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Improving Design Criteria for Septic Tank Systems

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By

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1. INTRODUCTION

The failure of septic tanks in treatment of wastewater has been responsible for causing health hazards due to contamination and pollution of groundwater and surface waters used for drinking water supplies. Most of these failures have been in the absorption field. Little or no actual research has been performed to establish design criteria for septic tank absorption fields to be used by local, state or federal Health Agencies or Pollution Control Agencies.

Historically, almost all design criteria has beed based on a percolation test and the number of bedrooms to be served. Both of these methods have repeatedly been shown to have little or no relationship to efficient absorption field performance.

This study was conducted to test the theory that failures can be corrected with relatively inexpensive changes in absorption field design.

Reported here are the results of an investigation of the septic tank effluent treatment capacity of gravel from local streams. The effluent was percolated through lysimeters containing various depths and sizes of gravel. The gravel was varied as to its physical characteristics, coefficient of uniformity and effective particle size as well as depth and size. The findings may lead to the modification of absorption fields for more efficient waste treatment.

2. PURPOSE AND SCOPE

This study had a twofold objective, which was examined in two phases. The objective was:

1) To determine the biodegradation efficiency of various sizes and depths of washed river gravel.

2) To establish from the data obtained in the preceding step some design parameters for the incorporation of an artificial soil into the soil absorption portion of a septic tank waste disposal system.

These goals were met in two phases. The first was the establishment of lysimeters of various sizes and depths of washed river gravel. These lysimeters were intermittently dosed-twice a day-with a constant amount of septic tank effluent.

Phase two encompassed the adjustment of dosage sizes to produce more efficient biodegradation of the waste.

Dosage of the lysimeters and collection of lysimeter effluent was begun in November, 1975, and continued until March, 1976. The samples collected were examined twice a week for COD and once a week for ammonia nitrogen, nitrate nitrogen, pH and phosphate.

3. PRESENTATION OF RESULTS

Influent and effluent chemical analysis data collected during this investigation are presented in tabular form in Appendix B. Graphical Figures 1 through Figures 74 presented in this section were derived from this data.

Maximum, minimum, and average chemical characteristics of the influent septic tank wastewater for the period of investigation are presented in Table II.

The relations between COD removal, time, dosage rate, COD loading rate and the size and depth of the soil column material are presented in graphical form. Other figures demonstrate phosphate removal as affected by time, phosphate loading, influent pH, effluent pH and the size and depth of lysimeter material. Another set of figures shows the relationship between the ratio of effluent inorganic nitrogen to influent inorganic nitrogen and time.

When referring to a particular lysimeter from here on it will be identified as shown in the following example. Lysimeter 3 which contains 24 inches of material passing a 1/2 inch sieve will be referred to as lysimeter 3. (24 in.: 1/2 in.).

3.1 COD Removal

Figure 1 through Figures 10 show the relationship of per cent COD removal to time for each lysimeter. The variations in dosage rate application in gallons per day per square foot are also displayed on

TABLE II

CHARACTERISTICS OF INFLUENT SEPTIC TANK SEWAGE

Constituent	Concentration (mg/l)		
	Maximum	Minimum	Average
pH	7.5	7.1	7.3
COD	2566	272	964
Phosphate (AsP)	17.25	8.25	12.86
Total Inorganic Nitrogen As(N)	107	34	67
Ammonia Nitrogen As(N)	61	7.5	41
Nitrate Nitrogen As(N)	46	4	27

these figures.

Figure 1 shows the COD removal over a sixty-three day period for lysimeter 3 (24 in.: 1/2 in.). A constant dosage of 1.29 GPD/sq.ft. was applied to this column. The initial COD analysis on the effluent was done nine days after dosing began. COD removal increased from 87% to 97% during the first week of analysis, then stabilized at approximately 97% until the last analysis, at which time the removal dropped to 94%.

Figure 2 is a graph of COD removal for lysimeter 11 identical to lysimeter 3 in depth and sieve size of material but whose coefficient of uniformity, C_u is 3.3 and effective size, D_{10} is 4.2 mm. compared to a C_u of 30 and D_{10} of 0.4 mm. in lysimeter 3. COD analyses were begun thirteen days after the initial dosage. A temporary increase in COD removal up to 95% was observed for seven days; however, a gradual decrease to 33% occurred over the next forty-six days. A significant increase resulted after that. On day 92 the dosage rate was decreased from 1.29 GPD/sq.ft. to 0.97 GPD/sq.ft., resulting in a significant increase for the next twenty-one days.

The COD removal in relation to time for lysimeter 13 (6 in.: 3/8 in.) is presented in Figure 3. The initial 39% COD removal established thirteen days after the first dosage application improved to 90% by the twentieth day. The lysimeter ponded at day 24, however, and was subsequently rested for two weeks. In the following fifty days COD removals rose from 45% to a peak of 81% and then dropped to 41%. At this time the dosage rate was decreased from 1.29 GPD/sq.ft. to 0.65 GPD/sq.ft. This dosage reduction led to a temporary increase in removal, but in general, COD removal decreased until dosing was discontinued on day 113.

The COD removal ability of lysimeter 14 (12 in.: 3/8 in.) in time

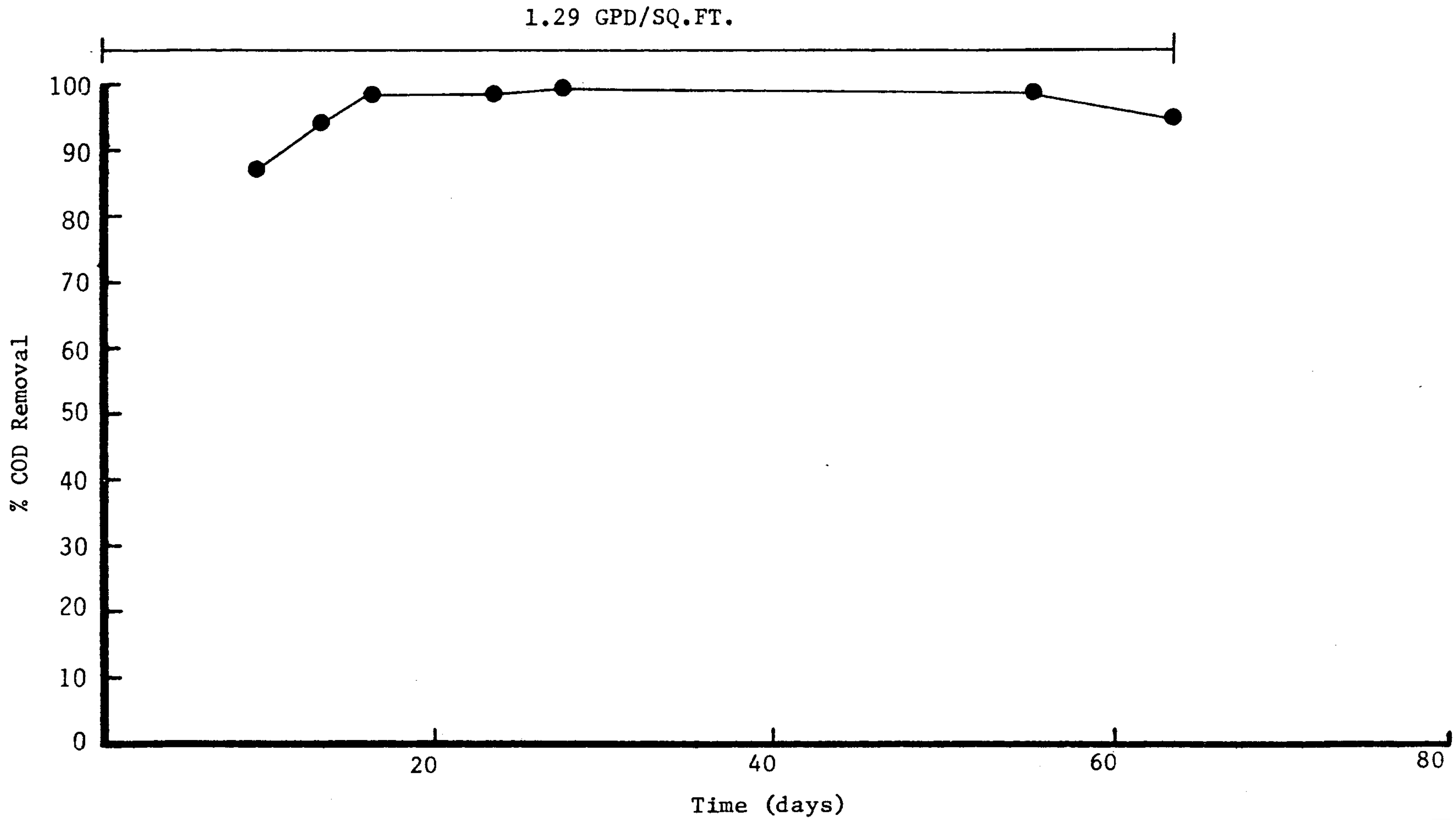

FIGURE 1 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 3 (Depth: 24 inches, Size: passed 1/2 inch sieve)

