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CONTROL SCHEMES FOR THE ACTIVATED-SLUDGE PROCESS

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CONTROL SCHEMES FOR THE ACTIVATED-SLUDGE PROCESS

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This report examines the feasibility of various control schemes which have been proposed for the activated sludge process. The time dependent performance of the process is simulated by means of a digital computer program. The study shows that a significant saving in electrical power is possible when the process is designed for dissolved oxygen control.

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ABSTRACT

A new time-dependent model for the activated-sludge process is described, and the model is used to investigate the potential advantages associated with a number of control schemes. The control schemes investigated by time-dependent computation include dissolved oxygen control, sludge wasting control, and sludge inventory control. Quantitative benefits are shown for some control schemes. For others, the potential advantages appear to be minimal.

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CONCLUSIONS

Computations made with a time-dependent digital computer model for the activated-sludge process show that dissolved oxygen control installed in a typical 25-mgd (1.1 m^3/sec) municipal treatment plant will reduce electrical power consumption for air supply by about 17 percent. By scheduling the blower in a step pattern, about 11.5 percent of the electrical power can be conserved. The potential for reducing the average dissolved BOD concentration in the effluent stream by means of food/microorganism control, using the final settler for sludge storage, appears to be minimal. The effectiveness of the final settler for separating dissolved and suspended fractions of BOD is an important aspect of the simulation for which adequate relationships are lacking.

INTRODUCTION

Control of the activated-sludge process to improve effluent quality and/or reduce the cost of treatment is receiving increased attention currently because of the national program to enhance and protect the environment. The purpose of this report is to describe most of the control schemes that have been proposed, to consider the feasibility of each scheme, and to present the results of exploratory computations made with a digital computer program that simulates the time-dependent performance of the system shown in Figure 1. The digital computer program, as it now stands, does not represent a fully adequate model for the system shown in Figure 1. The program is capable, however, of reliably computing various important aspects of the activated-sludge process and is best considered as a tool to be used in support of experimental programs or demonstration projects.

Measurements of process variables have been made at the Palo Alto, Calif. Wastewater Treatment Plant, and these measurements have been used to supply the digital computer program with a realistically varying influent stream vector and to check the computed performance in a cursory way. The purpose of the EPA sponsored study at Palo Alto has been to test the effectiveness of various control schemes for the activated-sludge process. The study is not complete at this time, and the measurements shown in this report are preliminary. The digital computer model has been of great value in interpreting the measurements and predicting certain aspects of the process performance before the test was initiated.

DESCRIPTION OF THE TIME-DEPENDENT MODEL

The time-dependent model for the equalization basin has been described in an earlier report[1] and will not be dealt with here. The model for the primary settler is based on the following relationship derived from the 24-hr composite removals of suspended solids from a large number of plants:

$$\text{Fraction of SS removed} = 0.82\, e^{-GPS/2780} \qquad (1)$$

GPS = overflow rate, gpd/sq ft

(gpd/sq ft) x .04074 = m/day

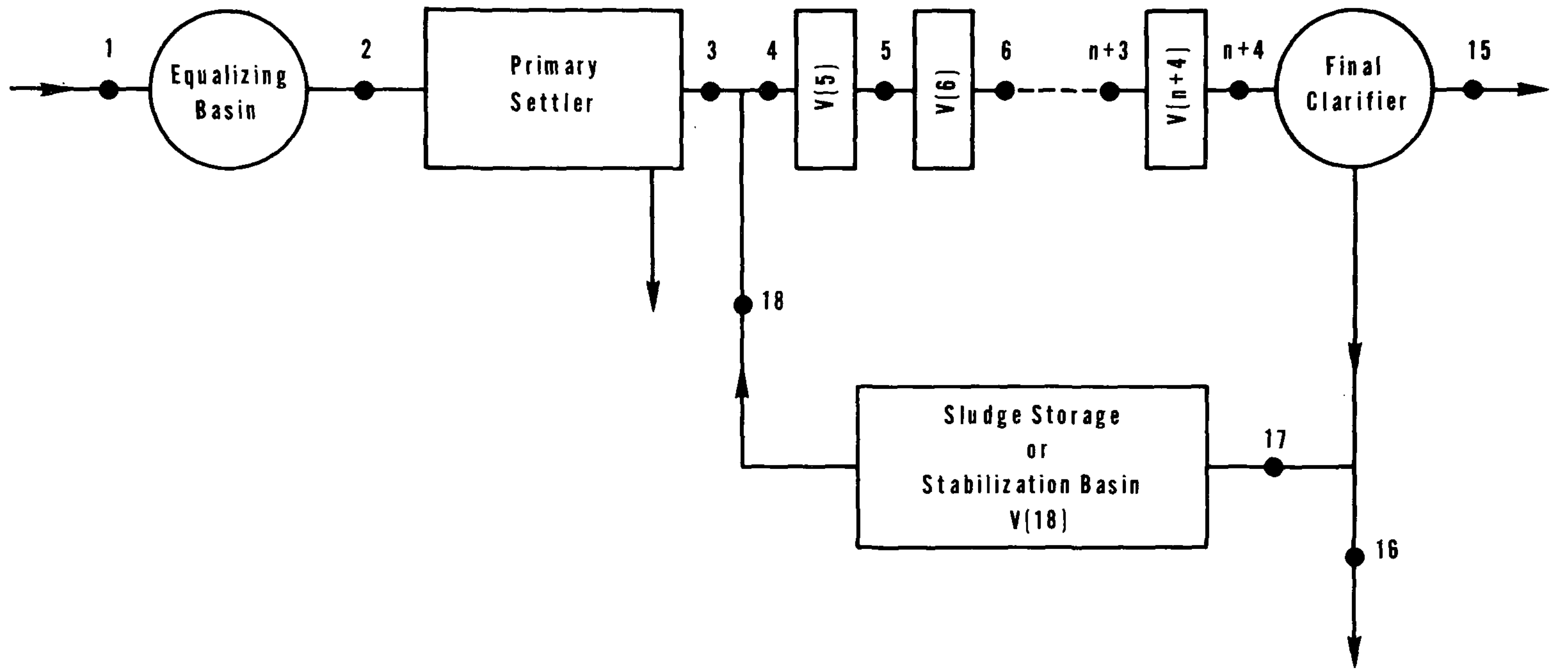


Figure 1. Flow diagram for time-dependent, activated-sludge process simulation.

A plot of suspended solids in the raw and primary effluent streams at Palo Alto is shown in Figures 2 and 3. There is some suggestion here that a delay across the primary settler of about 4 hr. is involved. The average detention time in the primary settlers at Palo Alto is 2.7 hr. A model for the primary settler developed by Bryant[2] visualizes the settler as effecting an instantaneous removal of suspended solids, followed by four idealized volumes in series. Perhaps the Bryant model could be adapted to represent the data shown in Figures 2 and 3, but this has not been attempted.

The model for the activated-sludge process is similar to the EPA model[3] developed in 1970. Some significant changes, however, have been made. For example, classes of suspended solids and substrates expressed as mg/l considered are as follows:

X(1,I) = heterotrophs
X(2,I) = Nitrosomonas
X(3,I) = Nitrobacter
X(4,I) = inert solids
X(5,I) = total suspended solids

S(1,I) = dissolved BOD
S(2,I) = particulate BOD
S(3,I) = ammonia nitrogen
S(4,I) = nitrite nitrogen

An important change was the consideration of inert solids represented by X(4,I). Here, the integer (I) represents the station number as shown in Figure 1. The inert solids are partially volatile and partially nonvolatile. The nonvolatile fraction of the inert solids in the program is represented by the symbol FNVOL. The total concentration of suspended solids is then computed as follows:

$$X(5,I) = X(1,I) + X(2,I) + X(3,I) + X(4,I) + S(2,I)/0.8 \qquad (2)$$

The biological kinetic equations used are the same as those described in the 1970 report[3]. The same rate equation was used for both dissolved and particulate BOD. Predicting the concentration of suspended solids that escape over the final settler weirs is still a major weakness of the program. This concentration can be taken as a small fraction of the mixed liquor suspended solids, or a functional relationship representing measured values can be used.

Since the use of the final settler as a storage facility was one of the important control ideas to be investigated, it was necessary to predict the concentration of suspended solids in the underflow stream as a function of time. For this purpose, some early measurements made by Zack[4] were used. These measurements appear to show that the concentration of suspended solids in the underflow stream is a linear function of the sludge inventory stored in the final settler. The sludge inventory in the final settler (SMUA) was expressed as pounds of sludge stored per square foot (kg/m^2) of settler surface area. The relationship

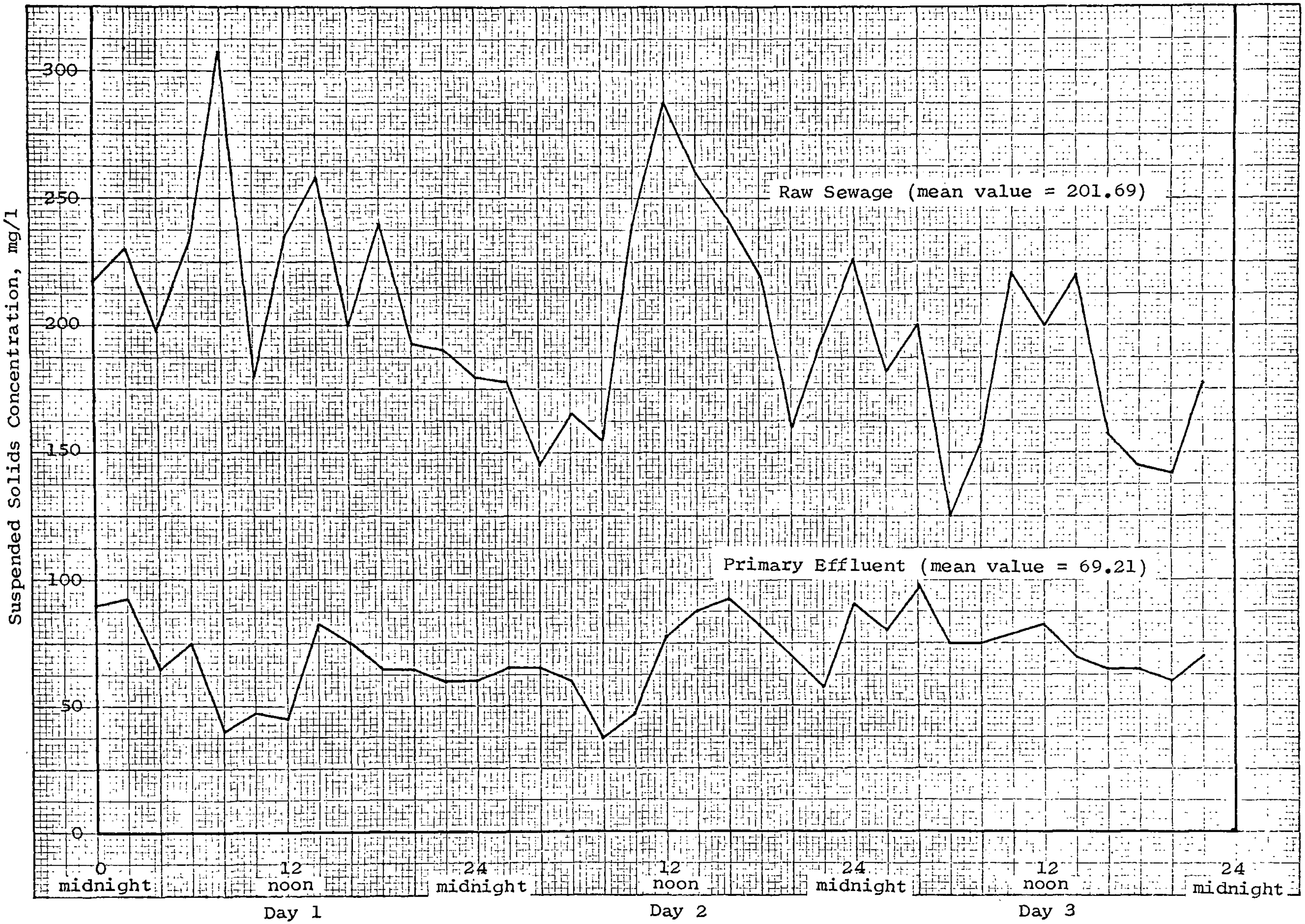


Figure 2. Suspended solids in raw sewage and primary effluent, Palo Alto, Calif., August 5-7, 1973.

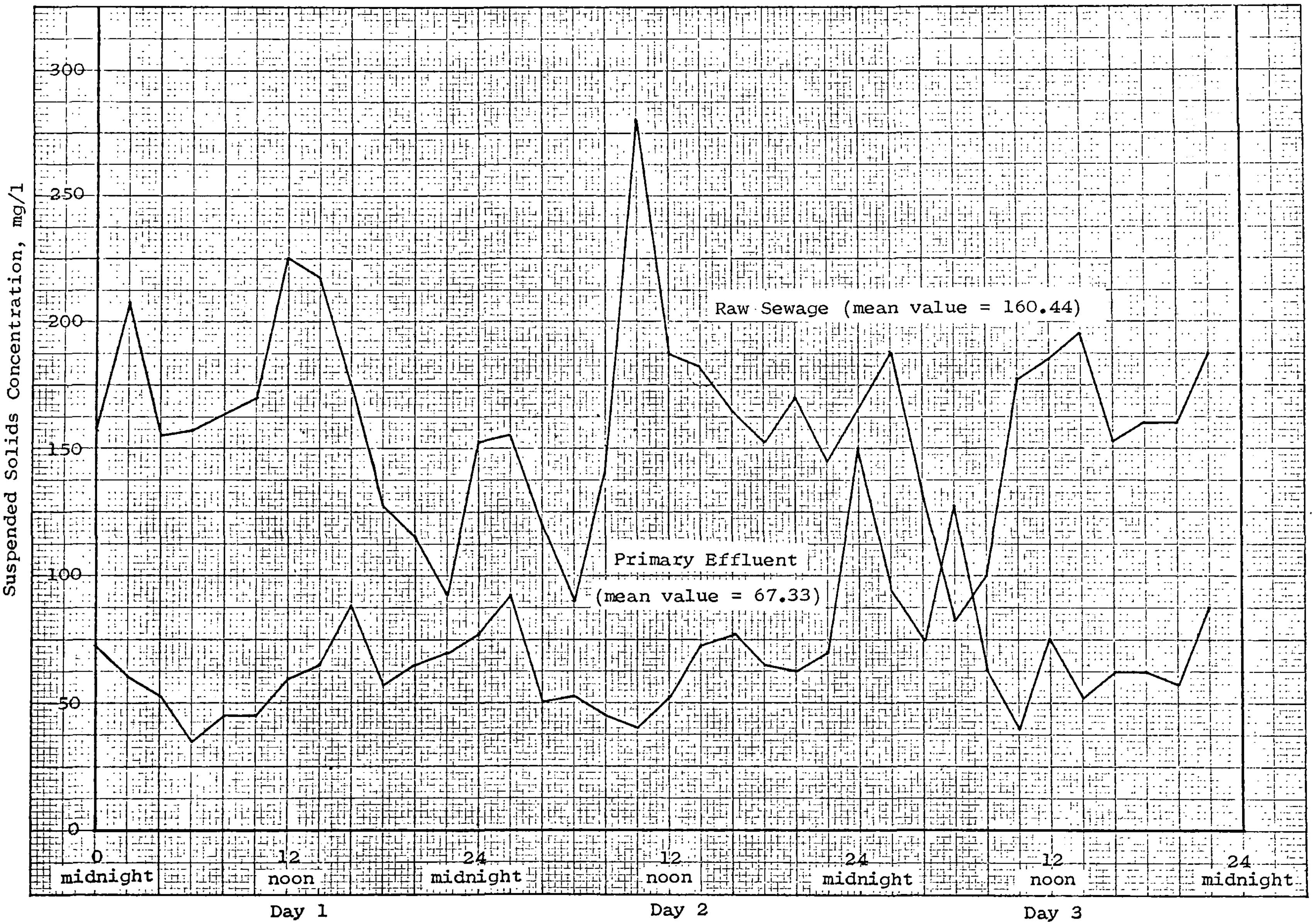


Figure 3. Suspended solids in raw sewage and primary effluent, Palo Alto, Calif., September 9-11, 1973.

derived from the measurements made by Zack is shown in Figure 4. The sludge inventory in the final settler is found by continuously integrating all sludge streams in and out of the final settler.

It was further assumed that some functional relationship exists between SMUA and the height of the sludge blanket in the final settler, as measured visually or by means of an on-line sludge blanket detector. The program is arranged so that the equalization basin, the primary settler, and the sludge storage tank can each be included or excluded from the calculation scheme. All of the exploratory calculations reported here were made with equalization basin and the primary settler excluded.

The program listing and the definitions for input and output variables are given in the Appendix. Comment statements are used in the program to explain the structure of the program.

The principal difference between the new time-dependent program described here and the old time-dependent program[3] is the inclusion of various kinds of control algorithms. A list of control schemes that can be simulated by the time-dependent model for the activated-sludge process is outlined as follows:

I. DISSOLVED OXYGEN CONTROL

A. Two-position, manual control of air blowers
B. Diffused-air aeration (PI feedback)
C. Mechanical aeration (PI feedback)

II. SLUDGE WASTING CONTROL

A. Q(16) = constant
B. Q(16) = fraction of Q(3)
C. SRT = constant
D. Q(16) = constant for specific time when sludge blanket exceeds depth limit

III. SLUDGE INVENTORY CONTROL

A. Sludge storage provided by final settler (no sludge storage tank)

1. Q(18) varied to fix mixed liquor suspended solids concentration = constant
2. Q(18) varied to hold food/microorganism ratio = constant
3. Mass rate of return = constant x incoming BOD load
4. Mass rate of return = function of air demand rate (DO = constant)
5. Step input for Q(18)

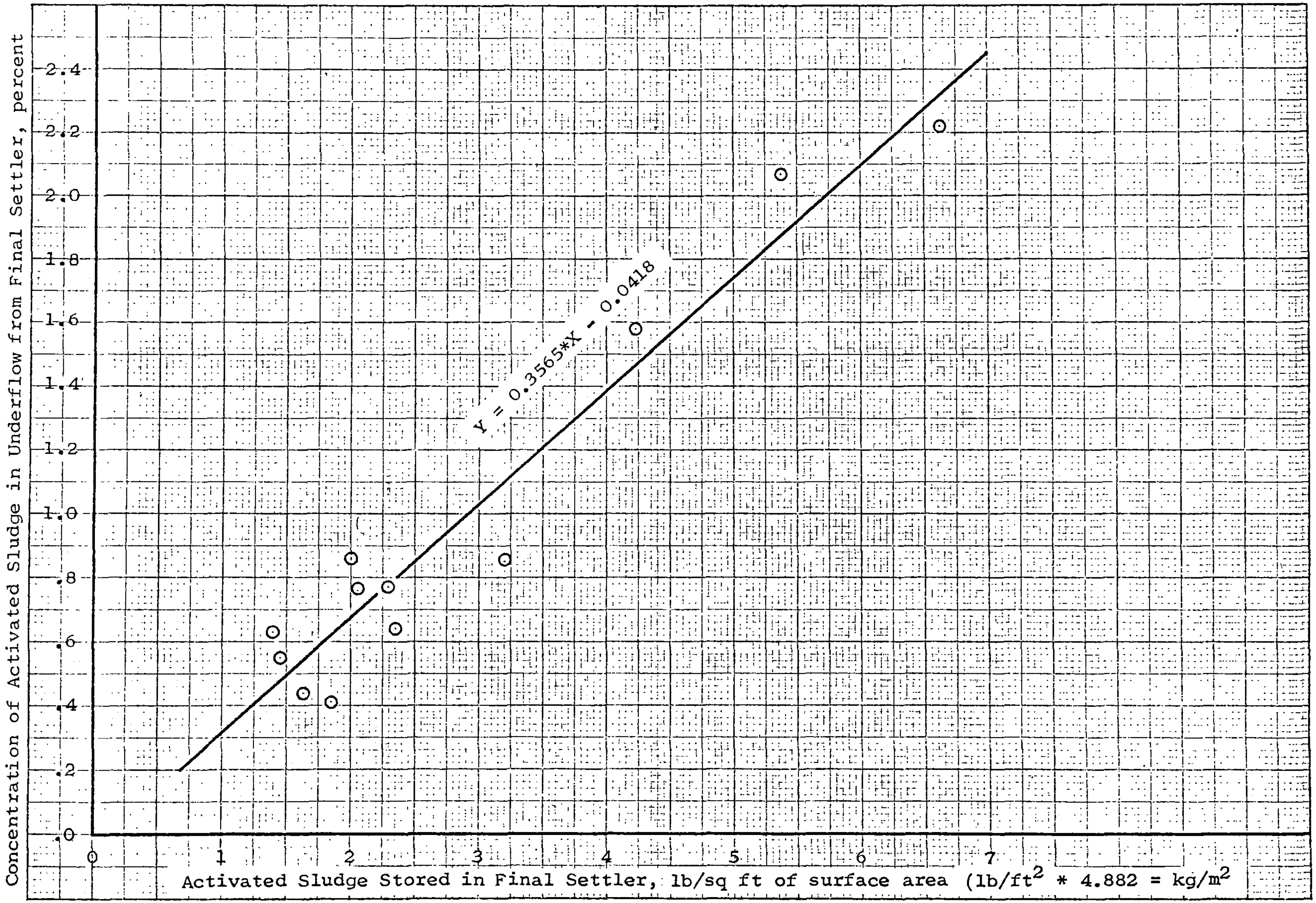


Figure 4. Sludge Compaction characteristics of final clarifier for activated sludge process. Source: Zack, S. I., Sewage Works Journal, 7(3): 514, May 1935.

