than during Run III when flows were the highest. Generally, the soluble COD values were from one-half to two-thirds the total COD value, but during periods of shock loading, the values obtained were considerably less than one-half those of the total COD. This indicates that, at least for short periods of time, mixed liquor populations operating with the extended aeration process are able to adequately treat wastewater flows even when aeration tank DO concentrations approach zero.

Table 6 tabulates the clarifier surface overflow rates for the design and peak daily and hourly flows as found in this study. Using the procedure suggested by Seymour (12), rates are given using both raw wastewater influent alone and raw wastewater flow with the various recycle flows. It can be seen that at design flow none of the values obtained even approach the criteria maximum. However, for the daily average of the day of the medium overload, Run II, the rate is marginal with the inclusion of approximately three hundred percent recycle flow, and exceeded at only a two hundred percent recycle flow on the day of the maximum shock load, Run III. For the maximum hourly flow, the overflow rate criteria is exceeded at the highest flow studied with approximately two hundred percent recycle flow. Solids loss to the effluent occurred even at times when the overflow rate was within the limit set by the standards, indicating that the criteria are set too high.

The plant used in this study had no means for the determination of the sludge recycle flow rate. An attempt was made

Table 6. Summary of Surface Overflow Rates

Flow Period	Run	Day	Flow		Surface Area	Surface Overflow Rate			
			Day gpd	Hour gpd	ft^2	0% Recycle	100% Recycle	200% Recycle	300% Recycle
						gpd/ft^2			
Design	I	1	2980		60.3	49	99	148	198
Peak Day	I	2	3775		60.3	63	125	188	250
" "	II	2	4445		60.3	74	147	221	295
" "	III	2	6536		60.3	108	217	325	434
Peak Hour	I	2		9900	60.3	164	328	493	657
" "	II	2		15100	60.3	250	501	751	1002
" "	III	2		25080	60.3	416	832	1248	1664

State of Kansas criteria (9): 1200 gpd/ft^2 at maximum flow

Ten State Standards criteria (10): 300 gpd/ft^2

to bucket measure the flow, but the flow was such that the bucket filled before a time could be recorded. It is assumed that the flow was at least three times the raw wastewater flow and probably greater. This magnitude of flow was determined to be necessary in order to keep the sludge return pump and line from plugging. These large recycle flow rates seem to be a factor with package plants as Seymour (12) reported recycle flows of three hundred to six hundred percent in the three plants of his study, and stated that the manufacturers had indicated even higher recycle rates than those computed, even though the Ten State Standards (10) call for a maximum recycle rate of only two hundred percent. Thus, it would appear that the technical design of the sludge return mechanism is insufficient to maintain low rates of recycle flow without plugging, or that design criteria and practice are inconsistent or erroneous in the choice of which flow into the clarifier to use as a standard. It seems logical to include the recycle rate in the flow that is most likely to be encountered in the field operation of the plant.

As was reported by Seymour (12), the solids loading rates, given in Table 7, also show an increase with increasing percentages of recycle flow included in the flow computation. Although no criteria are listed, ASCE MOP No. 36 (13) lists solids loadings rates of from twelve to thirty psf per day being used in field operations. However, as Seymour noted, these data can generally be considered to have come from large-scale plants

Table 7. Summary of Solids Loading Rates for Clarifier

Flow Period	Run	Day	Flow		Infeed (MLSS)	Solids Loading Rate			
			Day gpd	Hour gpd	mg/l	0% Recycle	100% Recycle	200% Recycle	300% Recycle
						psf/day			
Design	I	1	2980		4330	1.8	3.6	5.3	7.1
Peak Day	I	2	3775		4130	2.0	4.0	6.0	8.0
" "	II	2	4445		5110	2.7	5.4	8.1	10.8
" "	III	2	6535		5690	5.1	10.2	15.4	20.6
Peak Hour	I	2		9900	3660	5.0	10.0	15.0	20.0
" "	II	2		15100	4630	9.7	19.3	29.0	38.6
" "	III	2		25080	4895	17.0	33.9	50.9	77.9

$$\text{Solids loading rate} = \frac{\text{infeed (mg/l) x overflow rate}}{120{,}000}$$

rather than package plants, and thus are possibly not applicable to smaller, extended aeration treatment units.

The decrease in the mixed liquor concentration was thought to be a result of the sludge return pump, operating at constant flow, being unable to keep up with the increased inflow to the clarifier during periods of shock loading. This naturally would result in an increase in the amount of solids in the clarifier, possibly enhancing the loss of solids to the effluent. The attempts to increase the solids percentage of the recycle flow in Run III as inferred by Nicoll (2) were inconclusive and seemed neither to increase the mixed liquor concentration nor decrease the loss of solids to the effluent.

From Tables 6 and 7, it can be seen that at the lowest shock loading, 9,900 gpd, the air supply was acceptable to marginal in comparison with the criteria and below the limit set for the clarifier surface overflow rate. Even for the medium overload, 15,100 gpd, the values are only marginal. It was not until the maximum overload, 25,080 gpd, was reached that the criteria were uniformly exceeded. Thus, this does not seem to explain the solids unloading witnessed during the first two weeks of Run I, especially when other tests at comparable flow rates exhibited no solids loss. These first two weeks were during the period of lowest mixed liquor concentrations and the first weeks of the hydraulic shock loading applications. A possible explanation of the solids loss could be that the viable population was not yet adequately established.

CONCLUSIONS

1. The extended aeration process can effectively treat wastewater flows during periods of hydraulic shock loading by converting the influent organic load into bacterial cell mass even if the available dissolved oxygen goes to essentially zero for short periods of time. This treatment is not shown by the normal effluent tests, but only by soluble COD or BOD determinations.

2. The treatment efficiency of the process, as shown by the normal COD or BOD tests, is greatly diminished by the solids loss to the effluent during some periods of hydraulic overload. This is a result of poor physical treatment in the clarifier.

3. Solids loss to the effluent is a factor during hydraulic shock loading of extended aeration plants. This appears to result from underdesign of the clarifier, due possibly to a failure to include sludge recycle flow rates into the surface overflow rate calculation, or a failure to account for the probable occurrence of hydraulic shock loads to the plant. It may also result from a solids buildup in the clarifier due to the inability of the sludge return mechanism to keep up with the inflow to the clarifier.

4. There is an indication that the air requirements normally accepted for design are inconsistent with the results obtained for extended aeration plants operating under hydraulic shock loading conditions. In this study, air requirements were frequently not maintained during overload, but organic removal

by the microbial mass continued as has been noted. For longer periods of shock loading, it seems apparent that the criteria do not specify adequate air to maintain aerobic conditions in the aeration tank. This could lead to decreased treatment efficiency under the variable flow conditions encountered by package plants.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Further examinations are required at other ranges of mixed liquor concentrations, both higher and lower, than those used in this study. These tests could indicate both the effect on treatment efficiency of the mixed liquor concentration and the period of time that the process can operate effectively before sludge wasting is required when hydraulic shock loads are encountered.

2. This study was conducted entirely during the summer months. Results obtained during the winter months would also be valuable, particularly during periods of low flow when the problems of freeze-up, and the subsequent reaction during shock loading, would be most critical.

3. More information is needed on the oxygen requirements of extended aeration treatment plants operating both normally and under the influence of hydraulic shock loading in order to obtain more relevant values to be used as design criteria. Also of interest would be data on the length of time that extended aeration facilities can effectively operate with low aeration tank dissolved oxygen concentrations.

REFERENCES

1. Middlebrooks, E. J. and Garland, C. F., "Kinetics of Model and Field Extended-Aeration Wastewater Treatment Units," Journal of the Water Pollution Control Federation, Vol. 40, No. 4, April, 1968.

2. Nicoll, E. H., "Extended Aeration in British Package Plants," Journal of the Water Pollution Control Federation, Vol. 43, No. 2, February, 1971.

3. Morris, G. L., Van Den Berg, L., Culp, G. L., Geckler, J. R. and Porges, R., "Extended-Aeration Plants and Intermittant Watercourses," U. S. Public Health Service Publication No. 999-WP-8, Cincinnati, Ohio, Robert A. Taft Sanitary Engineering Center, July, 1963.

4. Briscoe, E. R. E., "Extended Aeration and Its Applications," Journal of the Institute of Water Pollution Control, Vol. 66, No. 4, 1967.

5. Ludzack, F. J., "Observations on Bench-Scale Extended Aeration Sewage Treatment," Journal of the Water Pollution Control Federation, Vol. 37, No. 8, August, 1965.

6. Pillai, N., Wheeler, W. C. and Prince, R. P., "Design and Operation of an Extended Aeration Plant," Journal of the Water Pollution Control Federation, Vol. 43, No. 7, July, 1971.

7. Pfeffer, J. T., "Extended Aeration," Water and Sewage Works, Vol. 113, June, 1966.

8. McCarty, P. L. and Broderson, C. F., "Theory of Extended Aeration Activated Sludge," Journal of the Water Pollution Control Federation, Vol. 34, No. 11, November, 1962.

9. Kansas State Department of Health, Environmental Health Services, "Policies Governing the Design of Sewerage Systems in Kansas," (with tentative addition for Extended Aeration), Topeka, Kansas, 1957.

10. Committee of the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, Health Education Service, "Recommended Standards for Sewage Works," Albany, New York, 1968.

11. Eye, D. J., Eastwood, D. P., Requena, F. and Spath, D. P., "Field Evaluation of the Performance of Extended Aeration Plants," Journal of the Water Pollution Control Federation, Vol. 41, No. 7, July, 1969.

12. Seymour, S. G., "Operation and Performance of Package Treatment Plants," Journal of the Water Pollution Control Federation, Vol. 44, No. 2, February, 1972.