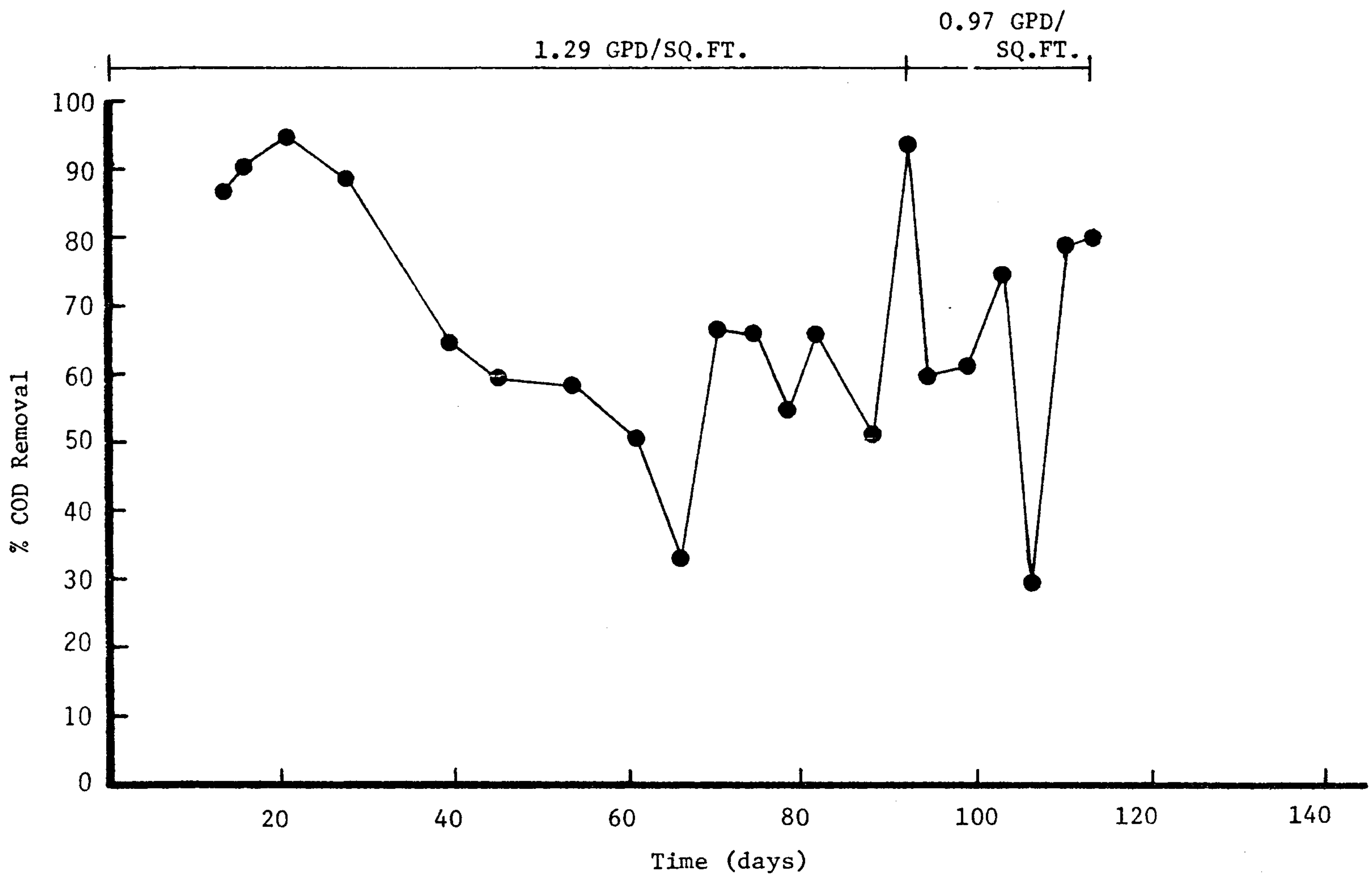

FIGURE 2 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 11 (Depth: 24 inches, Size: passed 1/2 inch sieve)

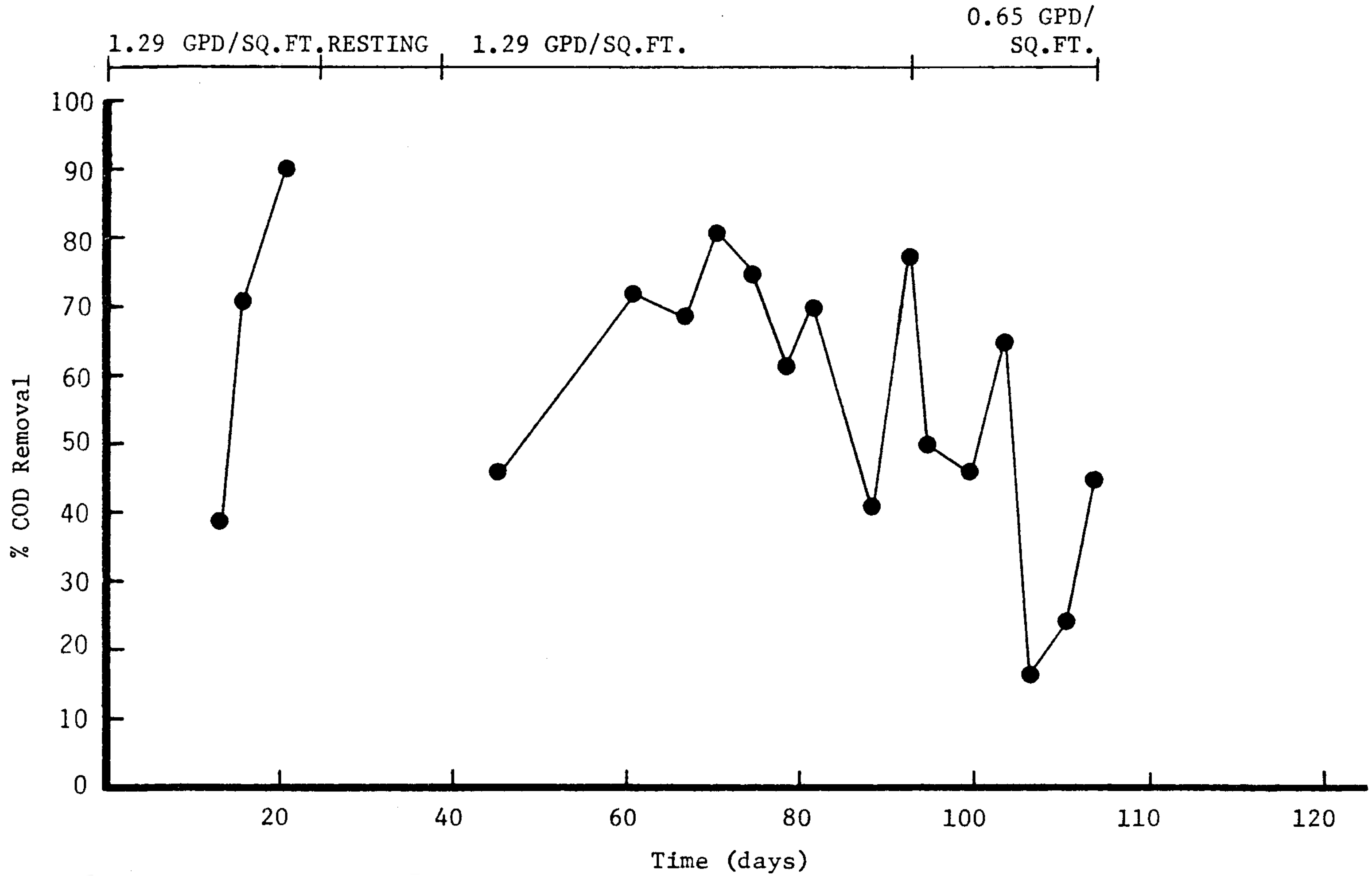

FIGURE 3 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 13 (Depth: 6 inches, Size: passed 3/8 inch sieve)

is represented in Figure 4. It was dosed with 1.29 GPD/sq.ft. until day 92 at which time the dosage was decreased to 0.97 GPD/sq.ft. The COD removal was erratic throughout the 113 days of dosage applications; however, an apparent small increase in removal efficiency resulted with the decrease in dosage rate. Removal ranged from 16% to 84% for the dosing period.

The COD removal in lysimeter 16 (18 in.: 3/8 in.) ranged from 37% to 100% as shown in Figure 5. After 119 days of the 1.29 GPD/sq.ft. dosage rate, the dosage was decreased to 1.13 GPD/sq.ft. No obvious changes in removal were detected. Figure 6 shows COD removal with time for lysimeter 15 (24 in.: 3/8 in.). Overall COD removal is better for the 24 inch depth than the 18, 12 and 6 inch depths of the same sieve size, however, it appears that a periodic decrease in removal efficiency occurs in the 24 inch depth. The increase in dosage rate from 1.29 GPD/sq.ft. to 1.89 GPD/sq.ft. on day 92 led to a decrease in overall removal efficiency.

Figure 7 demonstrates the ability of six inches of material passing a number 4 sieve in lysimeter 5 to remove COD. A fairly consistent removal range from 95% to 100% is maintained with the exception of one time on day 45. Only a 64% removal was achieved that day, but removals rose back to previous levels in the next fourteen days at which time it was discontinued. This drop in efficiency occurred sixteen days after the dosage rate was increased from 1.29 GPD/sq.ft. to 1.89 GPD/sq.ft.

Figure 8 depicting COD removal in lysimeter 6 (12 in.: no. 4) covers a period of seventy-four days with dosage applications of 1.29 GPD/sq.ft., 1.89 GPD/sq.ft., and 2.58 GPD/sq.ft. The variation in COD removal was much less pronounced for the twelve inch depth in