B. Separate sludge storage tank provided (no storage in final settler)

1. Q(18) varied to fix mixed liquor suspended solids concentration = constant
2. Q(18) varied to hold food/microorganism ratio = constant
3. Mass rate of return = constant x incoming BOD load
4. Mass rate of return = function of air demand rate (DO = constant)
5. Step input for Q(18)

Many of these control schemes are of the open loop variety, but some feedback controllers are included. All feedback control schemes are based on the traditional proportional plus reset (PI) or integral control. The object of feedback control is to make the controlled variable equal the set point value. For example, if the MLSS of the aerator is to be held at 2,000 mg/l by varying the rate at which sludge is returned from the final settler, the set point for MLSS would be 2,000 mg/l. The error in the controlled variable is then defined as the difference between the current value of the controlled variable (MLSS) and the set point value. In this case, the final control element is the volume of the return stream from the final settler. The first incremental change in the return rate is then found by multiplying the error by a constant sometimes called the proportional gain. If the error is integrated continuously with respect to time, the second incremental change in the return rate can be found by multiplying the current value of this integral by a second constant, usually taken as the proportional gain divided by the integral time. The total incremental change in return rate is the sum of these two increments. Both the proportional gain and the integral time must be found experimentally by operating the program with different values for proportional gain and integral time until the value of the controlled variable remains within an acceptable range around the set point. If the controlled variable changes very quickly, this type of controller will tend to lag, and a third increment, based on the derivative of the controlled variable with respect to time, may have to be included. The program does not, however, provide for derivative control.

TIME-DEPENDENT PRIMARY EFFLUENT CHARACTERISTICS

Measurements of significant process variables were made for a number of days at the Palo Alto Treatment Plant, but the measurements for August 6, 1973, were selected as input for the program. The influent stream vector (primary effluent) derived from the Palo Alto measurements and used as input for the time-dependent program is shown in Figures 5, 6, and 7.

The flow arrangement at the Palo Alto Plant on August 6, 1973, is shown in Figure 8. After November 5, 1973, the plant was arranged as shown in Figure 9.

Since a necessary input to the program is the biologically inert solids concentration entering the process, an analysis of the primary settler performance was made to estimate the fraction of the suspended solids entering the plant that is biologically inert. For example, the data showed that for the raw wastewater, the average BOD for August 6, 1973, was 200 mg/l, and the average suspended solids concentration was 202 mg/l. For the same day, the average BOD or primary effluent was 141.8 mg/l, and the average concentration of suspended solids in primary effluent was 66 mg/l. Therefore, since we can assume that the primary settler did not remove any dissolved BOD, it can be concluded that the ratio of BOD/SS is 0.43. The usually quoted value for BOD/VSS for biodegradable solids is 0.8. Therefore, it was assumed that 50 percent of the suspended solids entering the activated-sludge process were biologically inert. Thirty-three percent of these inert solids were further assumed to be inorganic.

The total aerator tankage at Palo Alto is 7.48 mg (28,312 m^3). This tankage is arranged as four separate, completely mixed tanks. Before November 5, 1973, three of these tanks [5.61 mg (21,234 m^3)] were in parallel, and the fourth [1,87 mg (7,078 m^3)] was a stabilization tank. The detention time for the aerator was therefore, 5.25 hr. at the average flow of 25.67 mgd (1,124 m^3/sec) on August 6, 1973.

DISSOLVED OXYGEN CONTROL SCHEME

The program has been equipped with the logic to control dissolved obygen (DO) by means of PI feedback control and to compute the power consumption based on the operating characteristics of the air blower, the diffusers, and the electrical induction motor.

A typical single stage compressor map, equipped with variable inlet guide vanes, was supplied by Dresser Industries, Inc. of Connersville, Indiana. This map is shown in Figure 10. The diffuser characteristics used were taken from the Chicago Pump

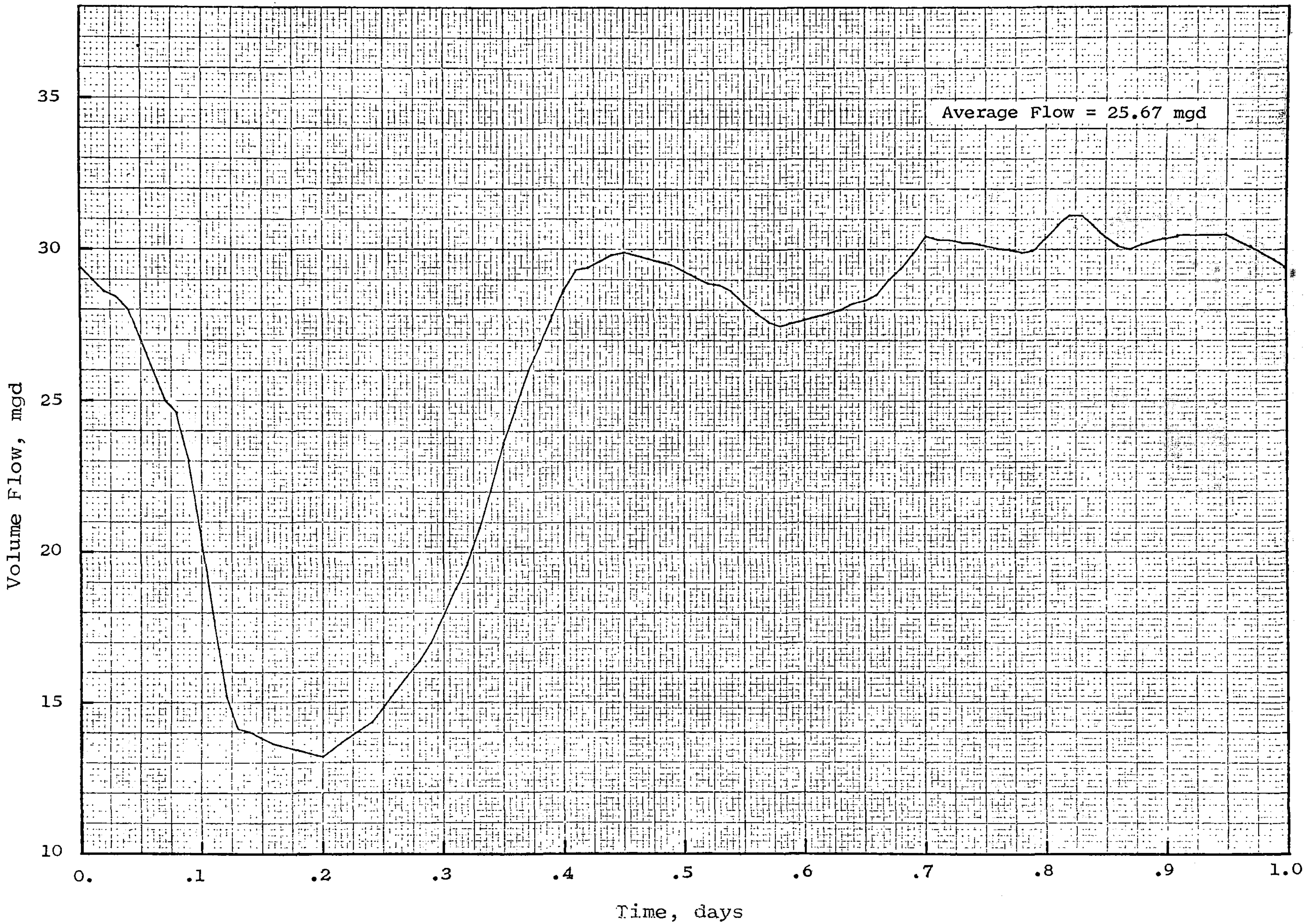


Figure 5. Primary effluent data derived from Palo Alto Plant measurements and used as input for the time-dependent program: Volume flow.

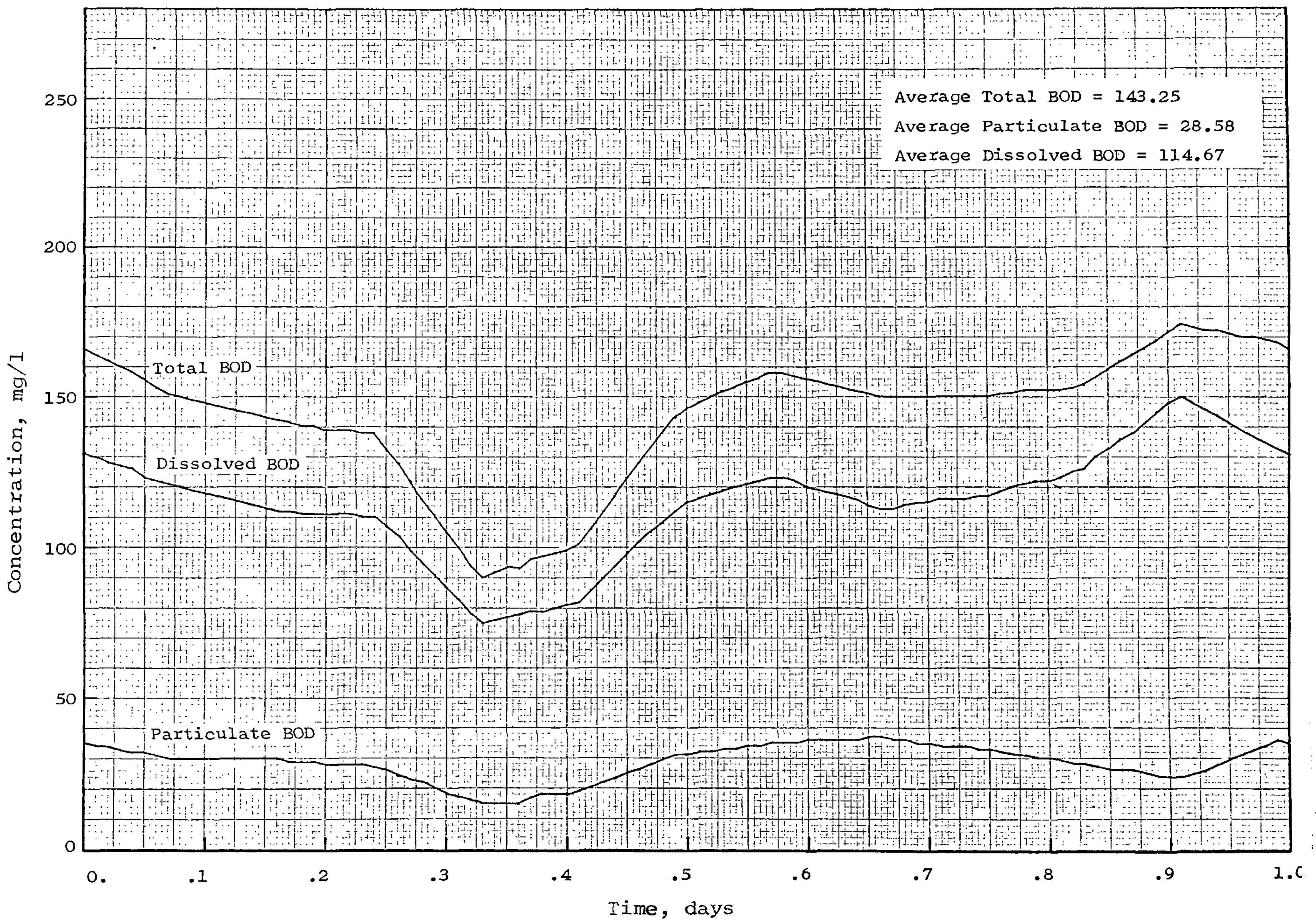


Figure 6. Primary effluent data derived from Palo Alto Plant measurements and used as input for the time-dependent program: BOD.

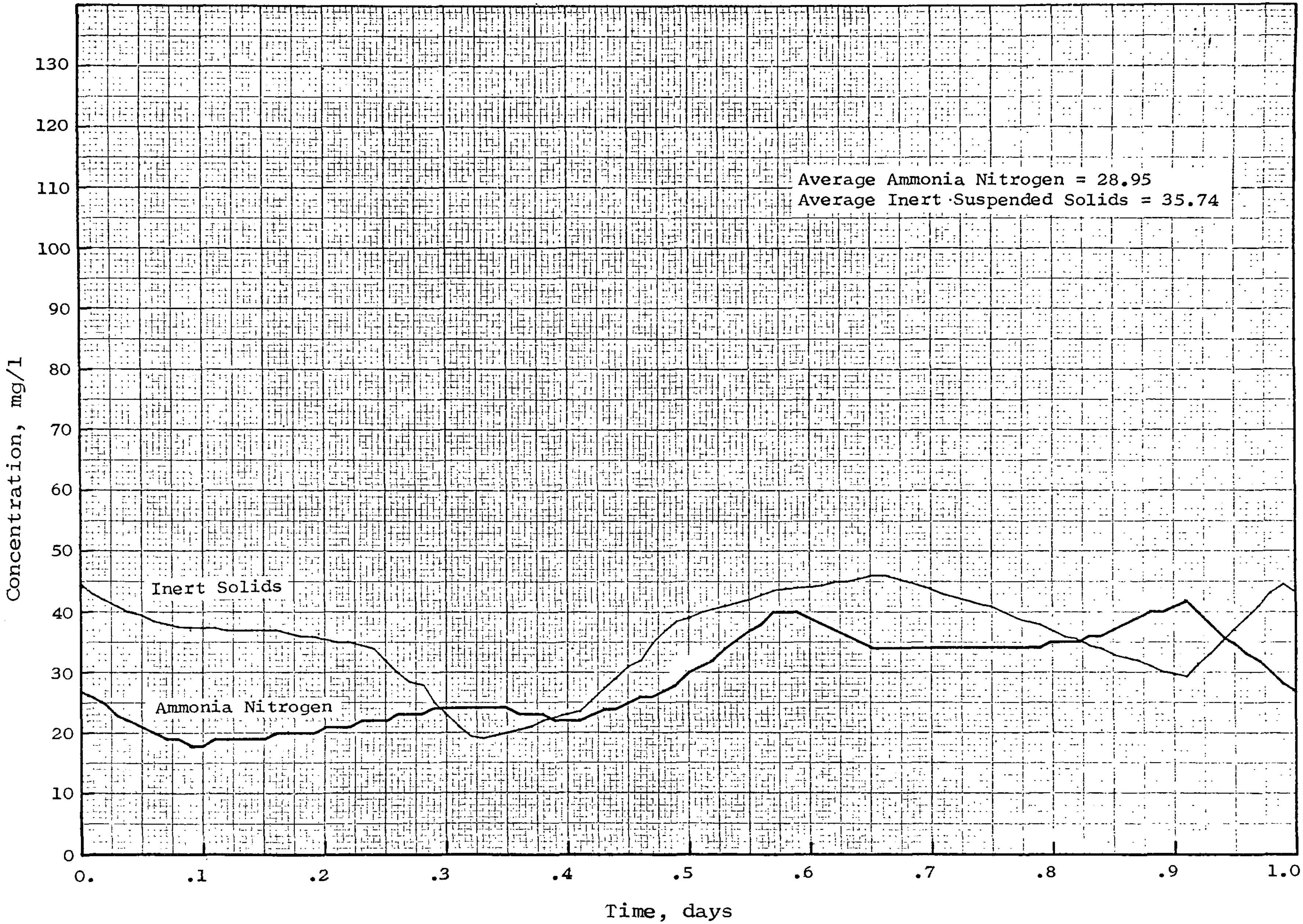


Figure 7. Primary effluent data derived from Palo Alto Plant measurements and used as input for the time-dependent program: Ammonia nitrogen and inert suspended solids.

