VARIATIONS IN RECYCLE SOLIDS
CONCENTRATIONS IN AN
ACTIVATED SLUDGE
PLANT

By

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CHAPTER I

INTRODUCTION

The purpose of this study was to determine if there was any variation in the sludge recycle concentration in an on line activated sludge plant; and if there was a variation, what effect it may have on some of the operational parameters and efficiency of the treatment plant.

Several mathematical models have been proposed to help explain how the kenetics of microbial growth in treatment plants occur. In nearly all of these models the recycle sludge concentration is assumed to be constant and at high concentrations. These models are also used to help design new treatment plants and to predict the quality of effluent that the new plant may produce. If the assumption of a constant recycle concentration is incorrect and if the variation does effect the plant efficiency then modifications to the models may be necessary to help in design and understanding of how the sewage treatment plant functions.

CHAPTER II

LITERATURE REVIEW

The return sludge concentration from the final clarifier is one of the main tools that the operator at a wastewater treatment facility has to control the number of micro-organisms in the aeration tank. This control of the population of micro-organisms will determine the amount of treatment the waste in the aeration tank will undergo and thus determines the quality of the effluent at the plant.

The return sludge concentration is determined by how well the biomass will flocculate and separate from the carrying water in the final clarifier. This separation of biomass from the water is accomplished by sedimentation, which has been the subject of much research and design effort.

Sedimentation Process

Sedimentation is a physical process by which solids are removed from the carrying water. This process is based on the difference between the specific gravity of the water (continuous phase) and the particle to be removed (discontinuous phase). If the particle is heavier than the water it will settle out; if it is lighter than the water it will rise to the top. The latter is undesirable in the final clarifier as this would allow solids to flow over the weir and decrease the quality of the effluent. Sedimentation in wastewater treatment has two functions. First, the solids are removed from the carrying water giving a clarified supernate and second the solids allowed to settle further will reduce their water content and their bulk; thereby giving a smaller quantity of sludge to deal with. Both of the functions are important to the wastewater field.

Fitch (1) has defined four distinct classifications of sedimentation. In a dilute concentration two types of settling can occur, both of which are classified as clarification by Fitch. In one type there is no distinct line of demarcation between the solids and the supernatant, but there is a changing concentration gradient. As the large particles begin to settle they will move toward the bottom and this will cuases the changes in concentration. At this time, the particles may or may not start to agglomerate or mass together. This is important because if they do not demonstrate agglomeration Fitch calls this class I. If agglomeration is demonstrated then it is class II. Class III occurs as the solids move closer together and begin to settle as a single mass with each particle remaining in its same relative position with the other particles surrounding it. This is also known as zone settling. As the particles continue to settle a change in their downward rate may be noticed, this is class IV settling or compression. Coe and Clevenger

(2) felt that this slowing is caused by mechanical support of the overlaying solids layers by those layers beneath them. Fitch (1), however suggests that mechanical support is not entirely responsible for this observed decrease due to the fact that the static head was not entirely accounted for by depth and density of the water, but rather some change in flow regime is also probably involved.

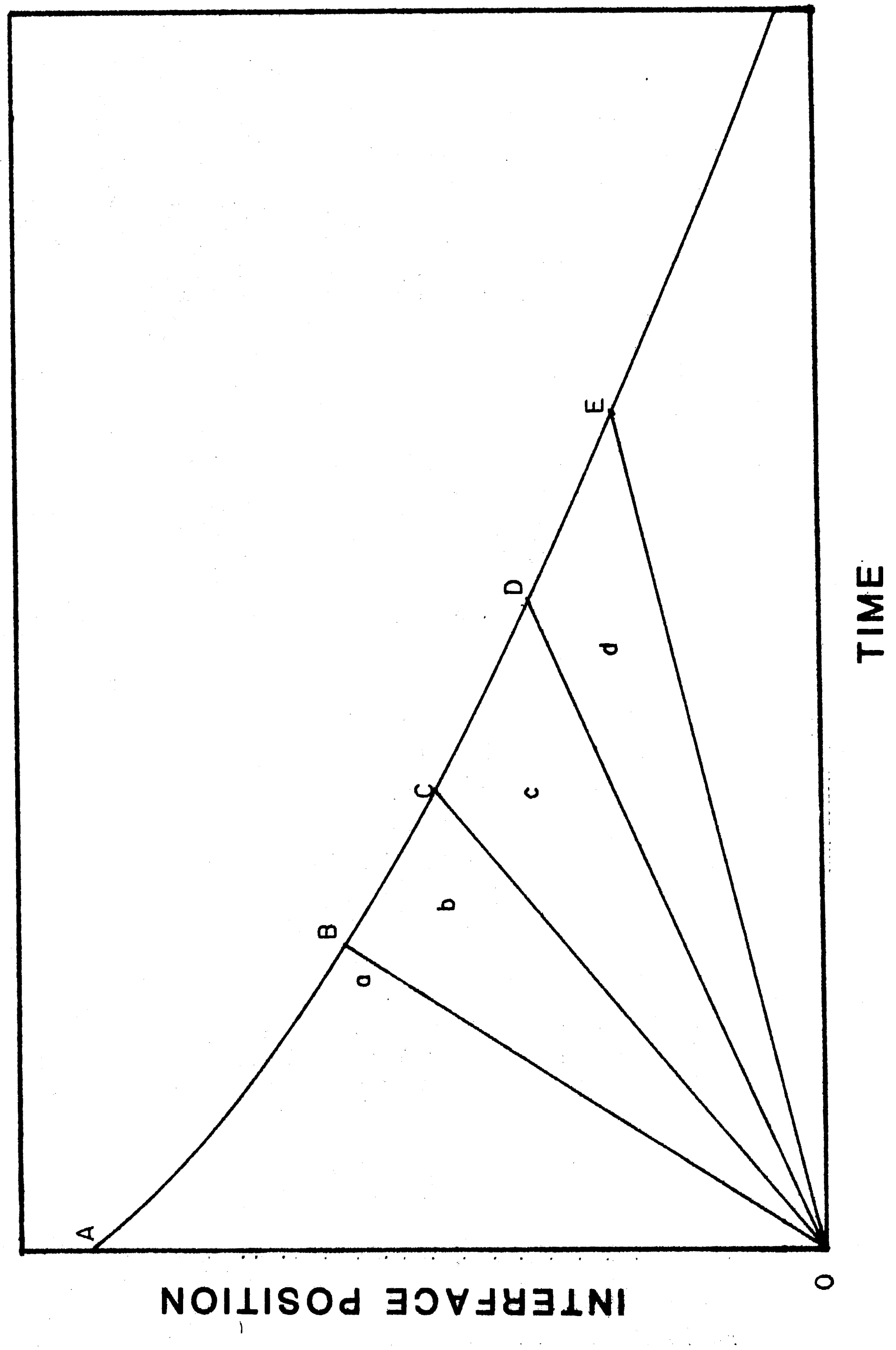
History of Sedimentation Design

Hazen (3) in 1904 published a quantitative analysis of class I suspension. Camp (4) later revised the above analysis and published a design equation and procedure for gathering data. This procedure can be found in most design books published now. Fitch (1) (5) was able to demonstrate that the overflow rate and the detention time influenced the solids removal in class II suspensions. The solids which are of sufficient size to settle out without agglomerations are removed as a function of overflow rate, and then the solids which must agglomerate are removed as a function of detention time, the greater time being needed to allow the particles to come together. Talmadge and Fitch (6) developed an equation for describing clarification in an activated sludge plant. The equation described the overflow rate for the initial gross removal of floc particles in the secondary clarifier.

The first thickening model was developed by Coe and Clevenger (2) in 1916. The importance of thickening is that it gives a more concentrated sludge or underflow. Solid flux is the parameter controlling their model due to the fact that they deal with solid concentrations in the zone and compression ranges. Solids flux is defined as the mass of solids transmitted downward per unit per time per unit area (2). The flux is important because as solid concentrations increase in zone and compression settling the rate of downward movement decreases. They had a different solids flux for each concentration of solids between the influent concentration and the underflow concentration. Coe and Clevenger (2) says that a layer in suspension has a certain solids handling capacity and that is it is lower than the handling capacity of the above layer then it will not be able to discharge particles as fast as it receives them and will increase in thickness.

Kynch (7) performed a mathematical analysis of thickening operations based on the assumption that at any point in a dispersion the velocity of fall of a particle depends on the local concentration of particles. The importance of Kynch's model can bee seen in Figure 1. A suspension of initial concentration "a" is introduced in a vessel and setles out at the uniform rate indicated by the slope of line AB. At the same time a layer of concentration "b" is propagated up from the bottom of the vessel at a constant velocity equal to the slope of line OB. At the interfact the settling rate is reduced to that of concentration "b." At point C the layer of concentration "b" has expired and the interface

Figure 1. Kynch's Model of Interface Position Versus Time


INTERFACE POSITION
TIME
0
A
B
C
D
E
a
b
c
d

subsides at a rate equal to the slope of line CD, which is characteristic of concentration "c" and so forth.

Talmadge and Fitch (6) using Kynch's model shows that multi-batch settling tests as advocated by Coe and Clevenger were not necessary since all layers with less capacity than those above them are ultimately propagated to the surface. Their settling rates may be determined from the slope of the interface time curve. They also developed a means of determining the area required for an arbitrarily selected rate limiting layer using a geometric construction method.

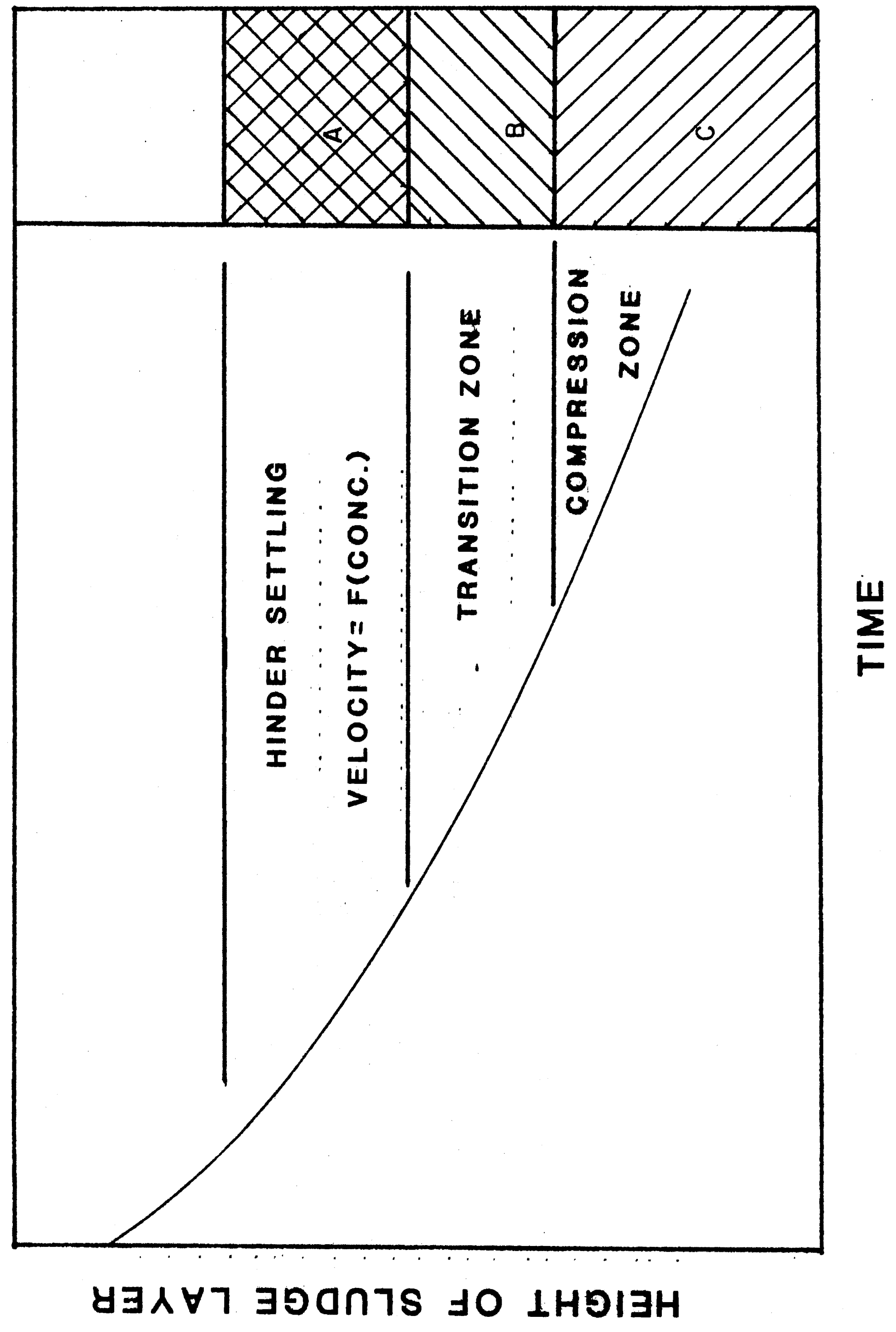
The Kynch analysis is the current design procedure for establishing the area of thickeners, but it seems highly idealized. It is based on the assumption that the particles are all the same size and shape, uniformly distributed in a horizontal plane. Shennon et al. (8) demonstrated that it applies to an ideal suspension of rigid glass spheres. He also observed concentration gradients rising at uniform velocities is settling suspensions of glass beads. However, Gaudin and Fuerstenau (9) obtained curved plots of upward propagation of layers of higher concentrations in settling test using a clay suspension.

Sedimentation as It Applies to a Final Clarifier

Katz et al. (10) divides suspensions into three general classes. Class I is discrete particles which do not flocculate and are found mostly in low concentrations. An example of this suspension is found in grit chambers and certain industrial waste. Class II consists of low solid concentrations that readily flocculate. An example of this suspension can be seen in the primary clarifier. Class III are materials of high concentration which may or may not flocculate. An example of this suspension is the sludge particles found in the final clarifier, and also some industrial waste such as that from paper and pulp.

The settling of class III suspensions have been described by Eckenfelder and O'Conner (11) as shown in Figure 2. During the initial settling period the sludge settle at a uniform velocity under conditions of zone settling. The rate of this settling is dependent on the initial concentration of solids. The concentration remains constant during this phase until the settling approaches the interface of critical concentration. Here the sludge begins to press against the layers of sludge below it and a transition zone occurs. The settling velocity decreases due to increasing density and viscosity of the suspension surrounding the particles. A compression zone occurs when the concentration becomes so great that layers below the floc start to help support the upper layer. The solids concentration here depends on depth of the sludge and the detention time of the solids in this zone.

Figure 2. Settling Zones for Class III Suspensions


A
B
C
HINDER SETTLING
VELOCITY= F(CONC.)
TRANSITION ZONE
COMPRESSION
ZONE
TIME
HEIGHT OF SLUDGE LAYER

Environmental Factors Affecting Sedimentation

The development of an activated sludge depends on numerous parameters including the waste characteristics, growth rate of the micro-organisms and availability of nutrients. The predominance of various types of organisms becomes important since the type of organism may influence the settling characteristics of the sludge. A sludge with a balance of nutrients generally gives a bacterial sludge which shows good subsidence. Waste high in carbohydrates or low in nitrogen may have filamentous type sludge which can be hard to settle due to their large surface area to volume ratio and their low density. The environmental conditions in the aeration tank can have an effect on sludge types and sediability. The factors effecting sludge characteristics include dissolved oxygen concentrations, pH, sludge age and intensity of aeration. Pipes (12) has attempted to classify sludge according to whether they bulk or not. The basic classification and their apparent causes are shown in Table I.

Settling Characteristics of Solids

The settling rate is normally obtained by observing the position of the water-solids interface as sedimentation occurs in a one liter graduate cylinder. The rate is then determined as the slope of the line expressed feet per minute or feet per hour.

TABLE I

CLASSIFICATION OF VARIOUS DIFFICULT-TO-SEPARATE ACTIVATED SLUDGES

Classification	Probable Cause
I. Bulking Sludge	
a) Non-filamentous Bulking	Presence of large quantities of extracellular materials with a high degree of hydration producing a sludge with excessive amounts of bound water.
b) Filamentous Bulking	The predomination of fungi; as a result of certain environmental factors, i.e., low pH, low dissolved oxygen.
II. Rising Sludge	Dentrification in the sludge blanket.
III. Septic Sludge	Excessive sludge detention times in the final clarifier resulting from poor clarifier design.
IV. Overaearated Sludge	Execessive aeration bubbles to be carried into the final clarifier and causes the sludge to be buoyed to the surface by the rising bubbles.
V. Floating Sludge	Presence of sludge particles whose density is less than water.
VI. Pinpoint Floc	Excessive turbulence in the aeration tank.
VII. Billowing Sludge	Hydraulic surges, density currents, stirring by sludge scrapers.

Katz et al. (10) and Dick and Ewing (13) have demonstrated the effect of mixed liquor solids on settling rates. This relationship is shown in Figures 3 and 4. In Figure 4 the initial settling velocity is plotted against initial depth for various mixed liquor suspended solids concentrations. It can be seen that the settling velocity decreases with an increase in mixed liquor suspended solids. Figure 3 shows the settling rate versus initial concentration. The decrease in settling rate is similar to that in Figure 4.

Temperature may effect the settling rate of activated sludge. Rudolfs and Lacey (14) found the settling rate to be reduced as the temperature was decreased. They state that the difference may be partially explained by the slower rate of sludge oxidation and flocculation which occurs at lower temperatures. The difference may also be due to an increase in the density of the water. Pflanz (15) shows data indicating a 1.5 to 2 time increase in effluent suspended solids of a final clarifier at similar surface loading rates as the temperature decreased from 29 degrees Centigrade to 14 degrees Centigrade. Hall (16) has also attributed short circuiting in sedimentation tanks due to temperature gradients.