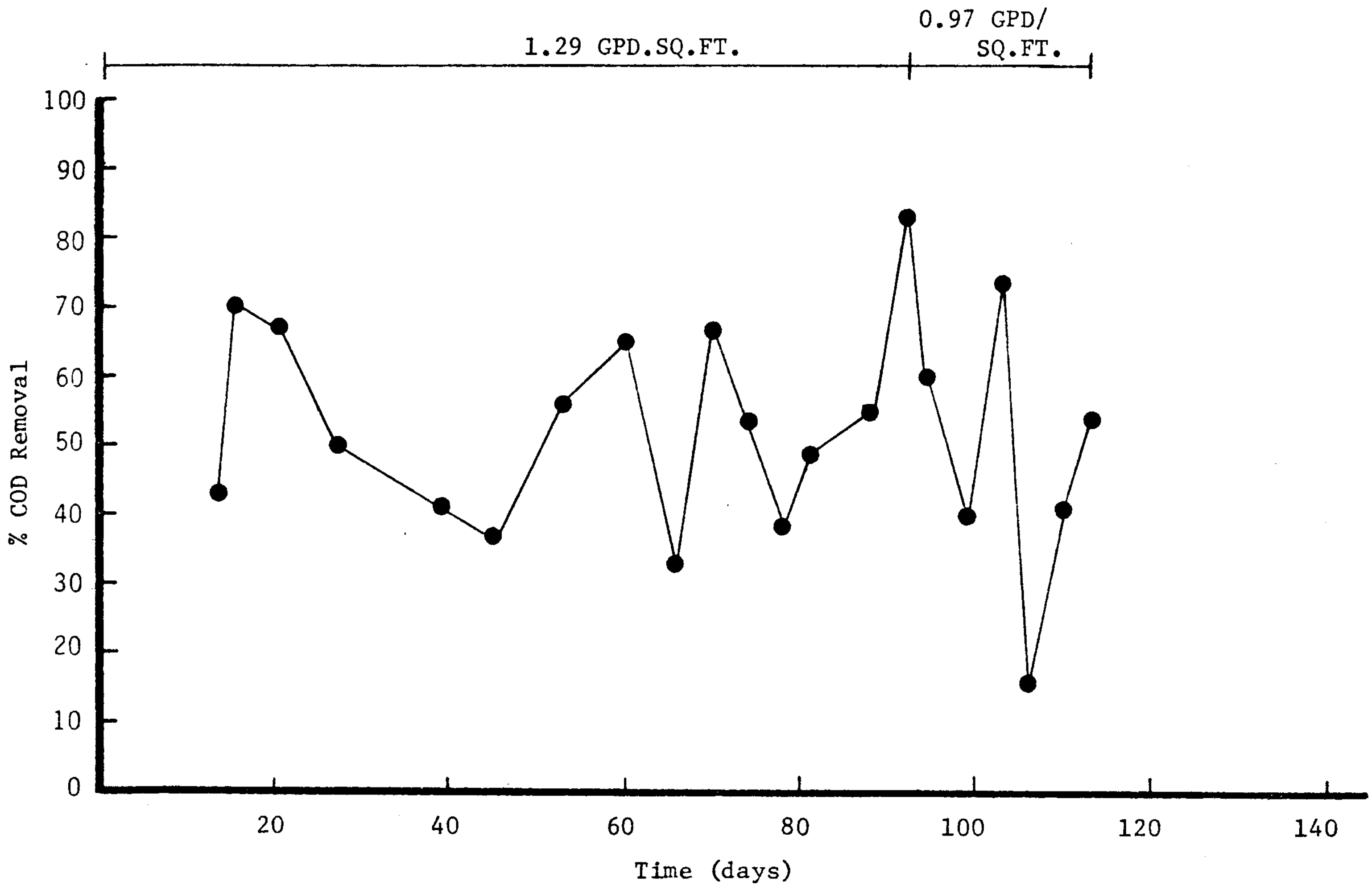

FIGURE 4 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 14 (Depth: 12 inches, Size: passed 3/8 inch sieve)

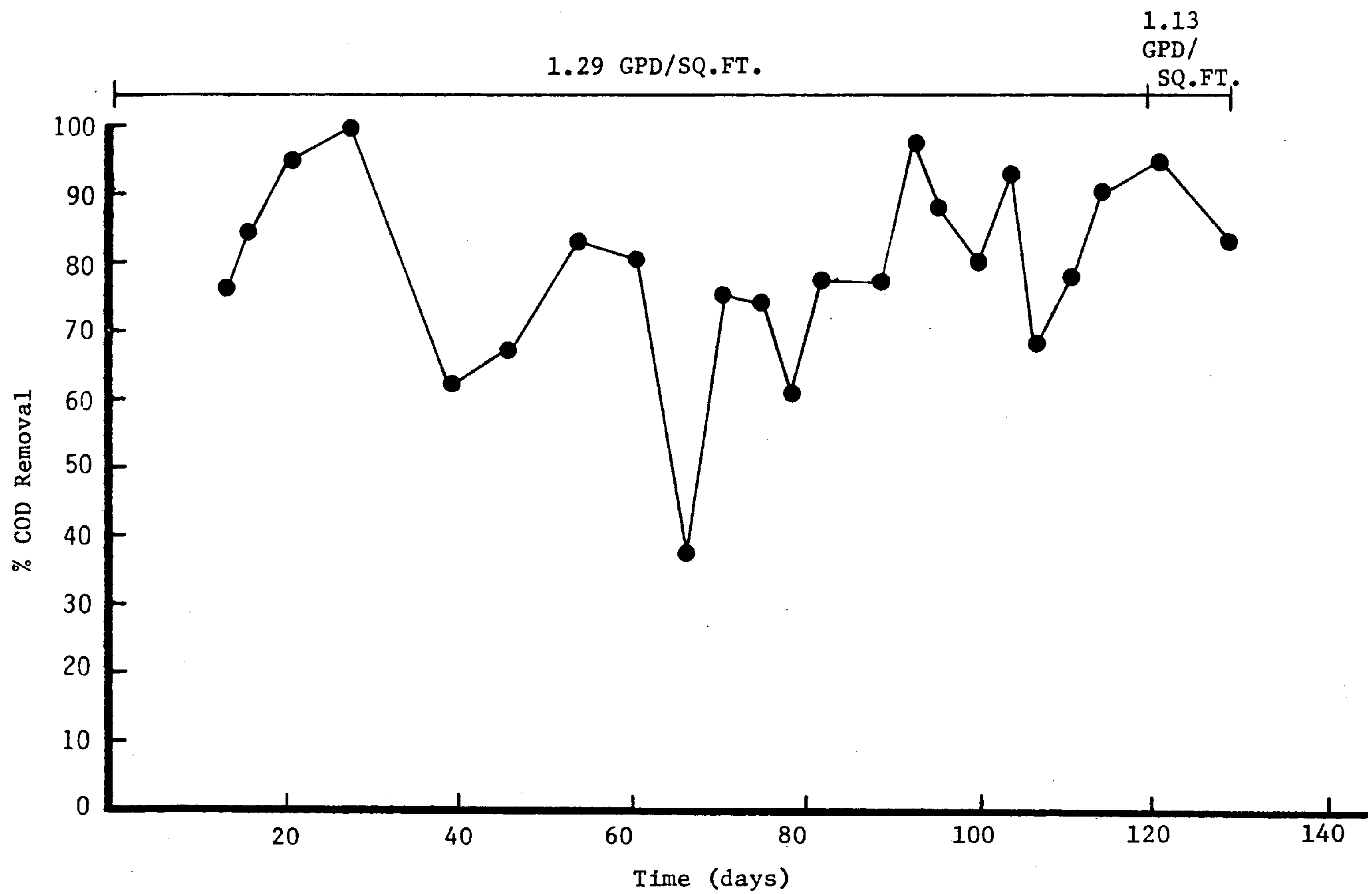

FIGURE 5 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 16 (Depth: 18 inches, Size: passed 3/8 inch sieve)

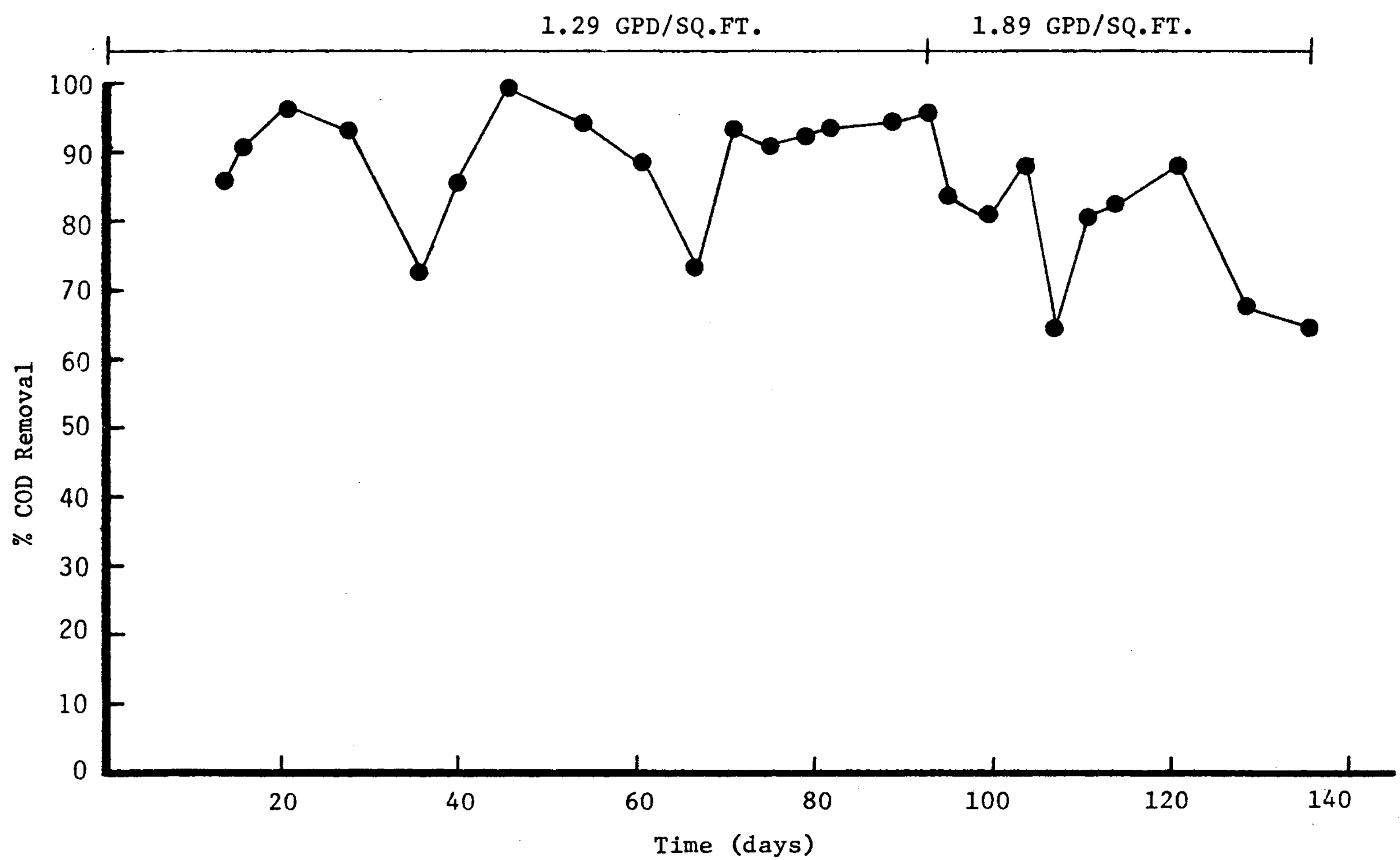

FIGURE 6 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 15 (Depth: 24 inches, Size: passed 3/8 inch sieve)