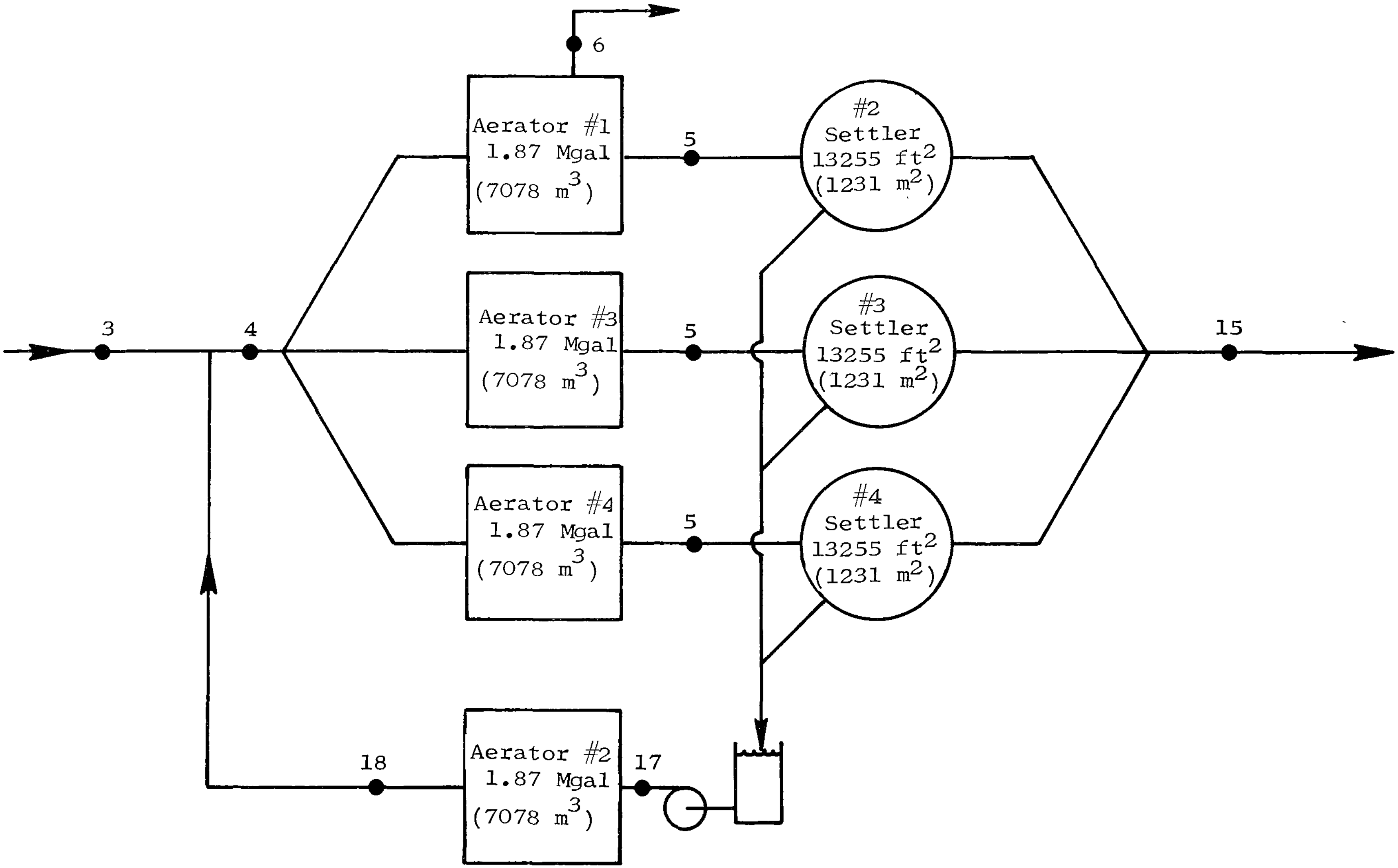


Figure 8. Flow arrangement for the activated sludge process at Palo Alto, Calif. before November 5, 1973

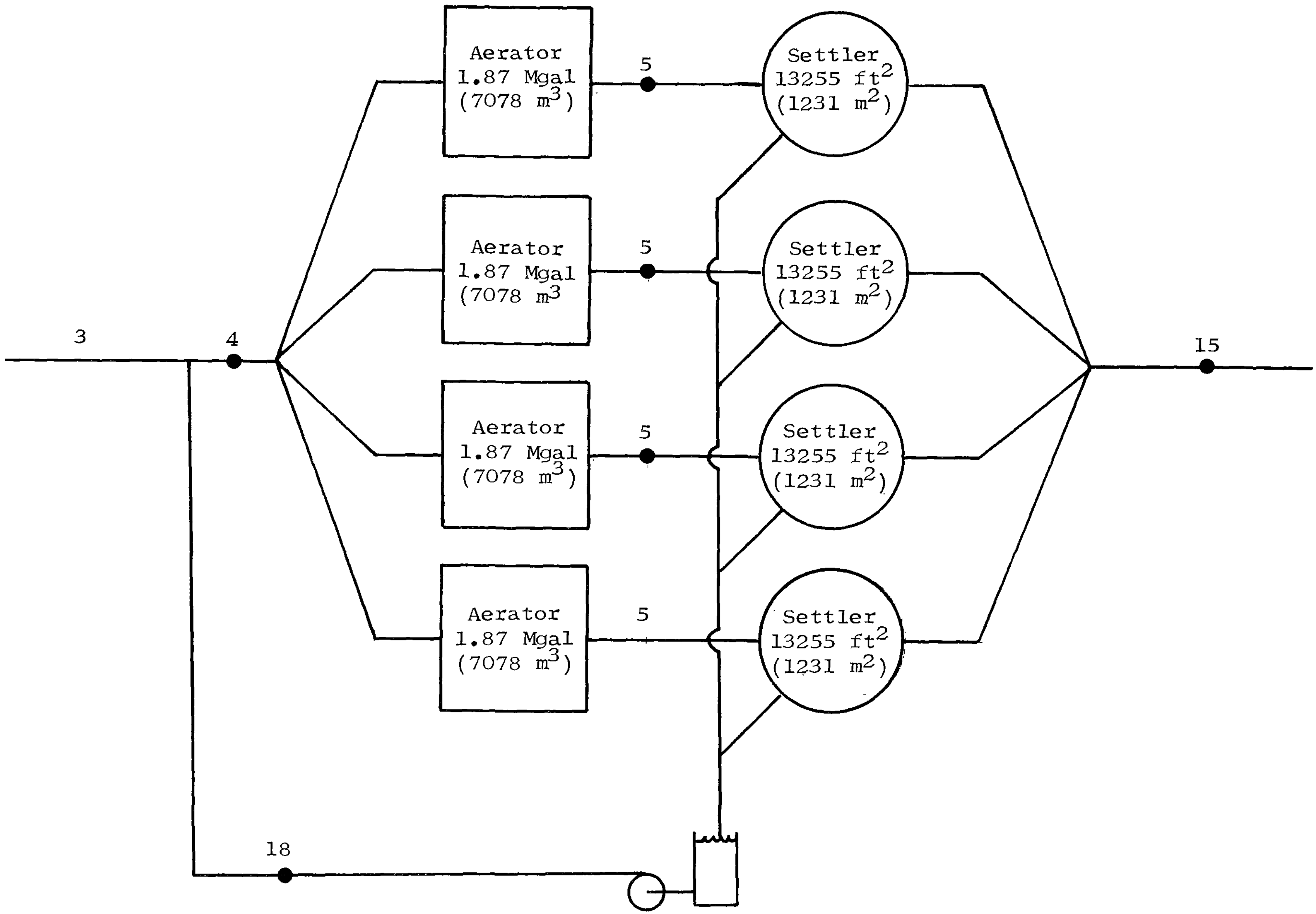


Figure 9. Flow arrangement for the activated-sludge process at Palo Alto, Calif. after November 5, 1973.

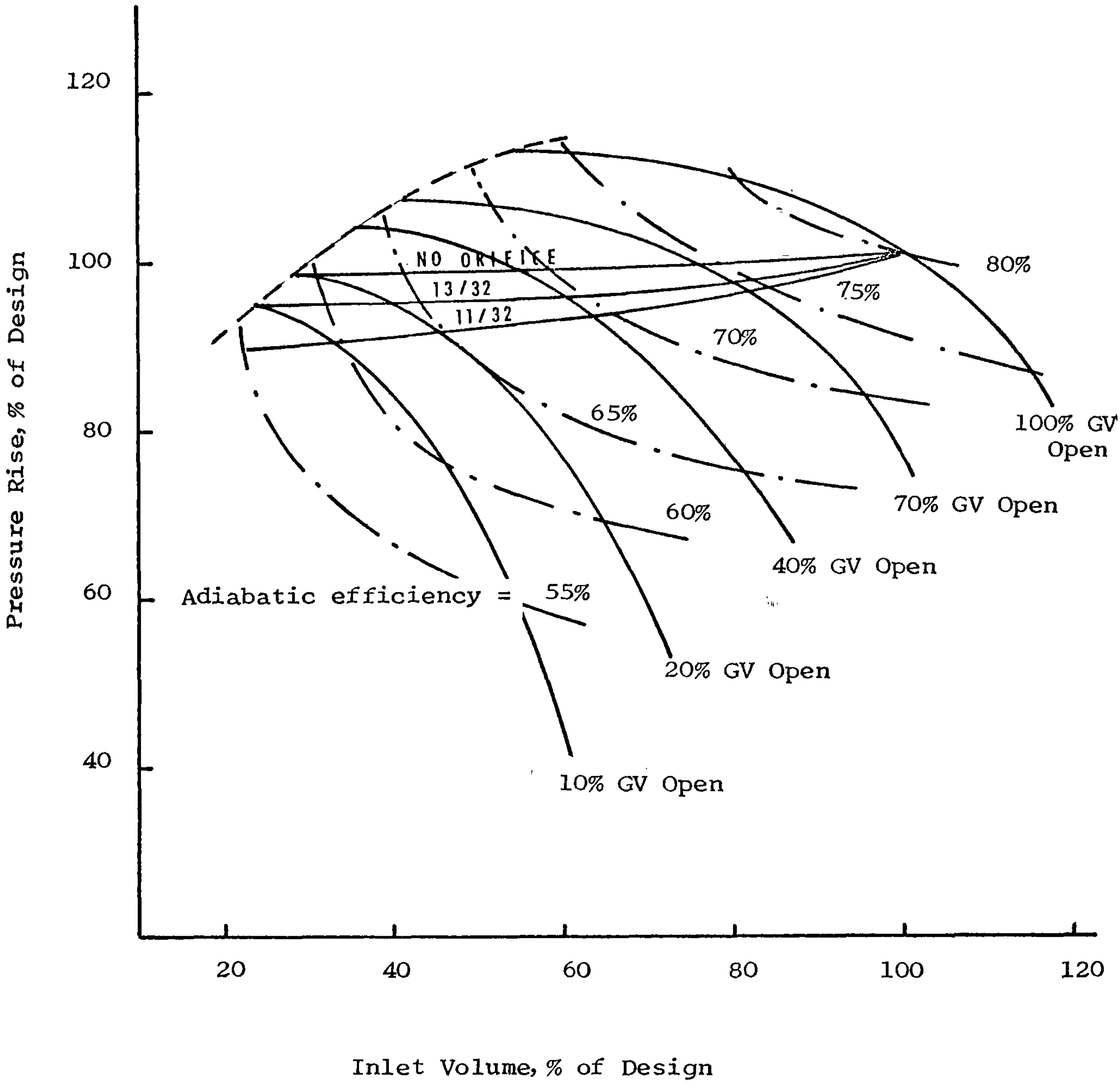


Figure 10. Estimated performance curve for Dresser Industries, Inc. single-stage, centrifugal compressor with backward leaning blade impeller and adjustable inlet guide vanes (GV).

Sewage Equipment Data Book c-1900. The fine bubble diffuser is called the Flexofuser and the coarse bubble diffuser is called the Discfuser. The pressure drop characteristics of the B-4 Swingfuser aerator and the Flexofuser diffuser were taken from data sheets appearing in Data Book c-1900. The following relationship between aeration efficiency and standard cubic feet of air per diffuser was used in the simulation:

$$\text{Aeration Efficiency} = 0.13 - 0.0013(\text{scfm/diffuser}) \qquad (3)$$

The Palo Alto Plant is equipped with turbine aerators in all four aeration basins, with the air supply being introduced under the turbines, which operate continuously. The turbine horsepower installed is 1,200 hp (0.895 MJ/sec), and the maximum amount of air that can be supplied by the positive-displacement, variable-speed air blowers is 8,000 standard cubic feet per minute (226.6 m^3/min). The computer program is not, therefore, equipped to simulate the aeration system at Palo Alto.

Since the compressor map is nondimensional, the design point scfm must be found and supplied to the program as input. This is designated as DPCFM in the program. The exit pressure of the compressor is determined by the aeration system design.

The design point for the Flexofuser diffusers was set at 12 scfm per diffuser. The diffusers are equipped with orifices to divide the air discharged equally between diffusers. For this exercise, a 13/32-in. diameter (10.3 mm) orifice was selected. The depth of submergence for the diffusers was set at 13 ft. (3.96 m). It is recommended that the diffusers be cleaned when fouling causes an additional drop across the diffuser of 2-3 in. (50-75 mm) of water. An average operating drop because of fouling was therefore assumed to be 1.5 in. (38 mm) of water. The pressure drop in the piping between the blower and the swing-arm aerators is negligible, but there is a very small pressure drop through the swing-arm aerator. The B-4 Swingfuser Aerator, manufactured by Chicago Pump, was used for the simulation. Since this is a small pressure drop compared to the 5.63 psi (0.3958 kg/m^2) caused by the 13 ft. (3.96 m) submergence, it is sufficient to estimate the air flow at 10 scfm per foot (0.929 m^3/min/m) of tank length. Therefore, since the header length of the aerator is 18 ft. (5.49 m), the flow through the aerator at the design point will be 180 scfm (5.1 m^3/min). The pressure drop across the Swingfuser aerator is only about 1 in. (25.4 mm) of water.

Based on the pressure-drop characteristics of the Flexofuser and Type B-4 Swingfuser, the pressure drop seen by the blower was computed versus air flow as a fraction of the design point [6.32 psi (0.4444 kg/m^2)] corresponding to 12 scfm per diffuser. The operating lines shown in Figure 10 were found for no orifice, 13/32-in. diameter (10.3 mm) orifice, and 11/32-in. diameter (8.73 mm) orifice. These three lines represent the limits of available equipment. The air blower cannot be operated with the inlet guide vanes less than 10 percent open or more than 100 percent open.

From the operating lines shown in Figure 10, the adiabatic efficiency of the blower and the power demand for compressing the air can be calculated. This is shown for the Flexofuser with no orifice, 13/32-in. diameter (10.3 mm) orifice, and 11/32-in. diameter (8.73 mm) orifice in Figure 11, expressed as horsepower demand per 1,000 scf (28.32 m^3) versus percent of design flow. The line for the 13/32-in diameter (10.3 mm) orifice was used in the computer program to compute brake horsepower demand. The corresponding inlet guide vane position, as a function of percent design flow along the operating line, is shown in Figure 12. Notice that for the 13/32-in. diameter (10.3 mm) orifice, the lowest air volume that can be delivered at the 10 percent inlet guide vane position is about 26 percent of the design point air volume.

Relationships for the electrical efficiency of AC induction motors were supplied by the Cincinnati Office of Westinghouse Electric Corp. Their estimates for a 40-hp and a 200-hp motor are shown in Figure 13. The estimate shown for the 200-hp motor was used in the power computation. The relationships used to calculate the oxygen demand of the biological system and the relationships used for correcting aeration efficiency to local conditions are fully described in References 1 and 5.

The dissolved oxygen control system developed at the Palo Alto Plant was operated over the 3-day period September 9-11, 1973. These three days fell on Sunday, Monday, and Tuesday. Volume flow into the plant on Sunday is significantly less than during the weekdays. Measurements of dissolved oxygen in one of the three aerators are shown in Figure 14. The computer simulation of the dissolved oxygen control loop was used to calculate the air demand using the standardized influent stream shown in Figures 5, 6, and 7. The results of this computation are also shown in Figure 14 for comparison. For the two weekdays, Monday and Tuesday, the agreement is reasonably good. The design point for the blower was set at 9,700 scfm (4.578 m^3/sec), and the aeration efficiency was taken as a fixed 14 percent. The set point for dissolved oxygen in the aerator was set at 1 mg/l, corresponding to the set point used at the Palo Alto Plant.

With DO control, the average power consumption was 1,544 kwh per day for each aerator. When the blower was operated at the design point, the power consumption was 1,858 kwh per day per aerator. Thus, the power saving with DO control was about 17 percent. The program is also equipped to step the air supply from the maximum value to a minimum value between 3 a.m. and noon.

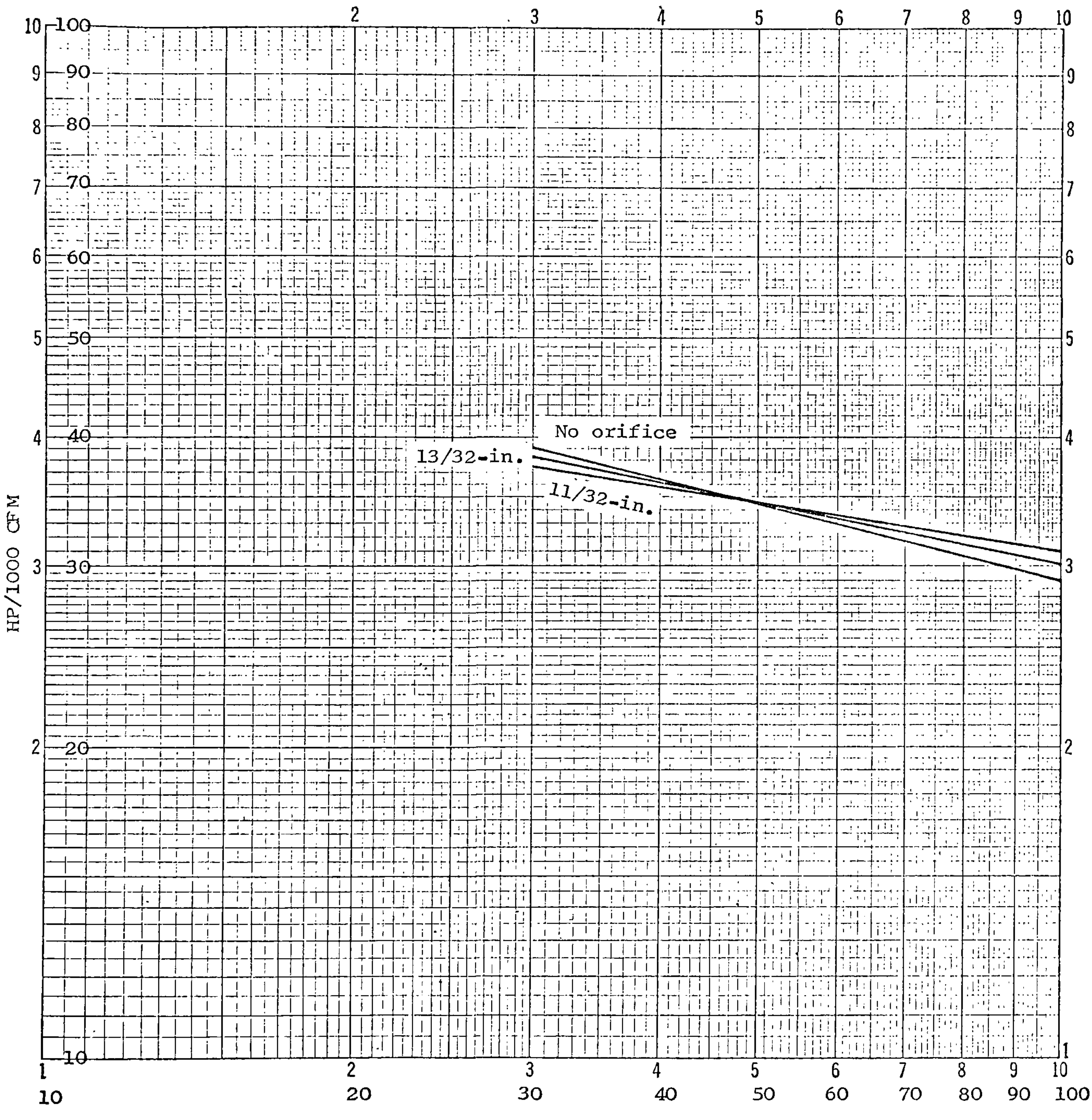


Figure 11. Brake horsepower demand for the Flexofuser with no orifice, 13/32-in. diameter orifice, and 11/32-in. diameter orifice.