13. American Society of Civil Engineers, "Sewage Treatment Plant Design," Manual of Engineering Practice No. 36 (Water Pollution Control Federation Manual of Practice No. 8), New York, 1959.

14. Water Pollution Control Federation, "Operation of Wastewater Treatment Plants," Manual of Practice No. 11, Washington, D. C., 1966.

15. Ramanathan, M., Gaudy, A. F., Jr., and Ragthaidee, W., "Responses of Extended Aeration Activated Sludge to Quantitative Shock Loads," Proceedings of the 19th Oklahoma Industrial Wastes and Pollution Control Conference, Stillwater, Oklahoma, 1968.

16. American Public Health Association, Inc., Standard Methods for the Examination of Water and Wastewater, Twelfth Edition, New York, 1965.

17. Sawyer, C. N. and McCarty, P. L., Chemistry for Sanitary Engineers, Second Edition, New York, McGraw Hill Book Company, 1967.

18. Hurwitz, E., Barnett, G. R., Beaudoin, R. E. and Kramer, H. P., "Nitrification and BOD," Sewage Works Journal, Vol. 19, No. 6, November, 1947.

19. Smith and Loveless, "Factory Built 'Oxigest' Extended Aeration Treatment Plant Operation and Maintenance," Lenexa, Kansas.

APPENDIX

Table 8. Summary of Data for Week 1, Run I

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD	BOD_5	COD mg/1	MLSS mg/1	% Vol.	SDI
26 Jun	1500	5000	3.0	480	185		40	20		92					
	2100	4500	4.3	1115	980		59	16		95					
27 Jun	0300	1500	5.4	395	155		190	11		52					
	0900	2500	5.3	410	160		28	9		93					
Composite		3660		755	580	250	44	12	33	84	96	36			
	1200	4000	4.1	460	210		51	38		89			3930		
	1300	5500	3.6	560	310		44	22		92					
	1400	8000	2.8	480	230		55	22		88					
	1500	10000	2.1	560	260		600	510		0			3205		0.337
	1600	10000	1.9	445	170		825	720		0					
	1700	6500	2.9	395	140		62	28		84					
	1800	5500	3.5	370	160		63	14		83			3230		0.344
	2100	4000	4.1	415	70		51	28		88					
28 Jun	0300	2000	5.4	280	190		44	14		85					
Composite		4225		455	160	235	292	210	33	36	83	12			
	1200	4750	4.3										3490		0.371
	1500	5500	3.4	380			59			84					
	2100	4500	3.9	310			51			84					
29 Jun	0300	1000[a]	5.8	405			44			89					
Composite		3110		425	210	205	44	22	<30	90	98	20			
	1200	0	5.2										3875		

Note: a. Vacuum and flow off 0315 to 1500 29 June 1972

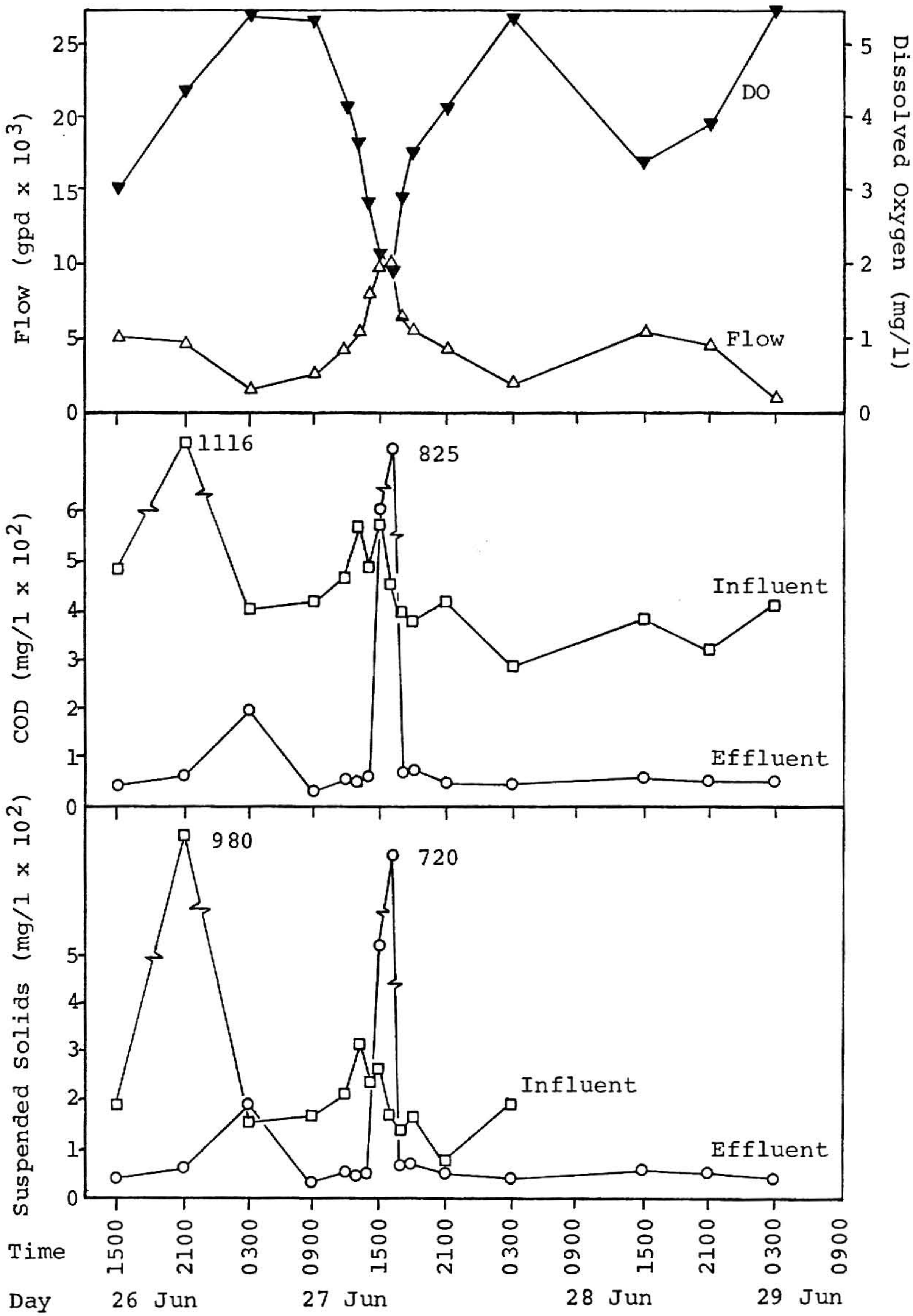

Figure 8. Summary of Data for Week 1, Run I

Table 9. Summary of Data for Week 2, Run I

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD	BOD_5	COD mg/1	MLSS mg/1	% Vol.	SDI
2 Jul	1500	9000[a]		430	360		128	130		70					
	2100	9000		250	145		140	163		44					
3 Jul	0300	2000		325	200		24	22		93					
	0900	2500		515	40		20			96					
Composite		5360		570	240	65	108		7	81	91	20			
	1200	3750	4.5	365	220		24			93			3375		
	1300	6500	3.8	730	260		32	14		96					
	1400	9500	2.5	710	600		52	24		93					
	1500	11500	2.0	650	310		404	320		38			3020		
	1600	10500	1.5	630	290		44	28		93					
	1700	7000	2.1	490	210		52	36		89					
	1800	6000	2.7	380	160		44	18		89			3280		
	2100	4000	4.2	460	130		32	6		93					
4 Jul	0300	2000	5.6	425	150		24			94					
	0900	22500[b]	3.4	190	70		1498	1380		0					
Composite		5695		350	210	115	724	640	44	0	64	20			
	1200	7500	2.0										3470		
	1500	4500	3.1	505	140		28	30		94					
	2100	4000	4.7	355	230		28	36		92					
5 Jul	0300	1000		365	290		28	38		92					
	0900	2000		170	220		32	38		81					
Composite		3170		375	130	70	44		<17	88	98	32			
	1200	3750											3990		
6 Jul	1200	3750											3660		

Notes: a. Excess flow until 2230 2 July 1972 due to new belt.

b. Vacuum and flow off 0700 to 0900 4 July 1972. Adjusted by Manhattan plant personnel 0900 to 1000. Reduced 1000 to 1300. Placed on diurnal flow at 1300.