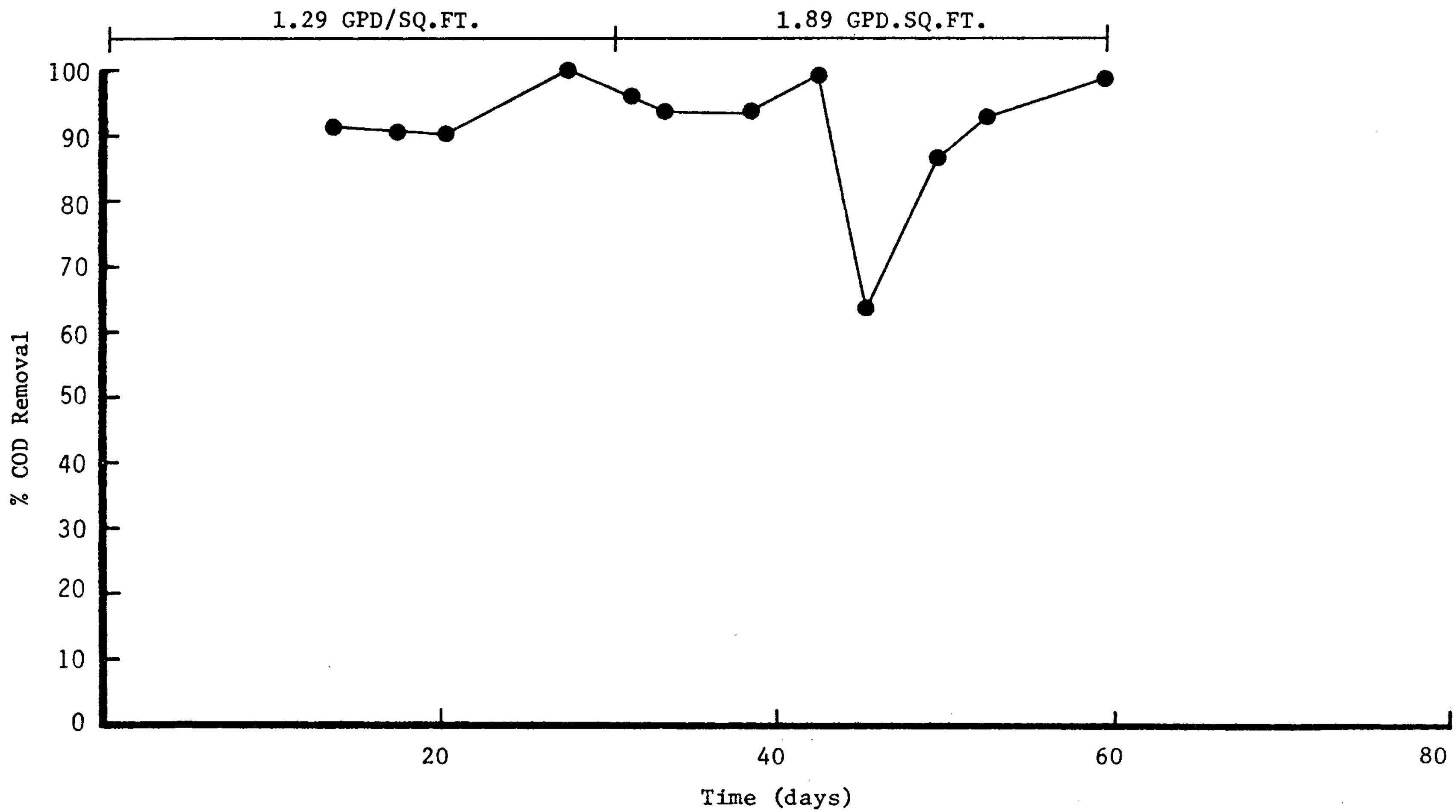

FIGURE 7 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 5 (Depth: 6 inches, Size: passed number 4 sieve)

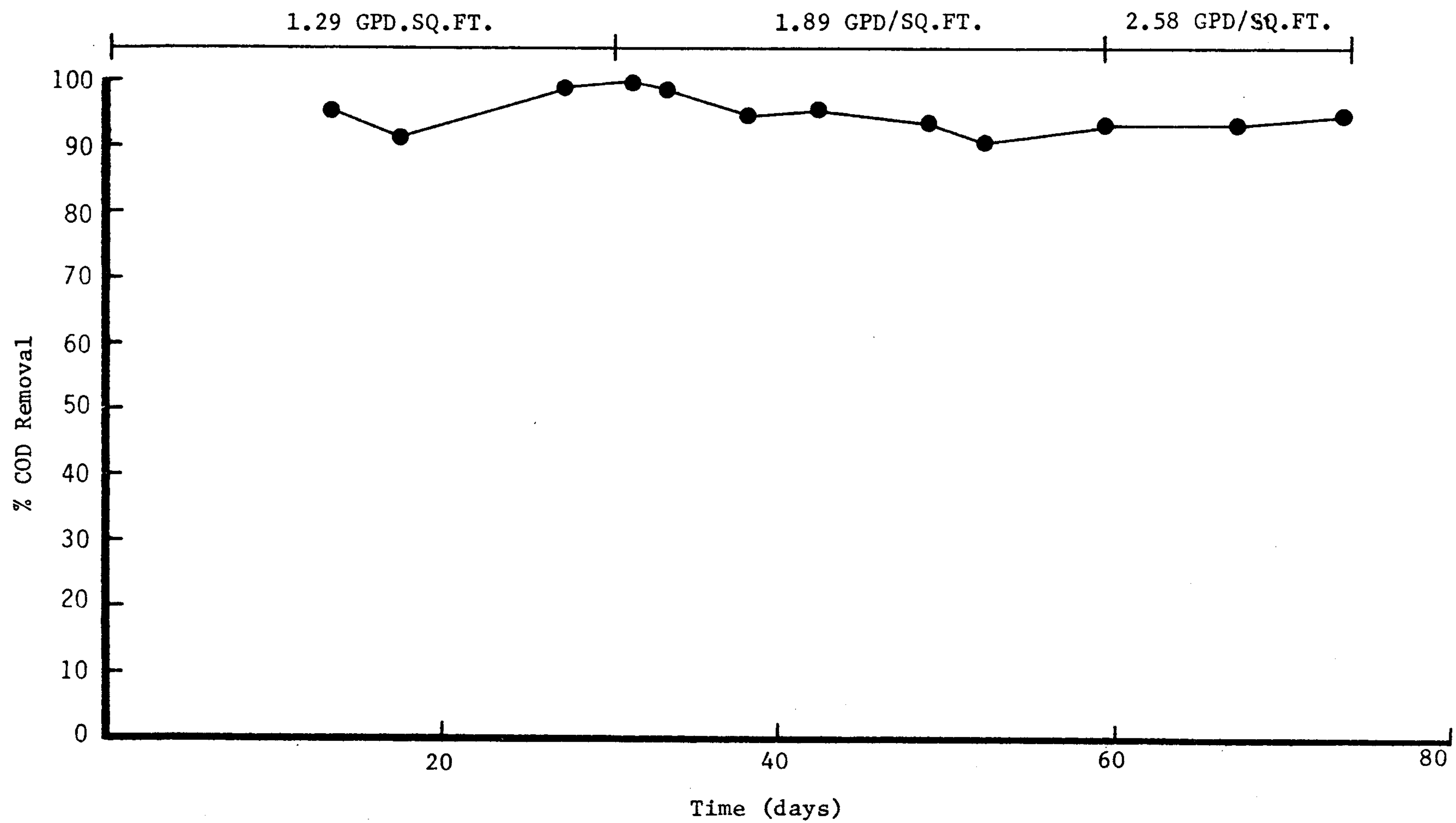

FIGURE 8 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 6 (Depth: 12 inches, Size: passed number 4 sieve)

this lysimeter than for the six inch depth of lysimeter 5.

Figure 9 shows COD removal for lysimeter 8 (18 in.: no. 4) for a period of 74 days. The dosage rate was increased from 1.29 GPD/sq.ft. to 1.89 GPD/sq.ft. The final decrease in dosage was due to the slow percolation rate following the increase in dosage on day 29. A final COD analysis on day 74 was a low of 80% for this lysimeter.

The COD removal for the 24 inch depth of material passing a number 4 sieve (lysimeter 7) is recorded in Figure 10. Again the removal varies only between 92% and 100%. An insignificant decrease occurs during the second dosage application rate. Dosage varied from 1.29 GPD/sq.ft. to 1.89 GPD/sq.ft. to 2.58 GPD/sq.ft. during the seventy-four days of septic tank effluent dosing.

The second set of figures shows COD loading in pounds/day/square foot in relation to COD removal in per cent. The line plotted through the points on each figure is a visual best fit of the recorded removals.

Figure 11 represents the COD loadings versus COD removal for lysimeter 3 (24 in.: 1/2 in.). The loading ranged from 0.0038 lbs/day/sq.ft. to 0.0278 lbs/day/sq.ft. The points fell closely to a line indicating increasing COD removal with increasing loading rate. The lowest removal recorded was 87%.

COD removal versus COD loading for lysimeter 11 (24 in.: 1/2 in.) is shown in Figure 12. Again there is a general tendency for increased COD removal with increased loading. However, the overall removal for lysimeter 11 is less than that for lysimeter 3. Loading varied from 0.0023 lbs/day/sq.ft. to 0.0208 lbs/day/sq.ft. while removal ranged from 30% to 95%.