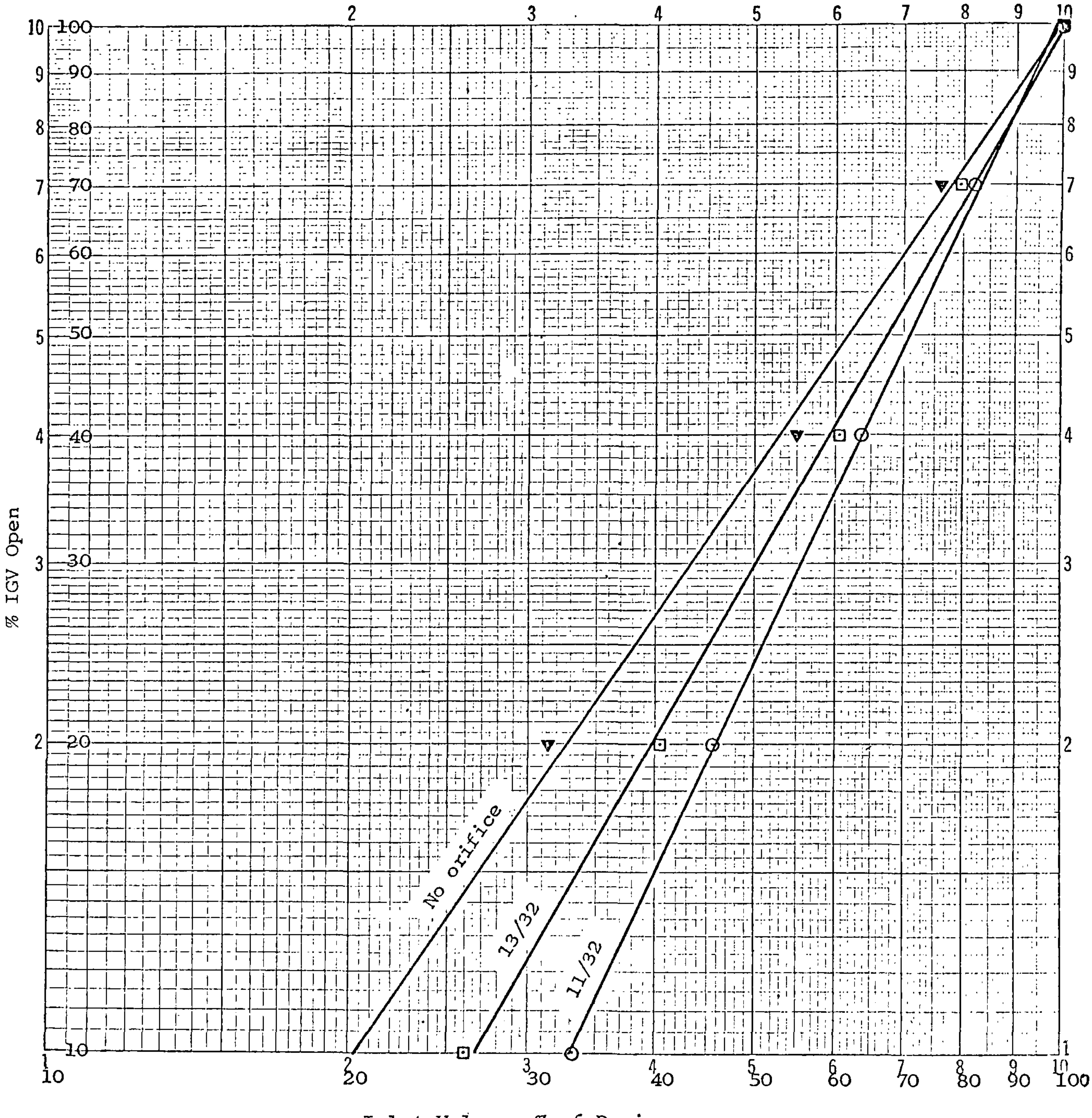


Figure 12. Inlet guide vane (IGV) position versus compressor operating point.

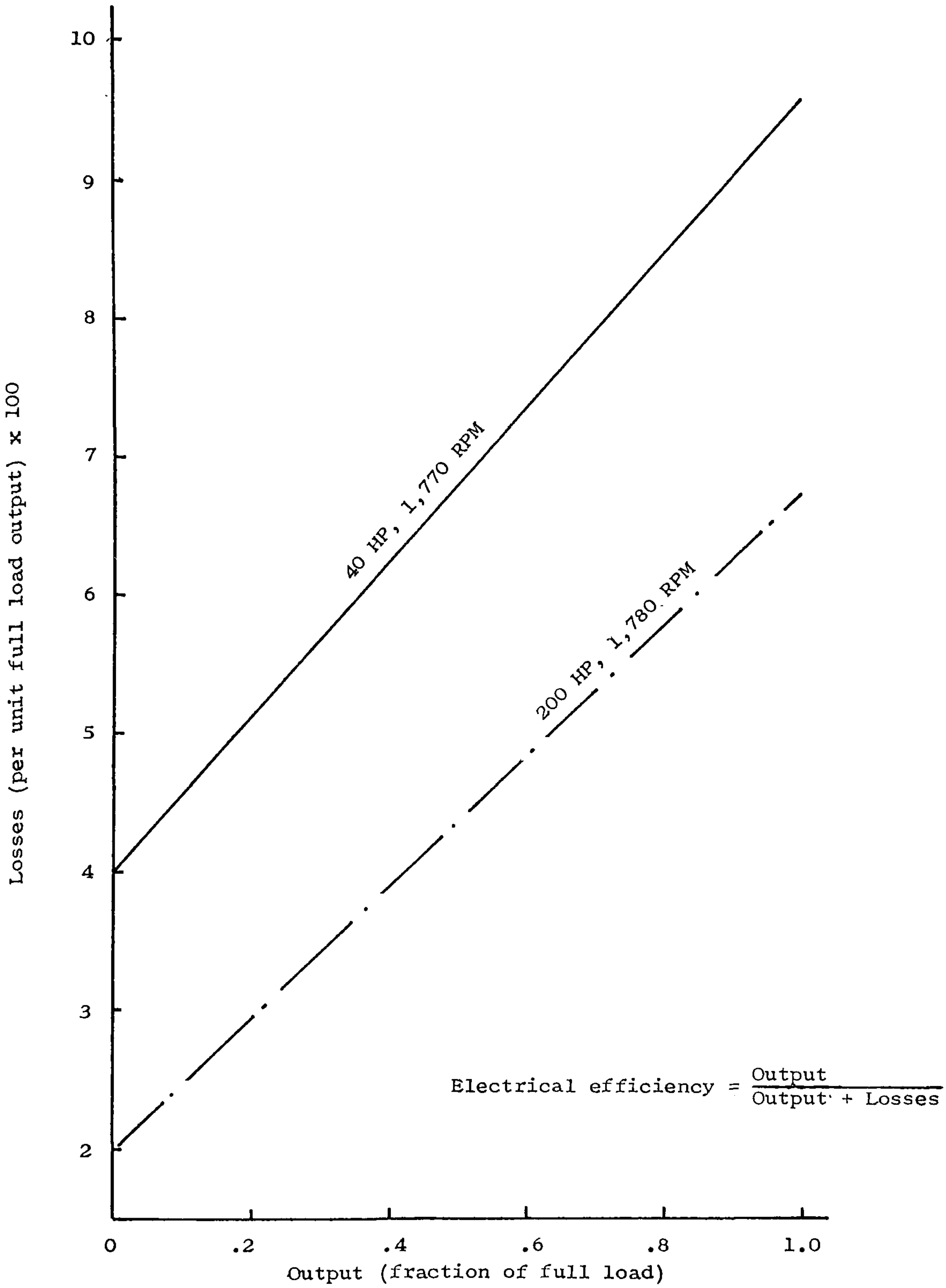


Figure 13. AC motor losses versus output.

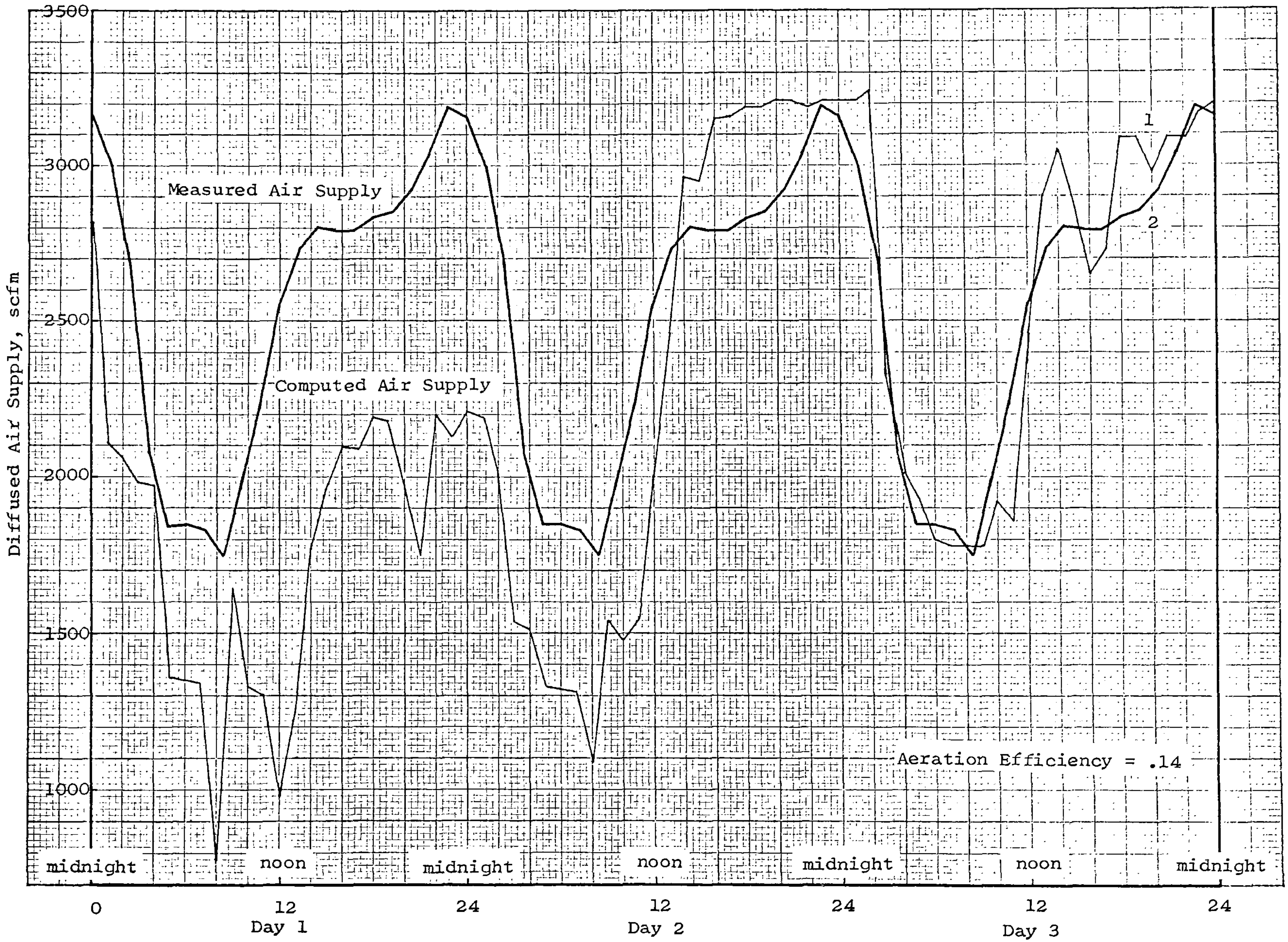


Figure 14. Palo Alto, Calif., baseline measurements of dissolved oxygen in one of three aerators, September 9-11, 1973.

When the minimum value was set at 6,000 scfm, the air supply was sufficient to hold the DO above 1 mg/l, and the average power consumption was 1,644 kwh per day per aerator for an average saving of 11.5 percent.

SLUDGE WASTING CONTROL

Wasting of activated sludge from the process is accomplished only through stream number 16. The volume (mgd), m^3/sec of stream 16, Q(16), can be set equal to a fixed value or to a fraction of the influent stream, Q(3). The concentration of the sludge wasted will be determined by the resulting sludge inventory in the final settler, and the mixed liquor suspended solids level in the aerator will find the proper level to make the mass into and out of the process balance.

Sludge retention time (SRT) is defined in the program as the mass of active solids in the aerator plus the sludge storage tank divided by the daily waste rate for active solids. The volume of stream 16 is adjusted at each time interval (0.01 days) to make the SRT equal the input value.

Finally, the program will set Q(16) equal to a specific value when the value of SMUA equals or exceeds a set point designated as SBLM. SMUA and SBLM are compared at intervals of 0.01 days (14.4 min.), and when SMUA becomes less than SBLM, the Q(16) is set equal to zero. This computational procedure is intended to simulate the use of an on-line sludge blanket detector for wasting control. The value SBLM is intended to represent a depth setting for the sludge blanket detector.

SLUDGE INVENTORY CONTROL

The object of sludge inventory control is to increase the concentration of active solids in the aerator when the BOD load on the process is at a maximum and to decrease the concentration of active solids in the aerator when the BOD load on the process is minimized. This can be done only if a mechanism for sludge storage is provided. The program provides for sludge storage in the final settler and in a separate sludge storage tank. The origin of this idea appears to be a paper by Westberg,[6] in which he pointed out that operation of the activated-sludge process can be optimized in a number of ways, depending on the object of the optimization.

For example, the average amount of BOD discharged per day to the receiving stream might be minimized. A cost/effectiveness ratio might be defined and used as a basis for optimization. The peak instantaneous BOD discharge might be minimized. Finally, the BOD in the aerator can be held at a constant value. This final criterion for optimization of operating policy has received much attention, and it can be shown that this is equivalent to holding the food/microorganism ratio in the aerator at a constant value. For example, consider the completely mixed activated-sludge process shown diagrammatically in Figure 9. The generally accepted relationship for the rate of change of substrate with time in the aerator is given by the following relationship:

$$dS/dt = Q_4(S_4 - S_5)/V - 4.8\ S_5\ X/[0.5(150 + S_5)] \quad (4)$$

where
S = BOD concentration, mg/l
X = active solids concentration, mg/l
t = time, days
V = aerator volume, mg, m^3
Q = volume flow, mgd, m^3/sec

If we assume that the BOD in the aerator is primarily dissolved, the BOD of stream (18) equals the BOD of stream (5); and if dS/dt is set equal to zero, the following relationship can be found:

$$Q_3\ (S_3 - S_5)/(VX) = 4.8\ S_5/[0.5(150 + S_5)] \quad (5)$$

If S_5 is dropped from the expression on the left, the generally accepted definition of food/microorganism ratio results. Since S_5 is normally small compared to S_3, the error in making this simplification is small. Notice, however, that the symbol X refers to active solids rather than to MLVSS.

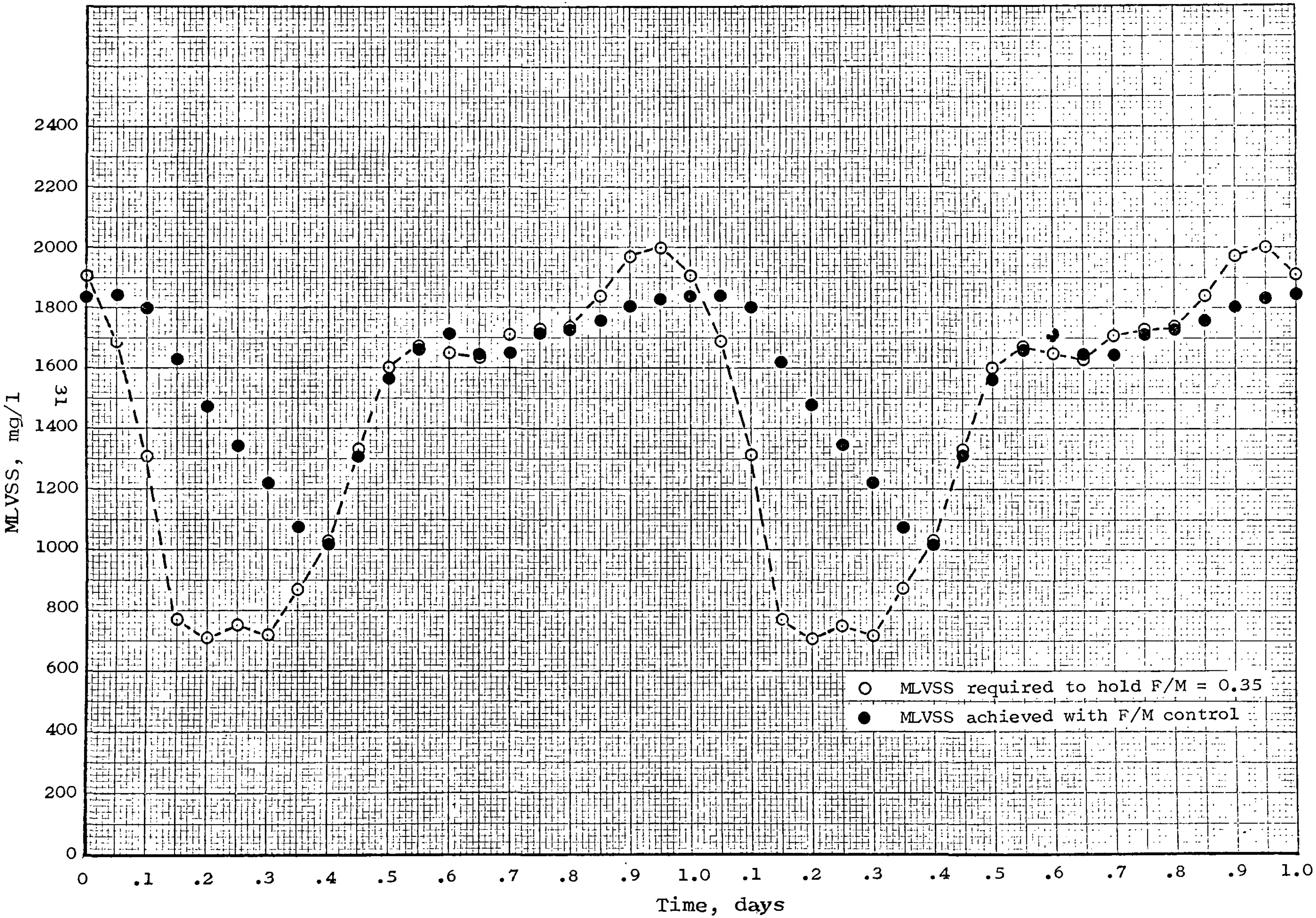
The program contains a PI control loop that computes the food/microorganism ratio existing in the aerator at each time point and then increases or decreases the volume flow in stream 18, Q(18), to make the F/M ratio in the aerator approach the set point value supplied to the program as input. Concentrated sludge from the final settler or the separate sludge storage tank is returned to the aerator by stream 18, and if F/M is above the set point, Q(18) is increased; or if F/M is below the set point, Q(18) is decreased. In this control loop, F/M is defined as the pounds of BOD per day entering the process at station 3, divided by the pounds of volatile suspended solids in the aerator.