Flocculation

Flocculation of bacteria is essential to the operation of the activated sludge process, without it the bacteria would stay dispersed and would be difficult to separate from

Figure 3. Settling Rate Versus Initial Solids Concentration

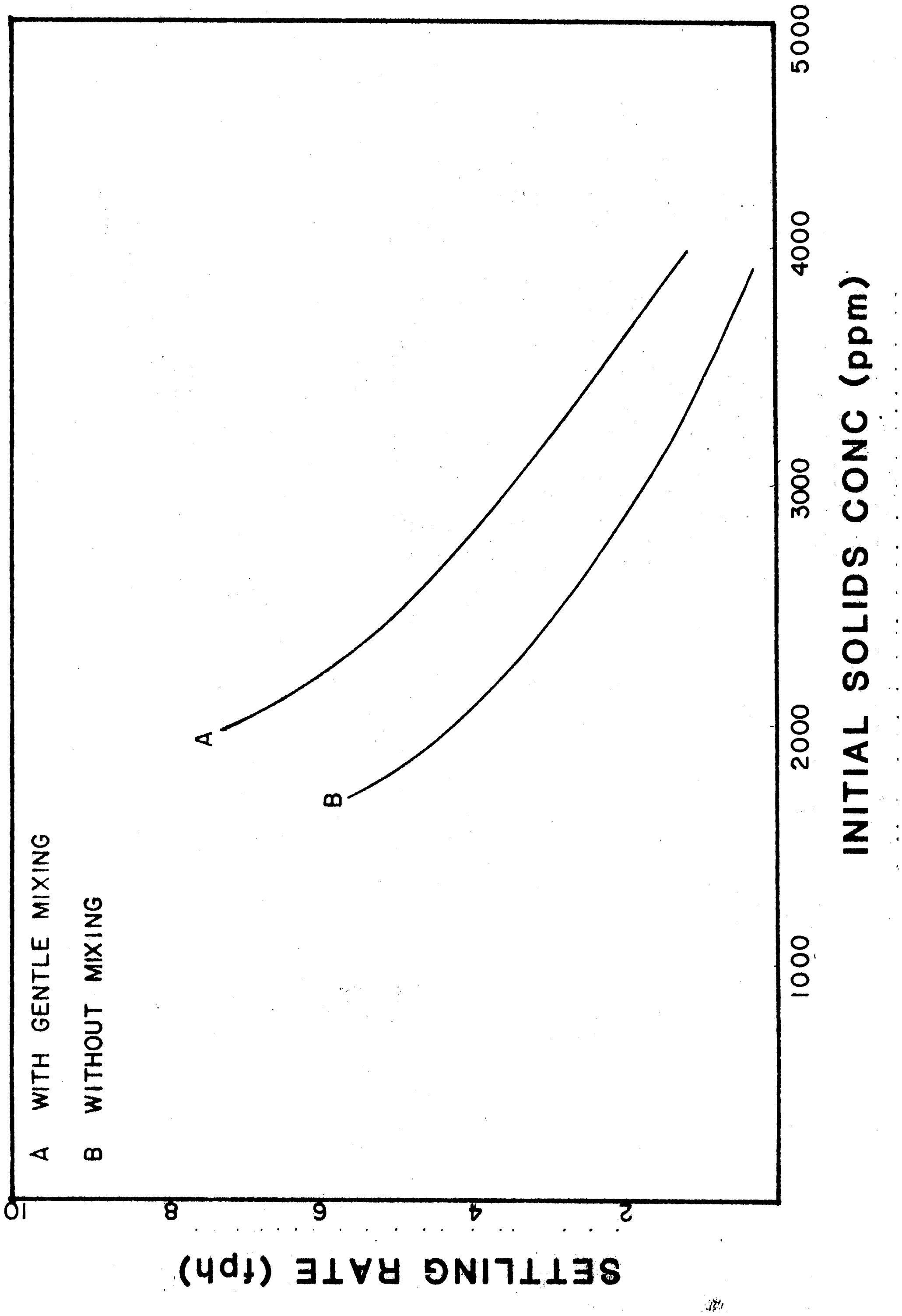
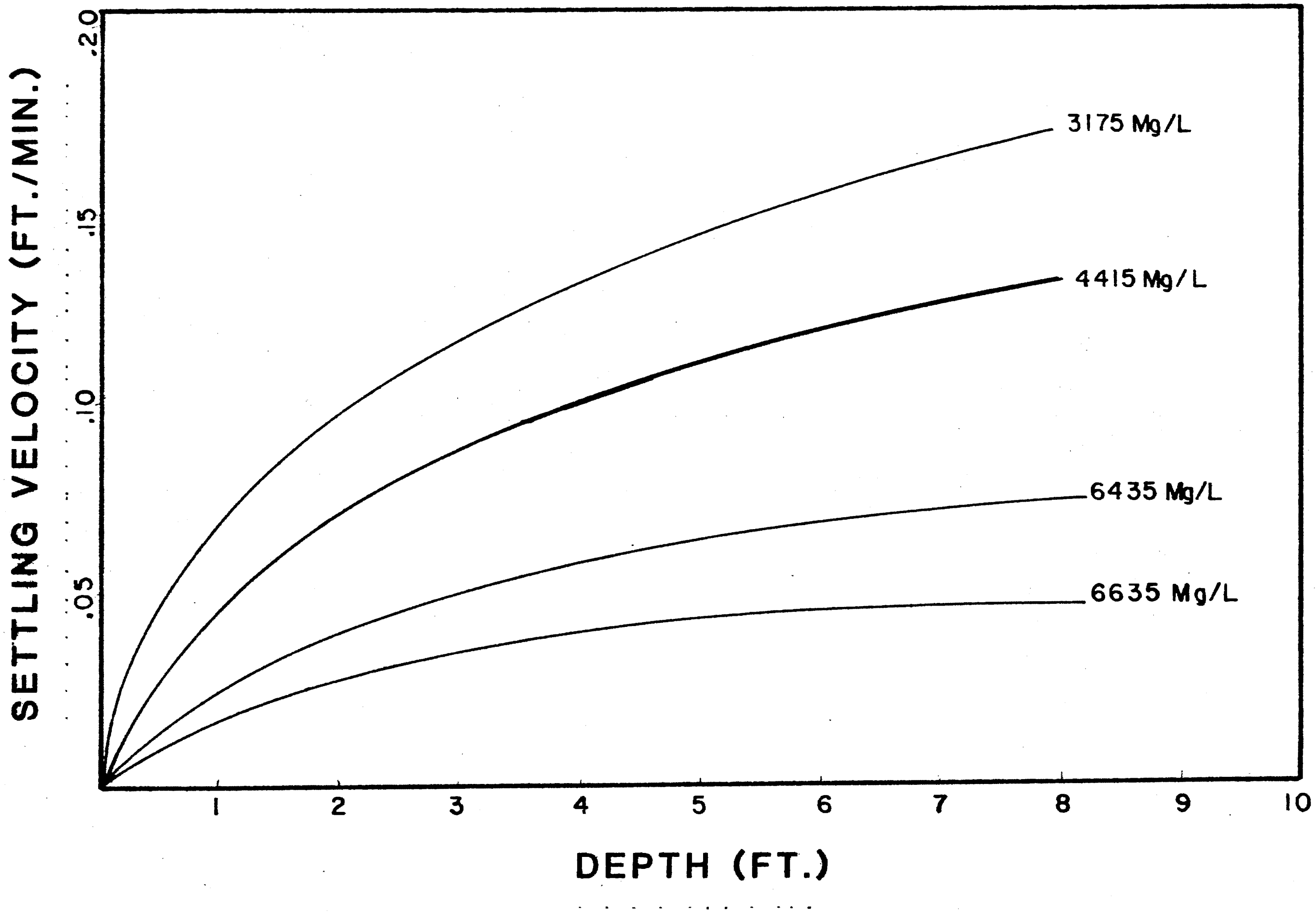

A WITH GENTLE MIXING
B WITHOUT MIXING
A
B
SETTLING RATE (fph)
10
8
6
4
2
1000
2000
3000
4000
5000
INITIAL SOLIDS CONC (ppm)

Figure 4. Settling Velocity Versus Depth


SETTLING VELOCITY (FT./MIN.)
.20
.15
.10
.05
DEPTH (FT.)
1
2
3
4
5
6
7
8
9
10
3175 Mg/L
4415 Mg/L
6435 Mg/L
6635 Mg/L

the water. Camp (17) has proposed that flocculation in sedimentation basins is due to the difference in velocities in the particles. The slower particles are overtaken as the larger, faster particles settle out due to gravity. Also due to different velocity gradients in the clarifier particles in faster gradients overtake particles in slower gradients. Also, the physical and chemical surfaces of the bacteria help to determine if the particles will flocculate. If the bacteria are in a healthy environment, they usually have a slime layer on them, these layers help in forming a floc.

Mathematical Models of Sedimentation

A number of mathematical expressions have been proposed in the literature which relate mixed liquor suspended solids concentration to the settling velocities of activated sludges. These equations are in most cases for specific sludges and may result in serious error when used for sludges other than those from which they were developed. These equations are presented in Table II to give an estimate of the general form that they take.

Control of Underflow Concentrations

The method of underflow concentration control is the sludge volume index. The S.V.I. can be used to indicate the settling characteristics of the sludge, thereby giving some indication of concentrations that you may expect and the

TABLE II

MATHEMATICAL EXPRESSIONS FOR SETTLING RATE AS A FUNCTION OF SOLIDS CONCENTRATION

Equation Presented By	Equation	
Krone (62)	$V - V_o(1 - KC)^{4.65}$	V = Group settling velocity V_o = Settling velocity of individual aggregates C = Initial concentration of suspended solids K = Volume of aggregate/gram of solids
Duncan and Kawata (63)	$V = ac^b$	V = Initial settling rate c = Initial solids content b = Empirical constant a = Sludge constant
Vesilind (11)	$V = V_oe-kc$	V = Initial settling rate V_o = Experimentally determined settling Rate at concentration c c = Sludge concentration k = Sludge constant

rate that you may withdraw the return sludge from the clarifier. Typical value for plants with a mixed liquor of 2000-3500 mg/l range from 80 to 150. As the mixed liquor values increase to 3000 to 5000 mg/l there is an increase in the loading rate and subsequent lower S.V.I. value. More recently a stirred S.V.I. test is taken which gives values 55 to 70 percent that of the standard test.

West (18) in a study for the Environmental Protection Agency found that return sludge concentrations and mixed liquor sludge concentrations change with return sludge flow percentages. He found that the return concentrations responded rapidly and inversely to return sludge adjustments, With an increase in return flow the concentration was reduced. He further states that mixed liquor suspended solids concentrations responded sharply to sludge wasting adjustments, but are not affected greatly by return sludge flow adjustments unless the plant is badly out of balance.

Importance of Cell Recycle in Design

The importance of cell recycle was first noted by Herbert (19). Basically his model states that after leaving a reactor the mixed liquor is passed through a concentration step. In his experiment cells were centrifuged and then recycled to the aerator to help keep the cells in the reactor at a high concentration. He used a concentration factor "c" defined as the concentration of cells in the recycle divided by the concentration of cells in the aeration tank.

To do this it was necessary to keep an accurate sensing of the cells in the recycle and aeration tank.

Other investigators have developed models to predict the effectiveness of plant designs (20) (21) (22). These investigators have also made use of a constant cell concentration in the return line. In their design methods they have assumed a concentration and it is used in the mathematical model to determine the size of the aeration basin and to predict the quality of effluent the plant will produce. One model is now used by the Environmental Protection Agency to evaluate and help determine the cost of alternative designs for new facilities that are to be funded by that agency.

A later model has been proposed by Gaudy (22) which also used a constant recycle concentration; however, this model has provisions for a sludge constancy tank to help deliver this constant concentration. By using this constant recycle rate the plant would be able to handle higher flows and still resist the dilution that conventional plants experience. More important this constant recycle would make it easier to run the plant in a steady-state, making it much more likely to produce the predicted effluent and making design decision more accurate.

CHAPTER III

MATERIALS AND METHODS

The plant used to conduct this study was the Ponca City Pollution Control Plant located one mile south of Ponca City on the banks of the Arkansas River. The plant was completed and accepted January, 1971. The plant is a four million gallon completely mixed activated sludge facility consisting of the followinf units.

Central Lift Station

The lift station is located just north of the facility and is equipped with two variable speed pumping units, each capable of producing 6,200 gallons per minute or 8.9 million gallons per day. Since one pump is considered a standby, the capacity of the lift station is 8.9 mgd. There are provisions for the installation of a third pump which could increase the capacity to nearly 18 mgd.

A mechanically cleaned bar screen precedes the pumps and it is equipped with a timer to control the period of operation. The screenings are removed daily and disposed of in a land fill.

Grit Chamber

The grit chamber consists of two separate, manually cleaned gravity removal type grit chambers. The velocity in the chamber is controlled by a proportional weir at the end of each chamber. The capacity of this unit is four million gallons per day.

Primary Clarifier

The primary clarifier is to provide gravity separation of floatable and settleable solids. The materials removed in the primary are sent to the anaerobic digester. This pumping is controlled by timers which have been set to give a sludge consistency of approximately five to eight percent. In case of an emergency the primary clarifier has a bypass that leads to the aeration tank.

The dimensions of the primary clarifier are: diameter 90 feet, S.W.D. 10 feet, weir length 284 feet, detention time 3.2 hours, overflow rate 600 gallons/ft^2/day, and effective hydraulic capacity 531,500 gallons.

Aeration Tank

The aeration tank was designed to remove 92 percent of the BOD$_5$. The tank is 200 feet long and 40 feet wide. It has a S.W.D. of 16 feet. This gives the tank a maximum hydraulic capacity of 1,000,000 gallons and a detention time of six hours at maximum design flow. The maximum air to the tank is 7200 cubic feet per minute. The air is supplied by three variable speed blowers with a capacity of 3600 cfm. One of the blowers is used as a standby.

Final Clarifier

The final clarifier removes the activated sludge from the carrying water discharged from the aeration tank and returns sludge to the aeration tank through the recycle line. The recycle pump is a variable speed allowing the recycle to vary from 0 to 100 percent of the flow of the plant.

The final clarifier has a diameter of 85 feet, a S.W.D. of 10 feet, weir length of 498 feet, a detention time of 2.5 hours, a hydraulic cpacity of 425,000 gallons, an overflow rate of 755 gallons/ft^2/day, and a weir overflow rate of 8,000 gallons/feet of weir/day. Sludge wasted from the final clarifier goes into the aerobic digester.

Aerobic Digester

The aerobic digester has a capacity of 65,000 cubic feet and is designed to give a detention time of 29 days. Air is supplied at about 1,000 cubic feet per minute for aeration and micing. When solids in the digester get to be approximately two percent, then the digester sludge should be wasted to the drying beds. The air is turned off and the solids allowed to settle before wasting. The supernatant when it is drawn off is returned to the aeration tank.

Anaerobic Digester

The anaerobic digester has a gas mixing device, which helps to keep a uniform mixture throughout the digester. This allows the total digester volume to be used for digesting. Supernatant from the anaerobic digester is also returned to the aeration tank.

Sampling Techniques

Samples were drawn from the final clarifier, from the point where the return sludge is trapped in a box structure while being pumped back to the aeration tank. Samples were taken every two hours in the test period except for four hours in the early mornings when the recycle pumps are turned off. The testing period ran for 24 hours, from eight in the morning to eight the following morning.

The samples were tested to determine the total solids, the total volatile solids, and the fixed residue as prescribed in Standard Methods (24). Plant operation data was provided by plant personnel.

CHAPTER IV

RESULTS AND DISCUSSION

One of the questions that this study was to examine was the variation in the concentration of solids in the recycle line or to establish if this concentration was constant as several mathematical models indicate. Figures 5 through 27 show that an hourly variation in recycle solids concentration was found during each day studied. It is also seen that there was no set variation. Extremes in a single day were found to vary from a high of 10,000 mg/l to a low of 7,250 mg/l. This 30 percent variation was found to occur within a six hour period.

Figure 28 shows the variation in the average daily recycle concentration of solids during the study period. This average daily concentration was determined from the hourly concentrations taken during a sample day. These sample days are not consecutive but rather random days so the graph shows daily variations seen at different weeks and months during the test period. It shows a variation in the recycle solids concentration ranging from a high of 9,945 mg/l to a low of 4,755 mg/l. This shows that a large variation in recycle solids concentration can be expected at different days during a month or even within a week.

Figure 5. Recycle Solids Concentration Versus Time
Sample Day 1

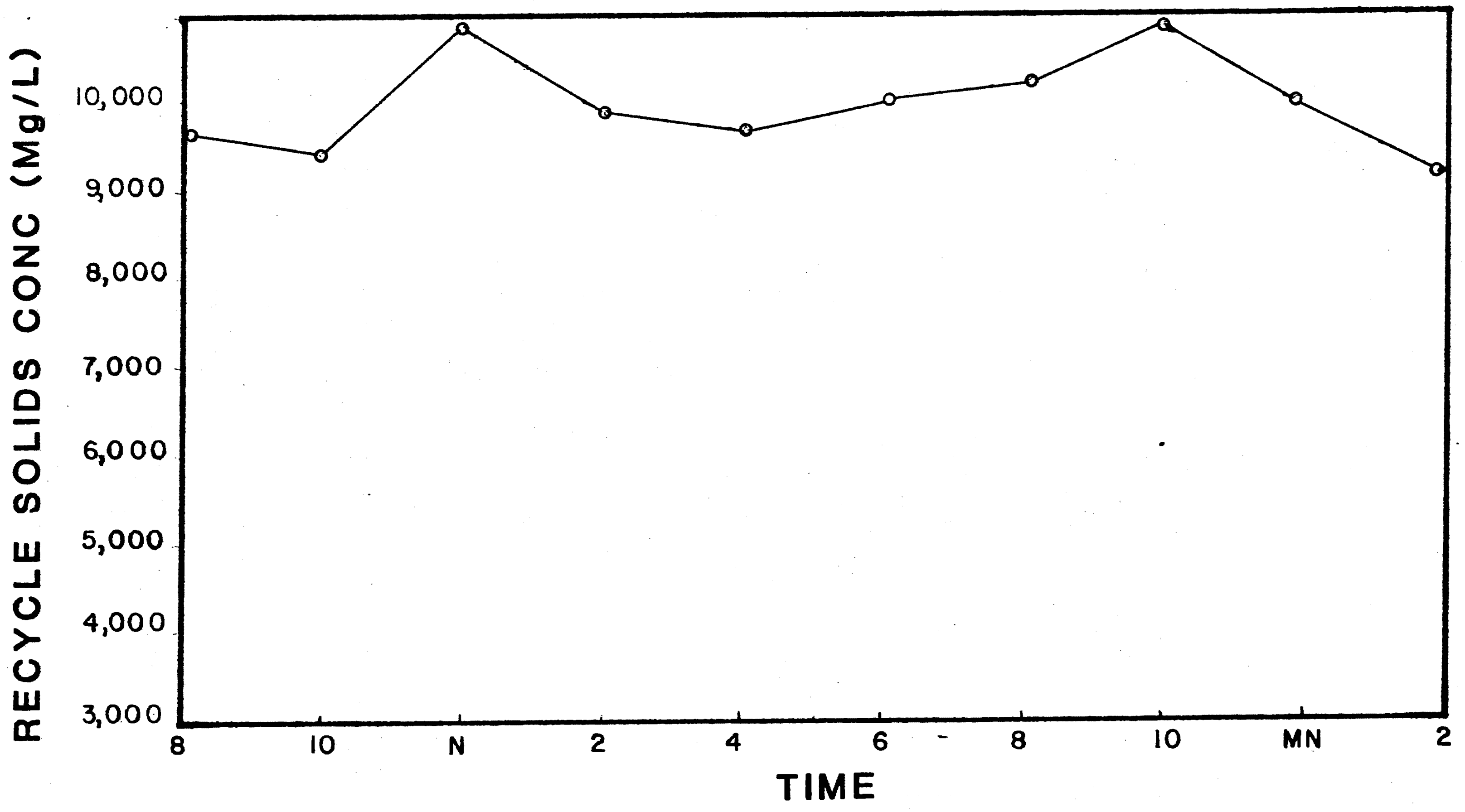

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 6. Recycle Solids Concentration Versus Time
Sample Day 2