An increase of COD removal from 16% at a COD loading of 0.0018

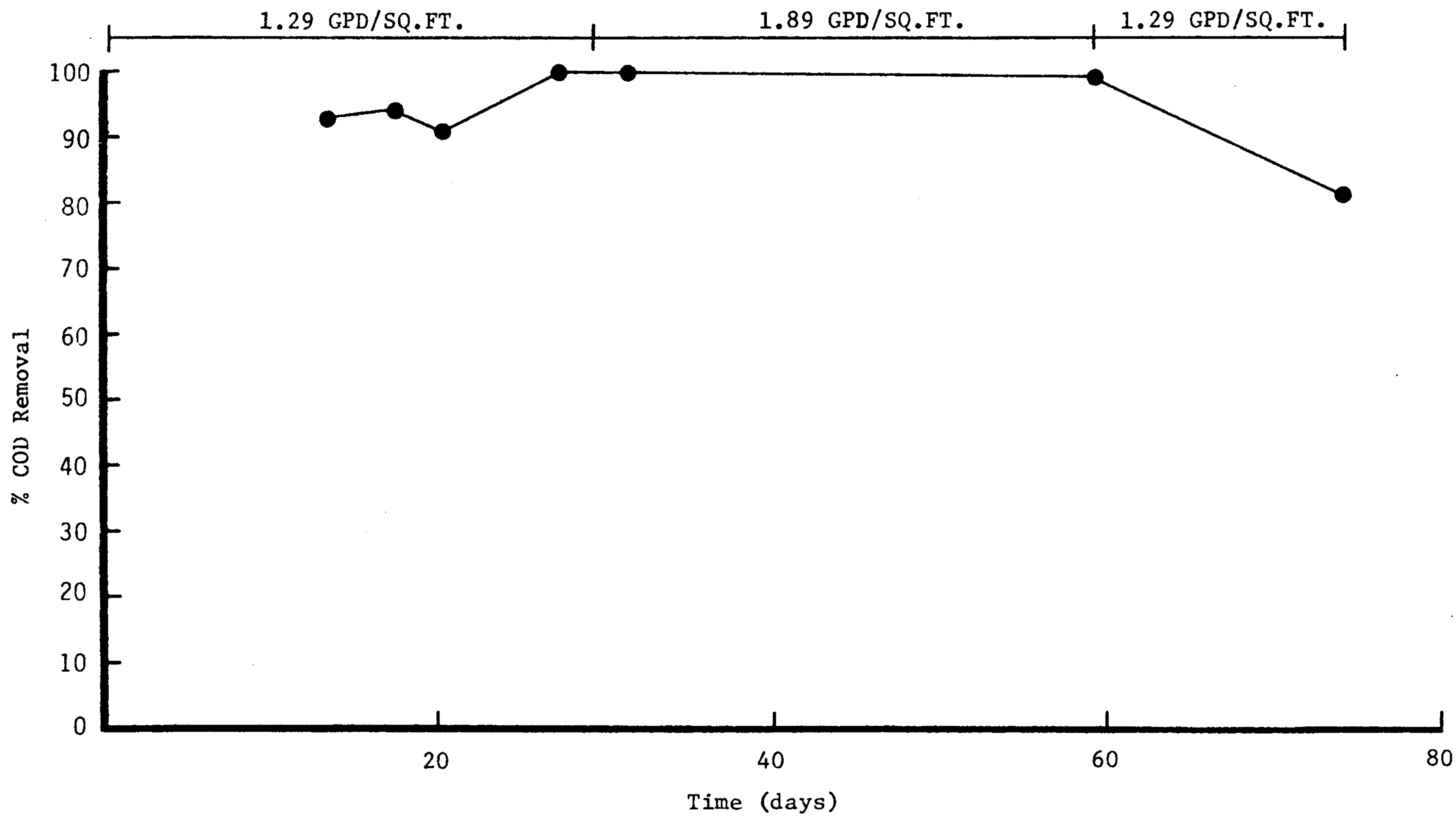

FIGURE 9 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 8 (Depth: 18 inches, Size: passed number 4 sieve)

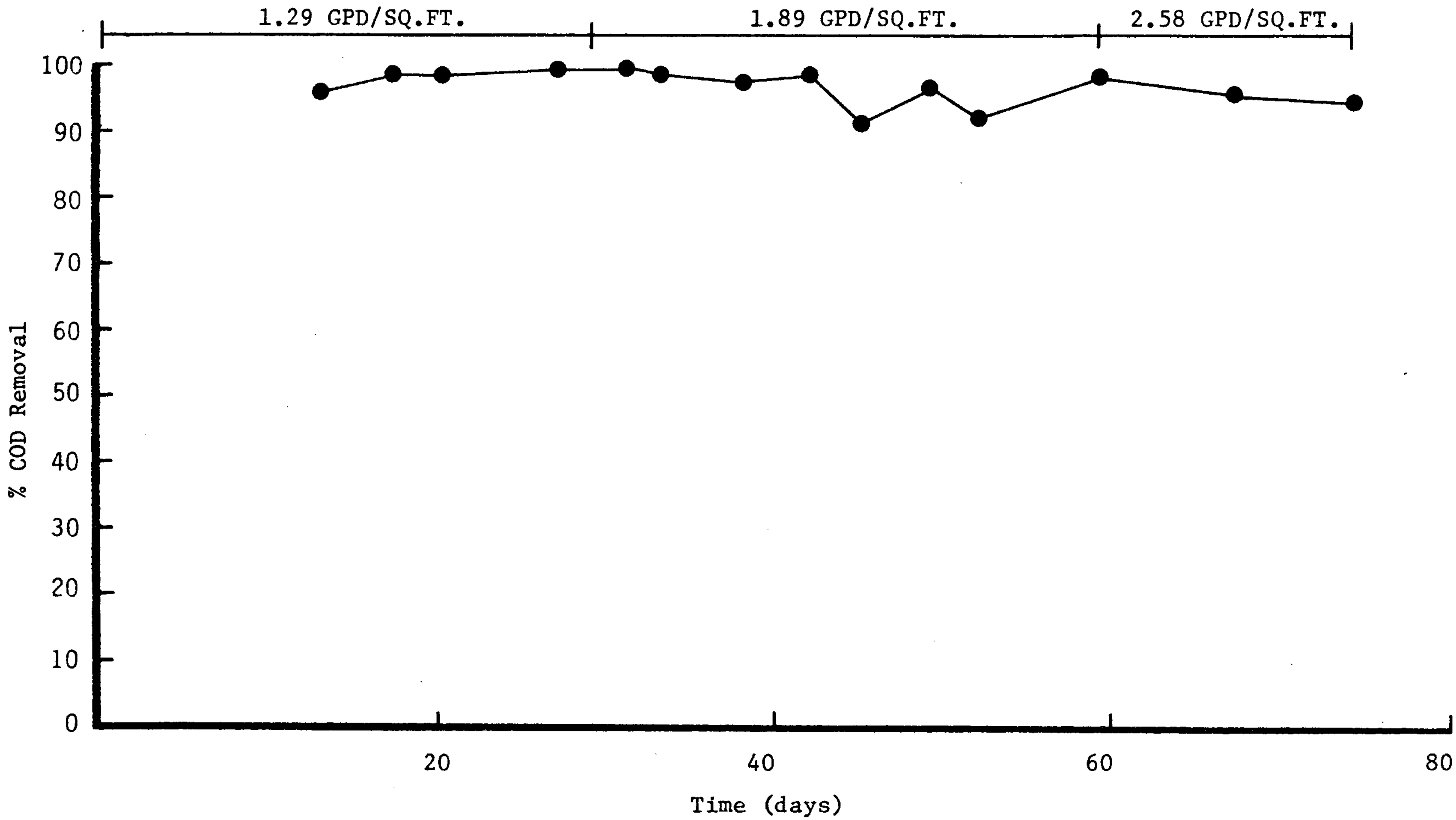

FIGURE 10 RELATIONSHIP BETWEEN TIME AND COD REMOVAL FOR LYSIMETER 7 (Depth: 24 inches, Size: passed number 4 sieve)

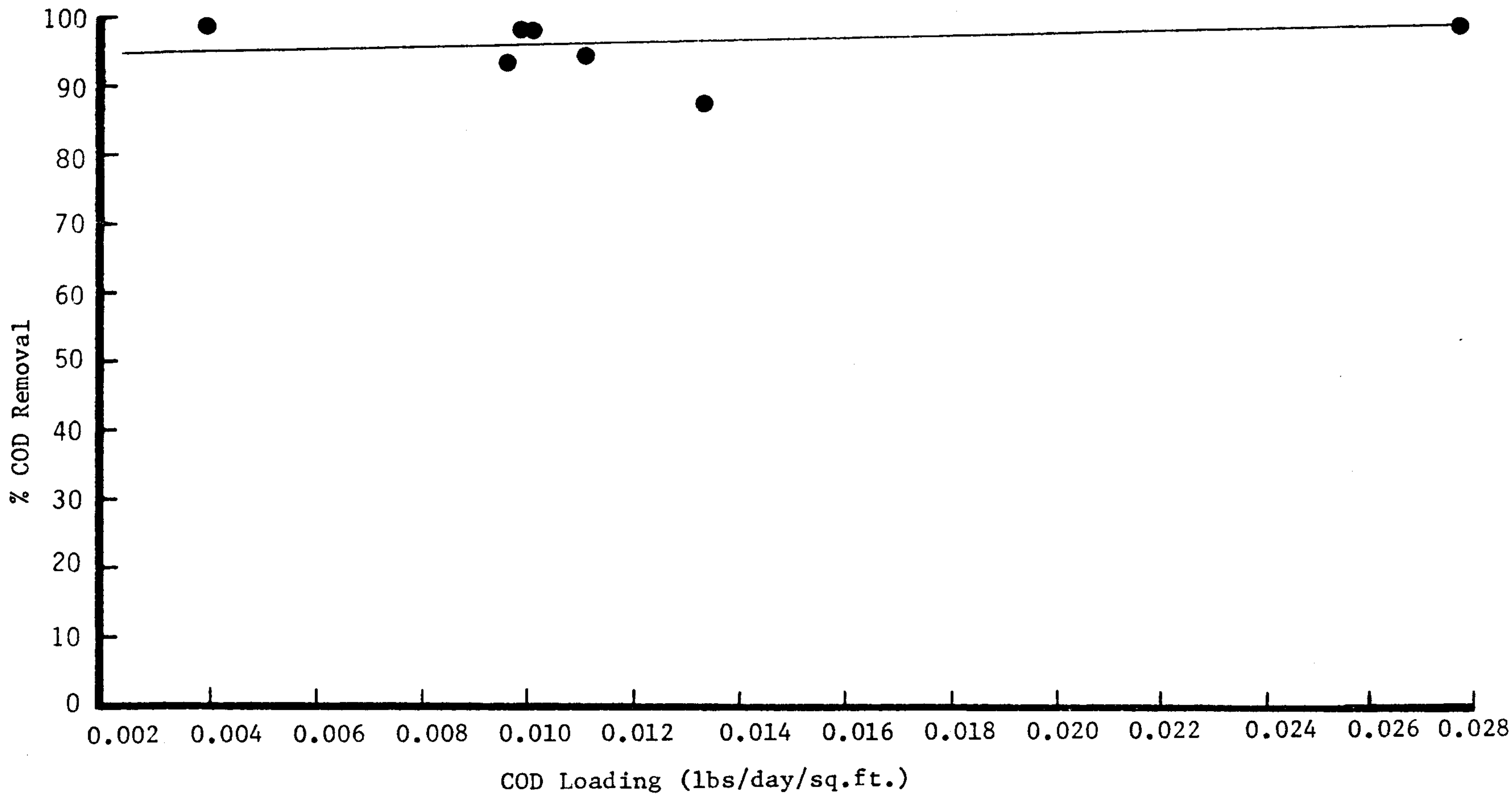

FIGURE 11 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 3 (Depth: 24 inches, Size: passed 1/2 inch sieve)