By trial and error, it has been found that this controller is not capable of holding the F/M in the aerator equal to the set point of 0.35. The best results obtained with the program are shown in Figure 15, where the open circled points are the concentrations of MLVSS in the aerator that must be achieved to hold F/M equal to 0.35. The solid circled points are the computed points using the F/M control loop. Two principal difficulties have been noted in attempting to hold the F/M ratio in the aerator constant. First, when the BOD load on the process drops by a factor of about four in the early morning hours, the MLVSS in the aerator cannot be reduced quickly enough to hold F/M constant. Second, when the load on the process is maximized in the evening hours, up to about midnight, the demand for sludge from the final settler becomes so excessive that the concentration of sludge out of the final settler approaches the concentration of MLVSS, and the required pumping rate becomes as high as 350 mgd (15.3 m^3/sec).

Also, the average BOD in the aerator is not reduced significantly by means of the F/M control strategy. This is shown (Figure 16) by a plot of BOD in the aerator versus time for the case where Q(18) is set equal to a fixed value [12 mgd (0.53 m^3/sec)], and where the F/M controller is in operation. The average BOD in the aerator, when Q(18) was set equal to 12 mgd (0.53 m^3/sec), was 8.31 mg/l. The average BOD in the aerator with the F/M control in operation was 8.37 mg/l. The average concentration of active solids in the aerator when Q(18) was held constant was 943.2 mg/l. If we substitute this average value with other average values for the input vector into equation (5), the BOD concentration in the aerator, when the F/M ratio is held constant, would be about 8.1 mg/l. From these observations, it seems clear that very little reduction in average BOD in the aerator is likely to be achieved with F/M control in a typical municipal plant such as the Palo Alto Plant.

The theoretical performance limits can be studied by assuming that F/M, as defined by equation (5), will be held constant and by substituting average values in the equation. For example, if S_5 is to be held fixed at 8 mg/l, the value for F/M, as defined by equation (5), is 0.486. Now, if the average Palo Alto values for flow [25.67 mgd (1.124 m^3/sec)] and BOD in the primary effluent (143.25 mg/l) are substituted into the left hand side of equation (5), the active solids concentration can be computed as 955 mg/l. To be more precise, the geometric means should be used; but for this simplified discussion, the arithmetic means will be used.

Since the yield coefficient has been assumed as 0.5 lb active solids per pound of BOD used, the production of active solids per day can be computed. The endogenous respiration rate at 20°C will be taken as 0.125 so that the amount of solids destroyed by endogenous respiration per day can be computed. The difference between the mass of solids generated and the



26 31

Figure 15. MLVSS required to make F/M equal to 0.35 MLVSS resulting from controlled return rate (Palo Alto Data, August 5-7, 1973).

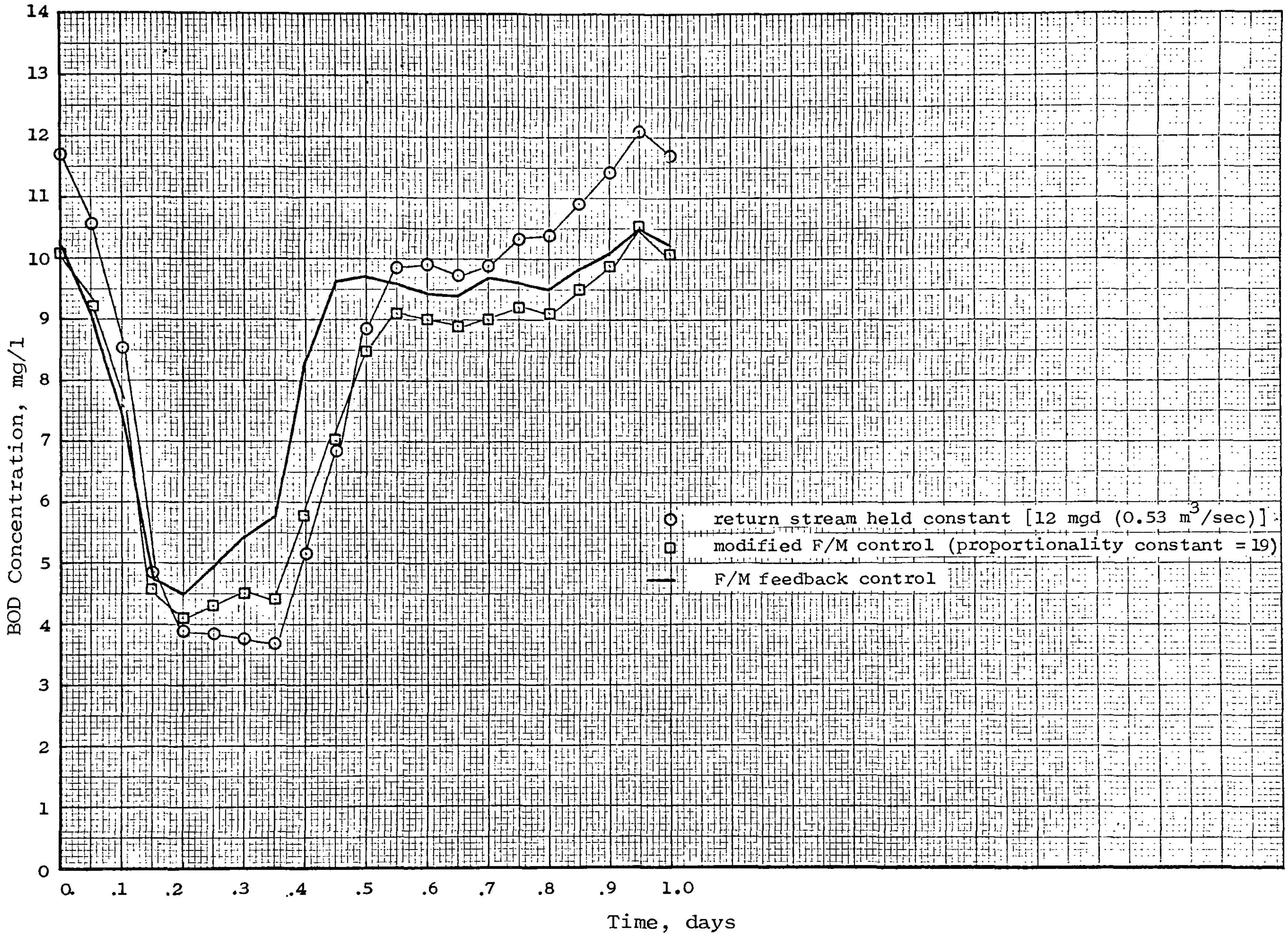


Figure 16. Total aerator BOD versus time (Palo Alto Data, August 5-7, 1973).

amount destroyed by endogenous respiration will give the mass of active solids wasted. Since the mass of active solids in the 7.48 (28,312 m^3) aerator and the waste rate are known, the SRT can be computed.

The concentration of active solids in the aerator, when the fixed value for substrate is set at 4, 5, 6, 8, 16, 24, and 32 mg/l, is shown plotted versus SRT in Figure 17. The average concentration of inert suspended solids entering the process at Palo Alto, however, was 35.74 mg/l. If sludge retention time is defined as the mass of solids in the aerator, divided by the daily wasting rate, the concentration of inert solids in the aerator can be expressed as follows:

$$MLISS = Q(3)*ISS3*SRT/V \qquad (6)$$

MLISS = concentration of biologically inert suspended solids in aerator, mg/l
ISS3 = concentration of biologically inert suspended solids in stream 3, mg/l
* = indicates multiplication

Therefore, the average concentration of inert suspended solids in the aerator will be 122.7 times the sludge retention time in days. The concentration of inert solids in the aerator, as a function of SRT, is shown in Figure 17.

If the total suspended solids concentration in the aerator is taken as the sum of the inert solids and the active solids, the mixed liquor suspended solids concentration can be computed as shown in Figure 17.

From Figure 17, it can be seen that the active solids level off at about 1,600 mg/l at SRT values above 40 days. The MLSS concentration is approaching 6,000 mg/l. Theoretically, then, the reduction in dissolved BOD is from 8 mg/l at MLSS = 2,000 mg/l to about 5 mg/l at MLSS = 6,000 mg/l. Thus, the maximum reduction in BOD in the aerator is about 38 percent. The performance of the final settler has not been considered in this analysis. The BOD contributed by active solids is about 1 mg/l of BOD per mg/l of active solids. Clearly, the performance of the final settler can dominate this kind of analysis.

The variation in MLVSS in the aerator, when the return stream Q(18) is set at a constant 12 mgd (0.53 m^3/sec), is shown in Figure 18. Notice that the maximum variation caused by the low flow in the early morning hours is only from 1,600 mg/l to about 1,800 mg/l. This deviation is readily corrected by means of a PI control loop that varies the return rate, Q(18), to hold MLSS constant. The effect on the process, however, is negligible. When MLSS is held constant by means of a controller, it is then possible to waste sludge when the sludge blanket in the final settler tends to exceed a specified level.

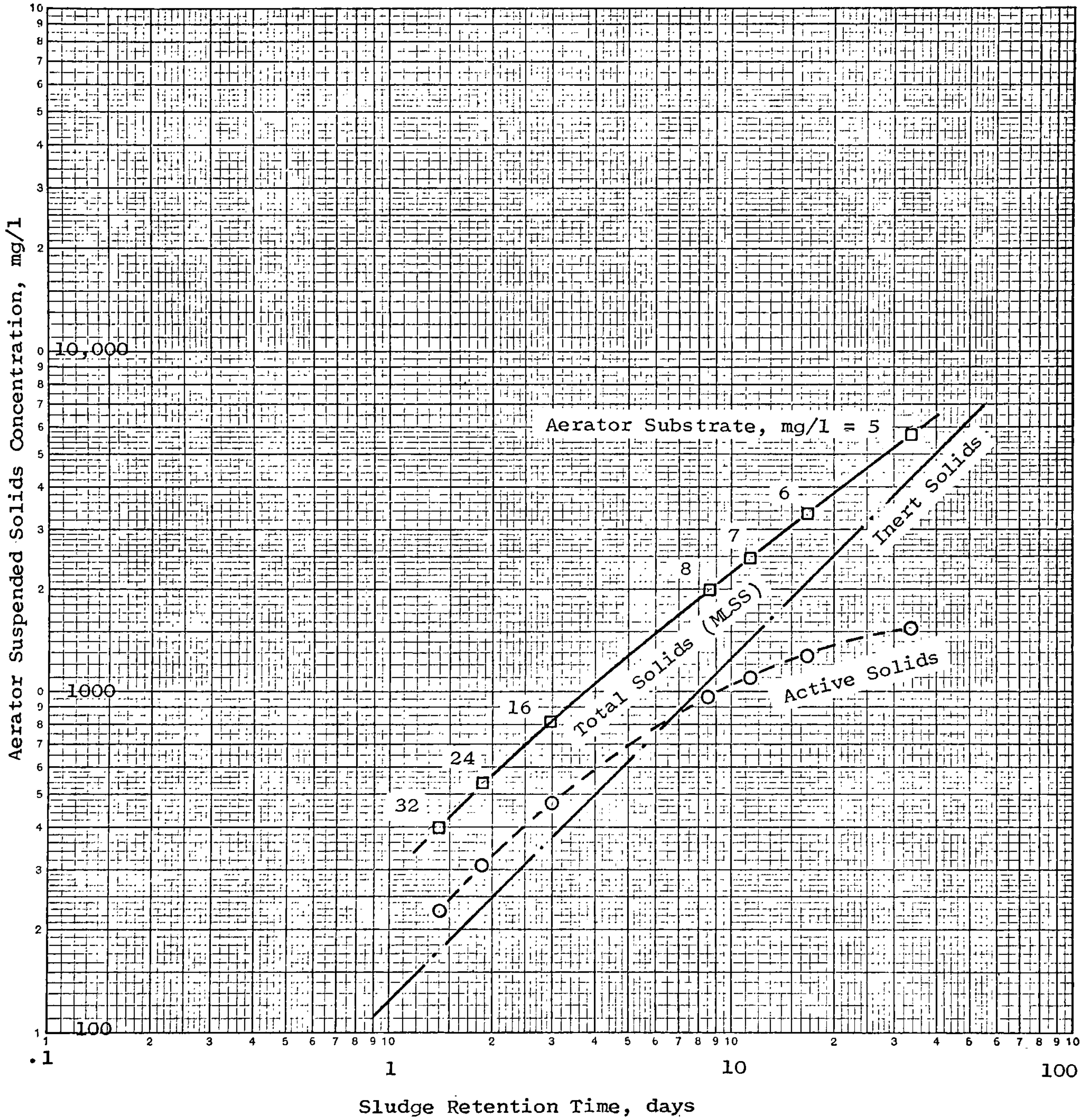


Figure 17. Relationship between aerator suspended solids and sludge retention time.

Because of the difficulty of designing a control scheme that will hold F/M constant in the aerator, it has been suggested that the mass rate of return be set equal to a constant times the incoming BOD load. The following equation is used in the program to accomplish this control idea:

$$Q(18) = CON*(S(1,3) + S(2,3)*Q(3)/[X(5,18) - X(4,18)*FNVOL] \quad (7)$$

It has been found, by trial and error, that a value of 19 for CON will make the average MLSS equal about 2,000 mg/l. The resulting MLVSS concentration in the aerator, when this type of control is used, is shown in Figure 18. This type of control tends to make MLVSS vary in a way that will reduce the variation of F/M, but the effect in a plant similar to the Palo Alto Plant is minimal. The resulting BOD concentration in the aerator, with this type of control, is shown in Figure 16.

Finally, one of the control schemes that is to be tested at Palo Alto involves using the demand air rate with DO control in operation to determine the return rate that will satisfy equation (7). The process was simulated with DO control, and Q(18) was found from equation (7). A relationship between the scfm demanded by the process and the required return rate, Q(18), resulted. These computed points for values of 19 and 25 for CON are shown in Figure 19. The equation of the straight line for CON = 19 is given as follows:

$$Q(18) = 0.0021225*(SCFM - 2750) \quad (8)$$

If this equation is used to find Q(18) from the measured air flow rate when the DO control loop is operable, the process should operate in a way to satisfy equation (7). This has been tried with the computer program, and the process performance was the same as that computed when equation (7) was used to find Q(18).

Since the amount of air demanded by the process can be related to the amount of new cells formed, the air consumption could also be used to determine the wasting rate. Because other more easily implemented methods are available for sludge wasting, this idea was not investigated with the computer program.

The principal difficulty in achieving a constant value for F/M in the aerator has been shown to be reducing the return rate sufficiently in the early morning hours to bring the MLVSS down to the required minimum value quickly enough. By hand calculation it was shown that if the return rate is set to zero at about 11 p.m. and held there until about 8:30 a.m., the MLVSS can be reduced sufficiently. The return rate must then be increased to

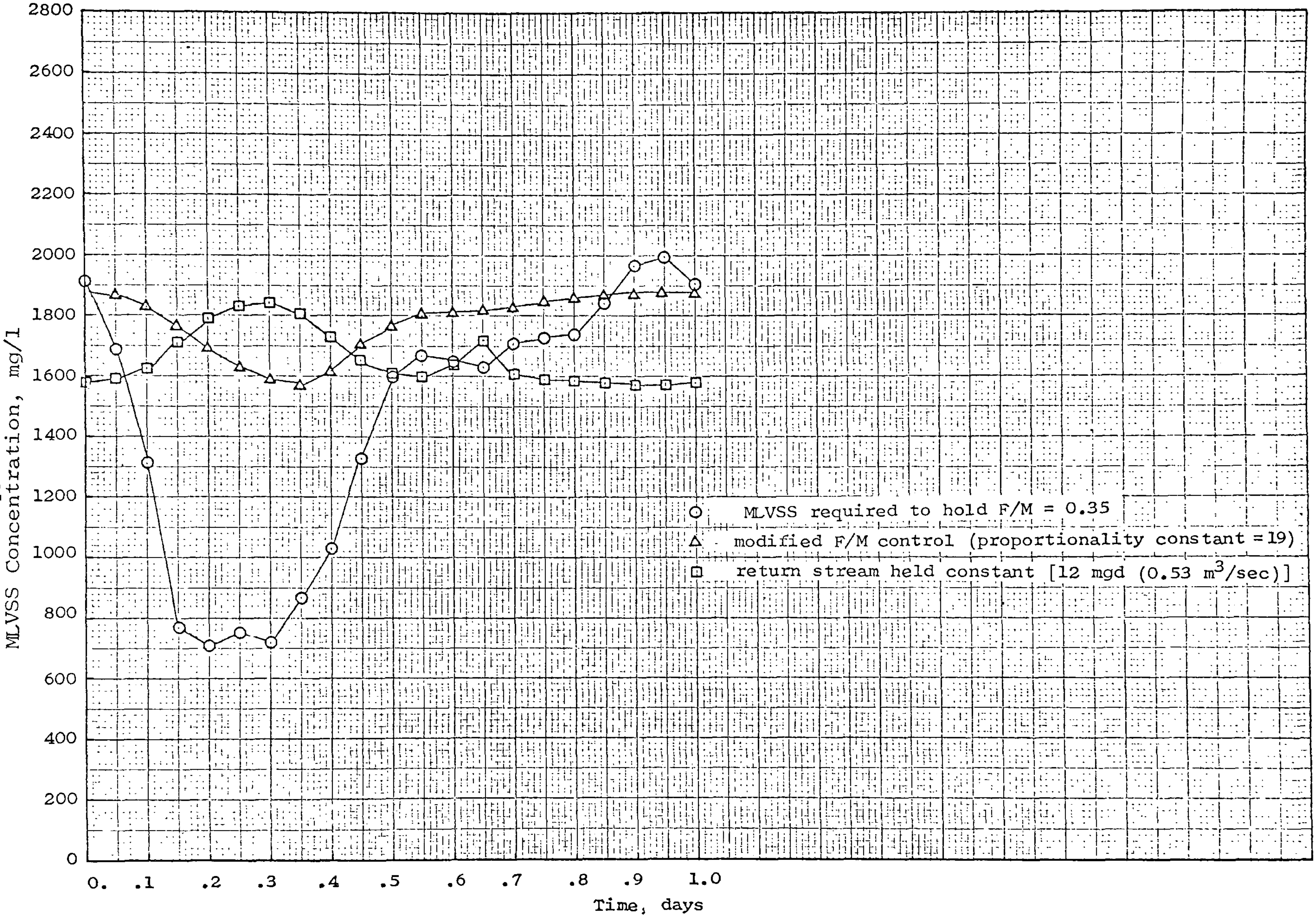


Figure 18. Aerator MLVSS versus time MLVSS with F/M control (Palo Alto Data, August 5-7, 1973).