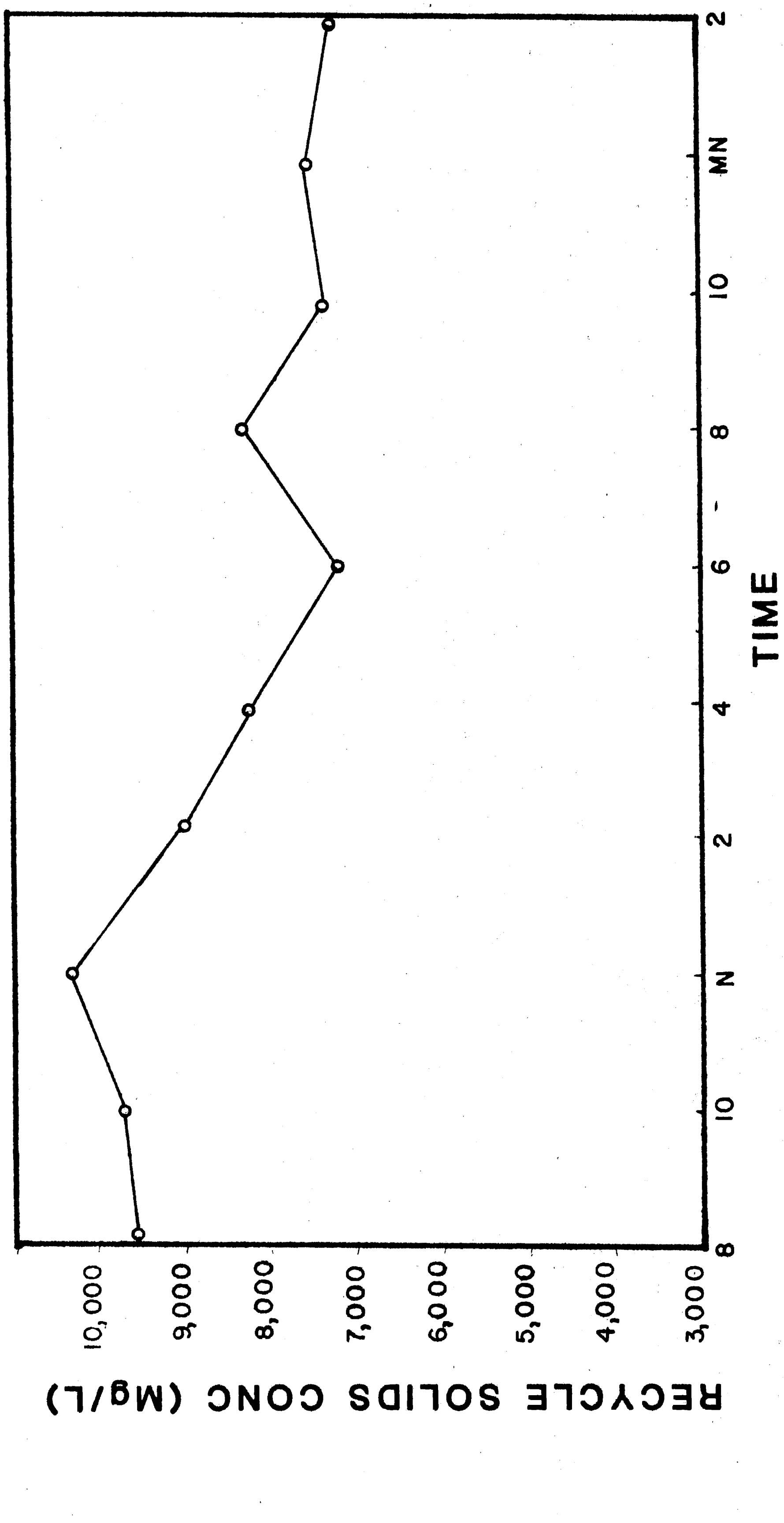

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
TIME
8
10
N
2
4
6
8
10
MN
2

Figure 7. Recycle Solids Concentration Versus Time
Sample Day 3

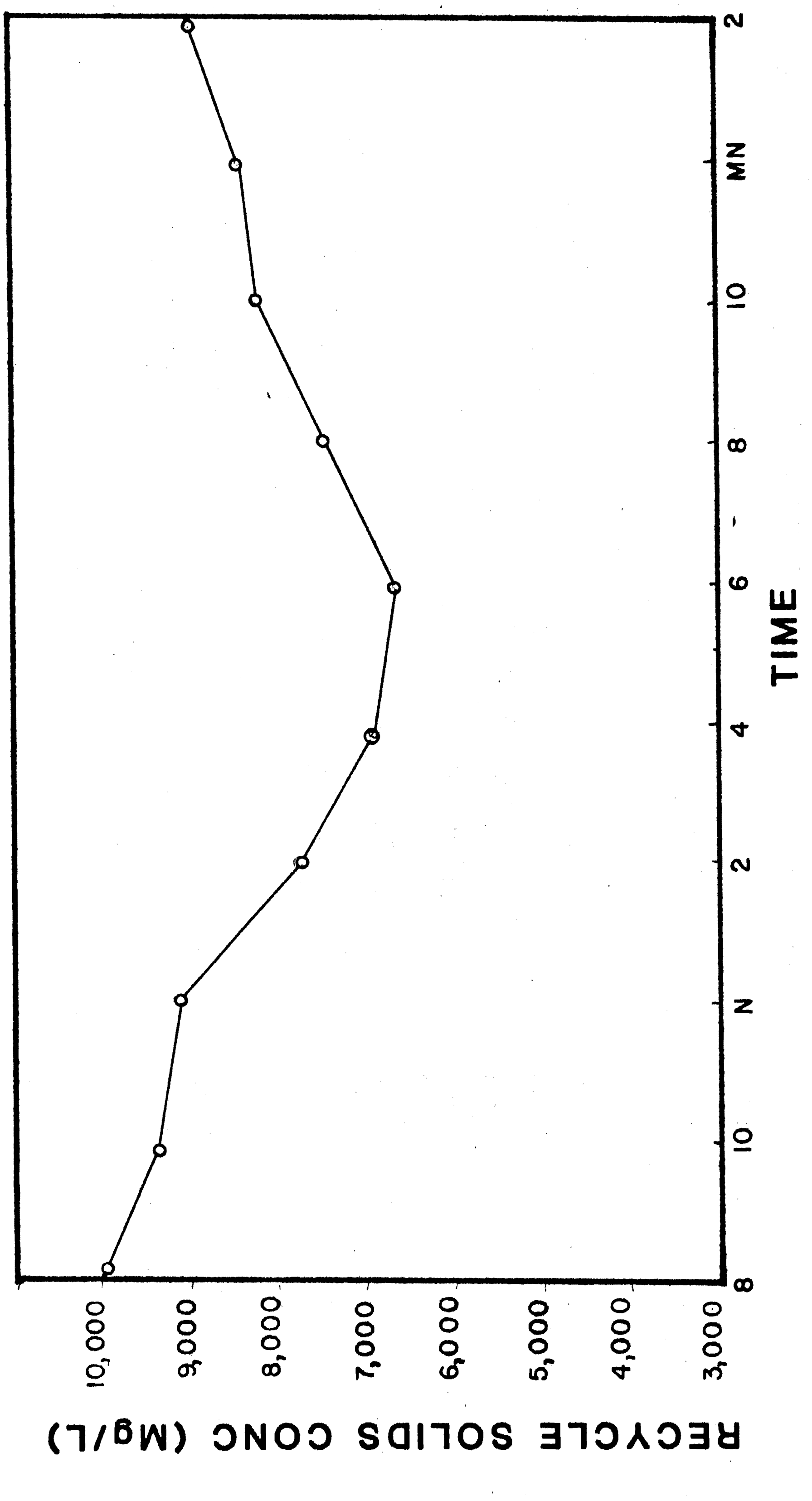

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
TIME
8
10
N
2
4
6
8
10
MN
2

Figure 8. Recycle Solids Concentration Versus Time
Sample Day 4

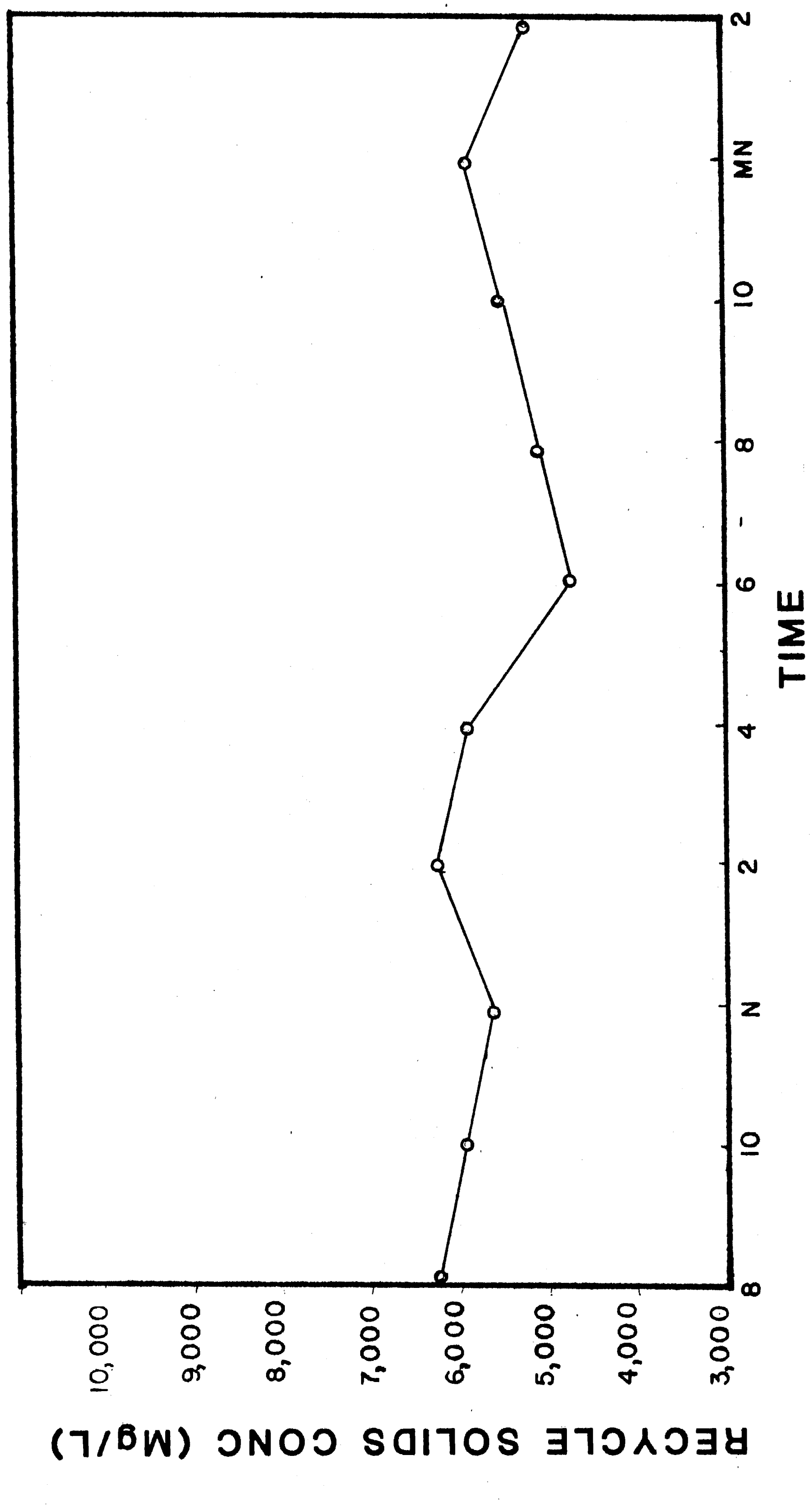

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 9. Recycle Solids Concentration Versus Time Sample Day 5

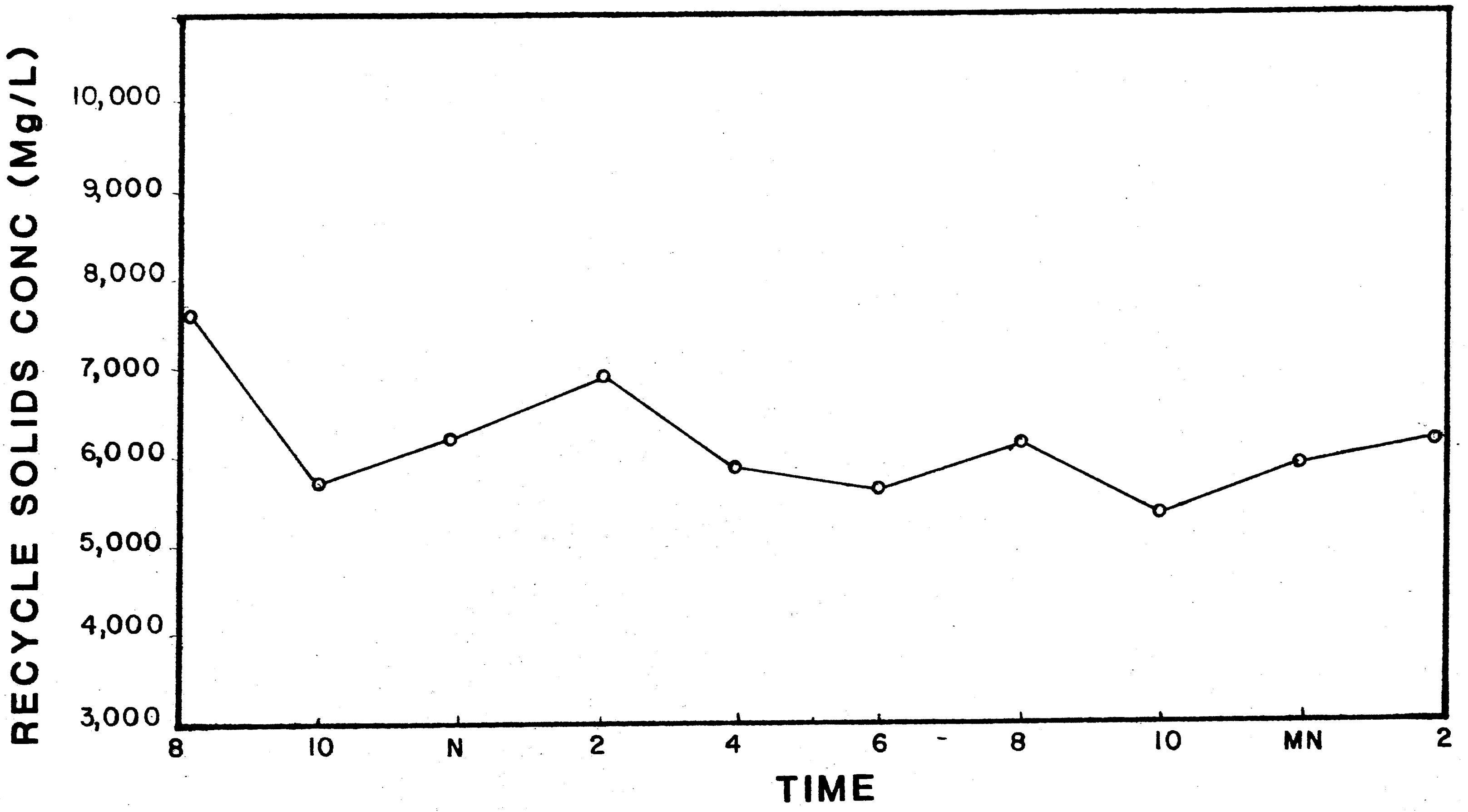

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 10. Recycle Solids Concentration Versus Time
Sample Day 6

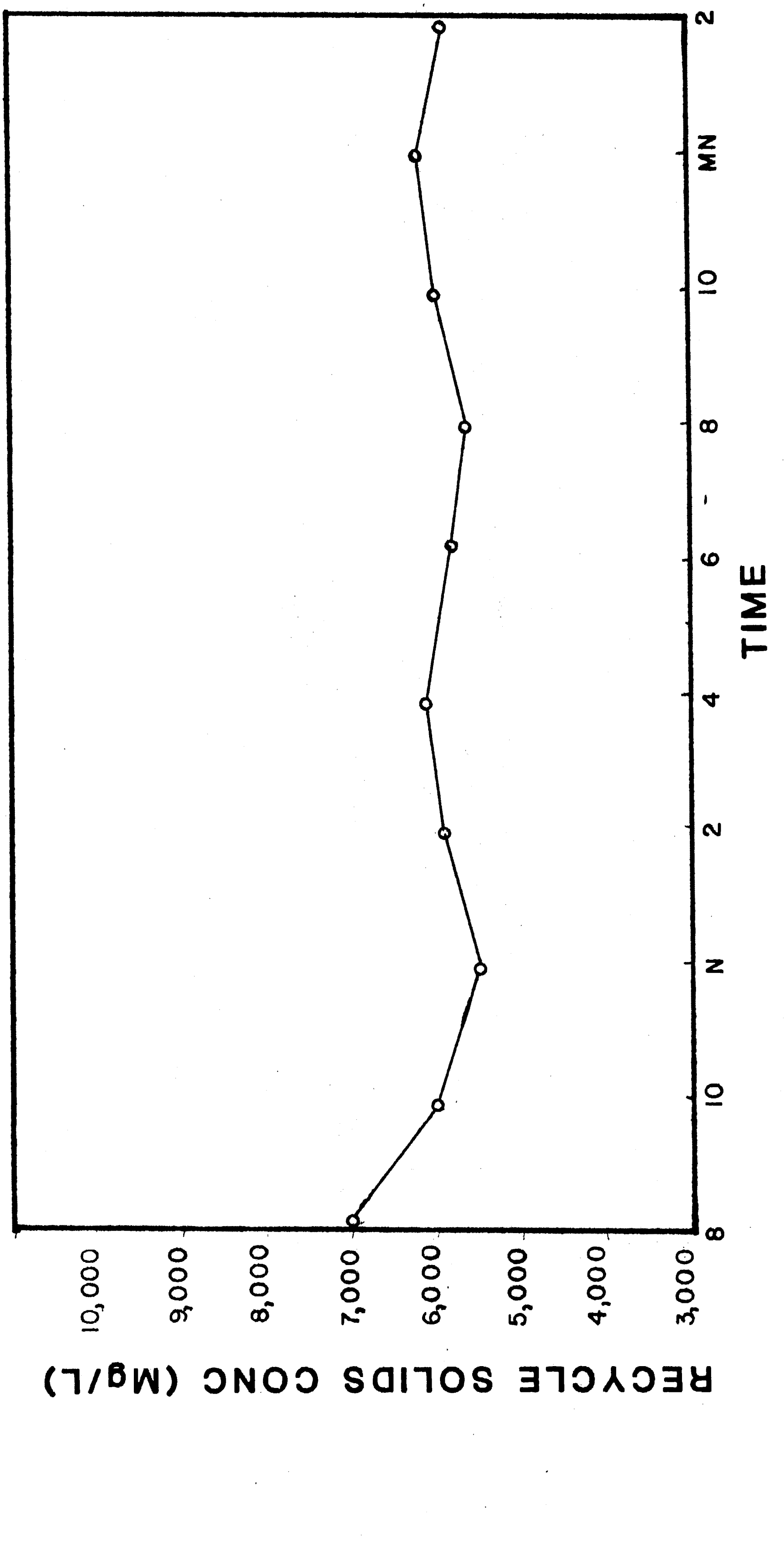

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 11. Recycle Solids Concentration Versus Time
Sample Day 7

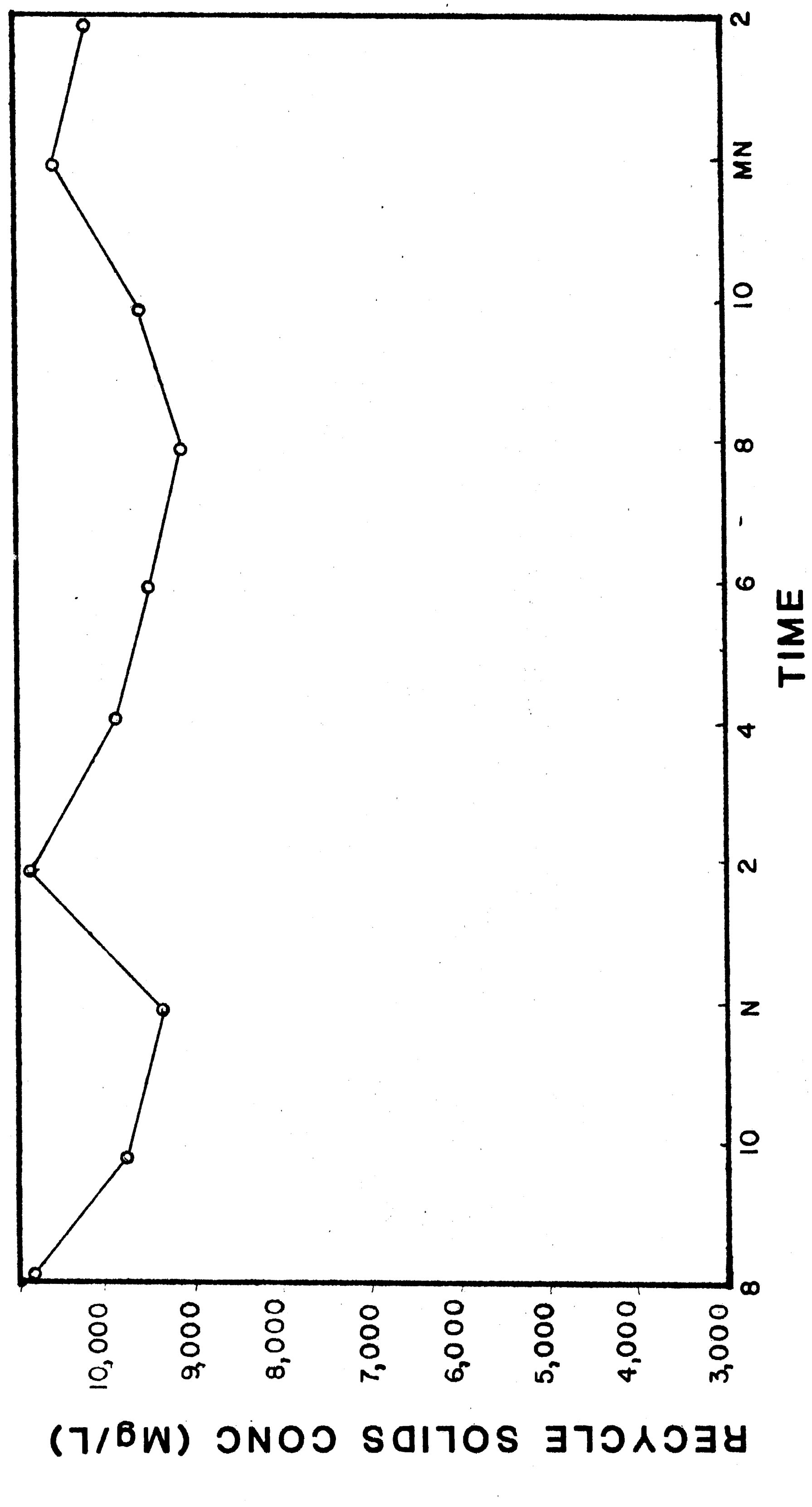

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 12. Recycle Solids Concentration Versus Time
Sample Day 8