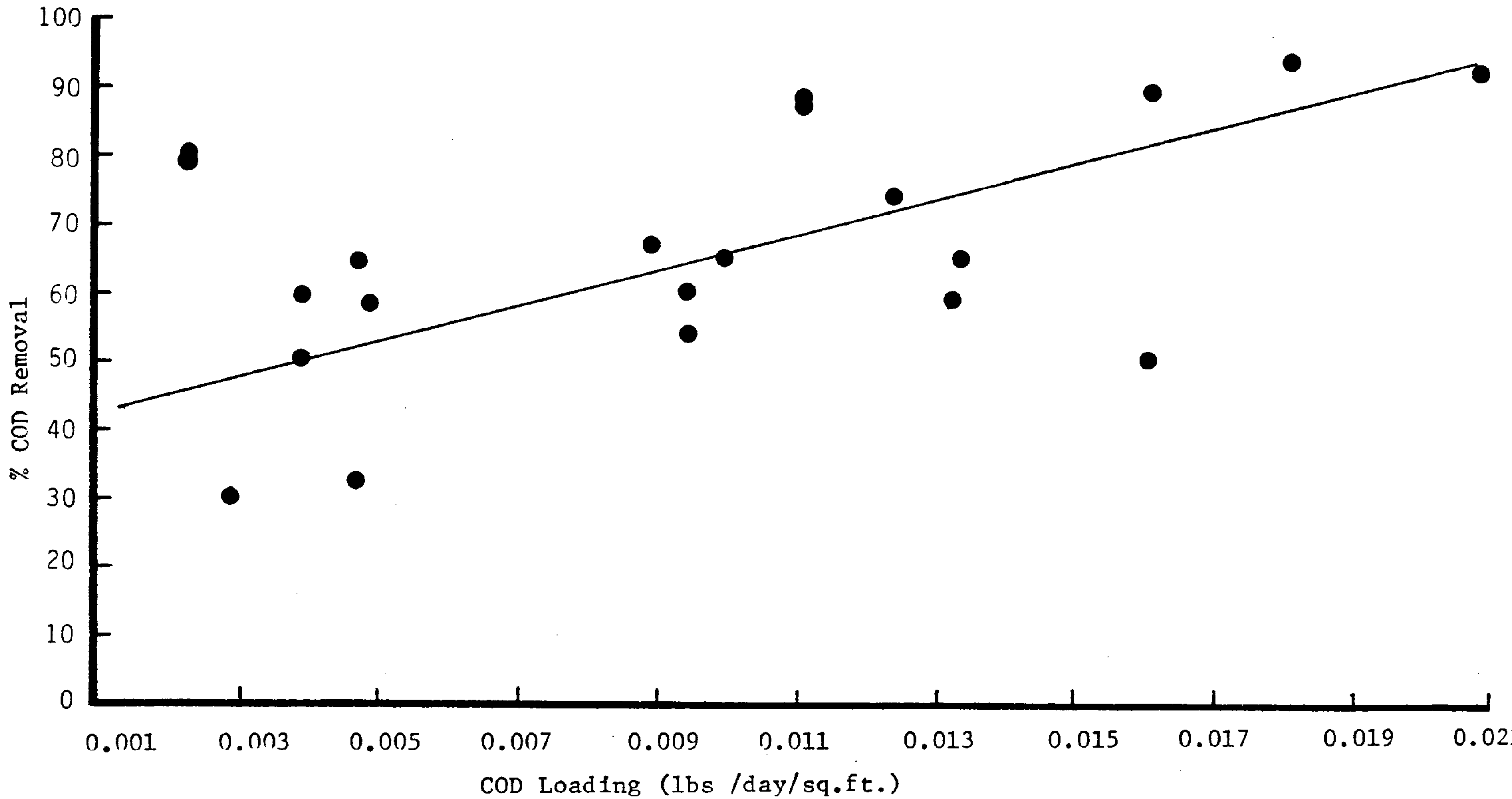

FIGURE 12 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 11 (Depth: 24 inches, Size: passed 1/2 inch sieve)

lbs/day/sq.ft. is demonstrated for lysimeter 13 (6 in.: 3/8 in.) in Figure 13.

In Figure 14 a general increase in COD removal with an increase in COD loading is demonstrated for lysimeter 14 although the removal is lower than that for lysimeter 13. Lysimeter 14 (12 in.: 3/8 in.) was loaded at rates varying from 0.0024 lbs/day/sq.ft. to 0.0208 lbs/day/sq.ft., and it attained removals ranging from 16% to 83%.

Figure 15 shows a significant inprovement in COD removal for lysimeter 16 (18 in.: 3/8 in.) over COD removal for lysimeters 13 and 14 which contain six inches and twelve inches of the same sieve size. Loading varies from 0.0028 lbs/day/sq.ft. to 0.0275 lbs/day/sq.ft. while removals were from 38% to 100%.

Further removal efficiency for lysimeter 15 is illustrated in Figure 16. Lysimeter 15 contains twenty-four inches of material passing a 3/8 inch sieve. The tendency of increasing COD removal for increased loading is not nearly so pronounced for the twenty-four inch depth. Removals range from 65% to 100% for loadings of 0.001 lbs/day/sq.ft. to 0.0382 lbs/day/sq.ft.

Figure 17 shows COD removal in relation to COD loading for six inches of material passing a number 4 sieve (lysimeter 5). Loading ranges from 0.0038 lbs/day/sq.ft. to 0.040 lbs/day/sq.ft. but the COD removals have a narrow range between 87% to 100% with only one exception.

Lysimeter 6 (12 in.: no. 4) has an even more narrow range of removal-90% to 100%-with loading similar to the previous one. This fact is illustrated by Figure 18.

Figure 19 and Figure 20 which show COD removal in relation to COD loading for eighteen inches and twenty-four inches of material passing a

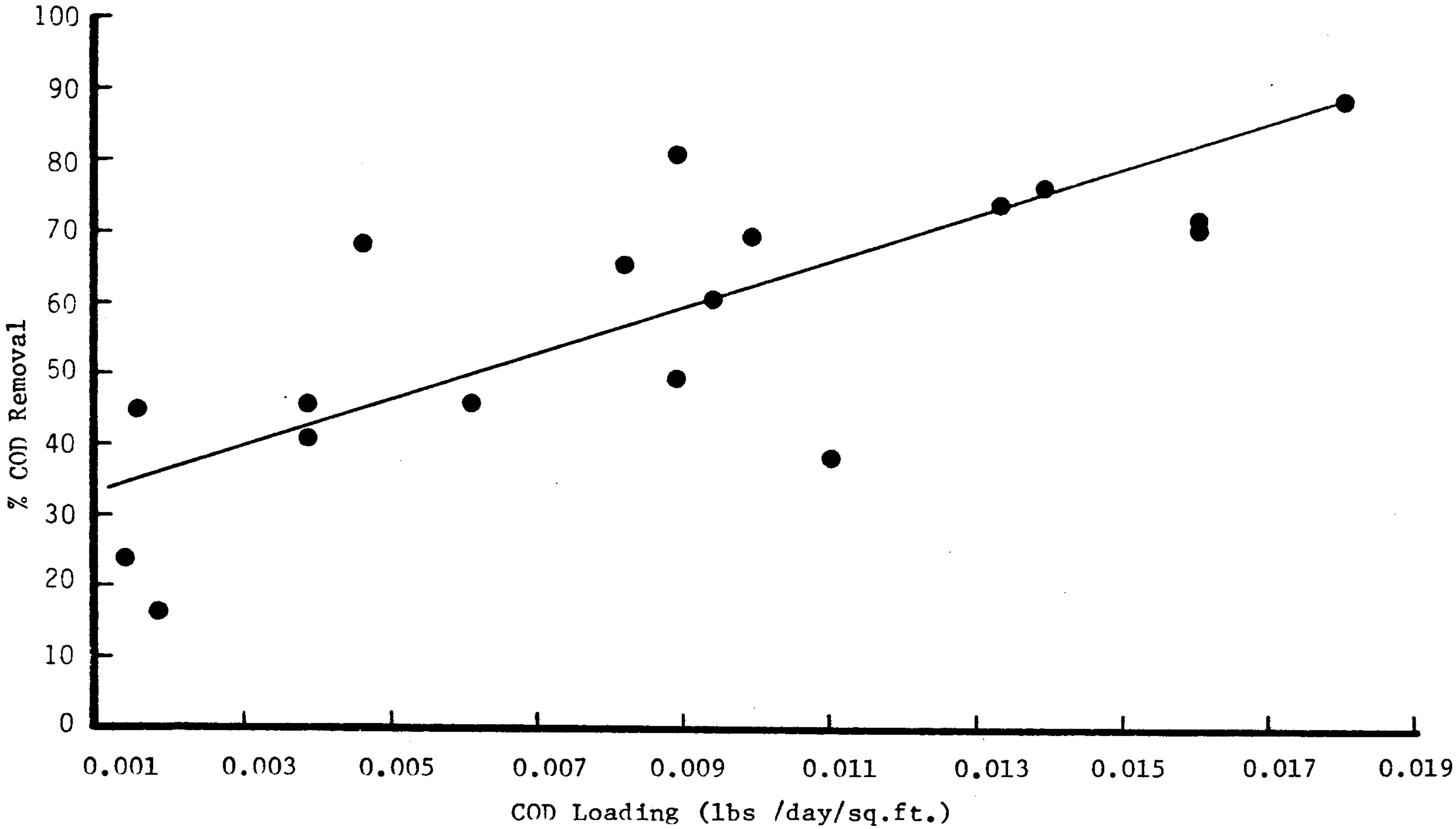

FIGURE 13 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 13 (Depth: 6 inches, Size: passed 3/8 inch sieve)