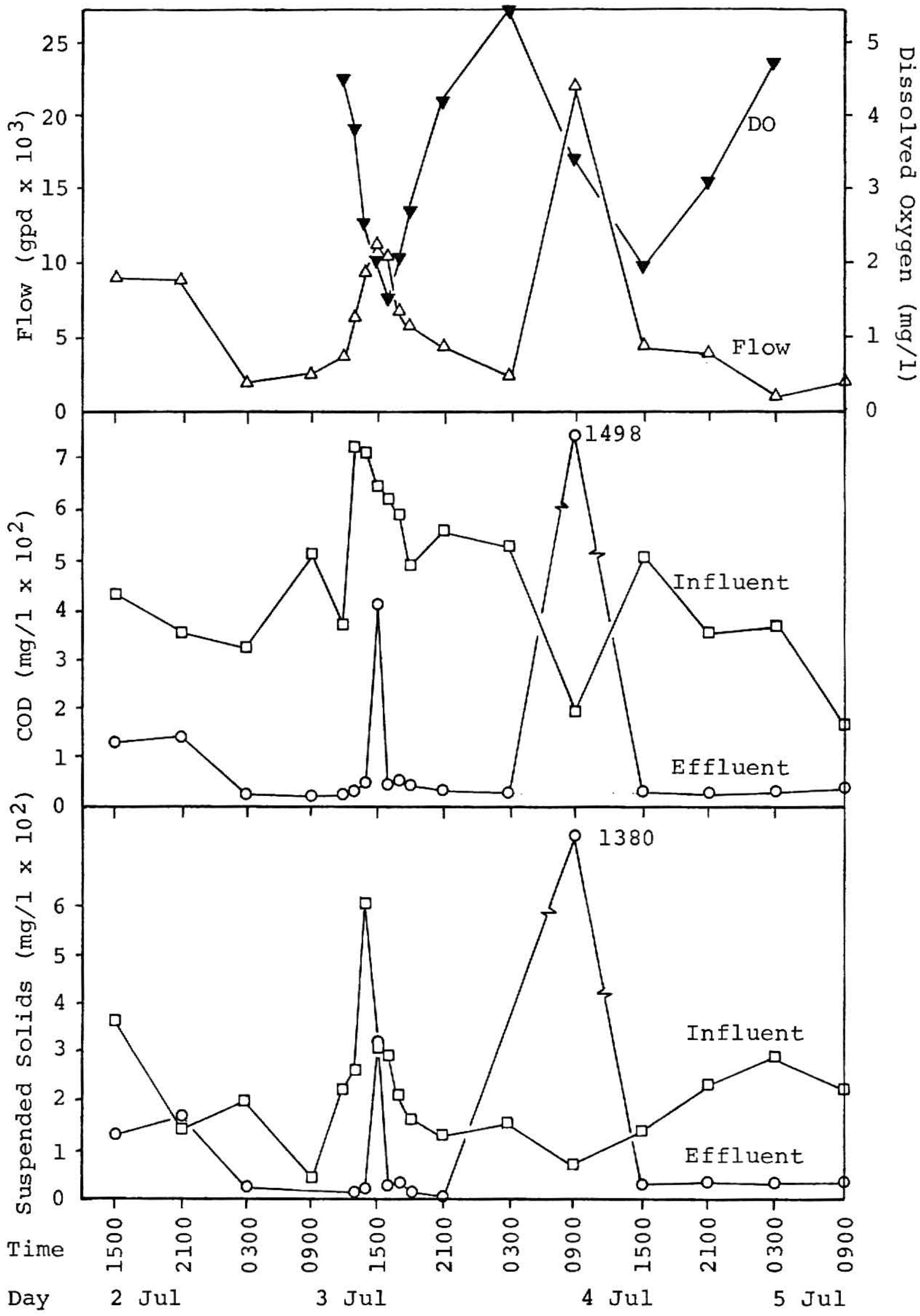

Figure 9. Summary of Data for Week 2, Run I

Table 10. Summary of Data for Week 3, Run I

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
9 Jul	1500	4500	2.1	535	50		131			76					
	2100	3500	1.2	350			47			86					
10 Jul	0300	1500	3.4	185			24			87					
Composite		2890		335	220	170	0	2	<8	100	96	8			
	1200	2500	2.4	650	140		8	10		99			4395	74	
	1300	5000	1.8	490	225		16	20		97					
	1400	7500	0.8	445	310		44	18		90					
	1500	9500	0.5	600	330		32	7		95			3690	65	
	1600	9500	0.4	480	250		28	14		94					
	1700	6000	0.6	685	190		24	18		97					
	1800	6000	1.1	395	140		32	11		92			3990	76	
	2100	3000	2.2	470	230		16	11		97					
11 Jul	0300	1000	4.0	335	70		28	6		92					
	0900	1500	4.2	210	75		20	15		90					
Composite		3775		525	290	210	4	20	<8	99	96	0			
	1300	3000	3.7										4240	69	0.451
	1500	4500	3.0	405	190		32	5		92					
	2100	3500	3.4	380	240		32	5		92					
12 Jul	0300	1250	5.5				24	7							
	0900	3000	5.9	320	100		28	8		91					
Composite		3000		335	210	170	0	14	<8	100	96	0			
	1300	2500	4.5										2180[a]	67	
13 Jul	1400	4250	2.1										2570[a]	72	0.857

Note: a. Sludge return inoperative.

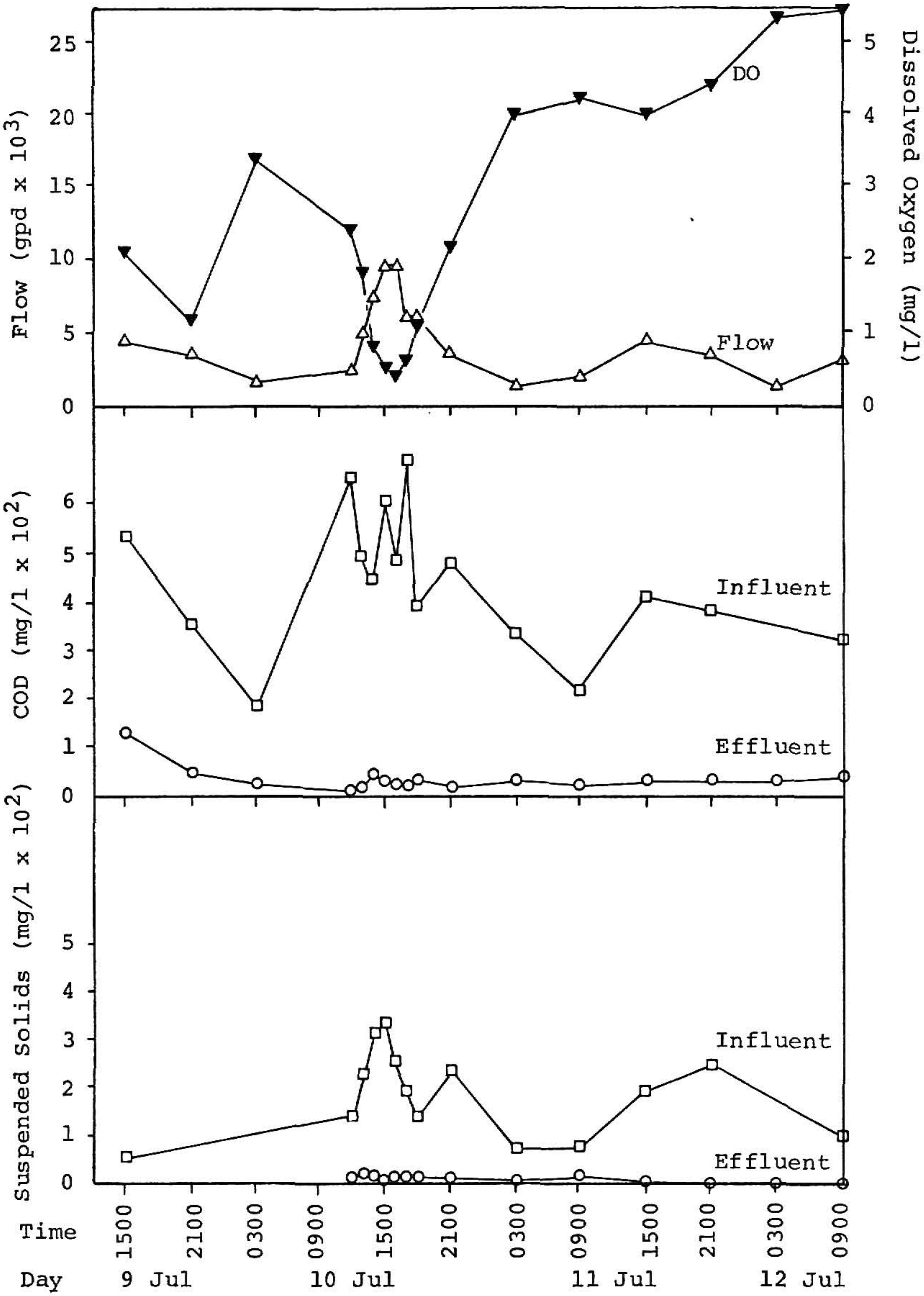

Figure 10. Summary of Data for Week 3, Run I

Table 11. Summary of Data for Week 4, Run I

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
16 Jul	1300	3500	3.4										4600		
	1500	4000	3.1	445	150		13	7		97					
	2100	3250	3.2	340	70		20	6		94					
17 Jul	0300	1500	4.5	260	40		25	8		91					
	0900	2250	4.1	495	170		25	17		95					
Composite		2660		375	140	125	36	18	<6	90	99	18			
	1200	2500	2.6	480	190		20	7		96			4640	71	0.884
	1300	4500	2.7	585	270		29	12		95					
	1400	7000	1.6	550	200		33	15		94					
	1500	8500	1.0	565	220		29	17		95			4475	72	0.746
	1600	8500	1.0	495	240		25	22		95					
	1700	4500	1.8	390	190		13	14		97					
	1800	5000	2.4	345	130		13	8		96			4620	72	
	2100	3000	3.5	335	220		22	10		93					
18 Jul	0300	1750	5.1	250	190		22	4		91					
	0900	2500	5.1	395	220		27	7		93					
Composite		3735		400	130	170	32	12	<6	92	99	27			
	1300	3500	4.2										4560	75	1.140
	1500	4500	3.6	795	310		35	8		96					
	2100	3250	3.5	405	190		27	13		94					
19 Jul	0300	1500	4.9				35	16							
	0900	2000	4.9	260	120		40			85					
Composite		2920		480	150	185	36	8	<6	99	99	27			
	1400	4000	3.6										4625	74	
20 Jul	1400	3000	3.4										4975	75	0.682
21 Jul	1400	2500	4.0										4865	76	0.685