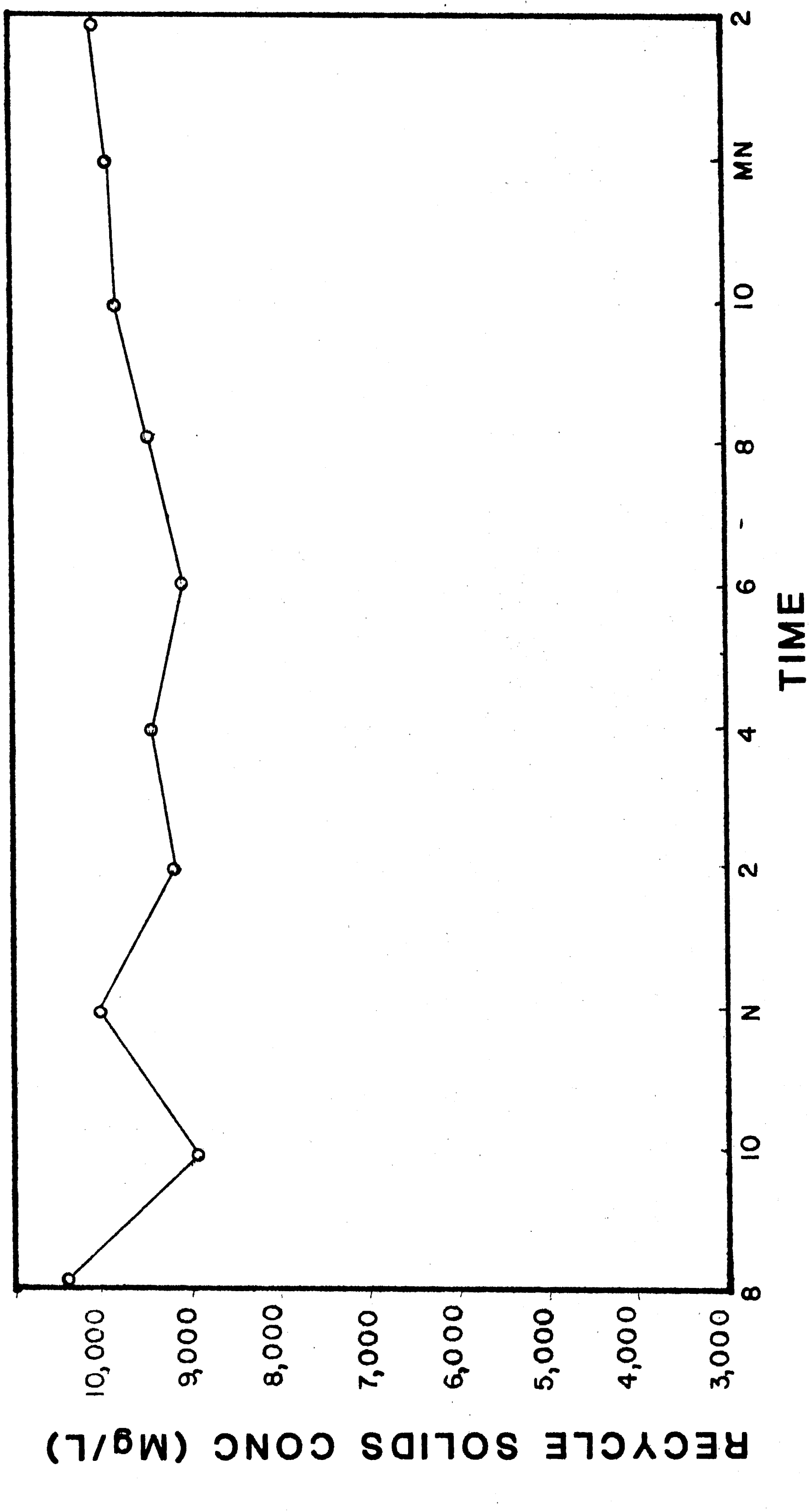

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 13. Recycle Solids Concentration Versus Time
Sample Day 9

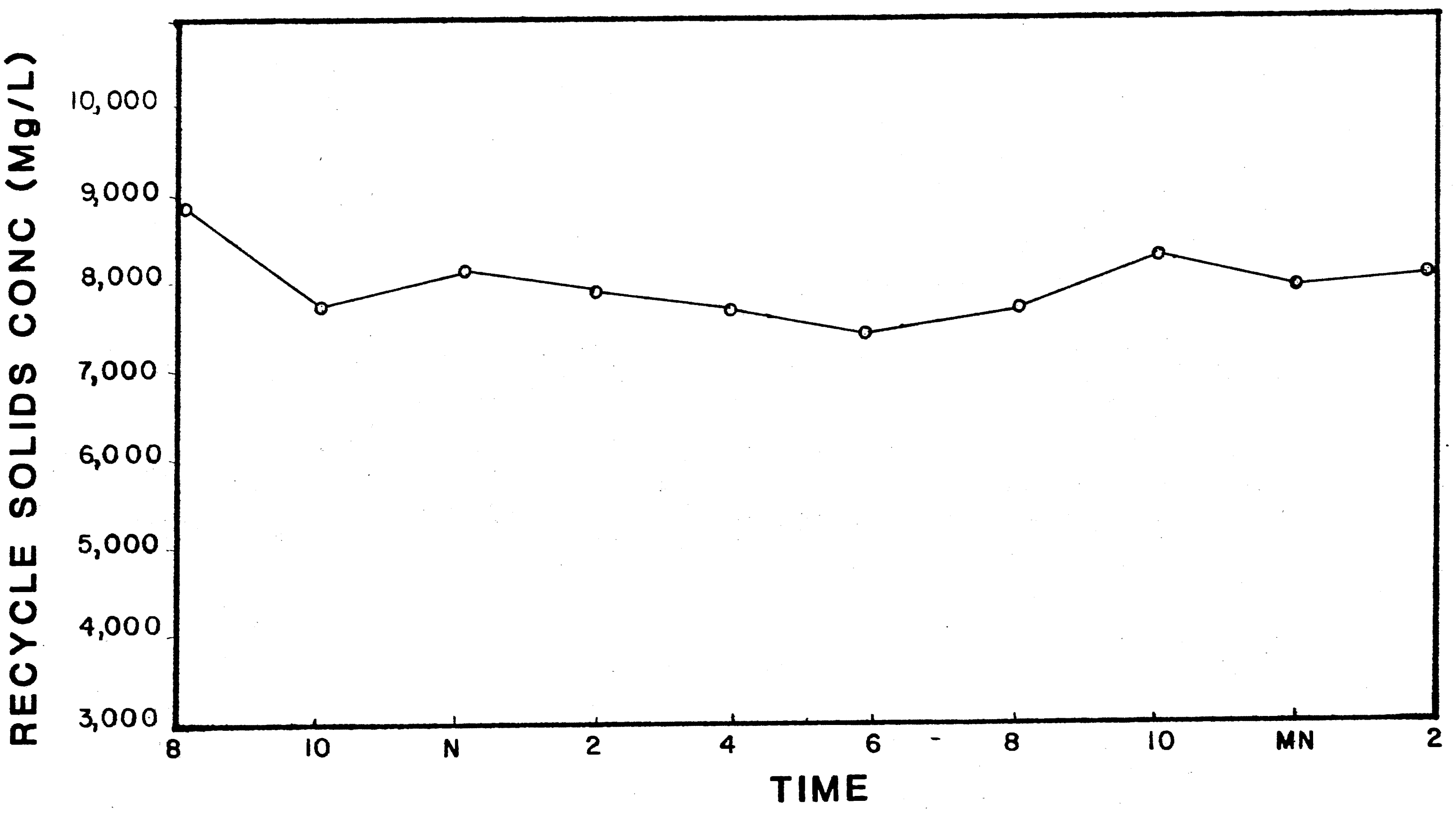

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 14. Recycle Solids Concentration Versus Time
Sample Day 10

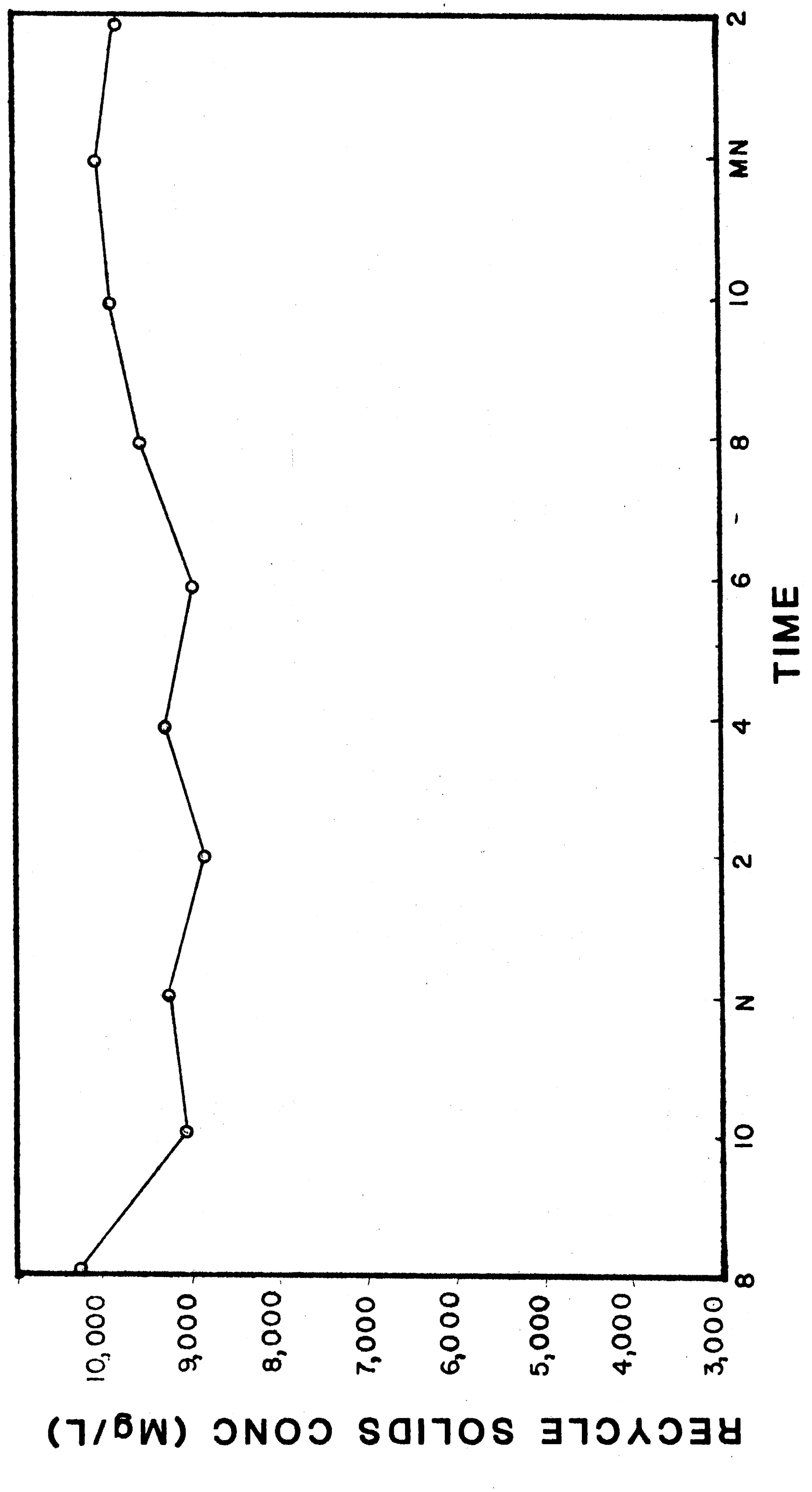

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 15. Recycle Solids Concentration Versus Time
Sample Day 11

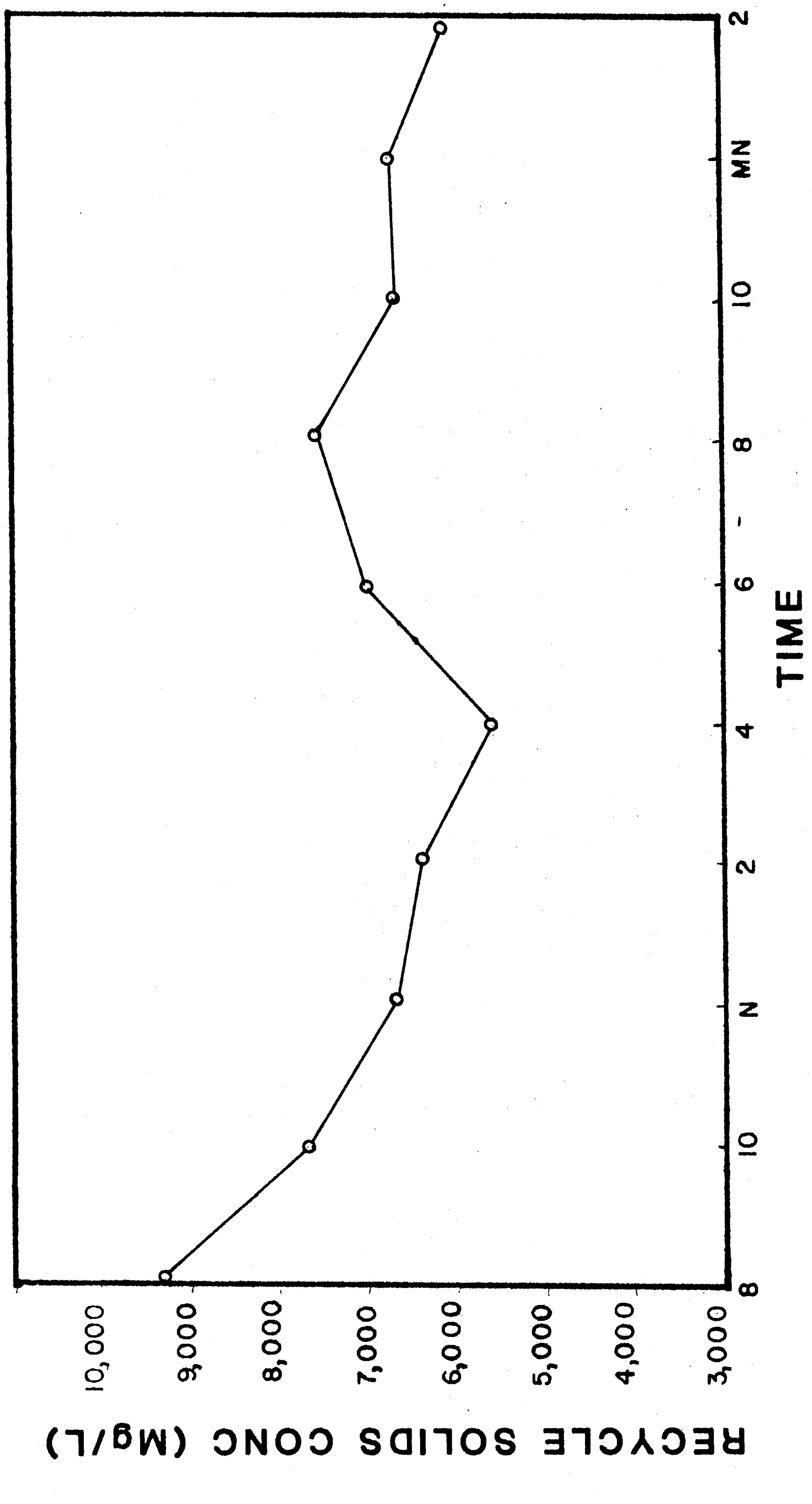

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 16. Recycle Solids Concentration Versus Time
Sample Day 12

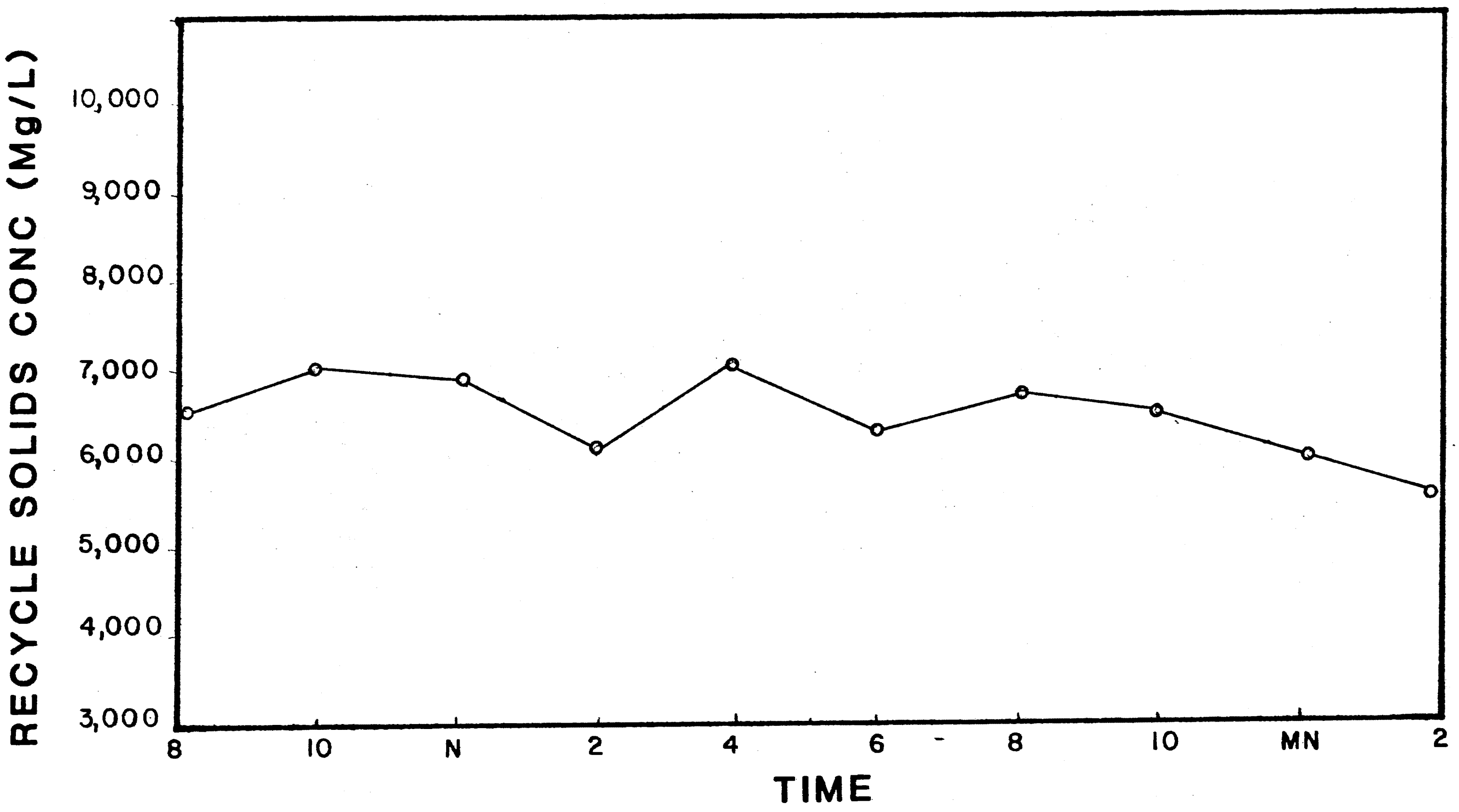

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 17. Recycle Solids Concentration Versus Time
Sample Day 13