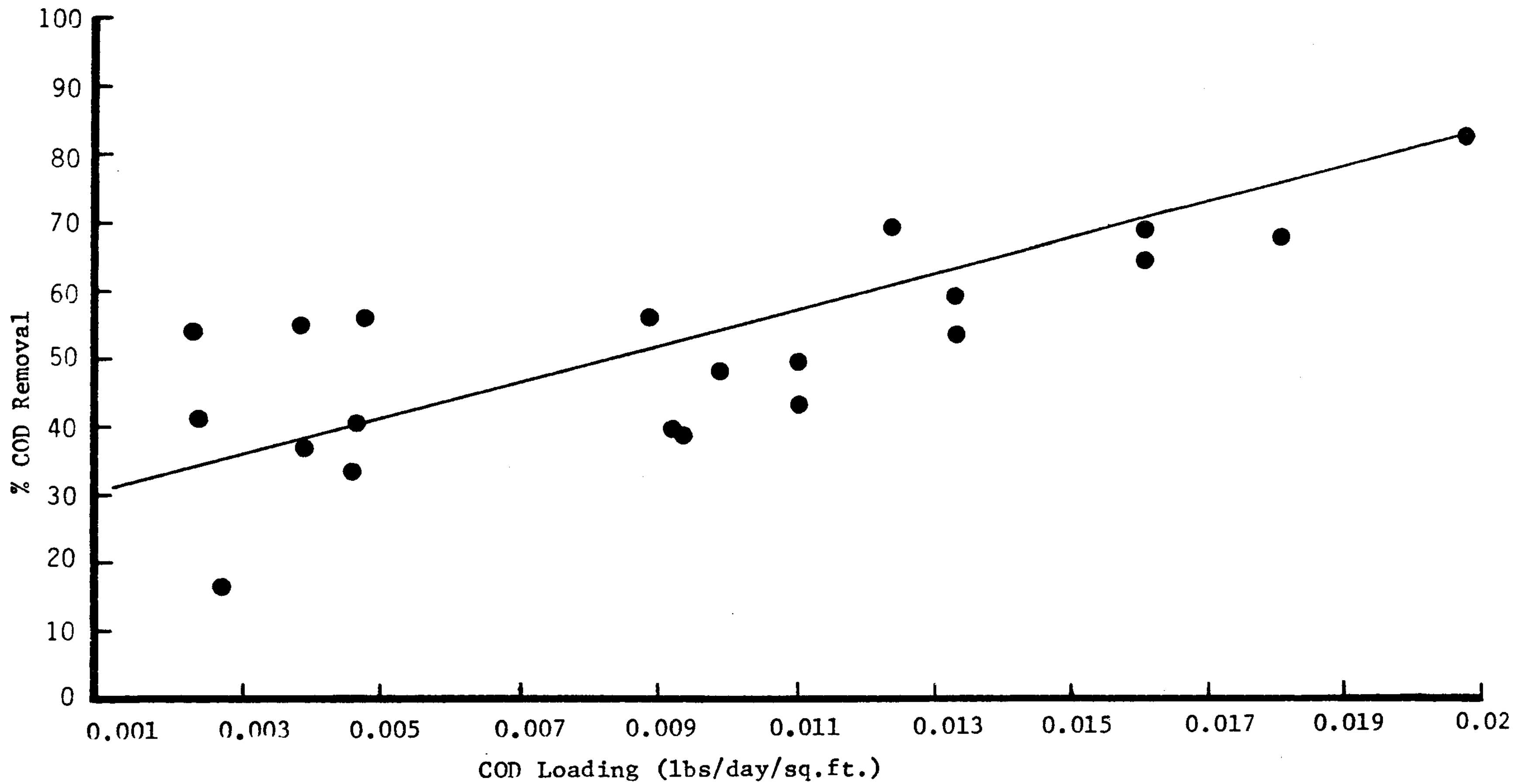

FIGURE 14 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 14 (Depth: 12 inches, Size: passed 3/8 inch sieve)

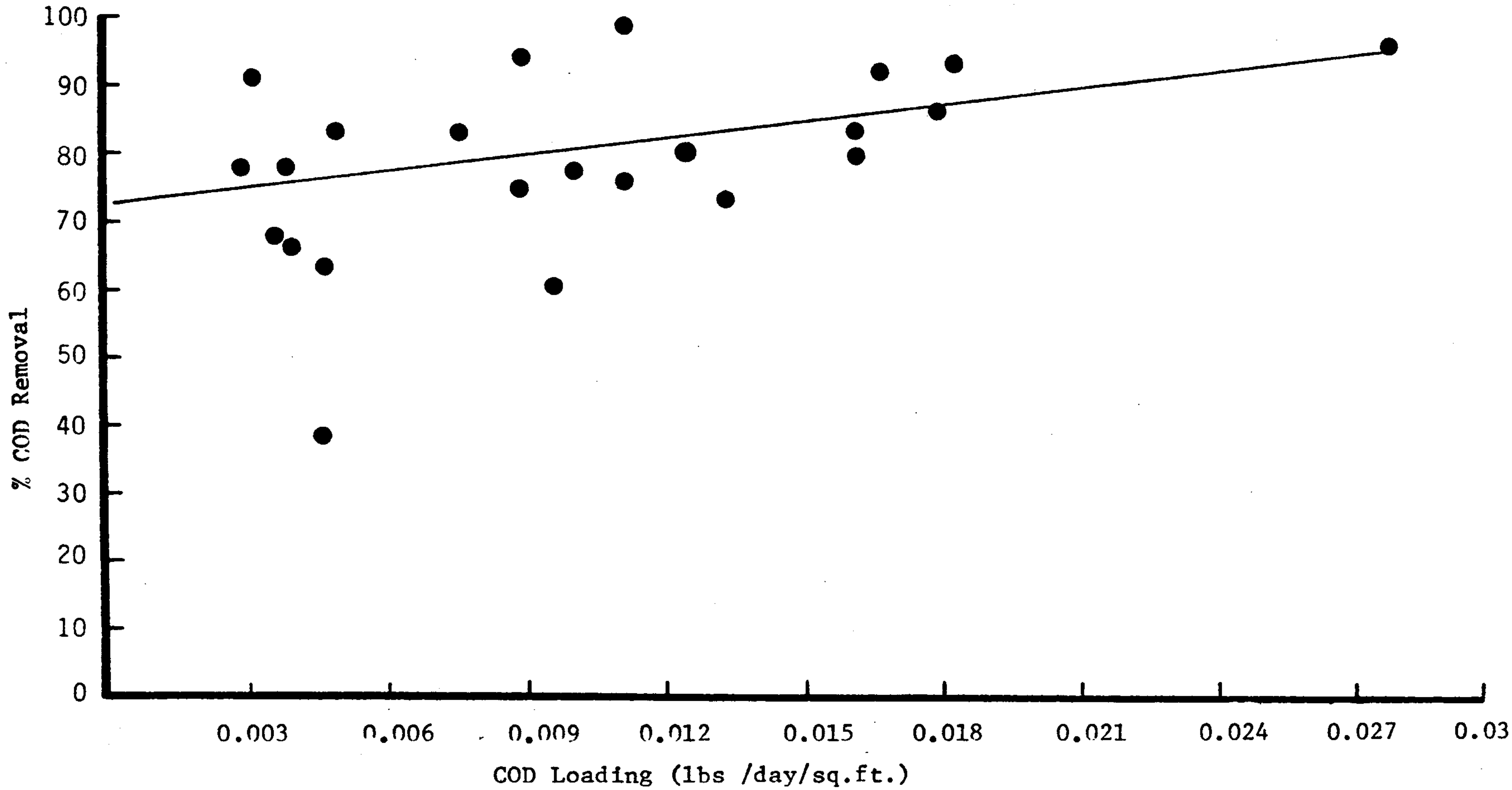

FIGURE 15 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 16 (Depth: 18 inches, Size: passed 3/8 inch sieve)