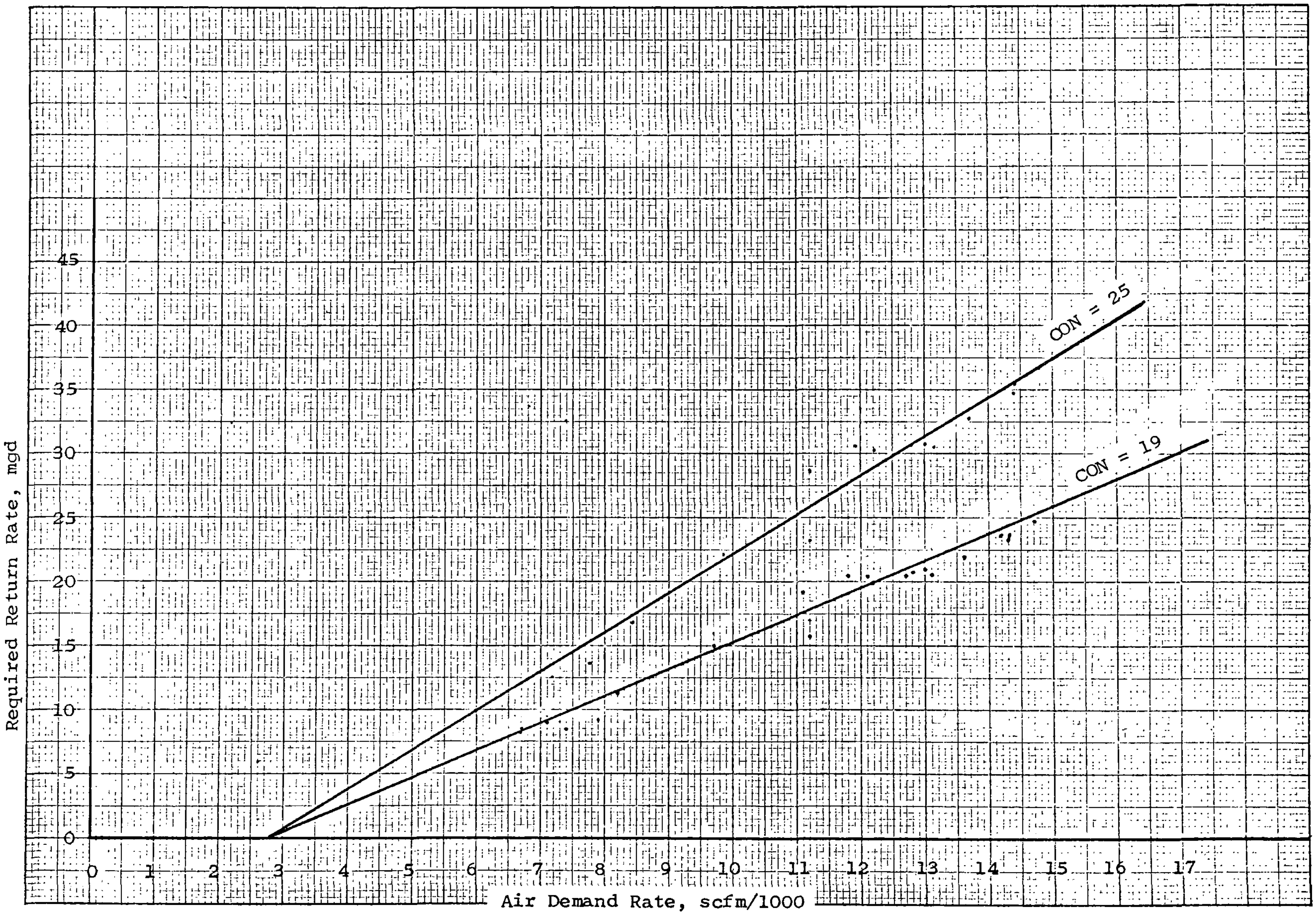


Figure 19. Relationship between return rate and air demand to make mass of sludge returned directly proportional to incoming load.

25 mgd (1.1 m^3/sec) until about noon when it can be returned to the normal 12 mgd (0.53 m^3/sec) until it is again set to zero at about 11 p.m. The computer program was provided with logic to simulate this kind of step control of the return rate. The program was then operated with this kind of control for Q(18), and the process was allowed to stabilize. The MLVSS in the aerator was found to stabilize at around 700 mg/l. Because of the many variables to be determined by trial and error in this kind of scheduling for Q(18), no satisfactory step schedule for Q(18) was ever found.

REFERENCES

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APPENDIX

PROGRAM OUTPUT VARIABLES

BODA	Average mass of BOD discharged per day at station No. 15, lb BOD/day
BODR	Average substrate removal rate, lb BOD removed per day/lb MLVSS in process
BODL	Average BOD loading, lb BOD entering per day/lb active solids in process
DKWH	Average electrical power consumption for air blowers, kwh/day
ASRT	Average sludge retention time, days (mass of active solids in process/total wasting rate, lb active solids per day)
AMLSS	Average mixed liquor suspended solids concentration in aerator, mg/l
XRSS	Concentration of suspended solids in final settler effluent stream divided by mixed liquor suspended solids concentration
URSS	Concentration of suspended solids in underflow stream from final settler divided by mixed liquor suspended solids concentration
SMUA	Sludge inventory in final settler, lb stored/sq ft of overflow area
BOUT	Total BOD concentration in final settler effluent, mg/l
FM	Food/microorganism ratio for aerator, lb of BOD entering process divided by lb of active solids in aerator
TCFM	Total air supplied to aerators, scfm
TAIR	Total air supplied to aerators and sludge storage tank, scfm
AERFF	Aeration efficiency, mass of air dissolved in water/mass of air supplied
DHP	Larger air blower setting for two position air control, scfm
DPL	Lower air blower setting for two position air control, scfm
THP	Air blower brake horsepower, hp
PIGV	Position of inlet guide vanes, fraction of full open
DPCFM	Design point air supply capacity for air blower, scfm
C1(1)	Maximum rate constant for synthesis (heterotrophs), day^{-1}

TIME DEPENDENT MATHEMATICAL MODEL FOR ACTIVATED SLUDGE

PROGRAM INPUT VARIABLES

IPS(1)	Program control: -1,0 indicates no equalization basin is provided, 1 indicates an equalization basin is used
IPS(2)	Program control: -1,0 indicates no primary sedimentation is provided, 1 indicates primary sedimentation is used
IPS(3)	Program control: -1 indicates no sludge storage is provided, 0 indicates final settler sludge storage is used, 1 indicates separate sludge storage (stabilization basin) is used
IPS(4)	Program control: -1 indicates modified F/M control with sludge storage, 0 indicates MLSS control with sludge storage, 1 indicates F/M control with sludge storage
IPS(5)	Program control: -2 indicates waste stream volume is constant, -1 indicates waste stream volume is proportional to the flow at station 3, 0 indicates SRT control of the waste stream by setting it equal to a fixed fraction of the aerator sludge per day, 1 indicates SBL control of the waste stream by setting it equal to a fixed rate when the sludge blanket level gets above a specified limit
IPS(6)	Program control: -1 indicates two position manual control of air blowers for dissolved oxygen control in the aeration tank, 0 indicates DO control with diffused air aeration, 1 indicates DO control with mechanical aeration (for no DO control, set PGDO(I) and RSDO(I) input values equal to zero)
IPS(7)	Program control: -1 indicates step input for influent variables (flow, dissolved BOD, particulate BOD, ammonia nitrogen, and inert solids) is provided, 0 indicates sine wave variation is used for influent variables, 1 indicates constant values are used for influent variables
XN	Total number of H-size time increments for the program to calculate (for example, 15 days would be XN = 1500 time increments of size H = .01)
H	Time increment between program calculations, days (an increment of .01 days is normally used)
T	Starting time of the first calculation, days

TD — The program will only begin to print out calculations at the time in days specified by this input value; if it is set equal to 0, then all of the calculations will be printed out

XCALC — The program will only print out every XCALCth calculation that the program makes; if XCALC is set equal to 1, then every calculation is printed out

QA — Average influent flow to the system, mgd

DT — Aerator detention time, hours

TL — Water temperature, degrees centigrade

V(18) — Volume of the stabilization basin, millions of gallons

GPS — Primary settler overflow rate, gpd/sq ft

GSS — Final settler overflow rate, gpd/sq ft

WRATE — Sludge wasting rate, fraction (fraction of stream 3 that is wasted for proportional control of sludge wasting)

FNVOL — Fraction of non-volatile inert suspended solids

SRT — Sludge retention time, lbs of sludge in the process/lbs of sludge wasted per day

SBLM — Set point for sludge blanket level control of sludge wasting, lbs of sludge in the final settler per sq ft of surface area

ALPHA — Aeration efficiency in wastewater/aeration efficiency in tap water

BETA — Oxygen saturation value of wastewater/oxygen saturation value of tap water

HPHRO — Efficiency measure for mechanical aerators, lbs of oxygen/hp-hr

RP — Atmospheric pressure at aerator/atmospheric pressure at sea level

QW — Constant sludge wasting rate for sludge blanket control of wasting, mgd

XNTKS — Number of equal volume sub-aerators in the system

CON — Proportionality constant for <u>modified</u> F/M control

SPML — set point for MLSS control with sludge storage, mg/l

PGML	Proportional gain for MLSS control
RSML	Reset constant for MLSS control
SPFM	Set point for F/M control
PGFM	Proportional gain for F/M control
RSFM	Reset constant for F/M control
Q16	Sludge wasting rate when the waste stream is held constant, mgd
DPH	Higher air supply set point for two position manual control of air blowers, scfm
DPL	Lower air supply set point for two position manual control of air blowers, scfm
TIME1	Beginning time for changing air supply set point for two position manual control of air blowers, time of day
TIME2	Ending time for changing air supply set point for two position manual control of air blowers, time of day
Q17	Sludge return rate when the return stream is held constant, mgd
CFMMG(18)	Air supply to the stabilization tank, scfm/million gallons
SPDO(I)	Set point dissolved oxygen level in aerator sub-volume I, mg/l
PGDO(I)	Proportional gain for DO control in aerator sub-volume I
RSDO(I)	Reset constant for DO control in aerator sub-volume I
Q1(I)*	100 step input values for influent flow, mgd
S11(I)*	100 step input values for influent dissolved BOD concentration, mg/l
S21(I)*	100 step input values for influent particulate BOD concentration, mg/l
S31(I)*	100 step input values for influent ammonia nitrogen concentration, mg/l
X41(I)*	100 step input values for influent inert solids concentration, mg/l