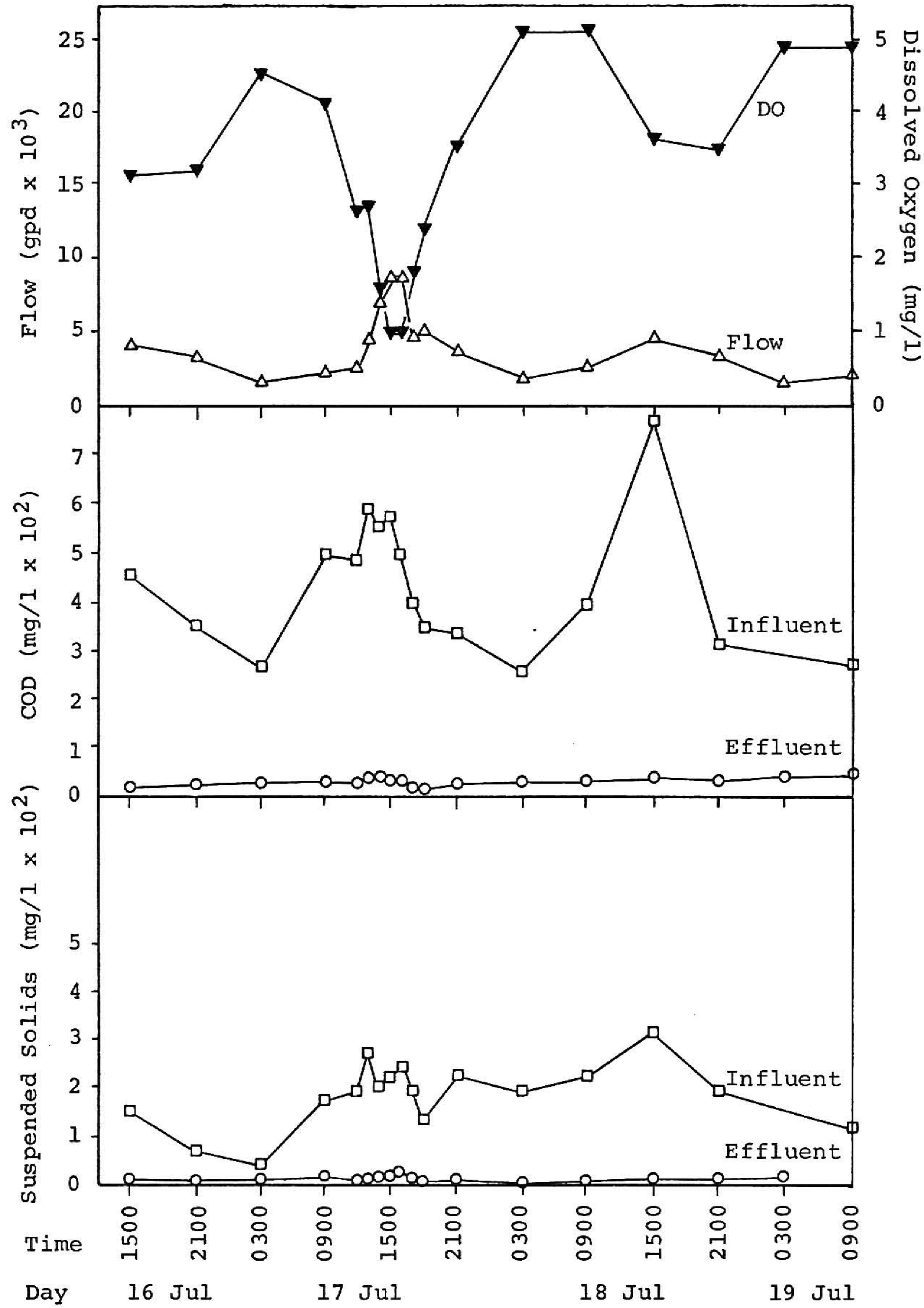

Figure 11. Summary of Data for Week 4, Run I

Table 12. Summary of Data for Week 5, Run I

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
23 Jul	1100	2750											4760	65	
	1500	4000		430	170		22	10		95					
	2100	3250		335	100		31	11		91					
24 Jul	0300	1250		250	110		27	6		89					
	0900	2000					18	9							
Composite		2700		380	110	175	18	7	<3	95	99	27			
	1200	2000		450	220		27	8		94			4610	65	
	1300	6000		490	260		27	10		95					
	1400	8000		535	350		31	8		94					
	1500	10000		515	290		27	35		95			3930	64	1.572
	1600	10000		455	180		31	12		93					
	1700	6600		365	100		42	13		88					
	1800	5000		545	160		45	8		92			4380	67	0.658
	2100	2500		425	130		33	11		92					
25 Jul	0300	1250		400	90		38	6		91					
	0900	1500		265	55		42	14		84					
Composite		3375		420	180	210	22		<3	95	99	13			
	1300	2250											4870	71	
	1500	4000		460	140		38	14		92					
	2100	2750		395	80		42	10		89					
26 Jul	0300	1000					33	15							
	0900	1500		290	70		45	12		84					
Composite		2350		440	90	190	18	5	<3	96	99	9			
	1300	2000											4835	68	0.744
27 Jul	1300	2500											4750	70	0.915
28 Jul	1300	2500											5015	71	0.697

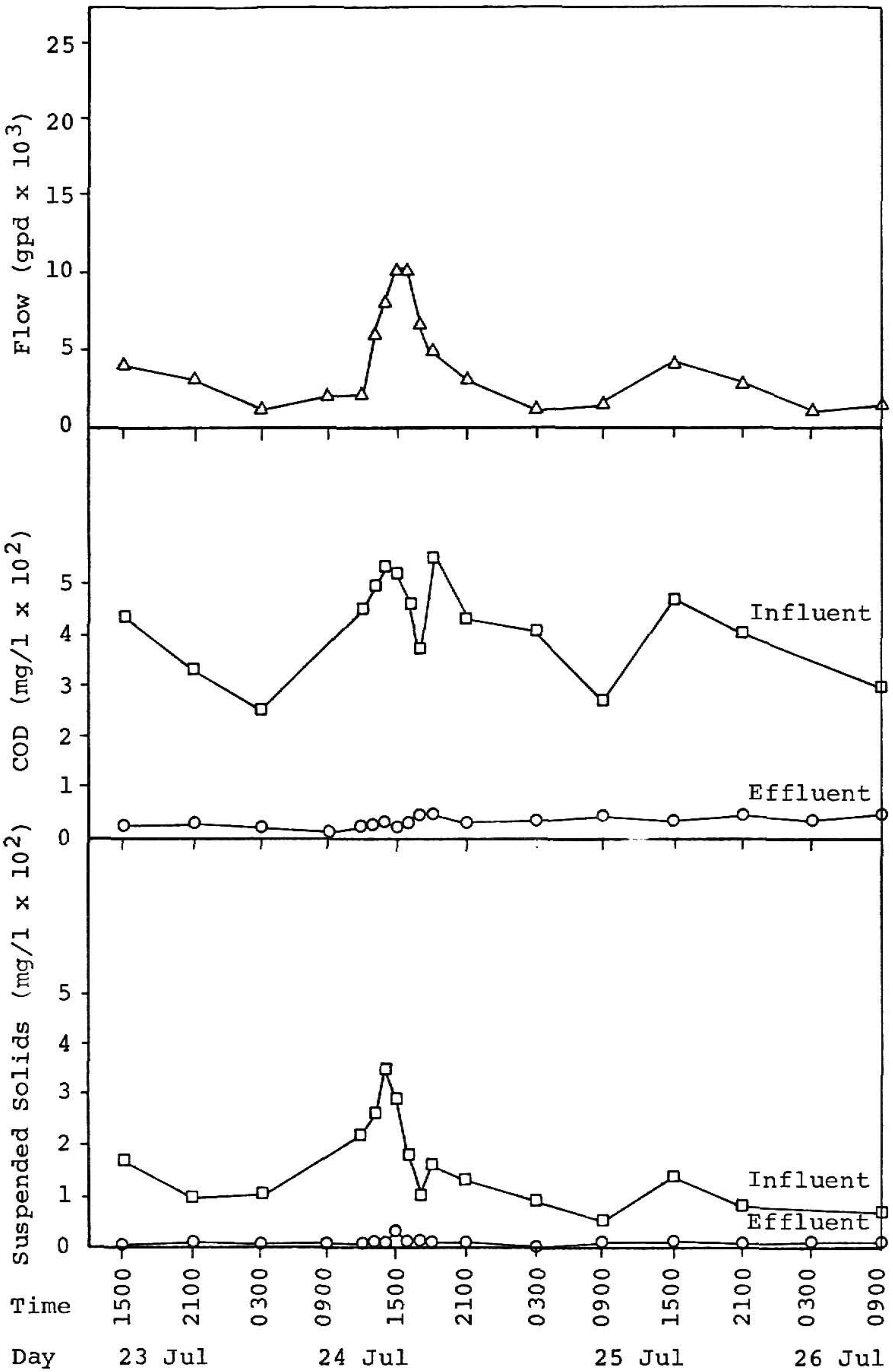

Figure 12. Summary of Data for Week 5, Run I

Table 13. Summary of Data for Week 6, Run II

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
30 Jul	1500	3500	3.7	435	190		32	13		93					
	2100	2500	4.0	330	100		32	11		90					
31 Jul	0300	1000	5.5	235	60		36	14		85					
	0900	1500	5.4				28	12							
Composite		2320		340	110	140	25	11	<2	93	99	33			
	1200	2660	4.2	480	150		40	11		92			4463	77	
	1300	3240	3.8	490	190		40	9		92					
	1310	4900	3.6	685	440		40	11		94					
	1320	10100	3.4	1705	1460		44	16		97					
	1330	12700	2.4	800	560		32	18		96					
	1345	15100	1.2	685	340		64	23		91					
	1400	15100	1.0	560	220		56	24		90					
	1500	14300	0.9	775	240		64	29		92			4170	80	1.191
	1600	15100	0.7	580	320		56	33		90					
	1630	15100	0.6	425	140		72	31		83					
	1645	9500	0.7	460	180		68	27		85					
	1700	5200	0.8	440	170		60	30		86					
	1800	5000	1.1	435	170		60	17		86			4450	77	
	2100	2750	2.6	400	160		48	6		88					
1 Aug	0300	1750	4.3	370	40		37	9		90					
	0900	2500	4.7	290	50		41	8		85					
Composite		4335		490	190	175	49	23	4	90	98	33			
	1300	3250	3.9										4420	77	0.589
	1500	5000	3.0	500	130		33	9		93					
	2100	4000	3.0	420	170		33	9		92					
2 Aug	0300	2000	4.4				45	8							
	0900	3000	4.6	385	140		29	12		93					
Composite		3550		435	190	180	25	15	3	94	99	33			
	1400	3500	2.9										4920	76	0.656
3 Aug	1300	4500	3.8										4410[a]	76	1.131

Note: a. Sludge return inoperative.