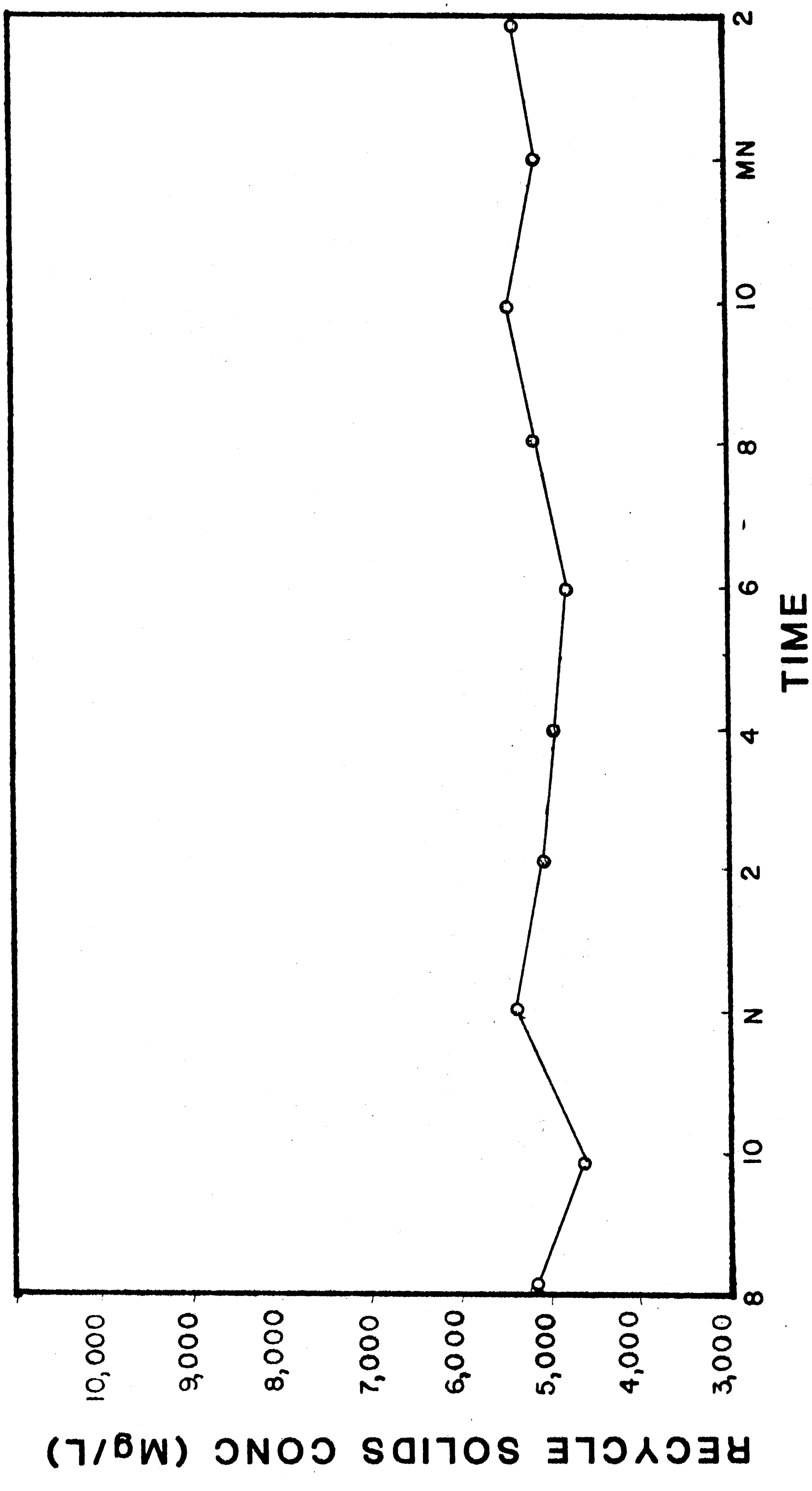

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 18. Recycle Solids Concentration Versus Time Sample Day 14

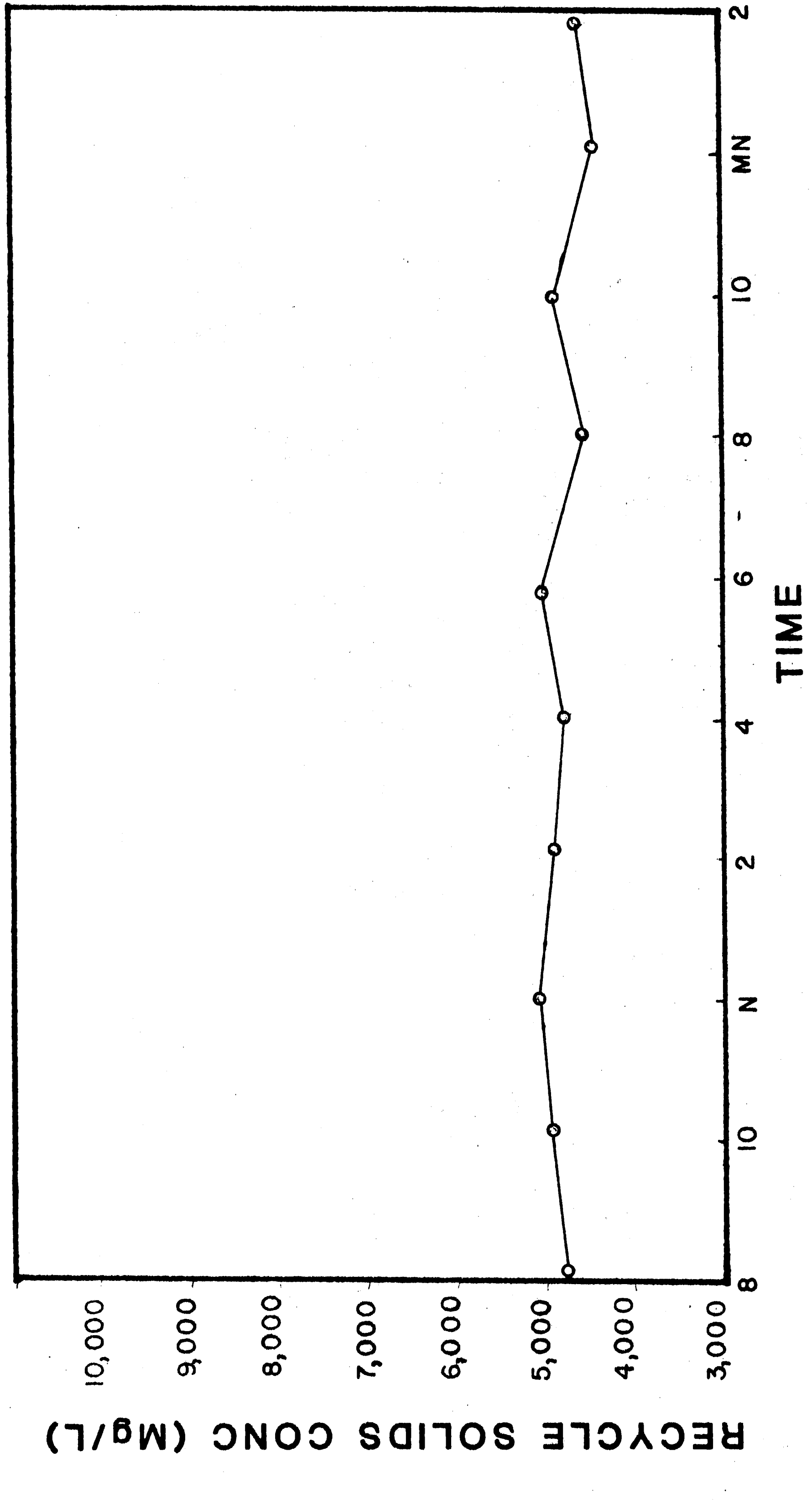

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 19. Recycle Solids Concentration Versus Time
Sample Day 15

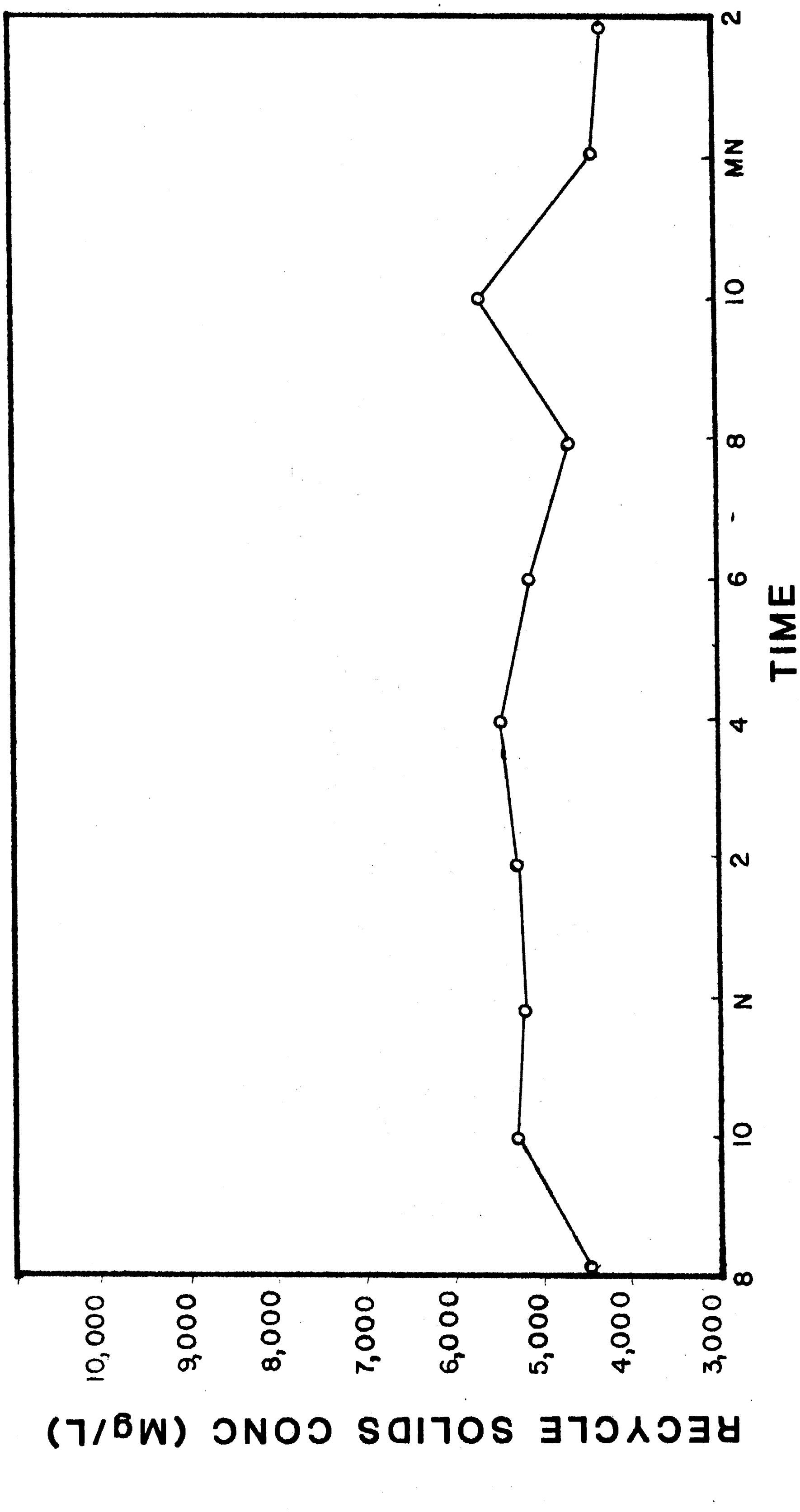

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 20. Recycle Solids Concentration Versus Time
Sample Day 16

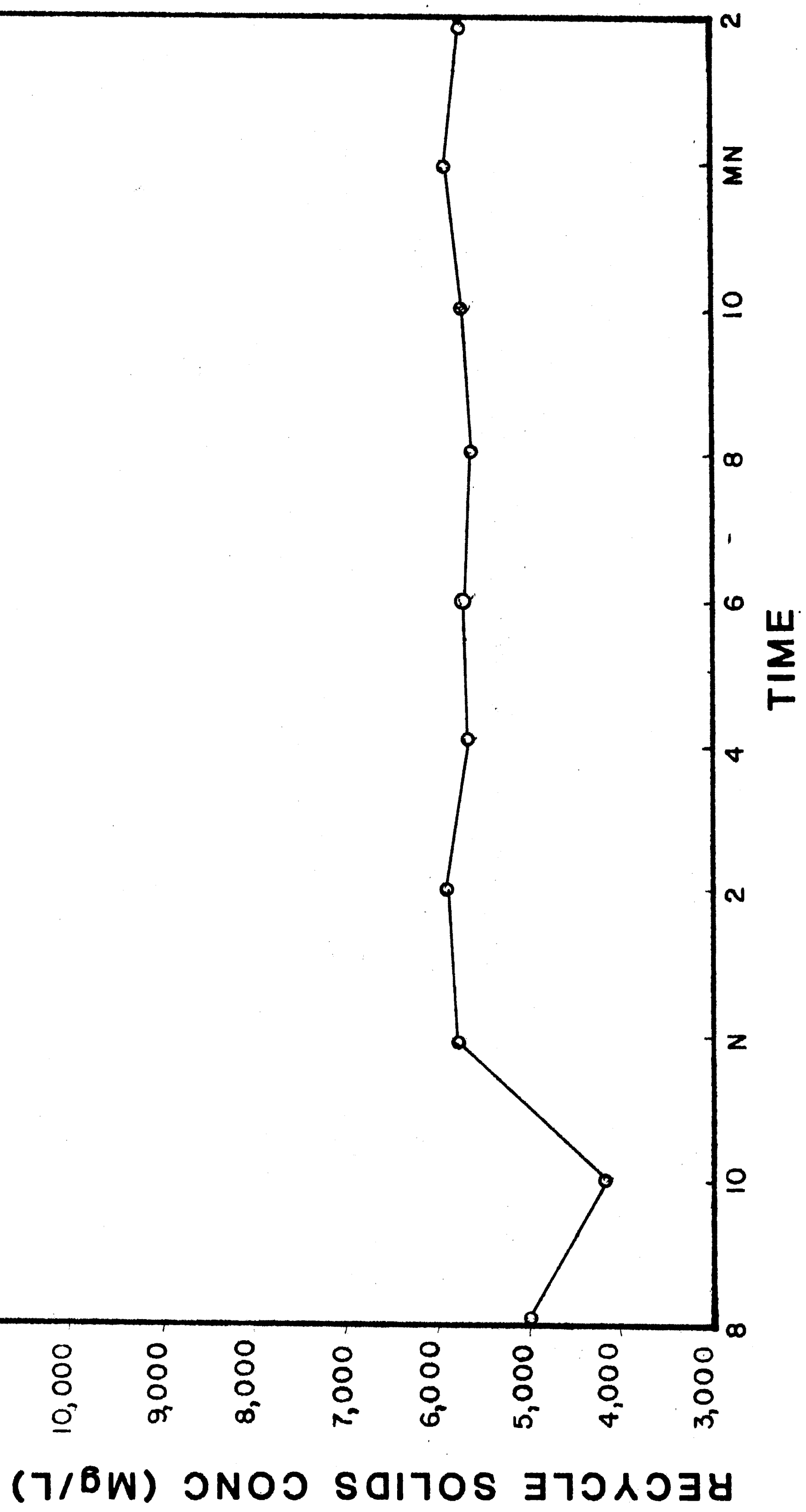

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 21. Recycle Solids Concentration Versus Time
Sample Day 17