*Note that the 100 step input values for Q1(I), S11(I), S21(I), S31(I), and X41(I) are only required if the IPS(7) = -1 option is used. All other input variables are always required to run the program.

```
C     THIS DECK USES BRUTE FORCE NUMERICAL INTEGRATION

      DIMENSION X(5,18),S(4,18),Q(18),V(18),C1(4),C2(4),C3(4),C4(4),
     . DELS(4,18),DELX(5,18),DLS18(4),DLX18(5),BODA(100),BODR(100),
     . BODL(100),DKWH(100),DO(18),HPMG(18),CFMMG(18),SPDO(18),EDO(18),
     . EDOI(18),PGDO(18),RSDO(18),IPS(10),DELS2(4),DELX2(5),
     . ASRT(100),AMLSS(100),Q1(100),S11(100),S21(100),S31(100),X41(100)

C     SET ALL DIMENSIONED VARIABLFS TO ZERO

      DATA X/90*0.0/,S/72*0.0/,Q/18*0.0/,V/18*0.0/
      DATA C1/4*0.0/,C2/4*0.0/,C3/4*0.0/,C4/4*0.0/
      DATA DELS/72*0.0/,DELX/90*0.0/,DLS18/4*0.0/,DLX18/5*0.0/
      DATA BODA,BODR,BODL,DKWH/400*0.0/,DO/18*0.0/,HPMG/18*0.0/
      DATA CFMMG/18*0.0/,SPDO/18*0.0/,EDO/18*0.0/,EDOI/18*0.0/
      DATA PGDO/18*0.0/,RSDO/18*0.0/
      DATA IPS/10*0/,DELS2/4*0.0/,DELX2/5*0.0/
      DATA ASRT,AMLSS,Q1,S11,S21,S31,X41/700*0.0/

C     FUNCTION STATEMENTS

      DSDTF(A,B,C,D,E,F,G)=Q4*(A-B)/C-D*B*E/(F+B)/G
      DXDTF(A,B,C,D,E,F,G)=Q4*(A-B)/C+D*B*E/(F+E)-G*B
      DSVTF(A,B,C,D,E,F)=(QIN*A-QOUT*B)/VL-C*B*D/(E+B)/F-B*(QIN-QOUT)/VL
      DXVTF(A,B,C,D,E,F)=(QIN*A-QOUT*B)/VL-B*(QIN-QOUT)/VL+C*B*D/(E+D)-
     . F*B
      DOUPF(A,B,C,D,E,F,G,H,P,Q,R,S,T,U,V)=A*(B-C)/D+.58*E*F*G/H/
     . (P+F)+4.6*Q*R*S/T/(U+R)+1.16*V*G

C     SET INITIAL VALUES

      IN=2
      IO=5
      IP=7
      III=0
      Y=0.
      XREM=0.
      XLOAD=0.
      BKWH=0.
      DELY=0.
      DELR=0.
      DELL=0.
      BKW=0.
      AS=0.
      AM=0.
      SRT1=0.
      M=0
      AERK1=0.
      AERK2=0.
      AXL=0.
      EXL=0.
      X4DT=0.
      X4DOT=0.
      EMLI=0.
      TCFM=0.
      DHP=0.
      THP=0.
      PFL=0.
```

```
      ELOSS=0.
      EEFF=0.
      PIGV=0.
      CFMDF=0.
      XRSS=0.
      URSS=0.
      SMUA=0.
      IC=0
      TAIR=0.

C   CLASSES OF PARTICULATES

C         X(1,I) = HETEROTROPHS
C         X(2,I) = NITROSOMONAS
C         X(3,I) = NITROBACTER
C         X(4,I) = INERT SOLIDS
C         X(5,I) = TOTAL SUSPENDED SOLIDS
C         S(1,I) = DISSOLVED BOD
C         S(2,I) = PARTICULATE BOD
C         S(3,I) = AMMONIA NITROGEN
C         S(4,I) = NITRITE

C   DEFINITION OF PROCESS VECTOR - IPS(I)

C         IPS(1)= -1,0, NO EQUALIZATION BASIN
C                    1, USE EQUALIZATION BASIN

C         IPS(2)= -1,0, NO PRIMARY SEDIMENTATION
C                    1, USE PRIMARY SEDIMENTATION

C         IPS(3)=   -1, NO SLUDGE STORAGE IS PROVIDED
C                    0, SLUDGE STORAGE IS PROVIDED - FINAL SETTLER STORAGE
C                    1, SLUDGE STORAGE IS PROVIDED - SEPARATE STORAGE V(18)

C         IPS(4)=   -1, MODIFIED F/M CONTROL
C                    0, MLSS CONTROL
C                    1, F/M CONTROL
C                    NOTE - THESE CONTROLS ARE NOT USED IF NO SLUDGE STORAGE

C         IPS(5)=   -2, Q(16) IS CONSTANT FOR SLUDGE WASTING
C                   -1, Q(16) IS PROPORTIONAL TO Q(3) FOR SLUDGE WASTING
C                    0, SRT CONTROL ON Q(16) FOR SLUDGE WASTING
C                    1, SBL CONTROL ON Q(16) FOR SLUDGE WASTING

C         IPS(6)=   -1, TWO POSITION MANUAL CONTROL OF AIR BLOWER
C                    0, DO CONTROL WITH DIFFUSED AIR
C                    1, DO CONTROL WITH MECHANICAL AIR
C                    NOTE - INPUT PGDO(I)=0. + RSDO(I)=0. I=5,K FOR NO DO CONTROL

C         IPS(7)=   -1, 100 STEP INPUTS - Q(1),S(1,1),S(2,1),S(3,1),X(4,1)
C                    0, SINE WAVE VARIATION - Q(1),S(1,1),S(2,1),S(3,1),X(4,1)
C                    1, CONSTANT AVERAGE VALUE - Q(1),S(1,1),S(2,1),S(3,1),X(4,1)

C   READ ALL CONSTANT INPUT VALUES

      READ(IN,101) (IPS(I),I=1,7)
  101 FORMAT(10I2)
      READ(IN,103) XN,H,T,TD,XCALC
      READ(IN,103) QA,DT,TL,V(18),GPS,GSS,WRATE,FNVOL
```

```
      READ(IN,103) SRT,SBLM,ALPHA,BETA,HPHRO,RP,QW,XNTKS
      READ(IN,103) CON,SPML,PGML,RSML,SPFM,PGFM,RSFM,Q16
      READ(IN,103) DPH,DPL,TIME1,TIME2,Q17,CFMMG(18)
  103 FORMAT(8F10.0)
      K=XNTKS+4
      READ(IN,104)  (SPDO(I),I=5,18)
      READ(IN,104)  (PGDO(I),I=5,18)
      READ(IN,104)  (RSDO(I),I=5,18)
  104 FORMAT(10F8.0)

      IF(IPS(7)) 106,108,108

  106 READ(IN,104) (Q1(I),I=1,100)
      READ(IN,104) (S11(I),I=1,100)
      READ(IN,104) (S21(I),I=1,100)
      READ(IN,104) (S31(I),I=1,100)
      READ(IN,104) (X41(I),I=1,100)

C     WRITE ALL CONSTANT INPUT VALUES

  108 WRITE(IO,100)
  100 FORMAT(1H1,/)
      WRITE(IO,101) (IPS(I),I=1,7)
      WRITE(IO,114) XN,H,T,TD,XCALC
      WRITE(IO,114) QA;DT,TL,V(18),GPS,GSS,WRATE,FNVOL
      WRITE(IO,114) SRT,SBLM,ALPHA,BETA,HPHRO,RP,QW,XNTKS
      WRITE(IO,114) CON,SPML,PGML,RSML,SPFM,PGFM,RSFM,Q16
      WRITE(IO,114) DPH,DPL,TIMF1,TIME2,Q17,CFMMG(18)
      WRITE(IO,114) (SPDO(I),I=5,K)
      WRITE(IO,114) (PGDO(I),I=5,K)
      WRITE(IO,114) (RSDO(I),I=5,K)
  114 FORMAT(10F10.3)

      IF(IPS(7)) 116,112,112

  116 WRITE(IO,114) (Q1(I),I=1,100)
      WRITE(IO,114) (S11(I),I=1,100)
      WRITE(IO,114) (S21(I),I=1,100)
      WRITE(IO,114) (S31(I),I=1,100)
      WRITE(IO,114) (X41(I),I=1,100)

C     SET INITIAL VALUES AND MAKE INITIAL CALCULATIONS

  112 C1(1)=4.8
      C2(1)=150.
      C3(1)=.125
      C4(1)=.5
      C1(2)=4.8
      C2(2)=150.
      C3(2)=.125
      C4(2)=.5
      C1(3)=.28
      C2(3)=1.
      C3(3)=.18
      C4(3)=.05
      C1(4)=1.
      C1(4)=0.
      C2(4)=2.1
      C3(4)=.18
```

```
      C4(4)=.02

      X(1,5)=750.
      X(2,5)=75.
      X(3,5)=5.
      X(4,5)=1200.
      X(5,5)=2000.
      S(1,5)=20.
      S(2,5)=60.
      S(3,5)=30.
      S(4,5)=1.
      DO 1 J=5,K
      DO 1 I=1,5
    1 X(I,J)=X(I,5)
      DO 2 J=5,K
      DO 2 I=1,4
    2 S(I,J)=S(I,5)

      IF(IPS(1)) 4,4,3

    3 V(2)=(QP-QA)/3.1416*1.25
      X(1,2)=50.
      X(2,2)=20.
      X(3,2)=10.
      X(4,2)=50.
      X(5,2)=150.
      S(1,2)=60.
      S(2,2)=140.
      S(3,2)=30.
      S(4,2)=0.

    4 IF(V(18)) 7,7,6

    6 X(1,18)=2300.
      X(2,18)=100.
      X(3,18)=15.
      X(4,18)=3500.
      X(5,18)=6000.
      S(1,18)=1.
      S(2,18)=1.
      S(3,18)=1.
      S(4,18)=0.

    7 T=.002
      ALP18=.90
      AER18=.17
      AERFF=.16
      APS=QA*1000000./GPS
      AFS=QA*1000000./GSS
      SMFS=SBLM*AFS
      QP=1.78*QA**.92
      CLA=ALPHA*1.025**(TL-20.)
      CSS=14.652-.41022*TL+.0079910*TL**2.-.000077774*TL**3.
      CSW=CSS*BETA*RP
      VAER=DT*QA/24.
      DPCFM=DPH


      DO 20 J=5,K
```

```
      V(J)=VAER/XNTKS
      CFMMG(J)=DPH/XNTKS/V(J)
   20 HPMG(J)=CFMMG(J)/39.45

C     BEGIN TIME-DEPENDENT CALCULATIONS ( BIG DO-LOOP )

      NSTOP=XN+1
      DO 1000 LL=1,NSTOP

C     SET DESIGN POINT CFM (DPCFM)

      IF (IPS(6))  170,179,179

  170 IT=T
      T1=IT+TIME1
      T2=IT+TIME2
      IF (T-T1)  177,171,171
  171 IF (T-T2) 173,177,177
  173 DO 10  J=5,K
      CFMMG(J)=(DPL/XNTKS)/V(J)
   10 HPMG(J)=CFMMG(J)/39.45
      GO TO 179
  177 DO 11  J=5,K
      CFMMG(J)=(DPH/XNTKS)/V(J)
   11 HPMG(J)=CFMMG(J)/39.45

C     GENERATE RAW WASTEWATER STREAM

  179 IF(LL-1) 553,553,150

  150 IF(IPS(7)) 151,152,154

  151 IC=IC+1
      Q(1)=Q1(IC)
      S(1,1)=S11(IC)
      S(2,1)=S21(IC)
      S(3,1)=S31(IC)
      X(4,1)=X41(IC)
      GO TO 156
  152 Q(1)=QA-(QP-QA)*SIN(6.283*T)
      S(1,1)=60.-40.*SIN(6.283*T)
      S(2,1)=140.-93.*SIN(6.283*T)
      S(3,1)=30.-20.*SIN(6.283*T)
      X(4,1)=90.-72.*SIN(6.283*T)
      GO TO 156
  154 Q(1)=25.67
      S(1,1)=114.67
      S(2,1)=28.58
      S(3,1)=28.95
      X(4,1)=35.74
  156 X(5,1)=X(4,1)+S(2,1)/.8

      IF(IPS(1)) 80,80,99

C     NO EQUALIZATION BASIN PROVIDED

   80 DO 81 I=1,4
   81 S(I,2)=S(I,1)
      DO 82 I=1,5
```

```
   82 X(I,2)=X(I,1)
      Q(2)=Q(1)
      GO TO 120

C     EQUALIZATION BASIN PERFORMANCE

   99 Q(2)=QA
      X4DOT=(Q(1)*X(4,1)-Q(2)*X(4,2))/V(2)-X(4,2)*(Q(1)-Q(2))/V(2)
      EXL=V(2)*X(1,2)/Q(1)/(S(1,1)+S(1,2))
      C1(1)=5.341-2.54*(ALOG(EXL))
      C1(1)=C1(1)*1.08**(TL-20.)
      IF(C1(1)-25.) 118,118,117
  117 C1(1)=25.
      GO TO 121
  118 IF(C1(1)-1.) 119,119,121
  119 C1(1)=1.
  121 DLV2=Q(1)-Q(2)
      C1(2)=C1(1)
      QIN=Q(1)
      QOUT=Q(2)
      VL=V(2)
      DO 631 I=1,2
  631 DELS2(I)=DSVTF(S(I,1),S(I,2),C1(I),X(1,2),C2(I),C4(I))
      DO 632 I=3,4
  632 DELS2(I)=DSVTF(S(I,1),S(I,2),C1(I),X(I,2),C2(I),C4(I))
      ST2=S(1,2)+S(2,2)
      DELX2(1)=DXVTF(X(1,1),X(1,2),C1(1),ST2,C2(1),C3(1))
      DELX2(2)=DXVTF(X(2,1),X(2,2),C1(3),S(3,2),C2(3),C3(3))
      DELX2(3)=DXVTF(X(3,1),X(3,2),C1(4),S(4,2),C2(4),C3(4))

  120 IF(IPS(2)) 124,124,122

C     NO PRIMARY SETTLER

  124 Q(3)=Q(2)
      DO 127 I=1,4
  127 S(I,3)=S(I,2)
      DO 128 I=1,5
  128 X(I,3)=X(I,2)
      GO TO 126

C     PRIMARY SETTLER PERFORMANCE

  122 GPS=Q(2)*1000000./APS
      S(1,3)=S(1,2)
      S(2,3)=S(2,2)*(1.-.82/EXP(GPS/2780.))
      S(3,3)=S(3,2)
      S(4,3)=S(4,2)
      Q(3)=Q(2)
      DO 125 I=1,4
  125 X(I,3)=X(I,2)*(1.-.82/EXP(GPS/2780.))
      X(5,3)=X(1,3)+X(2,3)+X(3,3)+X(4,3)+S(2,3)*.8

C     ACTIVATED SLUDGE AND FINAL SETTLER PERFORMANCE

  126 BUGS=0.
      BUGS=V(18)*X(1,18)
      DO 560 I=5,K
  560 BUGS=BUGS+V(I)*X(1,I)
```

```
      FM=(S(1,3)+S(2,3))*Q(3)/(X(5,5)-X(4,5)*FNVOL)/VAER
      URSS=(.3565*SMUA-.0418)*10000./X(5,K)
      GSS=Q(15)*1000000./AFS
      XRSS=556.*GSS**.494/X(5,K)**1.82/DT**.439
      X(5,15)=37.-20.*SIN(6.283*T-1.571)
      XRSS=X(5,15)/X(5,K)
      IF(XRSS-.1) 142,142,141
  141 XRSS=.1
  142 DO 140 I=1,5
      X(I,15)=X(I,K)*XRSS
      X(I,16)=X(I,K)*URSS
  140 X(I,17)=X(I,16)
      S(1,15)=S(1,K)
      S(1,16)=S(1,K)
      S(1,17)=S(1,K)
      S(2,15)=S(2,K)*XRSS
      S(2,16)=S(2,K)*URSS
      S(2,17)=S(2,16)
      DO 180 I=3,4
      S(I,15)=S(I,K)
      S(I,16)=S(I,K)
  180 S(I,17)=S(I,K)

      IF(IPS(5)) 229,231,232

  229 IF(IPS(5)+1) 320,330,330

C   Q(16) IS CONSTANT FOR SLUDGF WASTING

  320 Q(16)=Q16
      GO TO 230

C   Q(16) IS PROPORTIONAL TO Q(3) FOR SLUDGE WASTING

  330 Q(16)=Q(3)*WRATE
      GO TO 230

C   SRT CONTROL ON Q(16) FOR SLUDGE WASTING

  231 Q(16)=BUGS/SRT/X(1,K)/URSS-Q(15)*XRSS/URSS
      IF(Q(16)) 299,230,230
  299 Q(16)=0.
      GO TO 230

C   SBL CONTROL ON Q(16) FOR SLUDGE WASTING

  232 IF(SMUA-SBLM) 233,233,234
  233 Q(16)=0.
      GO TO 230
  234 Q(16)=QW

  230 IF(IPS(3)) 235,236,237

C   NO SLUDGE STORAGE PROVIDED

  235 Q(17)=((Q(3)-Q(16))*(1.-XRSS)-Q(16)*(URSS-1.))/(URSS-1.)
      Q(17)=-5.836735+2.122449*TCFM/1000.
      Q(17)=Q17
      IF(Q(17)) 262,264,264
```

```
  262 Q(17)=0.
  264 Q(18)=Q(17)
      Q(15)=Q(3)-Q(16)

      IF(V(18)) 247,247,245

C   FINAL SETTLER SLUDGE STORAGE IS PROVIDED

  236 IF(IPS(4)) 292,238,239

C        MODIFIED F/M CONTROL OF SUSPENDED SOLIDS - FINAL SETTLER

  292 Q(17)=CON*(S(1,3)+S(2,3))*Q(3)/(X(5,17)-X(4,17)*FNVOL)
      Q(17)=5.58*CON*Q(3)**2./(X(5,17)-X(4,17)*FNVOL)
      ITT=T
      TT=ITT
      IF(T-(TT+.34)) 391,391,392
  391 Q(17)=0.
      GO TO 398
  392 IF(T-(TT+.49)) 393,393,394
  393 Q(17)=25.
      GO TO 398
  394 IF(T-(TT+.94)) 396,396,397
  396 Q(17)=12.
      GO TO 398
  397 Q(17)=0.
  398 CONTINUE
      IF(Q(17)) 293,294,294
  293 Q(17)=0.
  294 Q(18)=Q(17)
      Q(15)=Q(3)-Q(16)
      GO TO 247

C        MLSS CONTROL OF SUSPENDED SOLIDS - FINAL SETTLER

  238 EML=SPML-X(5,K)
      EMLI=EMLI+EML*H
      Q(17)=Q(17)+PGML*EML+RSML*EMLI
      IF(Q(17)) 266,268,268
  266 Q(17)=0.
  268 Q(18)=Q(17)
      Q(15)=Q(3)-Q(16)
      GO TO 247

C        F/M CONTROL OF SUSPENDED SOLIDS - FINAL SETTLER

  239 EFM=FM-SPFM
      EFMI=EFMI+EFM*H
      Q(17)=Q(17)+PGFM*EFM+RSFM*EFMI
      IF(Q(17)) 272,274,274
  272 Q(17)=0.
  274 Q(18)=Q(17)
      Q(15)=Q(3)-Q(16)

  247 DO 210 I=1,5
  210 X(I,18)=X(I,17)
      DO 211 I=1,4
  211 S(I,18)=S(I,17)
      GO TO 245
```

```
C   SEPARATE SLUDGE STORAGE IS PROVIDED IN A RETURN TANK V(18)

  237 IF(IPS(4)) 296,240,241

C         MODIFIED F/M CONTROL OF SUSPENDED SOLIDS - RETURN TANK V(18)

  296 Q(18)=CON*(S(1,3)+S(2,3))*Q(3)/(X(5,18)-X(4,18)*FNVOL)
      IF(Q(18)) 297,298,298
  297 Q(18)=0.
      Q(17)=0.
      GO TO 214
  298 Q(17)=((Q(3)-Q(16))*(1.-XRSS)-Q(16)*(URSS-1.))/(URSS-1.)
      Q(17)=Q(18)
  214 Q(15)=Q(3)-Q(16)
      GO TO 245

C         MLSS CONTROL OF SUSPENDED SOLIDS - RETURN TANK V(18)

  240 EML=SPML-X(5,K)
      EMLI=EMLI+EML*H
      Q(18)=Q(18)+PGML*EML+RSML*EMLI
      IF(Q(18)) 276,276,278
  276 Q(18)=0.
      Q(17)=0.
      GO TO 279
  278 Q(17)=(Q(3)+Q(18))*(1.-XRSS)/(URSS-XRSS)-Q(16)
      Q(17)=Q(18)
  279 Q(15)=Q(18)+Q(3)-Q(16)-Q(17)
      GO TO 245

C         F/M CONTROL OF SUSPENDED SOLIDS - RETURN TANK V(18)

  241 EFM=FM-SPFM
      EFMI=EFMI+EFM*H
      Q(18)=Q(18)+PGFM*EFM+RSFM*EFMI
      IF(Q(18)) 282,282,284
  282 Q(18)=0.
      Q(17)=0.
      GO TO 286
  284 Q(17)=(Q(3)+Q(18))*(1.-XRSS)/(URSS-XRSS)-Q(16)
      Q(17)=Q(18)
  286 Q(15)=Q(18)+Q(3)-Q(16)-Q(17)

  245 BODA(III)=Y
      BODR(III)=XREM
      BODL(III)=XLOAD
      DKWH(III)=BKWH
      ASRT(III)=AS
      AMLSS(III)=AM
      SRT1=1./(X(1,K)*URSS/BUGS*(Q(16)+Q(15)*XRSS/URSS))
      BODIN=S(1,3)+S(2,3)
      BOUT=S(1,15)+S(2,15)+.84*X(1,15)
      SLDG=0.
      SLDG=V(18)*(X(5,18)-X(4,18)*FNVOL)
      DO 559 I=5,K
  559 SLDG=SLDG+V(I)*(X(5,I)-X(4,I)*FNVOL)
      DELY=Q(15)*8.33*(S(1,15)+S(2,15)+.84*X(1,15))
      DELR=(Q(3)*BODIN-Q(15)*BOUT)/SLDG
```

```
      DELL=BODIN*Q(3)/BUGS
      AXL=BUGS/Q(3)/BODIN
      C1(1)=5.341-2.54*(ALOG(AXL))
      C1(1)=10.0
      C1(1)=4.8
      C1(1)=C1(1)*(1.047)**(TL-20.)
      IF(C1(1)-25.) 551,551,552
  552 C1(1)=25.
      GO TO 557
  551 IF(C1(1)-1.) 554,554,555
  554 C1(1)=1.
  555 C1(2)=C1(1)

C   RE-ADJUST ALL STREAM VECTORS + INDEPENDENT VARIABLES

  557 Q(4)=Q(18)+Q(3)
      DO 300 J=5,K
  300 Q(J)=Q(4)
      DO(4)=(Q(3)*DO(3)+Q(18)*DO(18))/Q(4)
      DO(15)=DO(K)
      DO(16)=DO(K)
      DO(17)=DO(K)
      DO(18)=DO(17)
      DO 302 I=1,5
  302 X(I,4)=(Q(18)*X(I,18)+Q(3)*X(I,3))/Q(4)
      DO 303 I=1,4
  303 S(I,4)=(Q(18)*S(I,18)+Q(3)*S(I,3))/Q(4)

C   COMPUTE DERIVATIVES FOR ACTIVE SOLIDS

      Q4=Q(4)
      DO 520 J=5,K
      ST=S(1,J)+S(2,J)
      DELX(1,J)=DXDTF(X(1,J-1),X(1,J),V(J),C1(1),ST,C2(1),C3(1))
      DELX(2,J)=DXDTF(X(2,J-1),X(2,J),V(J),C1(3),S(3,J),C2(3),C3(3))
  520 DELX(3,J)=DXDTF(X(3,J-1),X(3,J),V(J),C1(4),S(4,J),C2(4),C3(4))

C   COMPUTE DERIVATIVES FOR SUBSTRATES

      DO 540 J=5,K
      DO 540 I=1,2
  540 DELS(I,J)=DSDTF(S(I,J-1),S(I,J),V(J),C1(I),X(1,J),C2(I),C4(I))
      DO 550 J=5,K
      DELS(3,J)=DSDTF(S(3,J-1),S(3,J),V(J),C1(3),X(2,J),C2(3),C4(3))
  550 DELS(4,J)=Q(4)*(S(4,J-1)-S(4,J))/V(J)-C1(4)*S(4,J)*X(3,J)/(C2(4)+
     . S(4,J))/C4(4)+C1(3)*S(3,J)*X(2,J)/(C2(3)+S(3,J))/C4(3)

C   COMPUTE DERIVATIVES FOR STABILIZATION TANK - V(18)

      IF(V(18)) 246,246,244

  244 X4DT=(Q(17)*X(4,17)-Q(18)*X(4,18))/V(18)-X(4,18)*(Q(17)-Q(18))/
     . V(18)
      QIN=Q(17)
      QOUT=Q(18)
      DLV18=Q(17)-Q(18)
      VL=V(18)
      ST18=S(1,18)+S(2,18)
      DLX18(1)=DXVTF(X(1,17),X(1,18),C1(1),ST18,C2(1),C3(1))
```

```
      DLX18(2)=DXVTF(X(2,17),X(2,18),C1(3),S(3,18),C2(3),C3(3))
      DLX18(3)=DXVTF(X(3,17),X(3,18),C1(4),S(4,18),C2(4),C3(4))
      DLS18(1)=DSVTF(S(1,17),S(1,18),C1(1),X(1,18),C2(1),C4(1))
      DLS18(2)=DSVTF(S(2,17),S(2,18),C1(2),X(1,18),C2(2),C4(2))
      DLS18(3)=DSVTF(S(3,17),S(3,18),C1(3),X(2,18),C2(3),C4(3))
      DLS18(4)=(QIN*S(4,17)-QOUT*S(4,18))/VL-C1(4)*S(4,18)*X(3,18)/
     . (C2(4)+S(4,18))/C4(4)-S(4,18)*(QIN-QOUT)/VL+
     . C1(3)*S(3,18)*X(2,18)/(C2(3)+S(3,18))/C4(3)

C     COMPUTE DISSOLVED OXYGEN REQUIREMENTS

  246 DO 920 J=5,K
      ST=S(1,J)+S(2,J)

      IF(IPS(6)) 892,892,894

  892 AERK1=.33347*CFMMG(J)*AERFF*ALPHA*1.025**(TL-20.)
      GO TO 896
  894 AERK1=HPMG(J)*HPHRO*CLA/9.02/8.33*24.
  896 AERK2=DOUPF(Q(J),DO(J),DO(J-1),V(J),C1(1),ST,X(1,J),
     . C4(1),C2(1),C1(2),S(3,J),X(2,J),C4(2),C2(2),C3(1))
      DO(J)=CSW-AERK2/AERK1-(CSW-DO(J)-AERK2/AERK1)/EXP(AERK1*H)
      IF(DO(J)) 897,898,898
  897 DO(J)=0.
  898 EDO(J)=SPDO(J)-DO(J)
      EDOI(J)=EDOI(J)+(SPDO(J)-CSW+AERK2/AERK1)*H-(CSW-DO(J)-
     . AERK2/AERK1)/AERK1/EXP(AERK1*H)

      IF(IPS(6)) 920,900,910

  900 CFMMG(J)=CFMMG(J)+PGDO(J)*EDO(J)+RSDO(J)*EDOI(J)
      IF(CFMMG(J)-150.) 905,920,920
  905 CFMMG(J)=150.
      GO TO 920
  910 HPMG(J)=HPMG(J)+PGDO(J)*EDO(J)+RSDO(J)*EDOI(J)
      IF(HPMG(J)) 915,920,920
  915 HPMG(J)=0.
  920 CONTINUE

      IF(V(18)) 932,932,929

  929 ST=S(1,18)+S(2,18)
      AERK1=.33347*CFMMG(18)*AER18*ALP18*1.025**(TL-20.)
      AERK2=DOUPF(Q(18),DO(18),DO(17),V(18),C1(1),ST,X(1,18),
     . C4(1),C2(1),C1(2),S(3,18),X(2,18),C4(2),C2(2),C3(1))
      DO(18)=CSW-AERK2/AERK1-(CSW-DO(18)-AERK2/AERK1)/EXP(AERK1*H)
      IF (DO(18))  930,930,931
  930 DO(18)=0.0
  931 EDO(18)=SPDO(18)-DO(18)
      EDOI(18)=EDOI(18)+(SPDO(18)-CSW+AERK2/AERK1)*H-(CSW-DO(18)-
     . AERK2/AERK1)/AERK1/EXP(AFRK1*H)
      CFMMG(18)=CFMMG(18)+PGDO(18)*EDO(18)+RSDO(18)*EDOI(18)
      HPMG(18)=CFMMG(18)/39.45

  932 IF(IPS(6)) 922,922,553

  922 TCFM=0.
      DO 925 J=5,K
  925 TCFM=TCFM+CFMMG(J)*V(J)
```

```
      TAIR=TCFM+CFMMG(18)*V(18)
      CFMDF=12.*TCFM/DPCFM
      AERFF=(12.994-.1313*CFMDF)/100.
      AERFF=.16
      DHP=DPCFM*.03009
      THP=TCFM*.03009/(TCFM/DPCFM)**.2045
      PFL=THP/DHP
      IF(QA-10.) 341,342,342
  341 ELOSS=.04007+.0555*PFL
      GO TO 343
  342 ELOSS=.02008+.0473*PFL
  343 EEFF=PFL/(PFL+ELOSS)
      BKW=THP*.7457/EEFF
      PIGV=100.*(TCFM/DPCFM)**1.689

C     CALCULATE ACCUMULATED BOD, BOD REMOVAL, BOD LOADING, KILOWATT HOURS,
C     AVERAGE SRT, AND AVERAGE MLSS - ALL FOR ONE DAY OF OPERATION

  553 III=III+1
      IF(III-101) 690,670,670
  670 III=1
  690 Y=Y+DELY*H
      BODA(III)=Y-BODA(III)
      XREM=XREM+DELR*H
      BODR(III)=XREM-BODR(III)
      XLOAD=XLOAD+DELL*H
      BODL(III)=XLOAD-BODL(III)
      BKWH=BKWH+BKW*24.*H
      DKWH(III)=BKWH-DKWH(III)
      AS=AS+SRT1*H
      ASRT(III)=AS-ASRT(III)
      AM=AM+X(5,5)*H
      AMLSS(III)=AM-AMLSS(III)

C     PRINT PROGRAM OUTPUT

      IF(M) 500,400,500
  400 IF(T-TD) 490,420,420
  420 WRITE(IO,425) T
  425 FORMAT(/,2X,'TIME = ',F6.2)
      WRITE(IO,435)
  435 FORMAT(2X,'STATION',4X,'MGD',6X,'HETEROTROPHS',3X,'NITROSOMONAS',
     . 3X,'NITROBACTER',3X,'INERT SOLIDS',5X,'TSS',12X,'DO',
     . 10X,'VOLUME',/)
      DO 440 L=1,K
  440 WRITE(IO,445) L,Q(L),(X(M,L),M=1,5),DO(L),V(L)
  445 FORMAT(5X,I2,3X,E10.4,4X,E10.4,4X,E10.4,4X,E10.4,4X,E10.4,4X,
     . E10.4,4X,E10.4,4X,E10.4)
      DO 450 L=15,18
  450 WRITE(IO,445) L,Q(L),(X(M,L),M=1,5),DO(L),V(L)
      WRITE(IO,460)
  460 FORMAT( )
      WRITE(IO,465)
  465 FORMAT(22X,'DISSOLVED BOD',2X,'PARTICULATE BOD',3X,'AMMONIA',
     . 6X,'NITRITE',6X,'SCFM/MG'.9X,'HP/MG'/)
      DO 470 L=1,K
  470 WRITE(IO,471) L,(S(M,L),M=1,4),CFMMG(L),HPMG(L)
  471 FORMAT(5X,I2,17X,E10.4,4X,E10.4,4X,E10.4,4X,E10.4,4X,E10.4,4X,
     . E10.4,4X,E10.4)
```

```
      DO 475 L=15,18
  475 WRITE(IO,471) L,(S(M,L),M=1,4),CFMMG(L),HPMG(L)
      WRITE(IO,485) BODA(III),BODR(III),BODL(III),DKWH(III),ASRT(III),
     . AMLSS(III),XRSS,URSS,SMUA,BOUT,FM
  485 FORMAT(9X,'BODA',6X,'BODR',6X,'BODL',6X,'DKWH',6X,'ASRT',5X,
     . 'AMLSS',6X,'XRSS',6X,'URSS',6X,'SMUA',6X,'BOUT',8X,'FM',
     . /,5X,6F10.3,2F10.4,3F10.3)
      WRITE(IO,486) TCFM,TAIR,AERFF,DHP,THP,PFL,PIGV,DPCFM,C1(1)
  486 FORMAT(9X,'TCFM',6X,'TAIR',5X,'AERFF',7X,'DHP',7X,'THP',7X,
     . 'PFL',6X,'PIGV',5X,'DPCFM',5X,'C1(1)',/,5X,2F10.2,F10.3,6F10.2)
  490 M=XCALC

C   UPDATE ALL VARIABLES BY MULTIPLYING DERIVATIVES BY DELTA TIME

  500 IF(IPS(1)) 807,807,804

  804 DO 806 I=1,4
  806 S(I,2)=S(I,2)+DELS2(I)*H
      DO 805 I=1,3
  805 X(I,2)=X(I,2)+DELX2(I)*H
      X(4,2)=X(4,2)+X4DOT*H
      X(5,2)=X(1,2)+X(2,2)+X(3,2)+X(4,2)+S(2,2)/.8
      V(2)=V(2)+DLV2*H

  807 DO 702 J=5,K
      DO 702 I=1,4
  702 S(I,J)=S(I,J)+DELS(I,J)*H
      DO 700 J=5,K
      DO 700 I=1,3
  700 X(I,J)=X(I,J)+DELX(I,J)*H
      DO 701 J=5,K
      X(4,J)=X(4,J)+H*((Q(J-1)*X(4,J-1)-Q(J)*X(4,J))/V(J))
  701 X(5,J)=X(1,J)+X(2,J)+X(3,J)+X(4,J)+S(2,J)/.8
      SMFS=SMFS+X(5,K)*8.33*H*(Q(K)-Q(15)*XRSS-(Q(16)+Q(17))*URSS)
      SMUA=SMFS/AFS

      IF(V(18)) 780,780,720

  720 DO 760 I=1,4
  760 S(I,18)=S(I,18)+DLS18(I)*H
      DO 761 I=1,3
  761 X(I,18)=X(I,18)+DLX18(I)*H
      X(4,18)=X(4,18)+X4DT*H
      X(5,18)=X(1,18)+X(2,18)+X(3,18)+X(4,18)+S(2,18)*.8
      V(18)=V(18)+(Q(17)-Q(18))*H

  780 DO 850 J=5,K
      DO 850 I=1,3
      IF(S(I,J)-.001) 830,830,850
  830 S(I,J)=0.
  850 CONTINUE
      DO 890 I=1,3
      IF(S(I,18)-.001) 870,870,890
  870 S(I,18)=0.
  890 CONTINUE


C   INCREMENT TIME AND PRINTOUT CONTROLS AND REPEAT CALCULATION
```

```
      T=T+H
      M=M-1
      IF(IC-100) 1000,895,895
  895 IC=0
 1000 CONTINUE
      CALL EXIT
      END
```