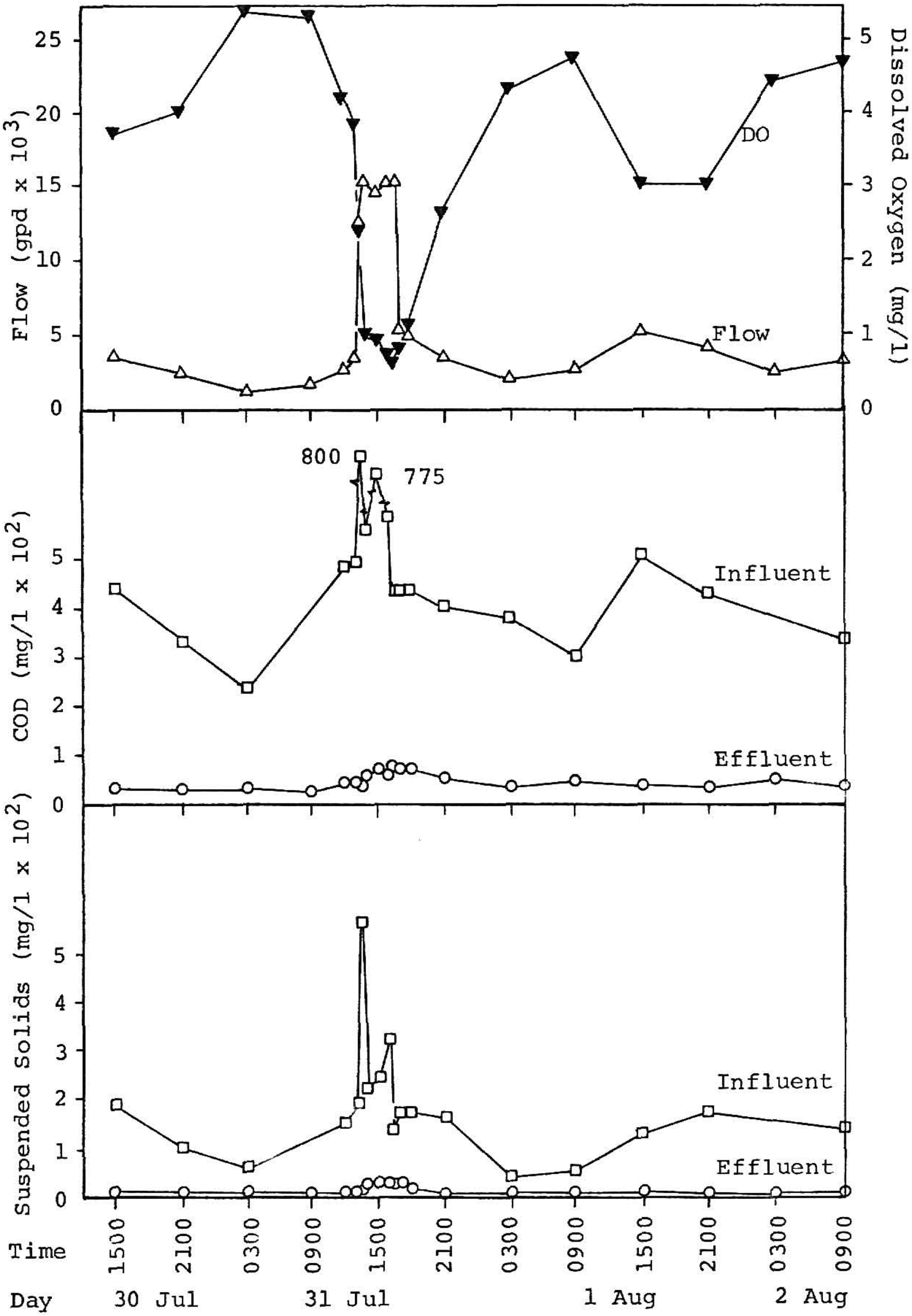

Figure 13. Summary of Data for Week 6, Run II

Table 14. Summary of Data for Week 7, Run II

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
6 Aug	1100	3500											4870	67	
	1500	5000		520	360		66	17		87					
	2100	4000		420	150		66	17		84					
7 Aug	0300	2500		425	160		62	17		85					
	0900	3000					46	15							
Composite		3750		400	210	185	33	15	4	92	99	33			
	1200	3170	3.0	635	210		46	14		93			4915	70	
	1300	8060	2.2	2170	1970		58	13		97					
	1315	12100	1.2	1050	810		58	17		95					
	1330	15100	0.4	855	420		58	28		93					
	1400	15100	0.2	580	260		62	23		89					
	1500	15100	0.2	585	280		57	24		90			4440	65	1.233
	1600	15100	0.1	640	220		53	40		92					
	1630	15100	0.1	500	160		62	32		88					
	1645	9500	0.2	390	150		62	30		84					
	1700	5040	0.2	445	120		57	29		87					
	1800	5190 a		345	120		56	25		84			4920	67	
	2100			345	150		40	15		88					
8 Aug	0300			405	140		40	12		90					
	0900			215	60		44	15		79					
	1300	b	2.4										5245	66	0.664
	1500	5000		575	170		20	9		97					
9 Aug	1400		2.0										6035	68	0.702
	1500	4500	2.8	410	220		29	32		93					
	2100	3750	2.6	415	170		29	13		93					
10 Aug	0300	1000	5.2	390			29	14		91					
Composite		2810		390	150	190	20	17	6	95	97	20			
	1400		2.5										5575	69	0.688
11 Aug	1400	3500											5265	69	1.120

Notes: a. Flow meter off 1815 7 August to 1300 8 August 1972; no composite.

b. Flow off 1800 8 August to 1330 9 August 1972.