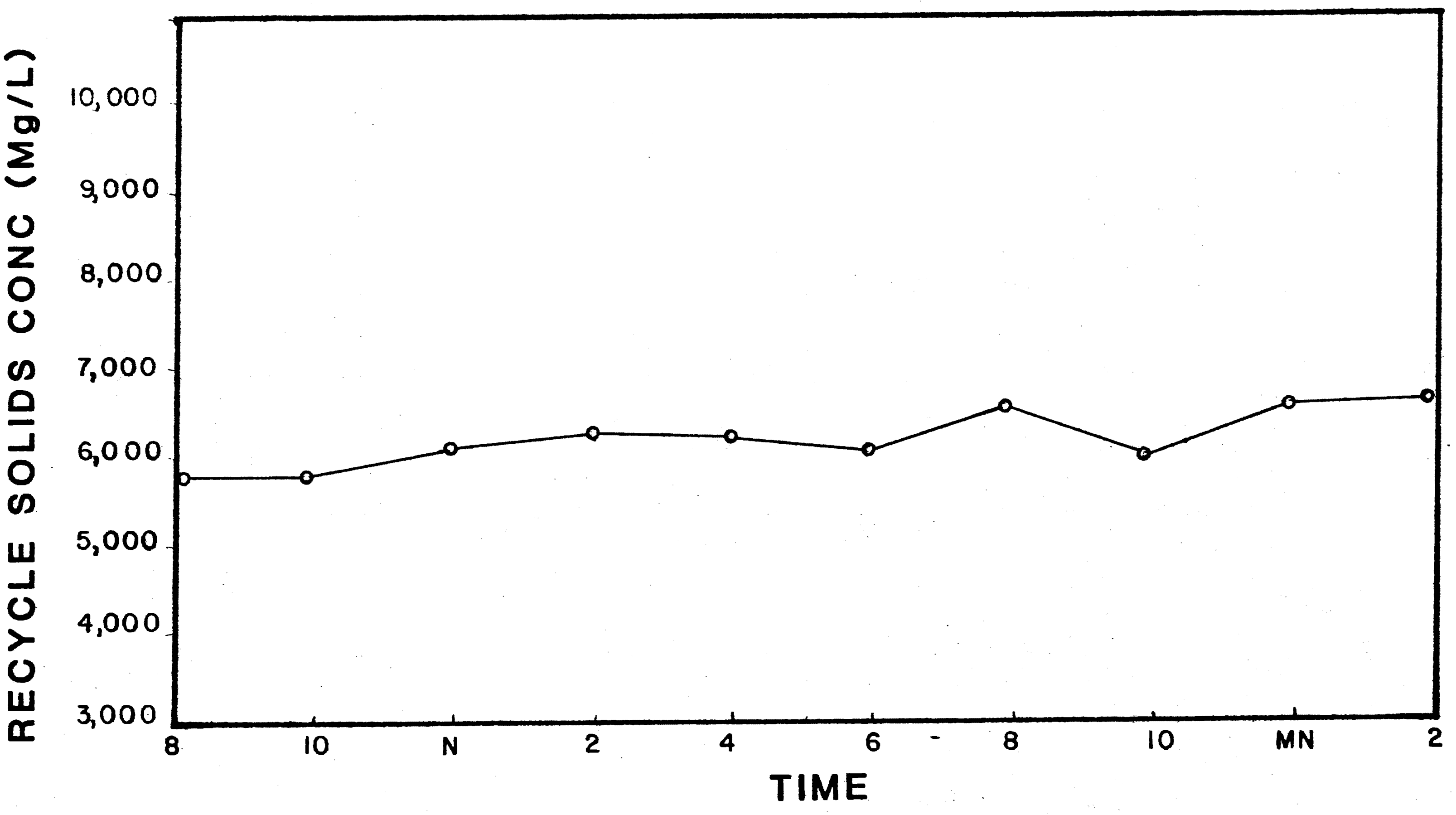

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
-
8
10
MN
2
TIME

Figure 22. Recycle Solids Concentration Versus Time Sample Day 18

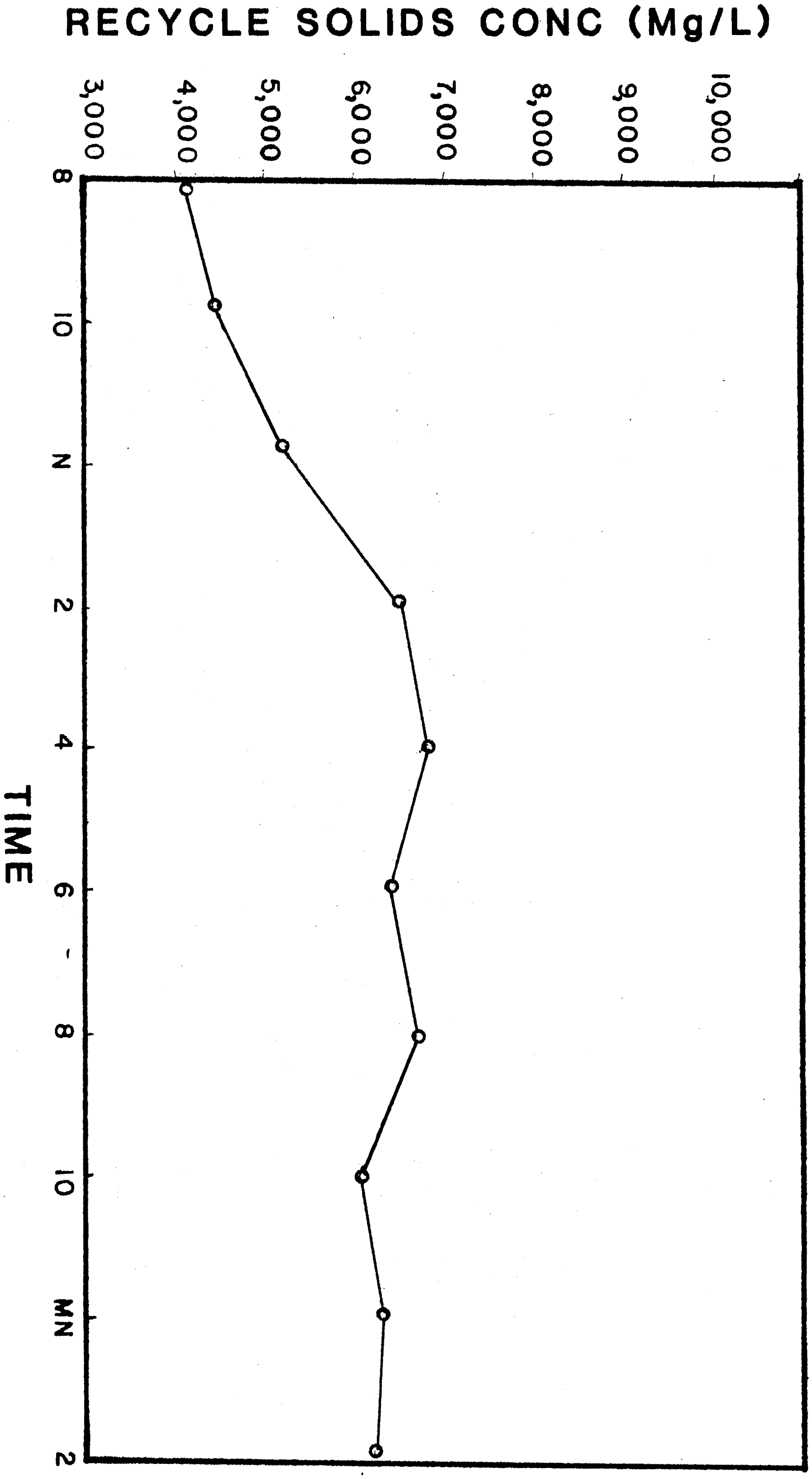

RECYCLE SOLIDS CONC (Mg/L)
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
TIME
8
10
N
2
4
6
8
10
MN
2

Figure 23. Recycle Solids Concentration Versus Time
Sample Day 19

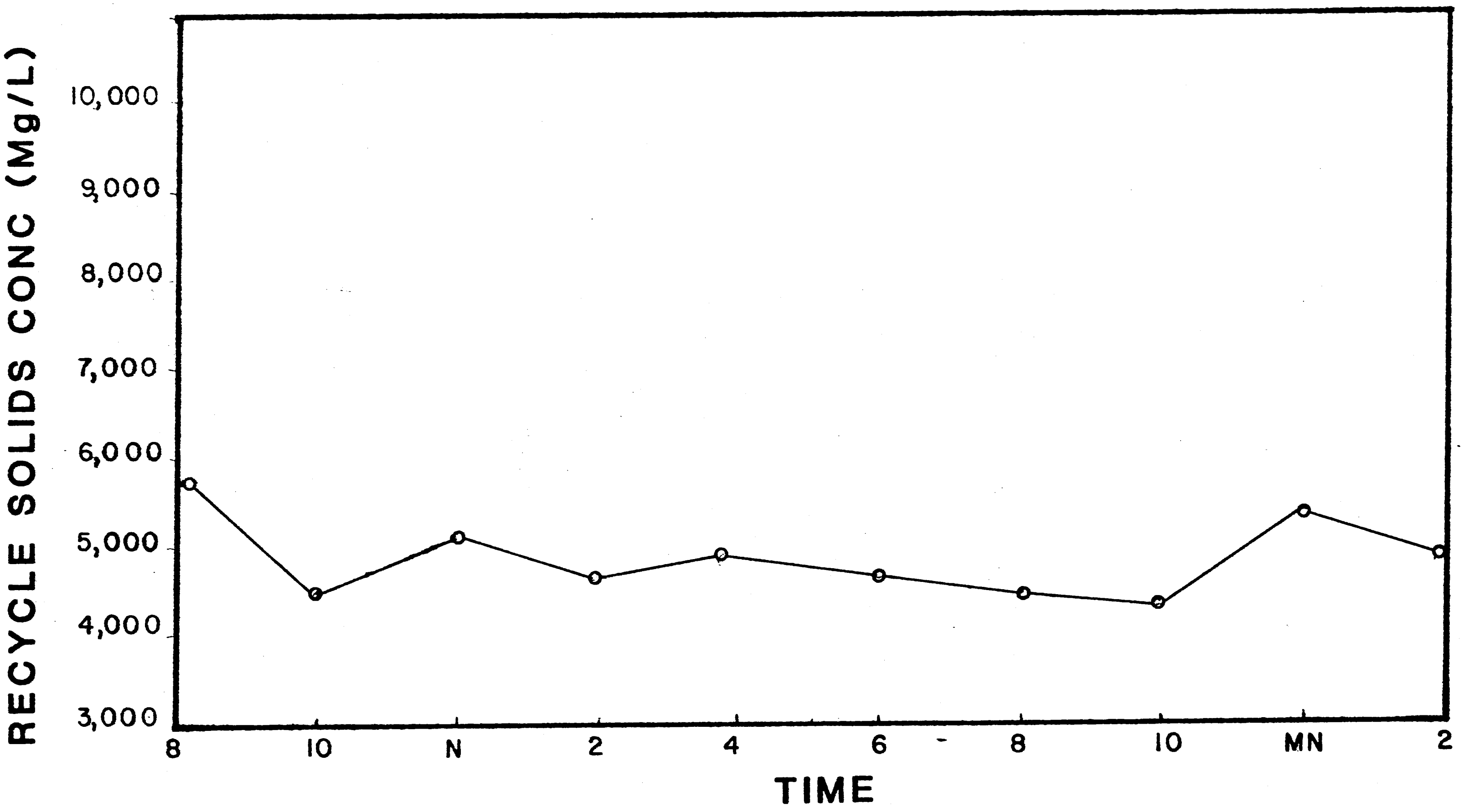

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 24. Recycle Solids Concentration Versus Time
Sample Day 20

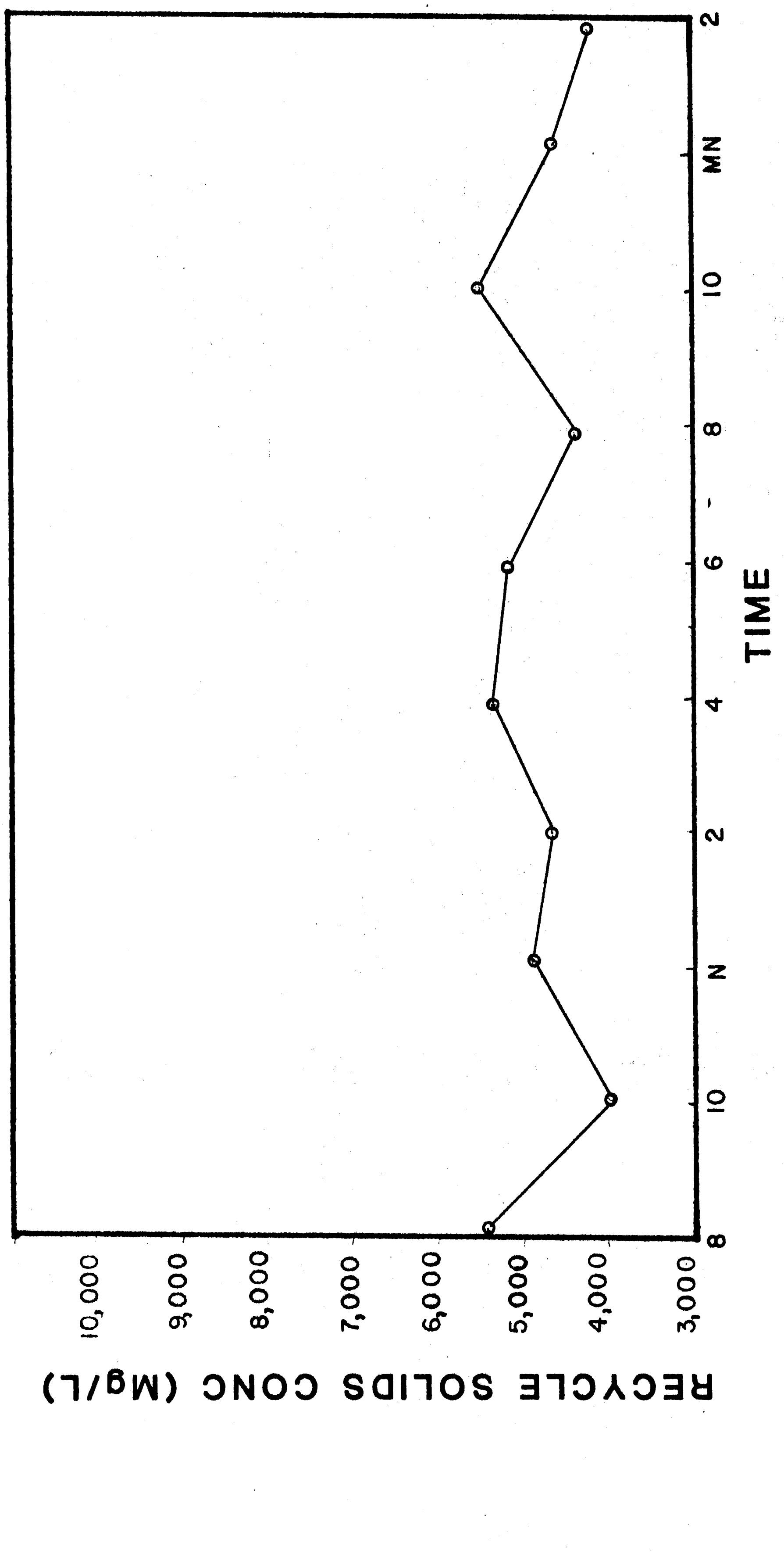

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 25. Recycle Solids Concentration Versus Time
Sample Day 21

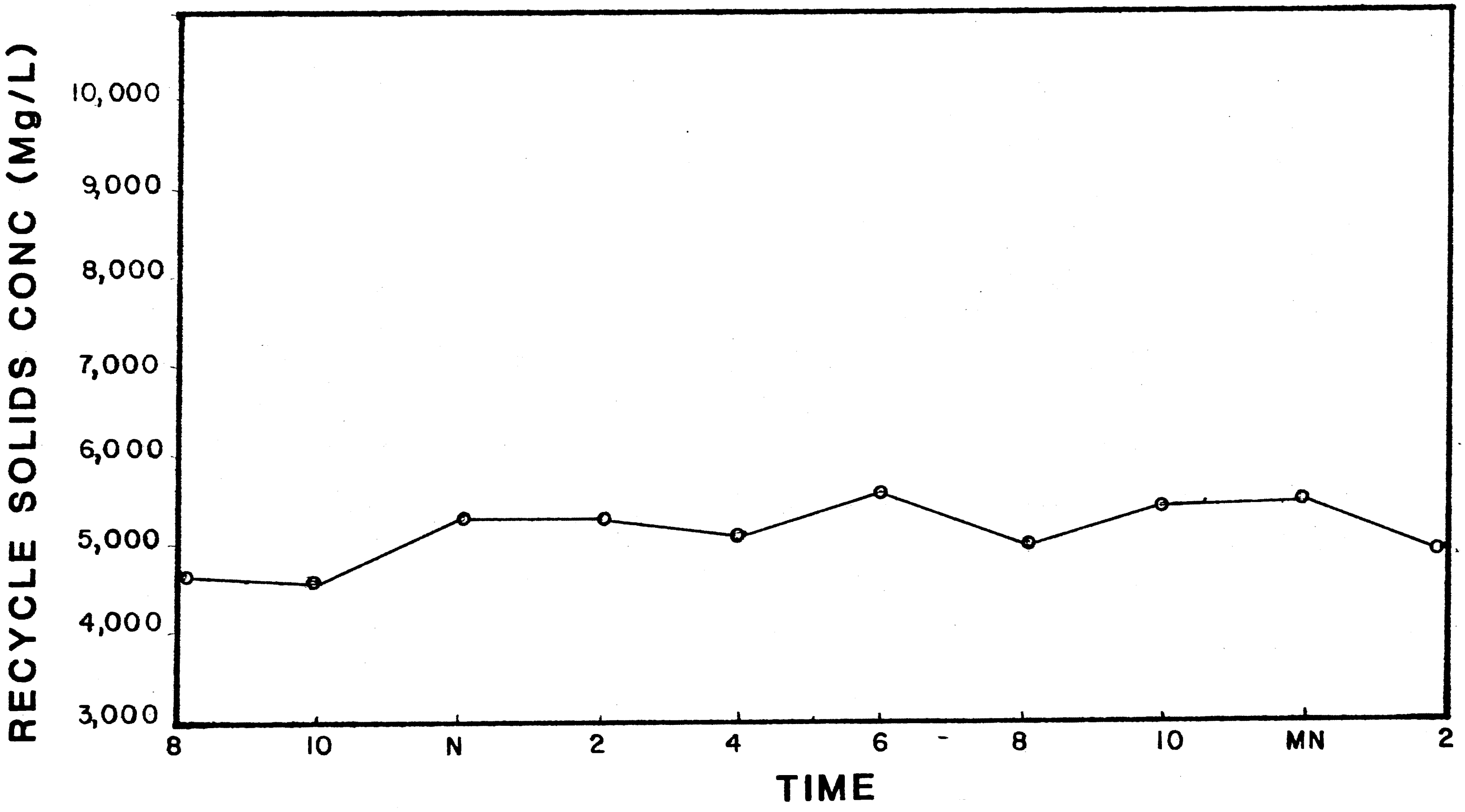

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 26. Recycle Solids Concentration Versus Time
Sample Day 22

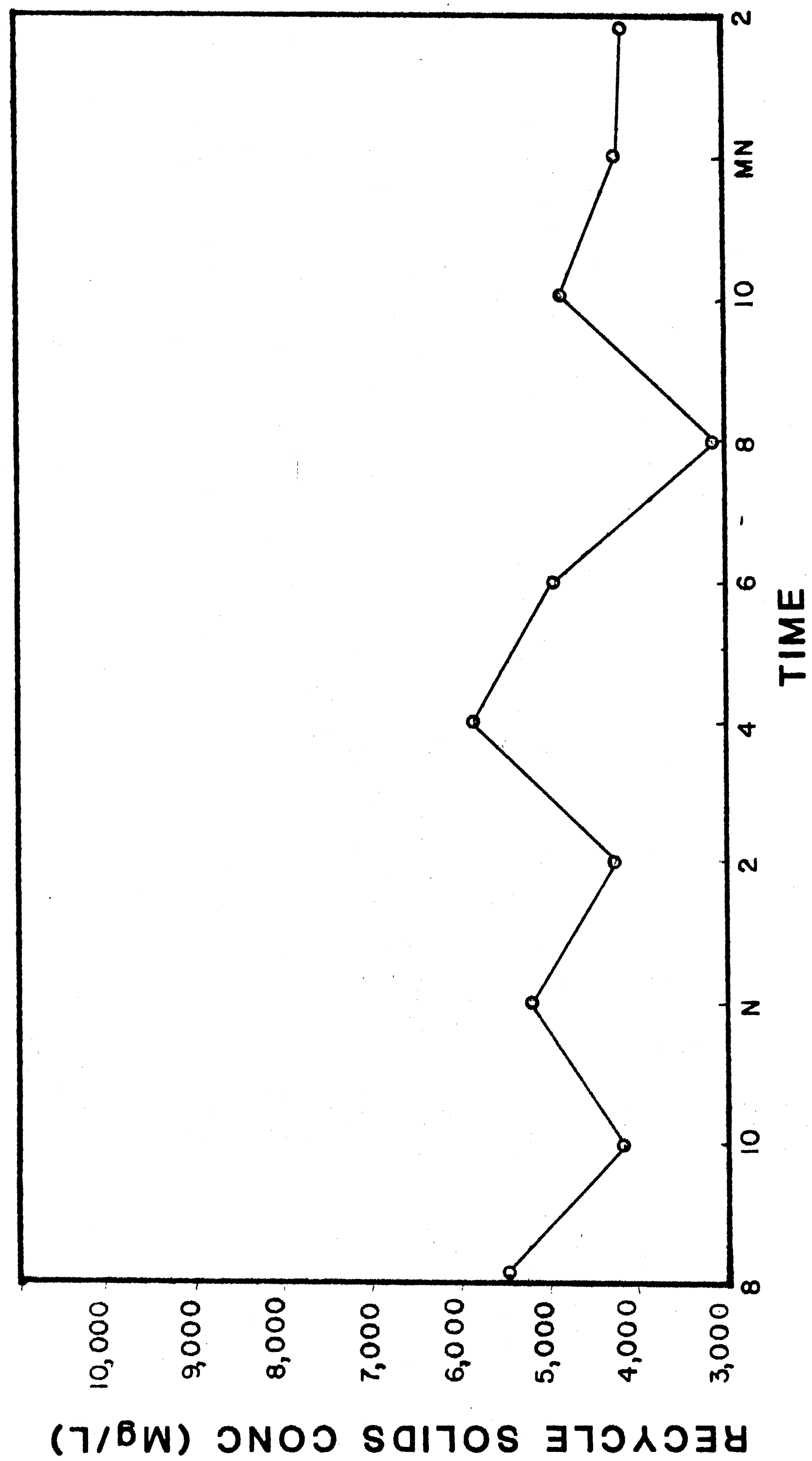

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
TIME
8
10
N
2
4
6
8
10
MN
2