SAMPLE PRINTOUT FROM COMPUTER PROGRAM

INPUT DATA

0 0-1 0-2 0-1

1500.000	0.010	0.000	14.000	5.000					
25.487	7.044	20.000	0.000	718.000	478.000	0.010	0.333		
10.000	1.800	0.900	0.900	3.500	1.000	0.500	1.000		
19.000	1250.000	0.010	0.000	0.350	600.000	0.000	0.140		
6840.000	5445.000	0.105	0.480	12.000	0.000				
1.000									
530.000									
18.000									
29.400	29.000	28.600	28.400	28.000	27.000	26.000	25.000	24.600	23.000
20.400	17.800	15.200	14.100	14.000	13.800	13.600	13.500	13.400	13.300
13.200	13.500	13.800	14.000	14.300	14.800	15.400	15.900	16.400	17.000
17.900	18.800	19.700	20.800	22.100	23.600	24.800	26.000	26.900	27.800
28.600	29.300	29.400	29.600	29.800	29.900	29.800	29.700	29.600	29.500
29.300	29.100	28.900	28.800	28.600	28.200	27.900	27.600	27.500	27.600
27.700	27.800	27.900	28.000	28.200	28.300	28.500	29.000	29.400	29.900
30.400	30.300	30.300	30.200	30.200	30.100	30.000	30.000	29.900	30.000
30.400	30.800	31.100	31.100	30.800	30.400	30.100	30.000	30.200	30.300
30.400	30.500	30.500	30.500	30.500	30.500	30.300	30.100	29.900	29.700
131.200	129.600	128.400	127.200	126.000	123.400	122.200	120.600	120.000	119.000
118.000	117.000	116.400	115.400	114.400	113.400	112.400	111.800	111.200	111.200
110.600	111.000	111.000	110.400	110.800	107.400	104.000	99.200	94.500	91.000
86.600	83.200	78.400	74.800	76.400	77.000	77.600	79.200	79.400	80.000
80.600	82.200	85.600	90.000	93.800	98.200	102.400	105.000	108.400	112.200
114.800	116.000	117.600	119.200	119.800	121.400	121.600	123.200	122.800	121.800
120.400	119.400	118.000	117.000	115.600	114.200	113.200	113.600	114.000	114.600
114.800	115.600	116.000	116.400	116.800	117.200	119.000	119.800	121.200	121.600
122.400	123.200	124.600	126.400	129.800	132.600	136.000	138.400	141.200	145.000
148.400	150.400	147.800	145.600	144.000	141.400	138.800	137.200	134.600	132.600
34.800	34.400	33.600	32.800	32.000	31.600	30.800	30.400	30.000	30.000
30.000	30.000	29.600	29.600	29.600	29.600	29.600	29.200	28.800	28.800
28.400	28.000	28.000	27.600	27.200	25.600	24.000	22.800	21.500	20.000
18.400	16.800	15.600	15.200	15.600	16.000	16.400	16.800	17.600	18.000
18.400	18.800	20.400	22.000	23.200	24.800	25.600	28.000	29.600	30.800
31.200	32.000	32.400	32.800	33.200	33.600	34.400	34.800	35.200	35.200
35.600	35.600	36.000	36.000	36.400	36.800	36.800	36.400	36.000	35.400
35.200	34.400	34.000	33.600	33.200	32.800	32.000	31.200	30.800	30.400
29.600	28.800	28.400	27.600	27.200	26.400	26.000	25.600	24.800	24.000
23.600	23.600	25.200	26.400	28.000	29.600	31.200	32.800	34.400	35.600
27.000	26.000	25.000	23.000	22.000	21.000	20.000	19.000	19.000	18.000
18.000	19.000	19.000	19.000	19.000	19.000	20.000	20.000	20.000	20.000
21.000	21.000	21.000	22.000	22.000	22.000	23.000	23.000	23.000	24.000
24.000	24.000	24.000	24.000	24.000	24.000	23.000	23.000	23.000	22.000
22.000	22.000	23.000	24.000	24.000	25.000	26.000	26.000	27.000	28.000
30.000	31.000	32.000	34.000	35.000	37.000	38.000	40.000	40.000	40.000
39.000	38.000	37.000	36.000	35.000	34.000	34.000	34.000	34.000	34.000
34.000	34.000	34.000	34.000	34.000	34.000	34.000	34.000	34.000	34.000
35.000	35.000	35.000	36.000	36.000	37.000	38.000	39.000	40.000	40.000
41.000	42.000	40.000	38.000	36.000	35.000	33.000	32.000	30.000	28.000
43.500	43.000	42.000	41.000	40.000	39.500	38.500	38.000	37.500	37.500
37.500	37.500	37.000	37.000	37.000	37.000	37.000	36.500	36.000	36.000
35.500	35.000	35.000	34.500	34.000	32.000	30.000	28.500	28.000	25.000
23.000	21.000	19.500	19.000	19.500	20.000	20.500	21.000	22.000	22.500
23.000	23.500	25.500	27.500	29.000	31.000	32.000	35.000	37.000	38.500
39.000	40.000	40.500	41.000	41.500	42.000	43.000	43.500	44.000	44.000
44.500	44.500	45.000	45.000	45.500	46.000	46.000	45.500	45.000	44.500
44.000	43.000	42.500	42.000	41.500	41.000	40.000	39.000	38.500	38.000
37.000	36.000	35.500	34.500	34.000	33.000	32.500	32.000	31.000	30.000
29.500	29.500	31.500	33.000	35.000	37.000	39.000	41.000	43.000	44.500

SAMPLE PRINTOUT FROM COMPUTER-PROGRAM

OUTPUT DATA

TIME = 14.00

STATION	MGD	HETEROTROPHS	NITROSOMONAS	NITROBACTER	INERT SOLIDS	TSS	DO	VOLUME
1	0.2970E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4450E 02	0.8900E 02	0.0000E 00	0.0000E 00
2	0.2970E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4450E 02	0.8900E 02	0.0000E 00	0.0000E 00
3	0.2970E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4450E 02	0.8900E 02	0.0000E 00	0.0000E 00
4	0.4170E 02	0.8868E 03	0.1227E 02	0.6442E-01	0.1008E 04	0.1942E 04	0.3027E 00	0.0000E 00
5	0.4170E 02	0.9034E 03	0.1250E 02	0.6563E-01	0.9952E 03	0.1914E 04	0.1054E 01	0.7480E 01
15	0.2955E 02	0.2690E 02	0.3725E 00	0.1954E-02	0.2963E 02	0.5699E 02	0.1052E 01	0.0000E 00
16	0.1400E 00	0.3081E 04	0.4266E 02	0.2238E 00	0.3394E 04	0.6529E 04	0.1052E 01	0.0000E 00
17	0.1200E 02	0.3081E 04	0.4266E 02	0.2238E 00	0.3394E 04	0.6529E 04	0.1052E 01	0.0000E 00
18	0.1200E 02	0.3081E 04	0.4266E 02	0.2238E 00	0.3394E 04	0.6529E 04	0.1052E 01	0.0000E 00

STATION	DISSOLVED BOD	PARTICULATE BOD	AMMONIA	NITRITE	SCFM/MG	HP/MG
1	0.1326E 03	0.3560E 02	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00
2	0.1326E 03	0.3560E 02	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00
3	0.1326E 03	0.3560E 02	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00
4	0.9714E 02	0.2764E 02	0.2492E 02	0.4941E 01	0.0000E 00	0.0000E 00
5	0.9398E 01	0.2336E 01	0.1732E 02	0.1717E 02	0.1631E 04	0.2317E 02
15	0.9398E 01	0.6957E-01	0.1732E 02	0.1717E 02	0.0000E 00	0.0000E 00
16	0.9398E 01	0.7969E 01	0.1732E 02	0.1717E 02	0.0000E 00	0.0000E 00
17	0.9398E 01	0.7969E 01	0.1732E 02	0.1717E 02	0.0000E 00	0.0000E 00
18	0.9398E 01	0.7969E 01	0.1732E 02	0.1717E 02	0.0000E 00	0.0000E 00

BODA	BODR	BODL	DKWH	ASRT	AMLSS	XRSS	URSS	SMUA	BOUT	FM
4599.969	0.260	0.539	5186.571	9.093	2005.343	0.0297	3.4108	1.948	32.067	0.421

TCFM	TAIR	AERFF	DHP	THP	PFL	PIGV	DPCFM	C1(1)
12204.56	12204.56	0.160	205.81	326.22	1.58	265.90	6840.00	4.80

TIME = 14.05

STATION	MGD	HETEROTROPHS	NITROSOMONAS	NITROBACTER	INERT SOLIDS	TSS	DO	VOLUME
1	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4000E 02	0.8000E 02	0.0000E 00	0.0000E 00
2	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4000E 02	0.8000E 02	0.0000E 00	0.0000E 00
3	0.2800E 02	0.0000E 00	0.0000E 00	0.0000E 00	0.4000E 02	0.8000E 02	0.0000E 00	0.0000E 00
4	0.4000E 02	0.9179E 03	0.1262E 02	0.6538E-01	0.1036E 04	0.1998E 04	0.3251E 00	0.0000E 00
5	0.4000E 02	0.9112E 03	0.1253E 02	0.6491E-01	0.1001E 04	0.1928E 04	0.1073E 01	0.7480E 01
15	0.2786E 02	0.2647E 02	0.3642E 00	0.1885E-02	0.2909E 02	0.5601E 02	0.1083E 01	0.0000E 00
16	0.1400E 00	0.3059E 04	0.4209E 02	0.2179E 00	0.3362E 04	0.6474E 04	0.1083E 01	0.0000E 00
17	0.1200E 02	0.3059E 04	0.4209E 02	0.2179E 00	0.3362E 04	0.6474E 04	0.1083E 01	0.0000E 00
18	0.1200E 02	0.3059E 04	0.4209E 02	0.2179E 00	0.3362E 04	0.6474E 04	0.1083E 01	0.0000E 00

STATION	DISSOLVED BOD	PARTICULATE BOD	AMMONIA	NITRITE	SCFM/MG	HP/MG
1.	0.1260E 03	0.3200E 02	0.2200E 02	0.0000E 00	0.0000E 00	0.0000E 00
2	0.1260E 03	0.3200E 02	0.2200E 02	0.0000E 00	0.0000E 00	0.0000E 00
3	0.1260E 03	0.3200E 02	0.2200E 02	0.0000E 00	0.0000E 00	0.0000E 00
4	0.9069E 02	0.2464E 02	0.2013E 02	0.5145E 01	0.0000E 00	0.0000E 00
5	0.8332E 01	0.2226E 01	0.1577E 02	0.1715E 02	0.1520E 04	0.2317E 02
15	0.8332E 01	0.6466E-01	0.1577E 02	0.1715E 02	0.0000E 00	0.0000E 00
16	0.8332E 01	0.7474E 01	0.1577E 02	0.1715E 02	0.0000E 00	0.0000E 00
17	0.8332E 01	0.7474E 01	0.1577E 02	0.1715E 02	0.0000E 00	0.0000E 00
18	0.8332E 01	0.7474E 01	0.1577E 02	0.1715E 02	0.0000E 00	0.0000E 00

BODA	BODR	BODL	DKWH	ASRT	AMLSS	XRSS	URSS	SMUA	BOUT	FM
4600.649	0.260	0.538	5186.446	9.093	2005.226	0.0290	3.3575	1.933	30.633	0.370

TCFM	TAIR	AERFF	DHP	THP	PFL	PIGV	DPCFM	C1(1)
11373.70	11373.70	0.160	205.81	308.43	1.49	236.05	6840.00	4.80

TIME = 14.10

STATION	MGD	HETEROTROPHS	NITROSOMONAS	NITROBACTER	INERT SOLIDS	TSS	DO	VOLUME

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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EPA-670/2-74-069		

4. TITLE AND SUBTITLE	5. REPORT DATE
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	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Robert Smith and Richard G. Eilers	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
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12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
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	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A new time-dependent model for the activated-sludge process is described, and the model is used to investigate the potential advantages associated with a number of control schemes. The control schemes investigated by time-dependent computation include dissolved oxygen control, sludge wasting control, and sludge inventory control. Quantitative benefits are shown for some control schemes. For others, the potential advantages appear to be minimal.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Waste treatment *Activated sludge process *Mathematical models *Time dependence *Process control	*Palo Alto (Calif.) wastewater plant *Dissolved oxygen control *Sludge wasting control *Sludge inventory control	13B

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