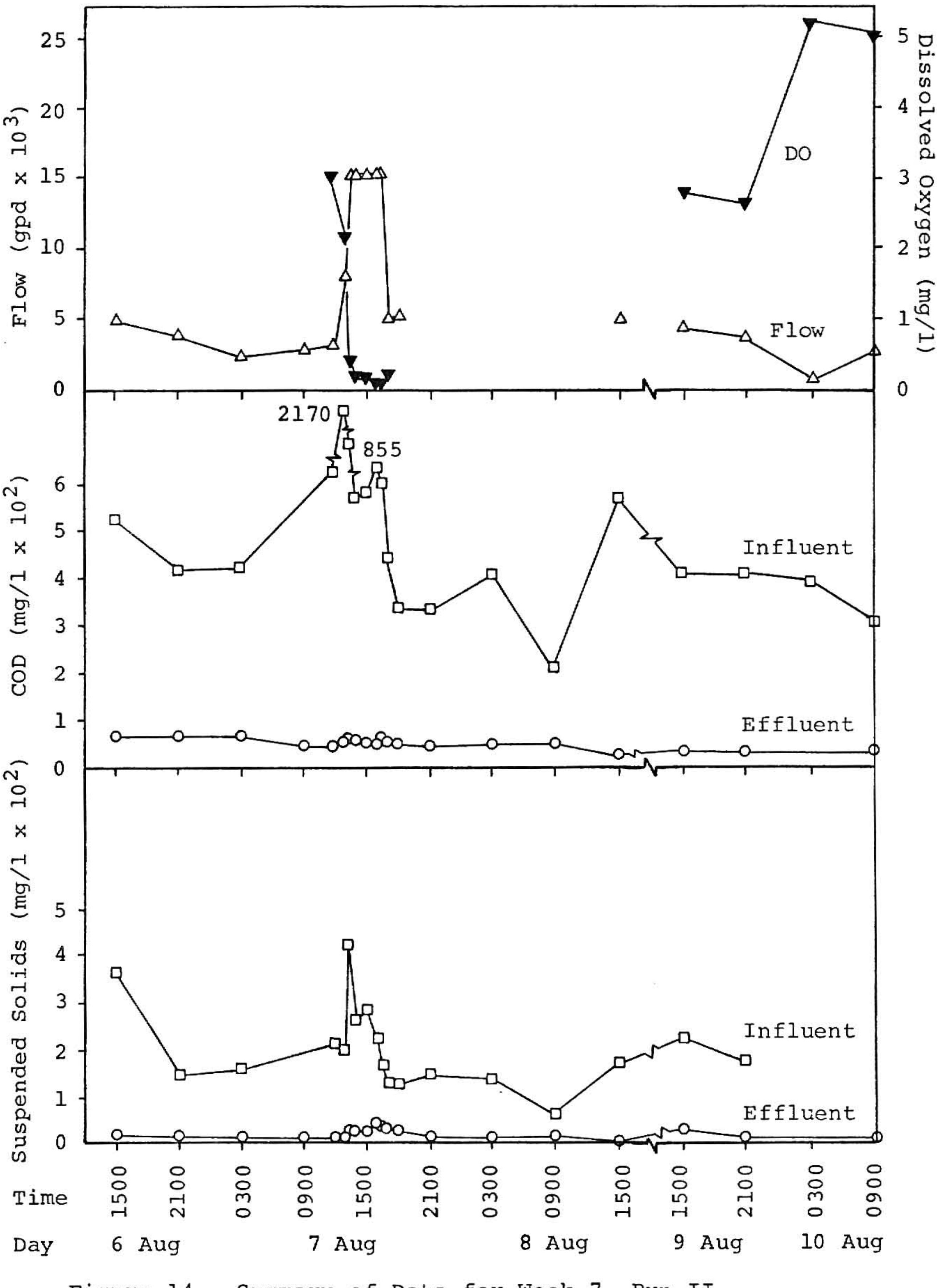

Figure 14. Summary of Data for Week 7, Run II

Table 15. Summary of Data for Week 8, Run II

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD	BOD_5	COD mg/1	MLSS mg/1	% Vol.	SDI
13 Aug	1500	4000		405	180		41	20		90					
	2100	3000		330	140		34	17		90					
14 Aug	0300	1000		325	130		34	18		90					
	0900	1750		195	140		46	20		76		44			
Composite		2530		385	160	135	36	16	<2	91	99	36			
	1200	2450	3.1	480	170		36	16		93			5360	65	0.734
	1300	8500	2.0	3915	4320		37	20		99					
	1315	12950	0.8	580	580		39	26		93					
	1330	15100	0.2	470	260		39	20		92					
	1400	15100	0.1	475	260		46	27		90		23			
	1500	15300	0.1	465	220		60	33		87		23	5280	69	1.427
	1600	15100	0.1	455	220		58	25		87		23			
	1630	15100	0.1	405	160		57	29		86		37			
	1645	9200	0.3	455	180		66	30		86		43			
	1700	5180	0.4	430	140		55	39		87		35			
	1800	5040	0.4	375	130		49	23		87		28	5305	67	
	2100	3250		410	110		46	17		89		28			
15 Aug	0300	1000		355	100		38	15		89					
	0900	1500		250	50		36	14		86					
Composite		4565		450	190	170	46	24	3	90	99	39			
	1300	3500											5675	68	0.946
	1500	4500		265	60		39	11		86					
	2100	3500		490	170		25	16		95					
16 Aug	0300	1500		260	120		33	12		88					
	0900	2000		555	130		40	20		93		24			
Composite		3020		390	180	145	31	13	3	92	99	26			
	1300	3000											5725	66	1.396
17 Aug	1300	3000											5650	68	1.378
18 Aug	1300	3000											5625	68	1.480

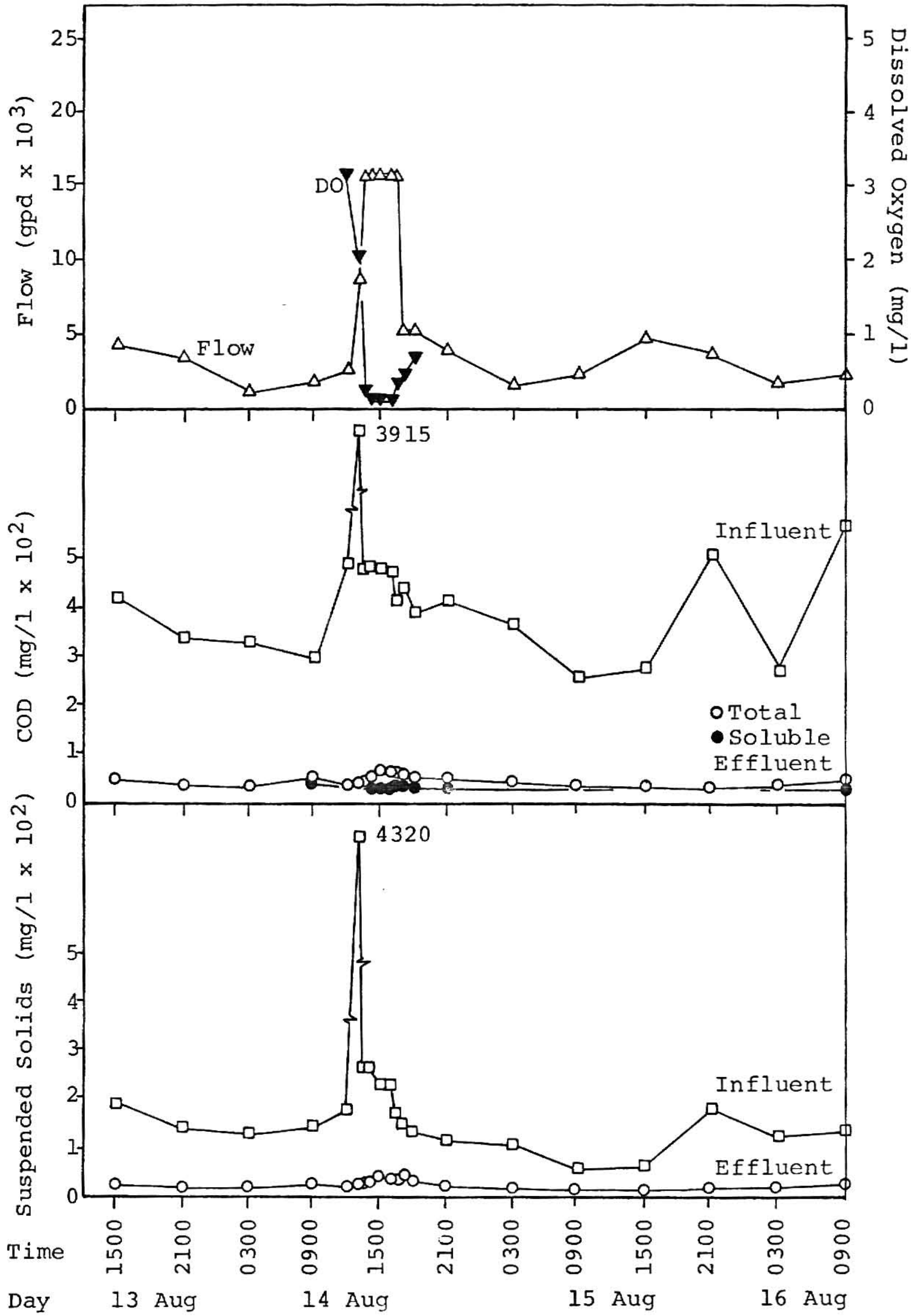

Figure 15. Summary of Data for Week 8, Run II

Table 16. Summary of Data for Week 9, Run III

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
20 Aug	1500	4500	1.8	455	210		74	62		84		29			
	2100	4500	2.6	395	180		61	46		85		42			
21 Aug	0300	2000	4.1	375	160		43	25		89					
	0900	2500	4.2	155	55		44	25		72		41			
Composite		3450		355	70	105	60	28	3	83	98	34			
	1200	3170	2.9	585	170		47	19		92		37	5935	66	1.798
	1300	15120	2.2	4295	5200		57	49		99		27			
	1315	19000	0.6	655	270		59	37		91		24			
	1330	25920	0.2	565	170		69	48		88		21			
	1400	25920	0.1	615	200		69	50		89		24			
	1500	22460	0.1	550	240		79	54		86		25	4765	67	1.702
	1600	22460		465	250		88	80		81		27			
	1630	22460		470	350		88	84		81		49			
	1645	12960		470	420		85	66		82		38			
	1700	5470		370	260		77	72		79		30			
	1800	5180		405	190		64	38		84		28	5630	66	
	2100	3500		455	150		51	30		89		29			
22 Aug	0300	2000		385	180		43	18		89		27			
	0900	2500		230	120		40	17		83					
Composite		6135		515	140	190	60	40	6	88	98	51			
	1300	3000											5650	68	0.774
	2100	3500		820	360		31	12		96					
23 Aug	0300	1500		380	120		34	12		91					
	0900	2250		180	90		38	16		79					
Composite		3070		515	190	235	35	4	3	93	99	26			
	1300	3000											6260	65	1.423
24 Aug	1400	4000											5755	66	0.811
25 Aug	1300		4.2										5665	67	1.416