Figure 27. Recycle Solids Concentration Versus Time
Sample Day 23

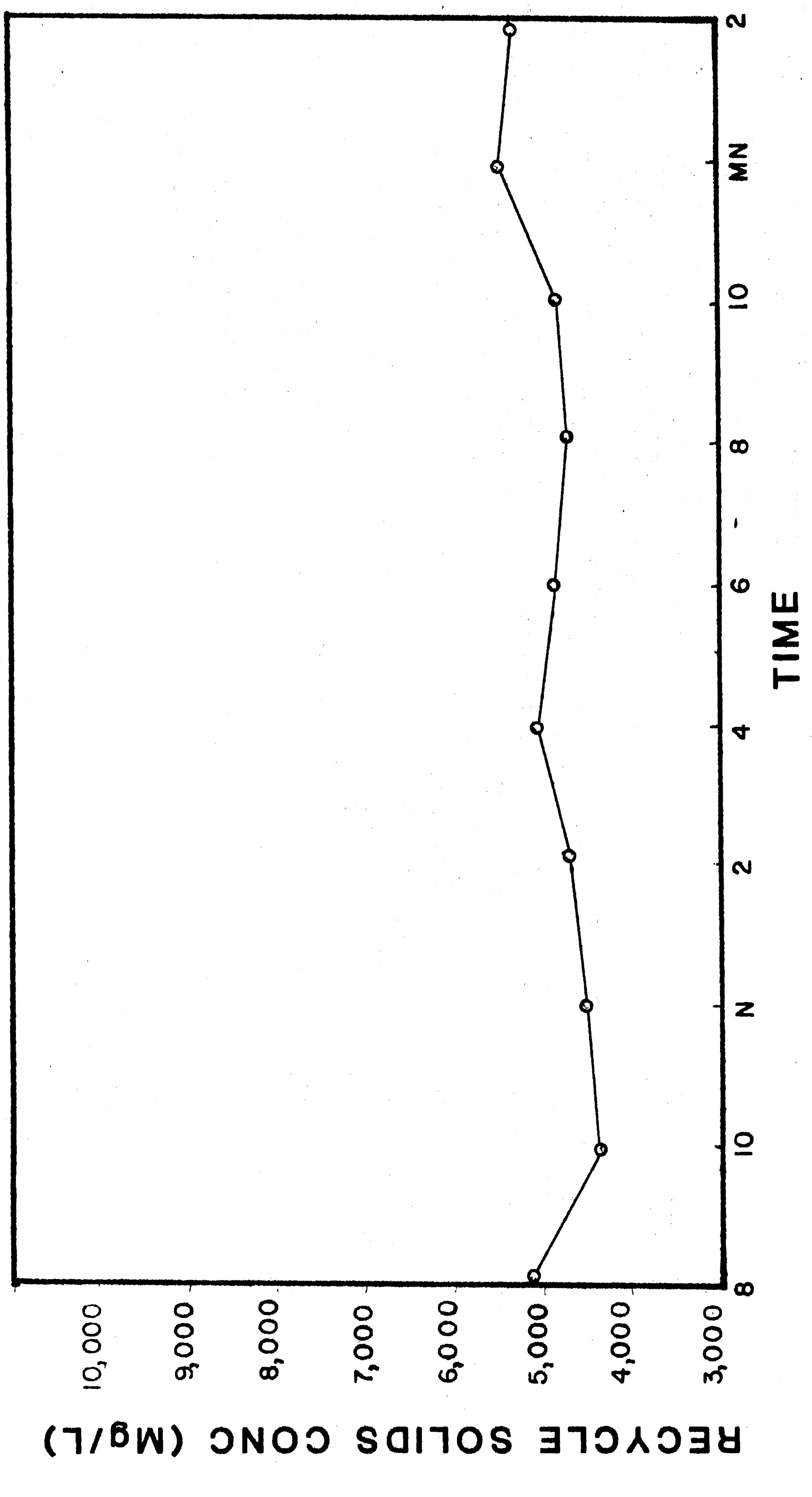
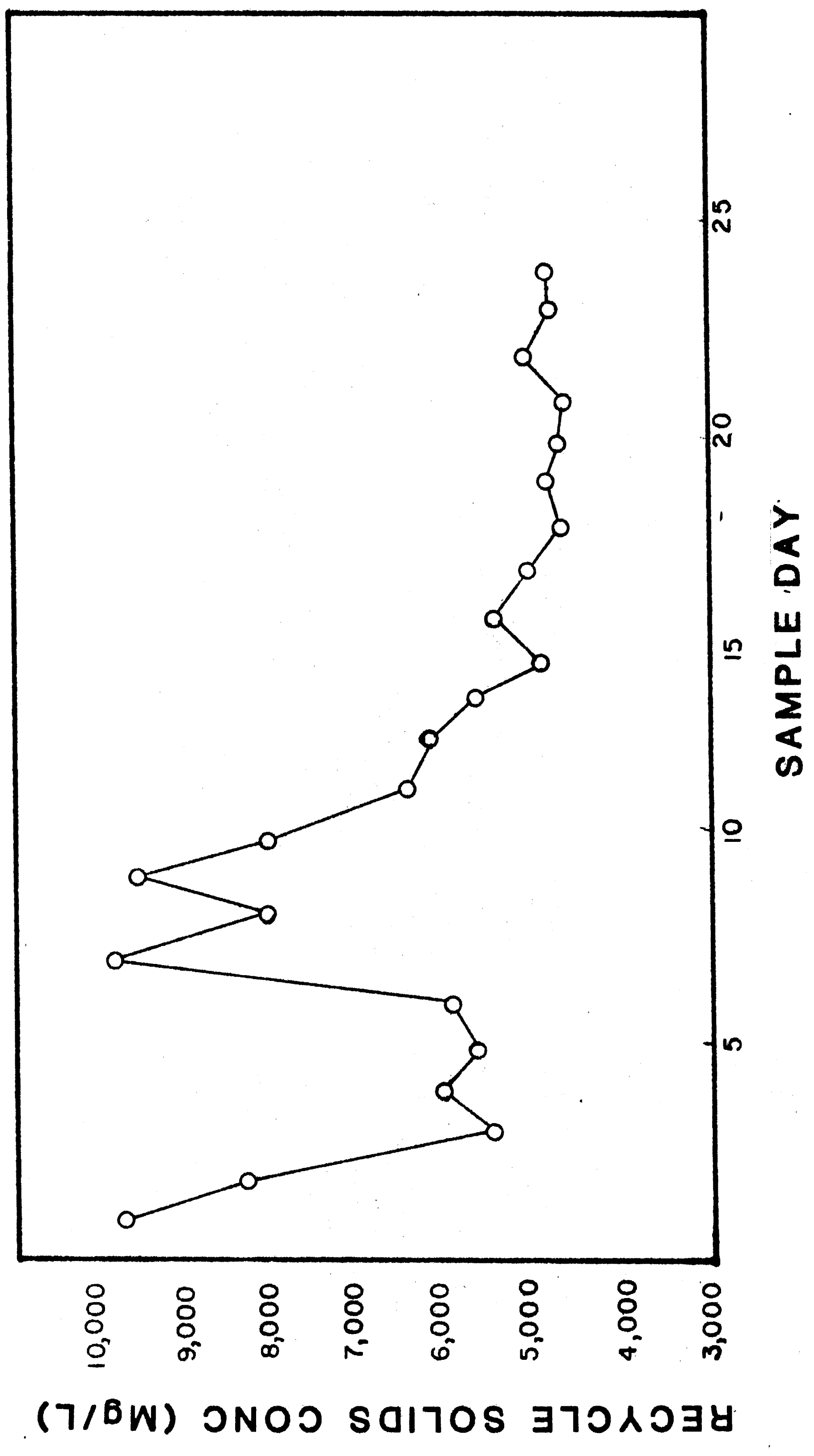

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
8
10
N
2
4
6
8
10
MN
2
TIME

Figure 28. Average Recycle Solids Concentration Versus Sample Day


RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
5
10
15
20
25
SAMPLE DAY

Another question that this study was to examine is the effect of the recycle solids concentration variation on some of the operational parameters of the treatment plant and how it might effect the efficiency of the plant. Plotting the recycle solids concentration versus the solids concentration of the aeration tank shows a correlation between the two values. Figure 29 shows a gradual increase in the solids of the aeration tank as the solids in the recycle line increases. This gradual increase continues up to an aeration solids concentration of 2100 mg/1 as shown by the data collected during this study. It appears that a higher increase in recycle solids are needed to give a comparable increase in aeration solids at high recycle concentrations but this study did not have sufficient data to make a definite correlation as to this observation.

Volatile suspended solids are those particles in the suspended solids which can be oxidized and driven off as a gas at $600^{o}C$. These are generally the organic particles found in the suspended solids and are used to measure the biological stability of the sewage. The graph in Figure 30 shows a correlation between the concentration of solids in the recycle line and concentration of volatile suspended solids. It shows a slow increase in volatiles with an increase in recycle solids concentration. This increase appears to become less at higher recycle concentrations indicating a lesser correlation at volatile concentrations above 1200 to 1300 mg/1 in this study.

Figure 29. Total Solids Concentration Versus Sample Day

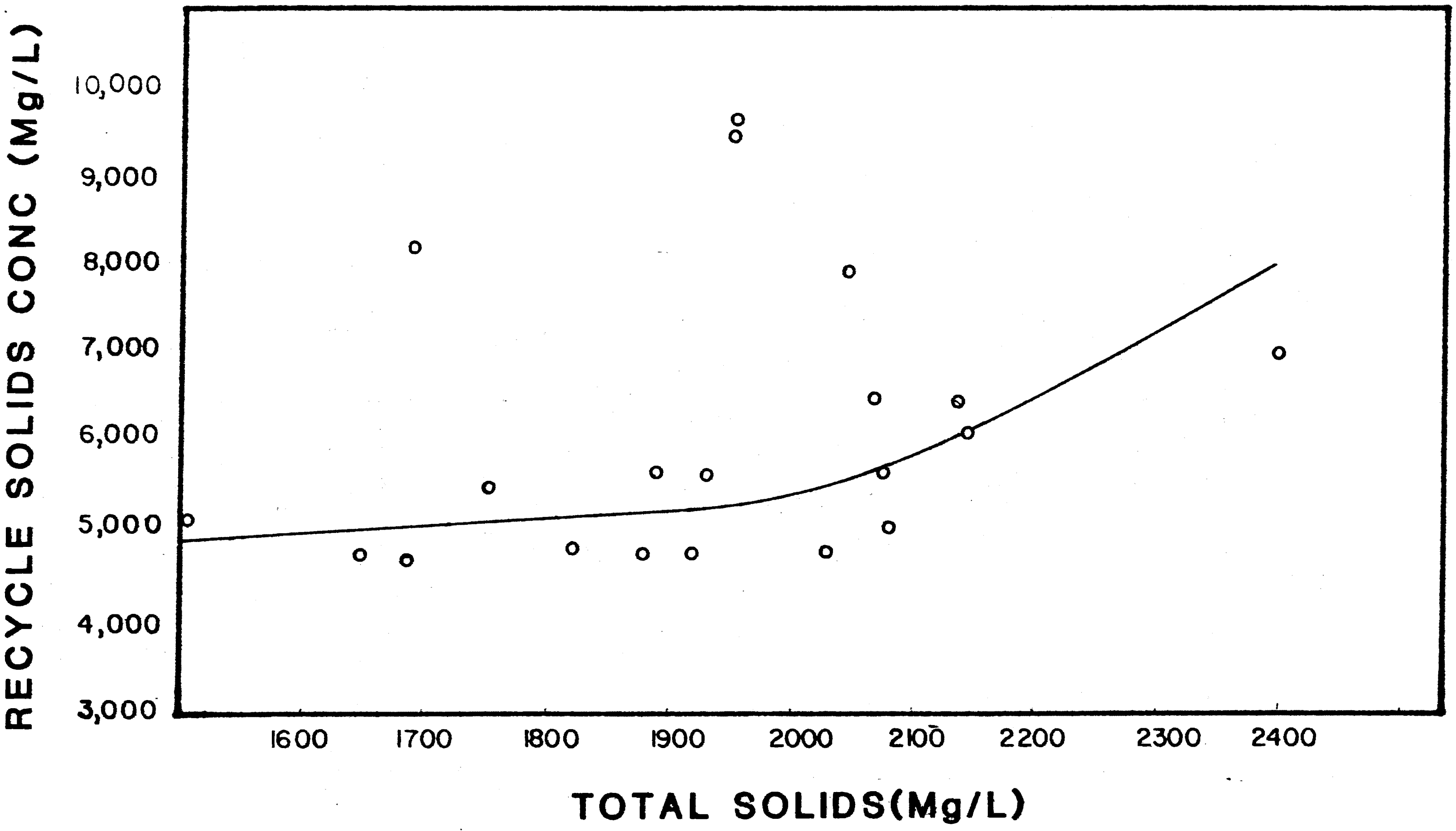
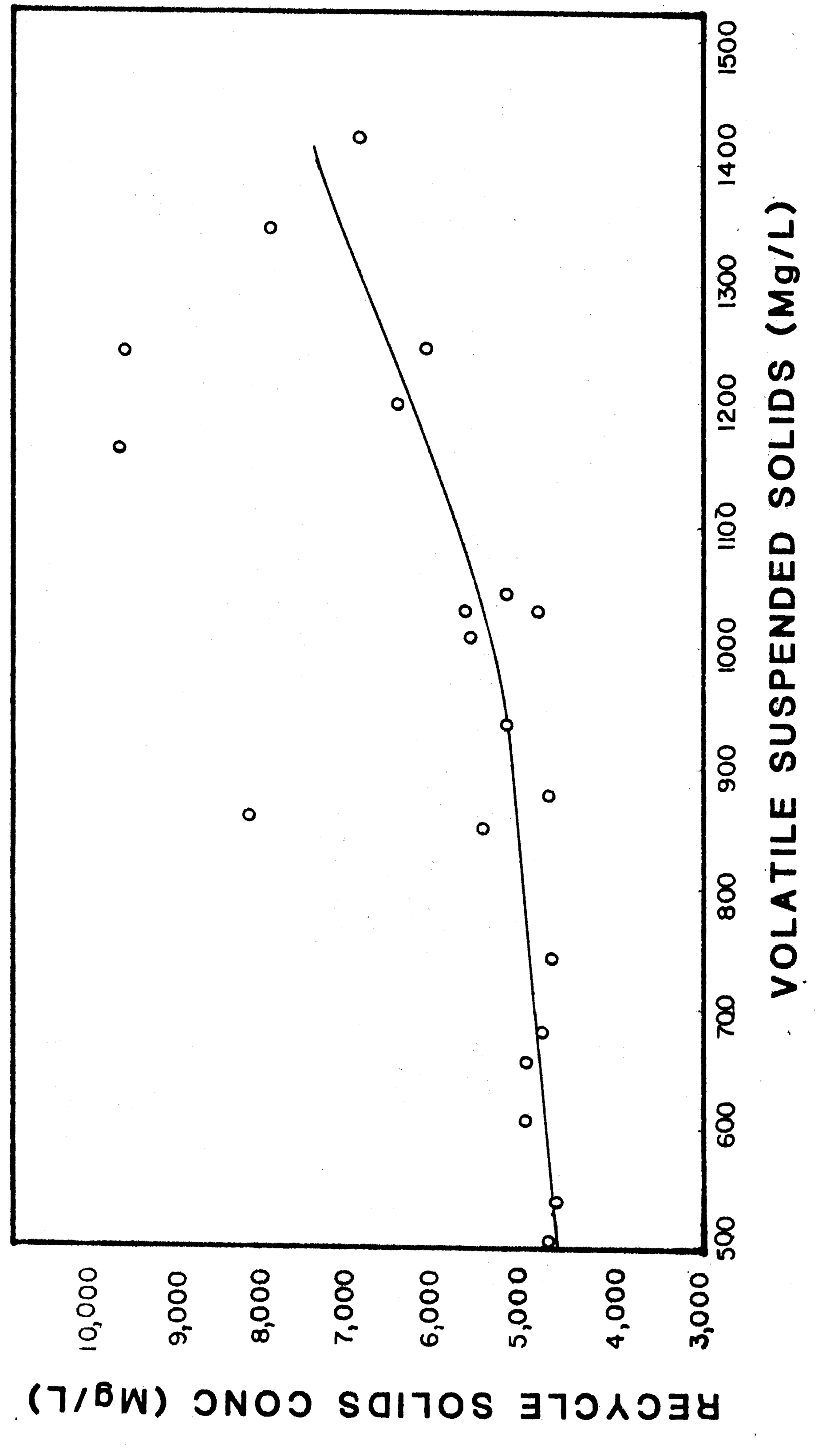

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
1600
1700
1800
1900
2000
2100
2200
2300
2400
TOTAL SOLIDS(Mg/L)

Figure 30. Volatile Suspended Solids in Aeration Tank Versus Recycle Solids Concentration


RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
500
600
700
800
900
1000
1100
1200
1300
1400
1500
VOLATILE SUSPENDED SOLIDS (Mg/L)

The suspended solids are that part of the total solids which will be left in the filtrate. As can be seen in Figure 31 there exists a correlation between recycle solids concentration and the concentration of suspended solids. As the concentration of solids in the recycle approach 5400 to 5600 mg/l the graph begins to increase very rapidly. It was found that the days with extremely high recycle solids concentrations occurred on days in which the flow had increased substantially. It is the feelings of the author that this increase in total recycle solids may be due to an increase in grit, at least in part. This would account for the loss of correlation between suspended solids and volatile suspended solids at higher recycle solid values. This could also explain why this loss of correlation is less when comparing total solids in the aeration tank with recycle solids concentration.

The relation between the recycle concentration and percent of BOD_5 removed was examined in Figure 32. As can be seen from the graph there is no close correlation between the two values.

Some aspects of plant operation were examined to determine if there was any relationship between them and the solids concentration in the recycle line. Aspects that were checked are mean cell residence time, detention time in the clarifier, and the value determined for the sludge volume index.