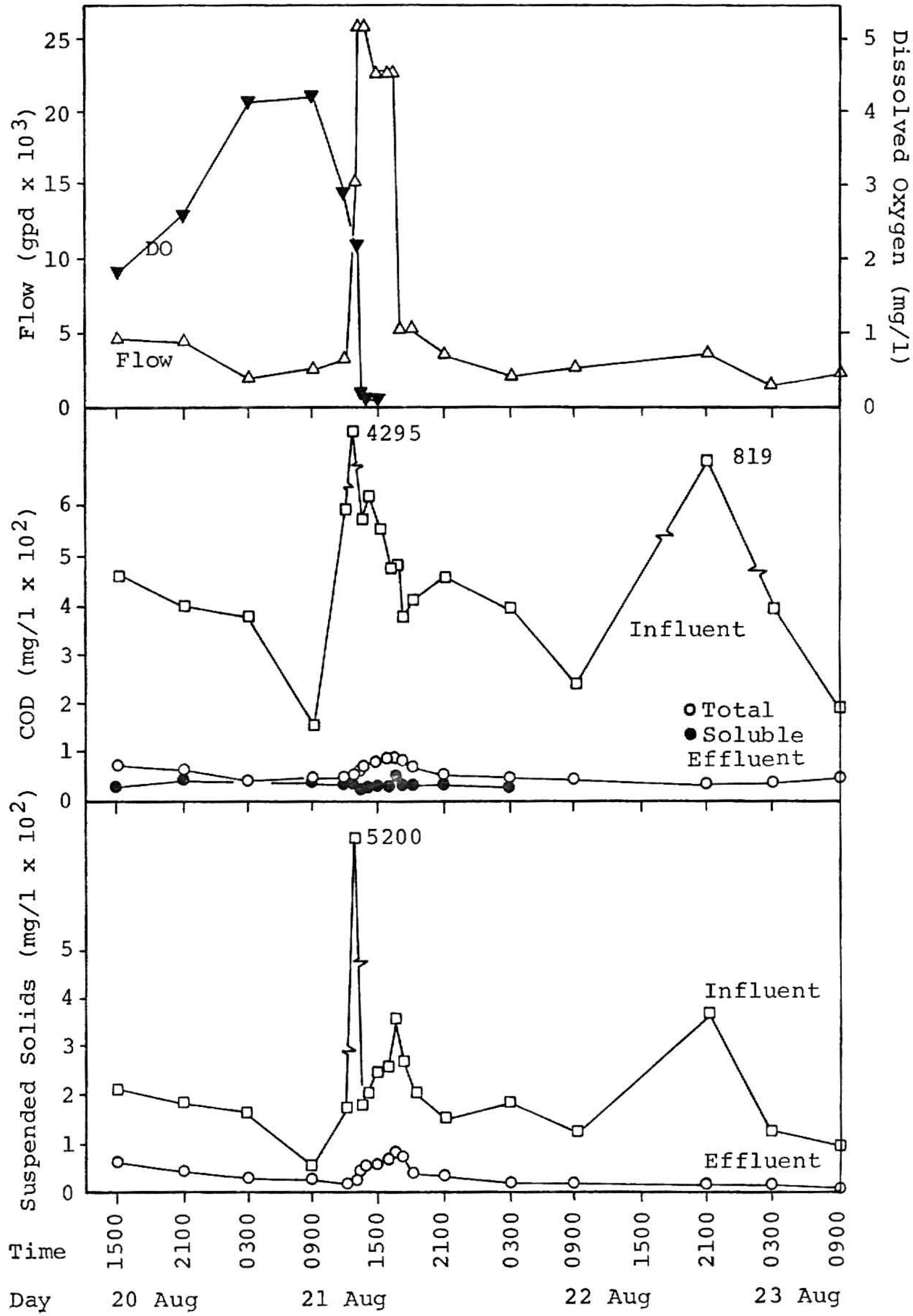

Figure 16. Summary of Data for Week 9, Run III

Table 17. Summary of Data for Week 10, Run III

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD mg/1	SS mg/1	BOD_5 mg/1	COD	BOD_5	COD mg/1	MLSS mg/1	% Vol.	SDI
27 Aug	1500	a		600	260		37	14		94					
	2100			295	100		31	8		90					
28 Aug	1300	3600	1.0	610	200		50	28		92		49	5635	66	0.880
	1330	11502	0.8	1045	4470		58	28		95		28			
	1345	15550		315	320		55	32		82		26			
	1400	24500		870	500		68	40		93		24			
	1500	25000		530	280		163	130		66		24	4465	67	
	1600	25000		685	220		165	132		76		26	4470	71	1.490
	1700	25000		400	150		164	122		59		50			
	1715	12700		405	160		93	50		77		41			
	1730	5760		445	170		75	38		83		35			
	1800	5760		390	180		77	42		80		35	5410	66	
	2100			460	290		67	30		86		57			
29 Aug	0300						47	22				35			
	0900			175	60		46	26		74		29			
	1300												5870	67	
	1500			430	170		41	50		90					
	2100			445	190		47	20		90		25			
30 Aug	0300			280	130		40	23		86					
	0900			340	170		73	19		79		24			
	1300												5775	68	0.704

Note: a. Flow meter inoperative; no composite.

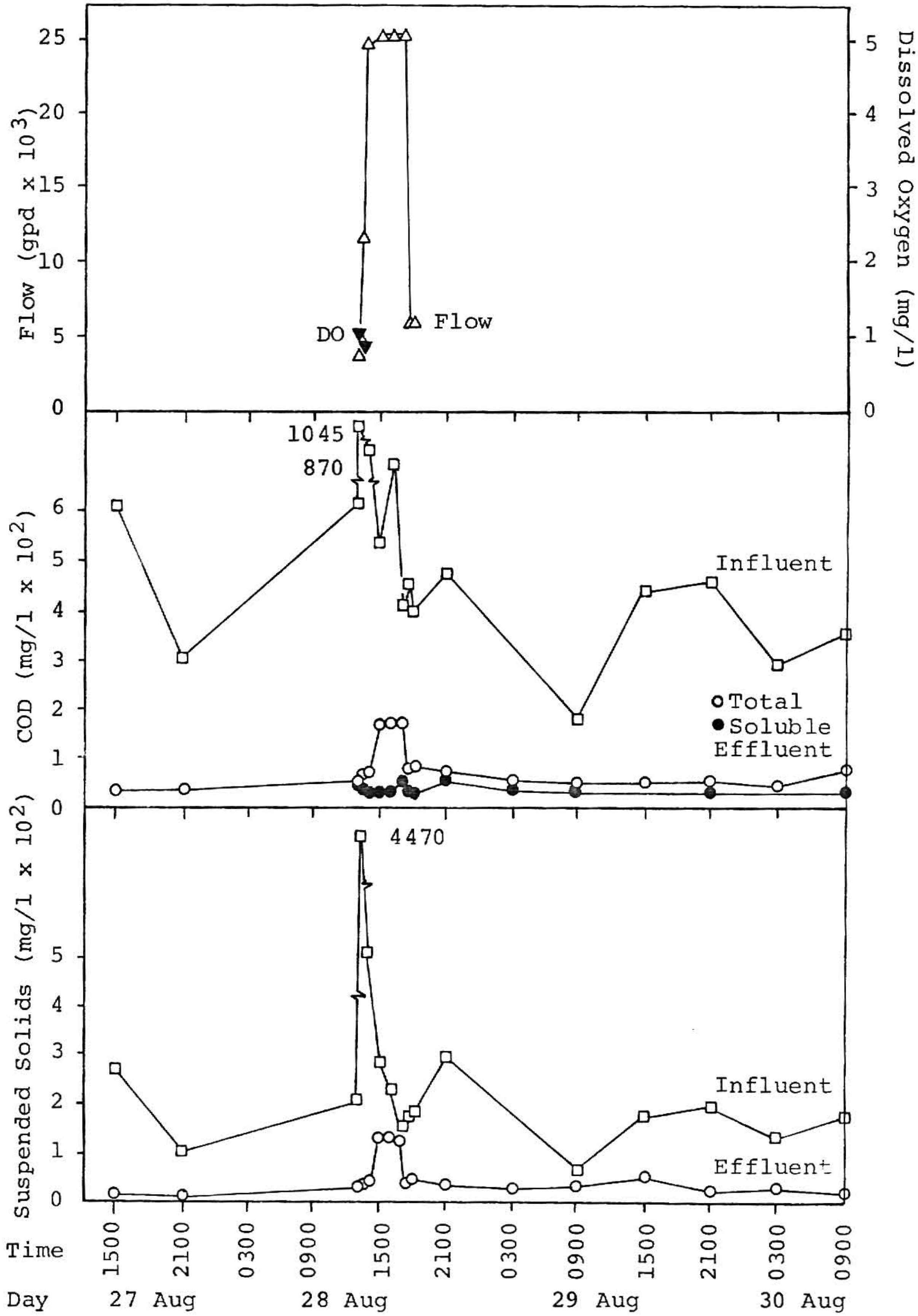

Figure 17. Summary of Data for Week 10, Run III

Table 18. Summary of Data for Week 11, Run III

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
17 Sep	1300	4000											5875	63	
	1500	4750		590	400		35	19		94					
	2100	3750		300	190		83	20		72		27			
18 Sep	0300	1500					34	22							
	0900	2250		250	150		31	16		88					
Composite		3160		370	90	190	30	6	<3	92	99	35			
	1300	3890		435	220		33	13		93			5940	64	0.743
	1330	11500		1010	790		53	32		95		24			
	1345	16850		710	570		47	30		93		20			
	1400	24900		625	770		55	37		91		18			
	1500	24900		625	300		174	140		72		21	4935	65	0.823
	1600	24900		625	180		156	114		75		44	5205	64	0.882
	1700	24900		360	140		144	112		60		35			
	1715	12950		625	170		128	84		80		29			
	1730	6050		380	90		160	98		58		55			
	1800	6050		345	60		179	134		48		34	5700	63	
	2100	3750		450	160		78	58		82					
19 Sep	0300	2000					45	20							
Composite		6835		470	230	230	127	94	7	73	97	46			
	1300	4750											5990	65	

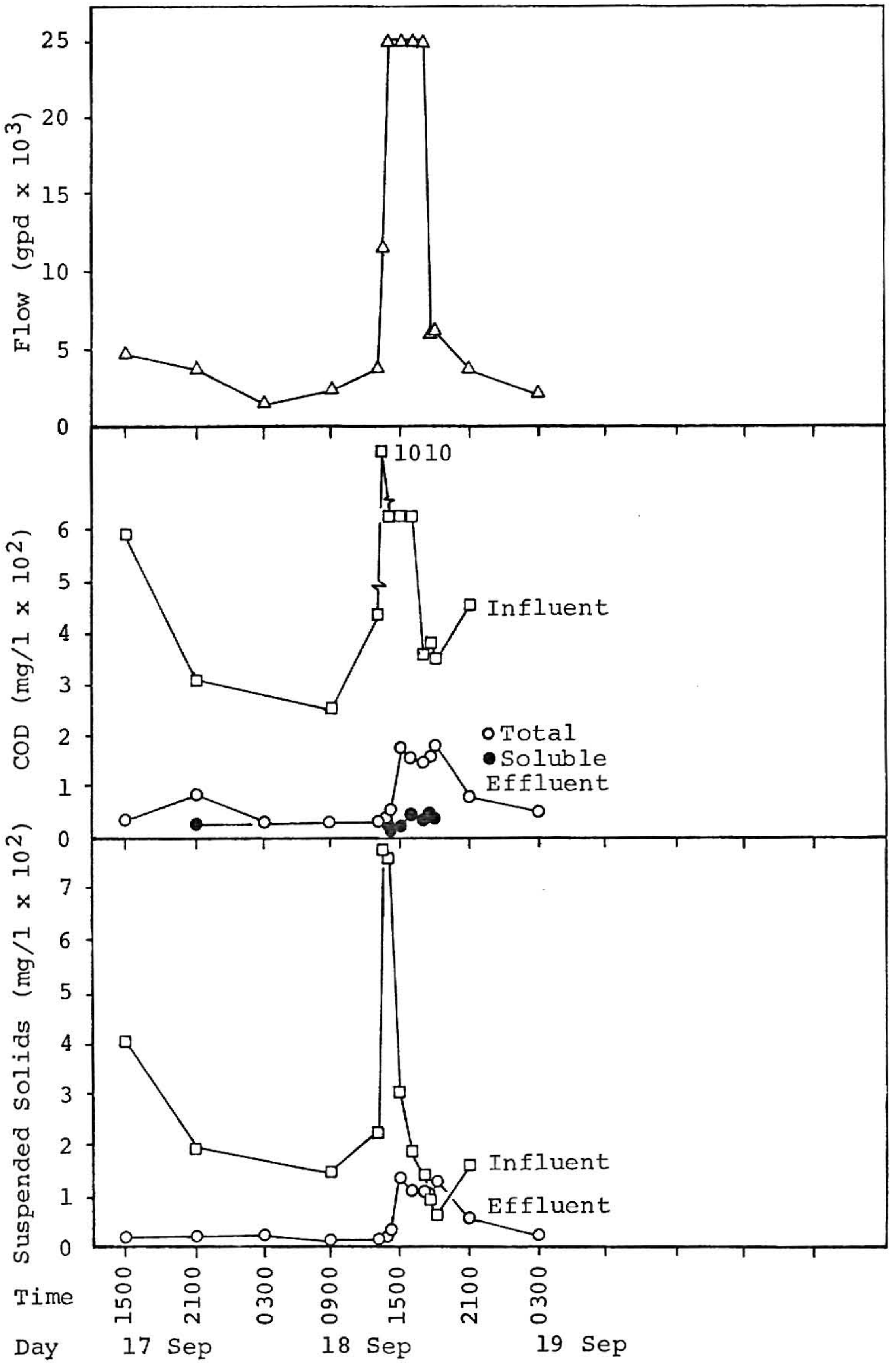

Figure 18. Summary of Data for Week 11, Run III

Table 19. Summary of Data for Week 12, Run III

Date	Time	Flow	DO	Influent			Effluent			% Rem.		Sol Eff	Aeration Solids		
		gpd	mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD mg/l	SS mg/l	BOD_5 mg/l	COD	BOD_5	COD mg/l	MLSS mg/l	% Vol.	SDI
24 Sep	1200	4250											5600	63	
	1500	5000		560	200		33	14		94					
	2100	4000		360	90		29	7		92					
25 Sep	0300	2000		290	70		25	7		91					
	0900	2250		160	20		28	5		82					
Composite		3470		360	120	170	51	13	<3	86	99	35			
	1300	4320		475	160		34	13		93			5630	64	0.633
	1330	12100		1425	6680		33	16		98					
	1345	17300		1250	1450		82	36		94		14			
	1400	25000		690	520		165	142		76		22			
	1500	25000		930	340		322	312		65		24	5430	65	0.610
	1600	25000		630	290		599	540		5		20			
	1700	25000		400	210		311	272		22		36			
	1715	12700		400	190		188	210		53		27			
	1730	6340		500	180		122	92		76		31			
	1800	6050		375	170		118	82		68		26	5625	66	0.618
	2100	4000		595	210		70	44		91		15			
26 Sep	0300	1750		325	70		38	15		89					
	0900	2000		205	60		38	17		82					
Composite		6645		610	210	245	251	224	13	59	95	41			
	1300	4250											5350	67	0.582

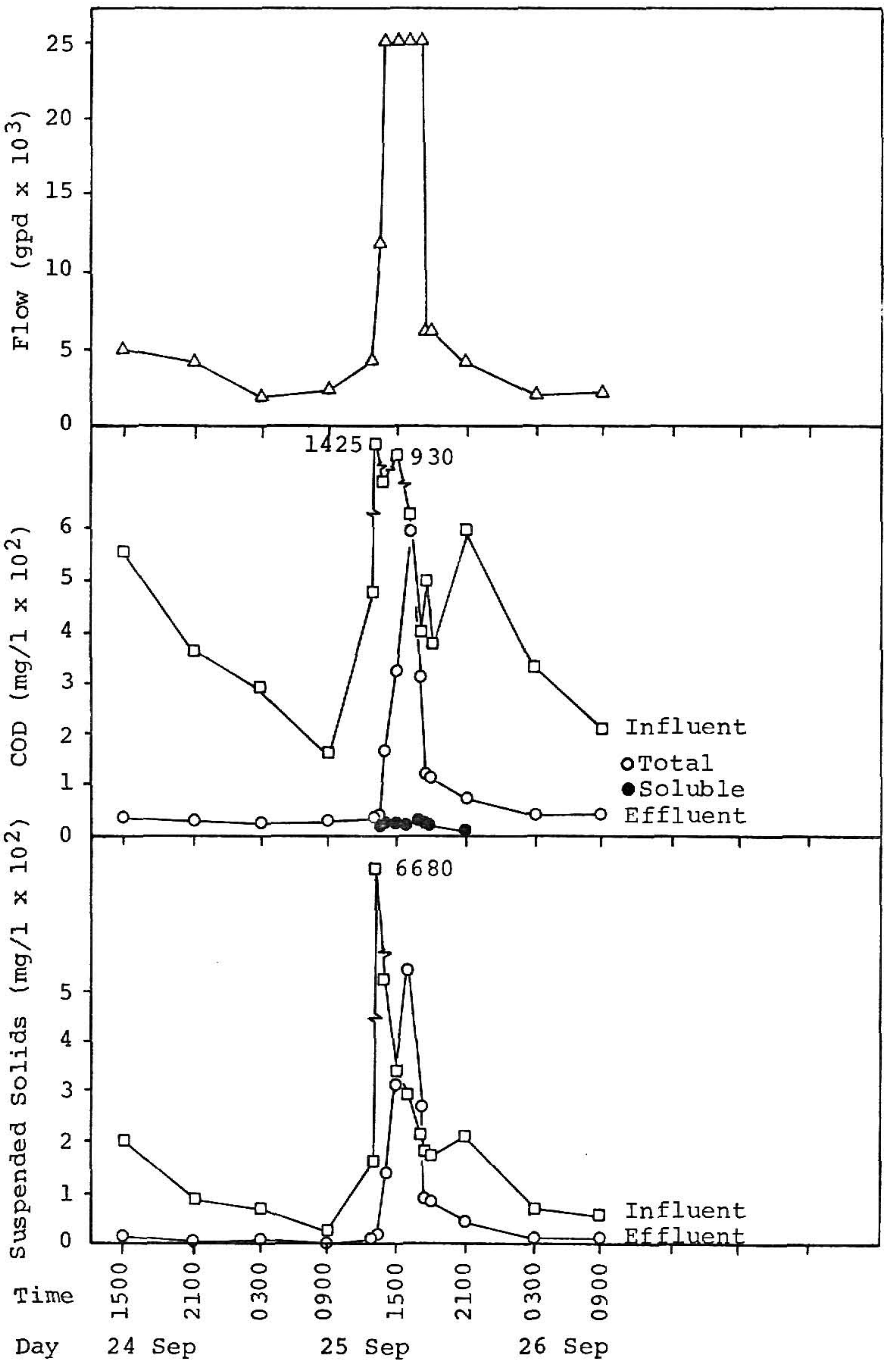

Figure 19. Summary of Data for Week 12, Run III

PILOT PLANT STUDIES ON THE EFFECT OF HYDRAULIC SHOCK LOADS ON THE EXTENDED AERATION ACTIVATED SLUDGE TREATMENT PROCESS

by

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AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

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ABSTRACT

This research tested the effect of hydraulic shock loads on the extended aeration sewage treatment process. This was done using municipal sewage and a 3,000 gallon pilot plant. Flow was established on a normal diurnal cycle and various shock load flow rates were then applied. It was revealed that the application of the shock load caused the dissolved oxygen in the aeration tank to diminish, often to near zero, for short periods of time, but that treatment efficiency as measured by the soluble COD remained high, indicating a good transfer of influent organic matter into microbial cell mass.

The removal of the biological solids by the clarifier was hindered during periods of high flow resulting in solids loss to the effluent and an increased effluent total COD. This is thought to result from an inconsistency in the inclusion of the sludge recycle flow rate in the computation of the surface overflow rate, resulting in underdesign of the clarifier.