Figure 31. Suspended Solids in Aeration Tank Versus Recycle Solids Concentration

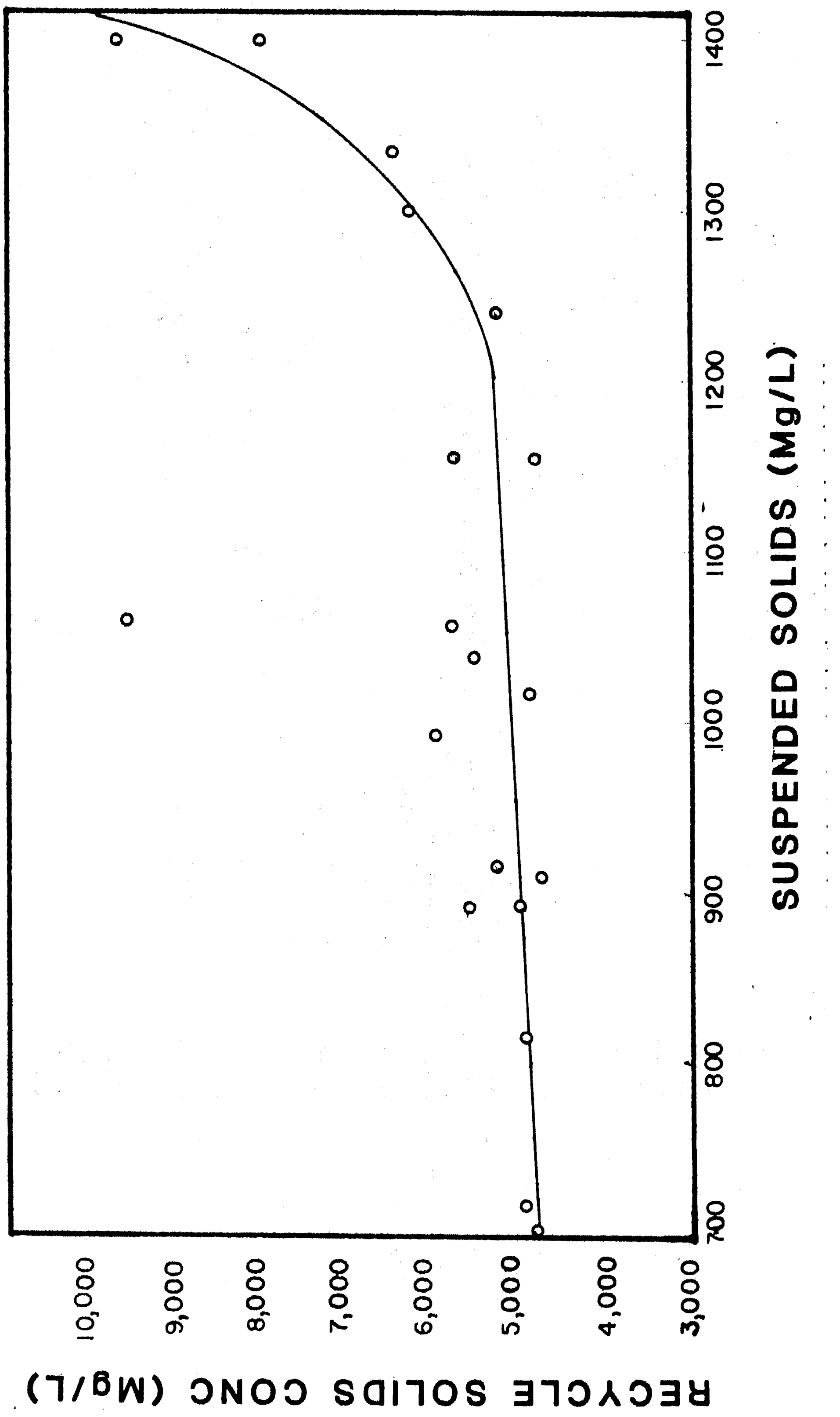
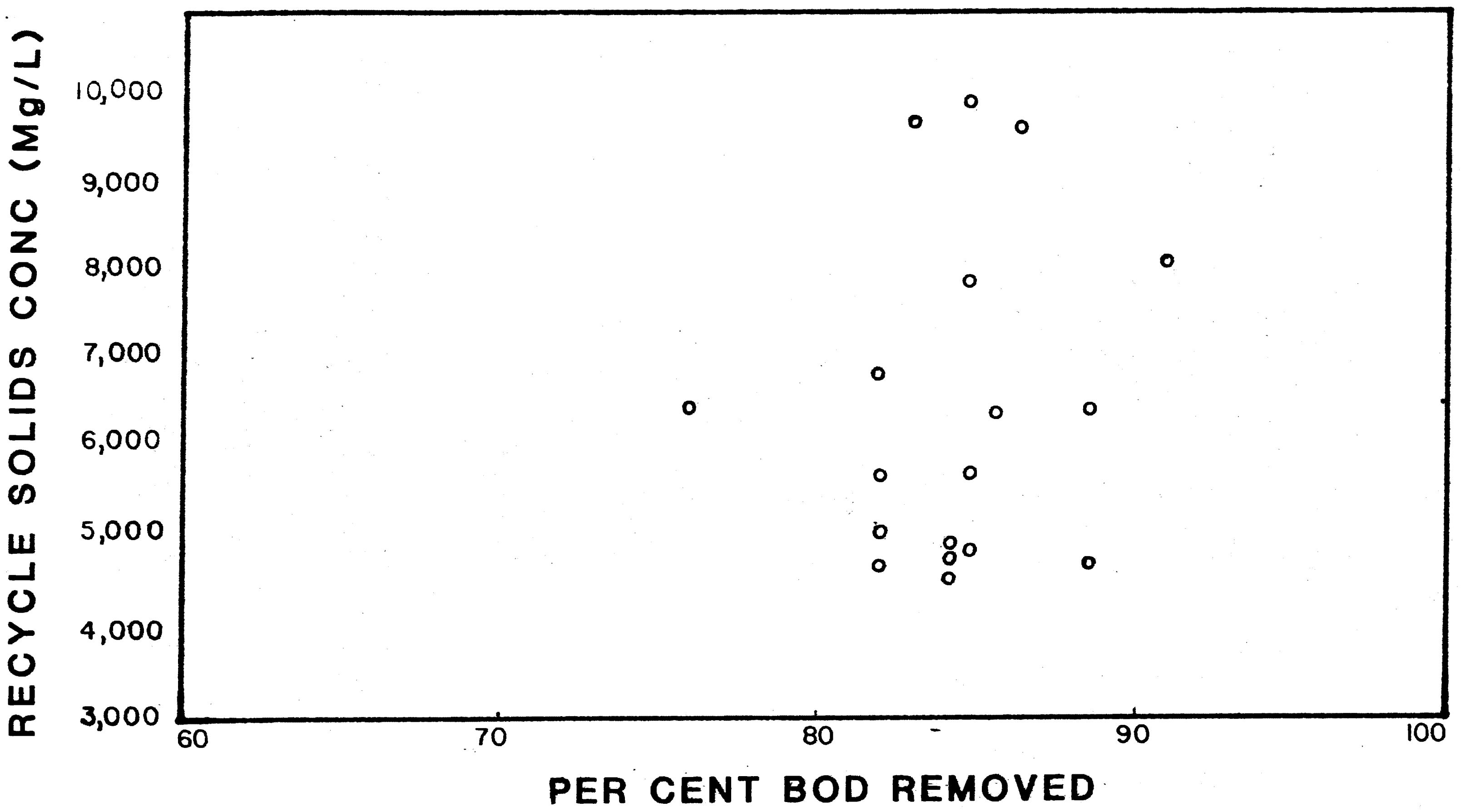

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
SUSPENDED SOLIDS (Mg/L)
700
800
900
1000
1100
1200
1300
1400

Figure 32. Percent BOD_5 Removed Versus Recycle Solids Concentration


RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
60
70
80
90
100
PER CENT BOD REMOVED

The mean cell residence time (Θ_c) is defined as:

$$\frac{VX}{Q_w X + (Q - Q_w)\ X_E}$$

Where V is the volume of the aeration tank, X is the solids concentration in the aeration tank, X_E is the solids concentration in the effluenet, Q is the flow, and Q_w is the amount of liquid wasted from the aeration tank. If the amount of soilds in the effluent are extremely small then the equation can be reduced to give an approximate Θ_c defined as:

$$\frac{VX}{Q_w\ X_R}$$

The above equation can give an approximate Θ_c if the waste is taken from the recycle line. This approximate Θ was used in this study to compare the relationship of Θ_c to the recycle solids concentration.

When Θ_c is plotted against the recycle solids concentration as in Figure 33 it is possible to see a correlation between the two values. The data reflects what with a Θ_c of 0 to 6 days the cell concentration remains fairly low, but with a Θ_c greater than six days there exists a strong correlation between an increasing Θ_c and an increase in the recycle solids.

The effect of clarifier detention time was determined by plotting detention time versus recycle solids concentration in Figure 34. As can be seen no correlation can be made concerning the two values from the data collected in

Figure 33. Approximate Θ_c Versus Recycle Solids Concentration

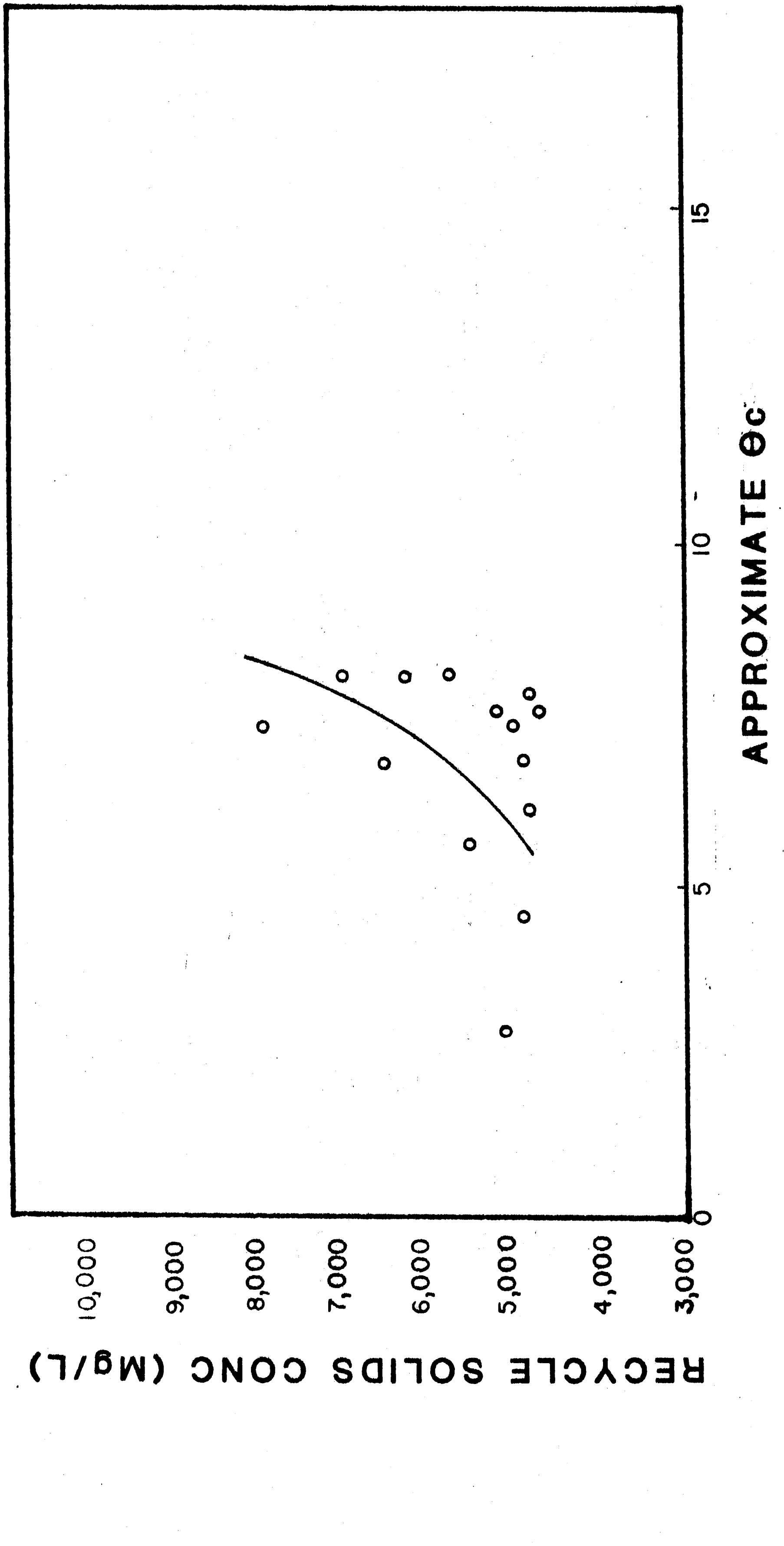
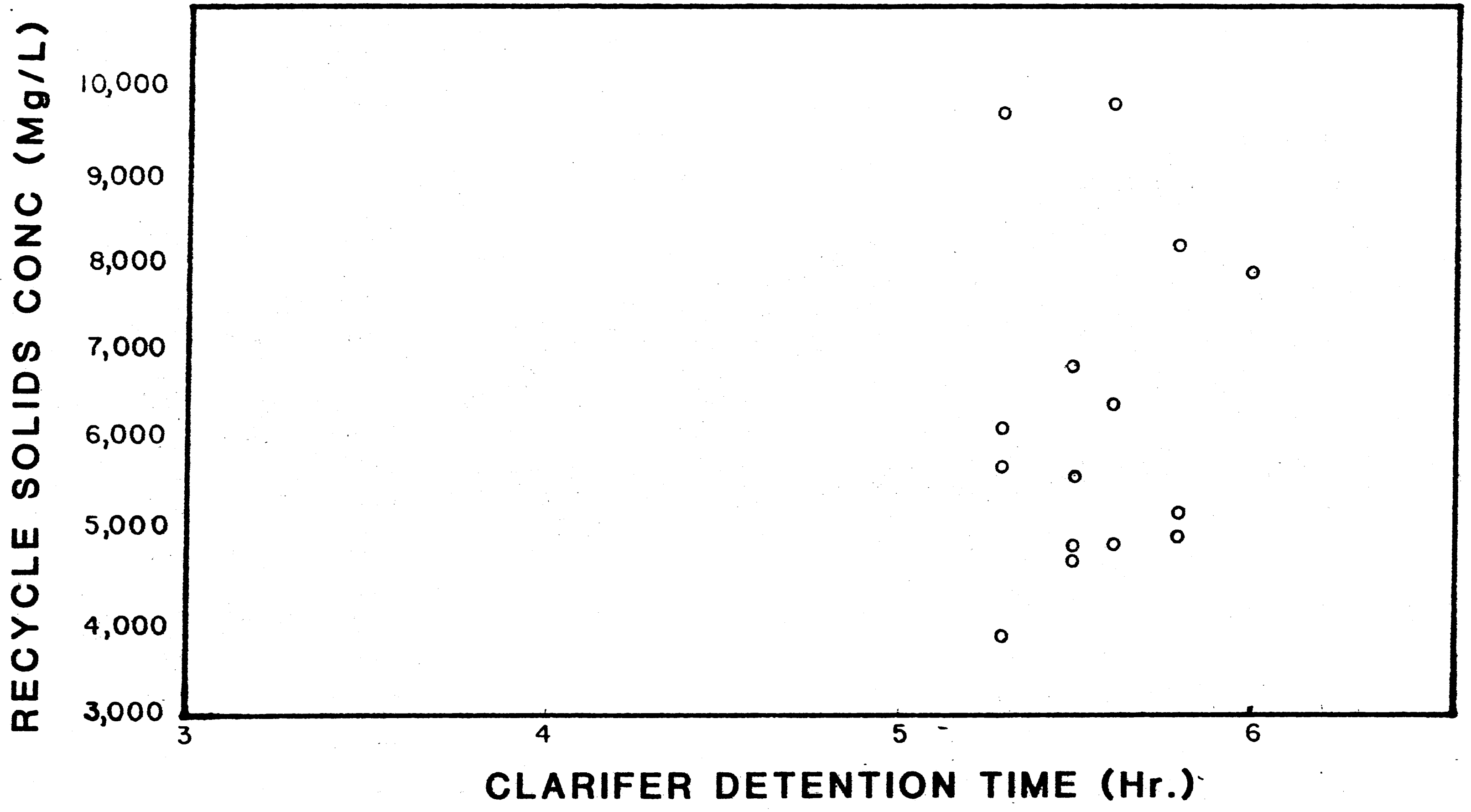

RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
0
5
10
15
APPROXIMATE θc

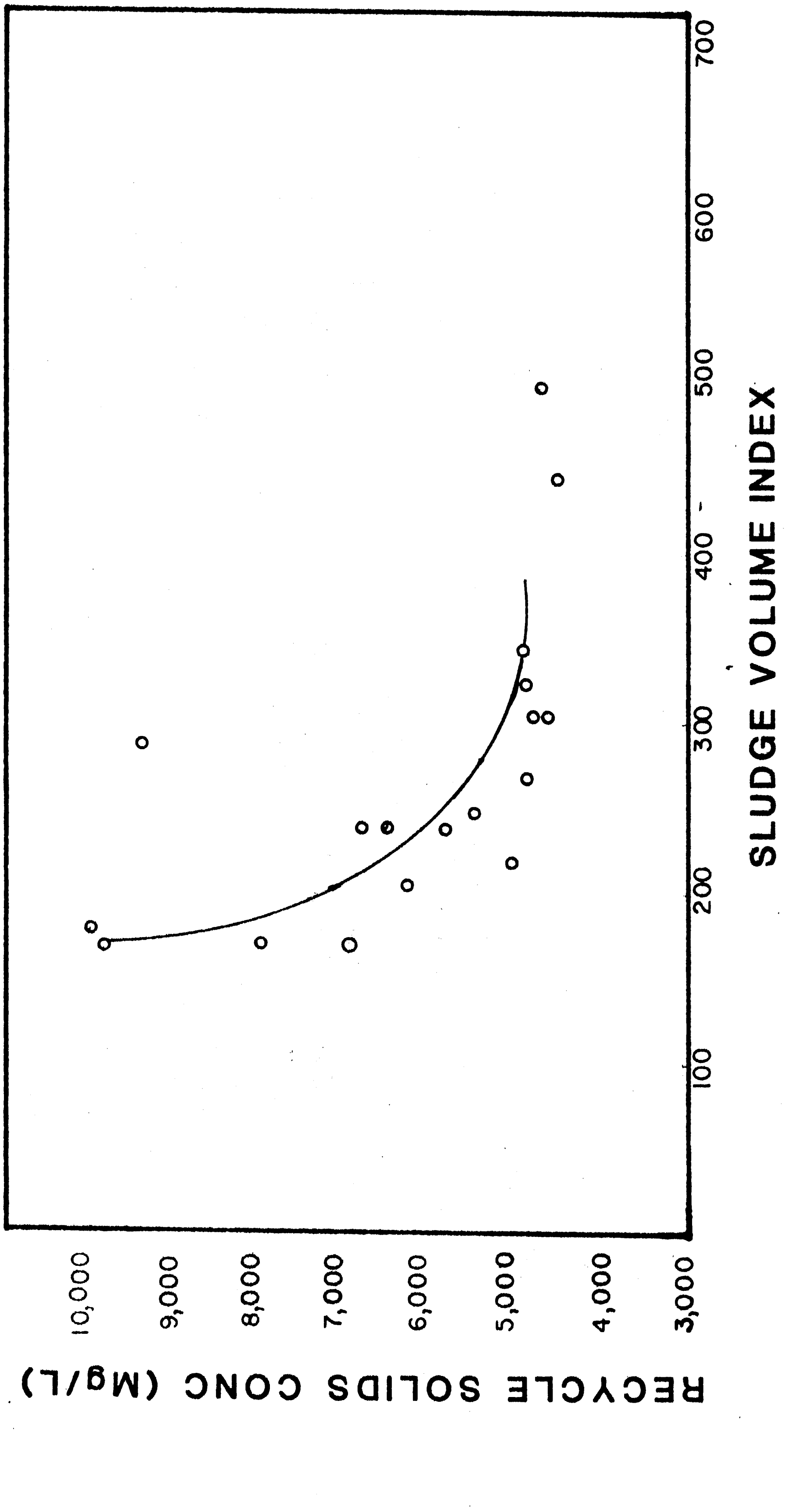
Figure 34. Clarifier Detention Time Versus Recycle Solids Concentration


RECYCLE SOLIDS CONC (Mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
3
4
5
6
CLARIFER DETENTION TIME (Hr.)

this study. We can conclude then that detention time was not an important factor in the concentration of recycle solids.

Figure 35 indicates that the ability of the sludge to settle, which is shown by the sludge volume index, does effect the recycle solids concentration. During this study period a lower sludge volume index indicated a higher concentration of recycle solids. This was found to hold true until sludge volume indexes of greater than 360 were encountered.

Figure 35. Sludge Volume Index Versus Recycle Solids Concentration


SLUDGE VOLUME INDEX
100
200
300
400
500
600
700
RECYCLE SOLIDS CONC (Mg/L)
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000

CHAPTER V

CONCLUSIONS

This study has led to the conclusions listed below. These conclusions are based on the data collected during the study period and may not be valid for other Activated Sludge Plants.

1. There is, in fact, a variation in the recycle solids concentration. This variation can be seen on an hourly, daily, weekly, or monthly basis.

2. There has been a positive correlation established concerning the recycle solids concentration with the concentration of the total solids, suspended solids, and the volatile suspended solids found in the aeration tank.

3. No clear correlation could be established between the recycle solids concentration and the percent of BOD_5 removed by the treatment plant.

4. A correlation was found to exist between the mean cell residence time and the recycle solids concentration.

5. No clear correlation could be found between the detention time and the recycle soilds concentration during the study period.

6. There was a correlation found between the recycle solids concentration and the sludge volume index.

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