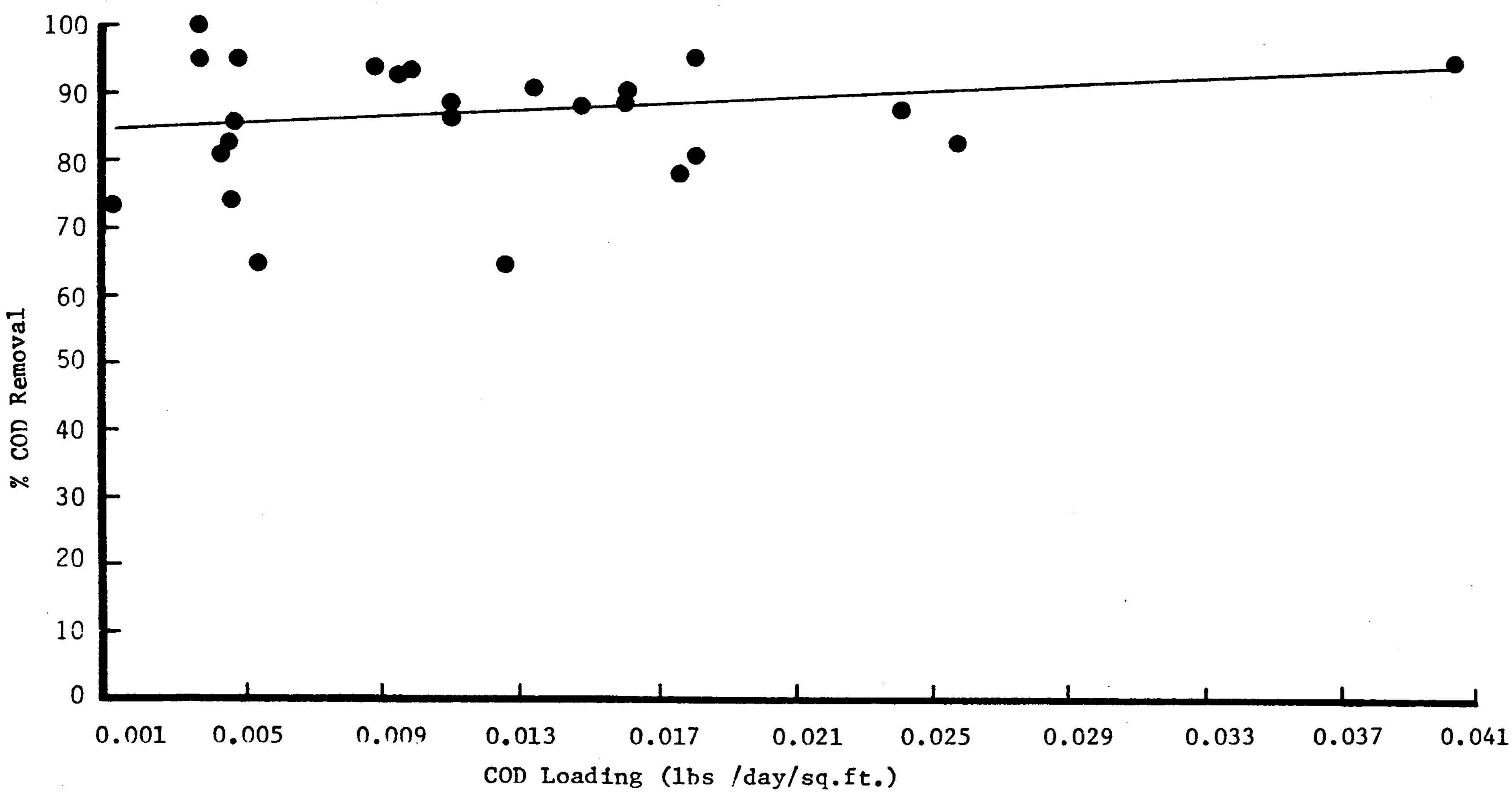

FIGURE 16 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 15 (Depth: 24 inches, Size: passed 3/8 inch sieve)

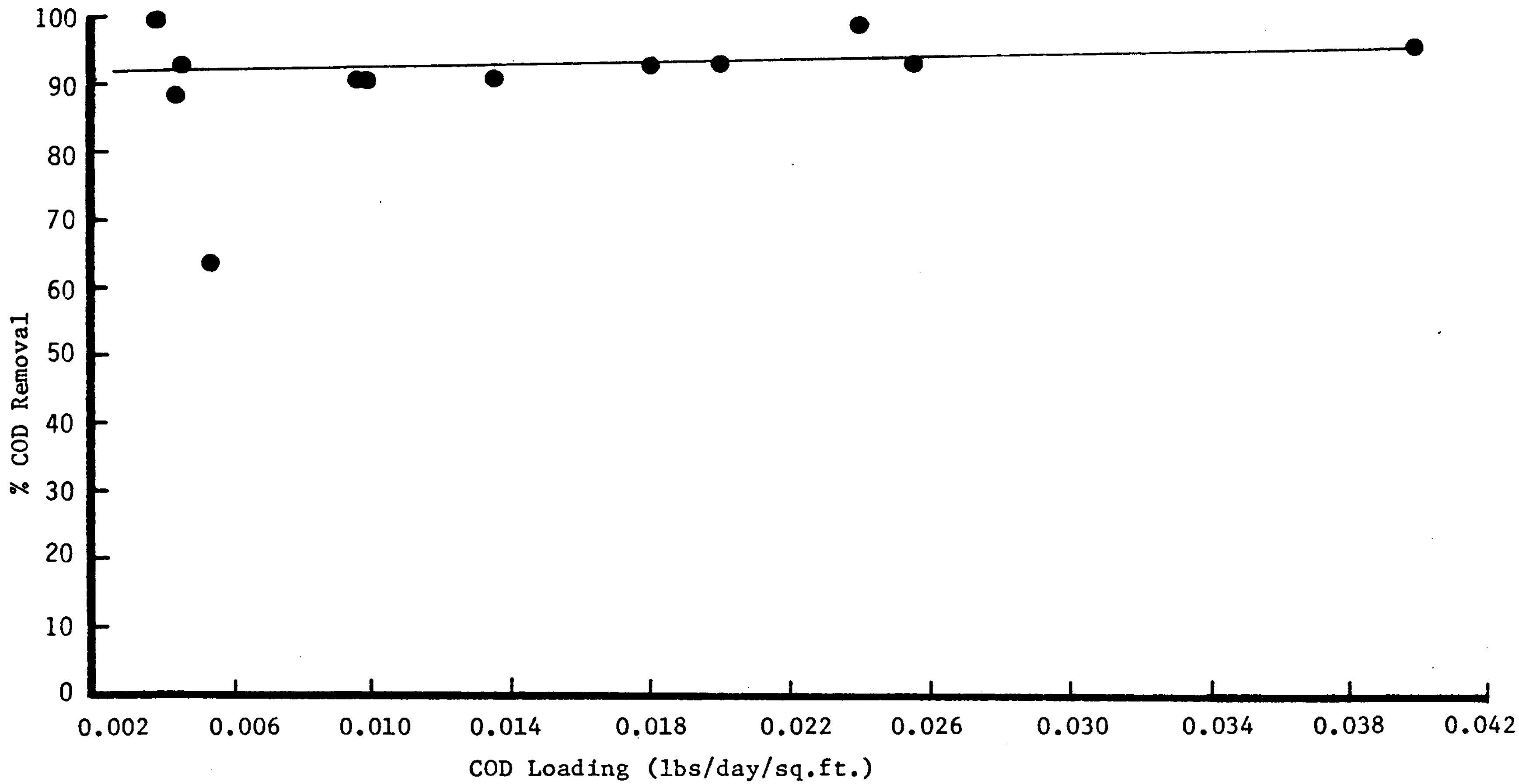

FIGURE 17 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 5 (Depth: 6 inches, Size: passed number 4 sieve)

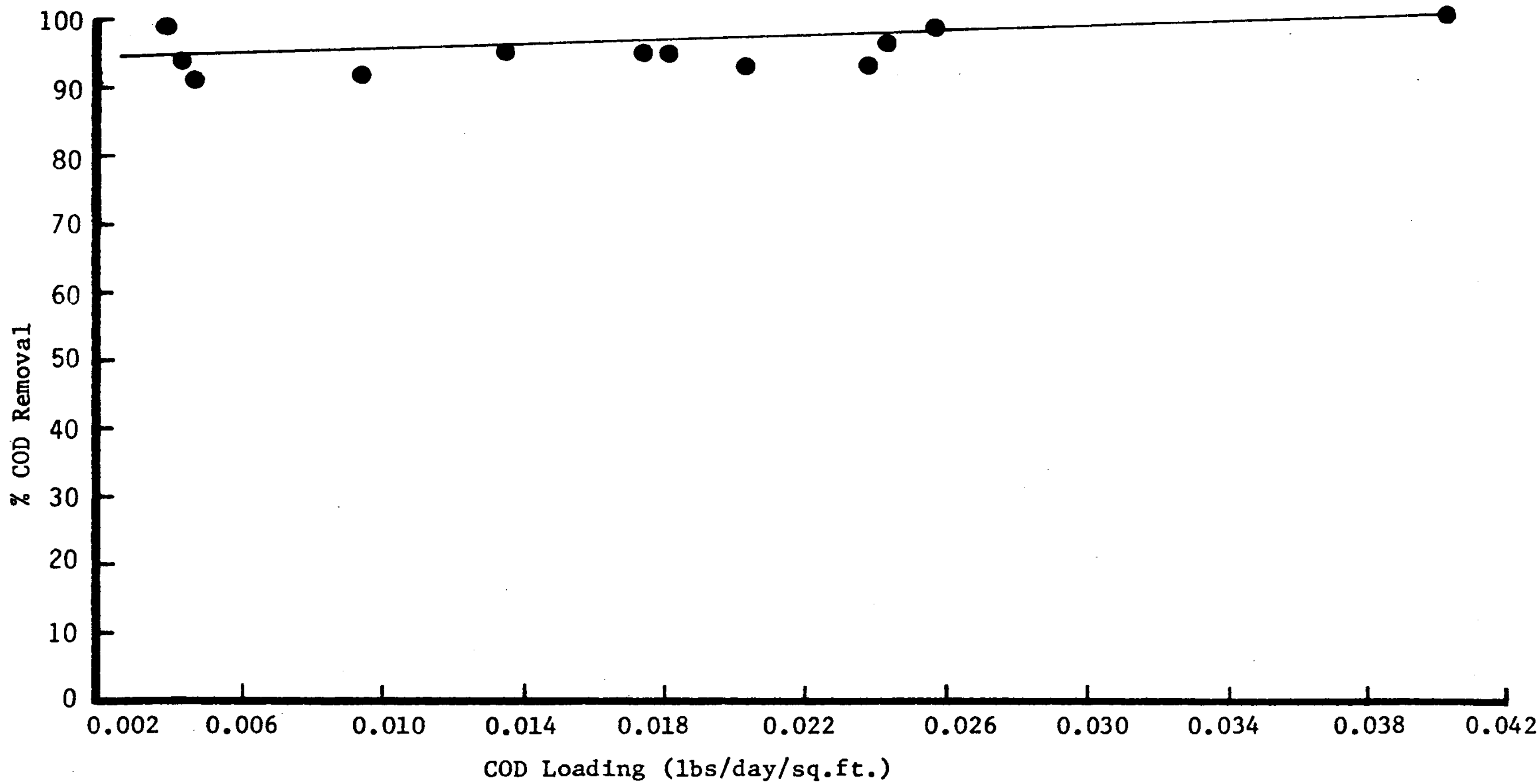

FIGURE 18 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 6 (Depth: 12 inches, Size: passed number 4 sieve)

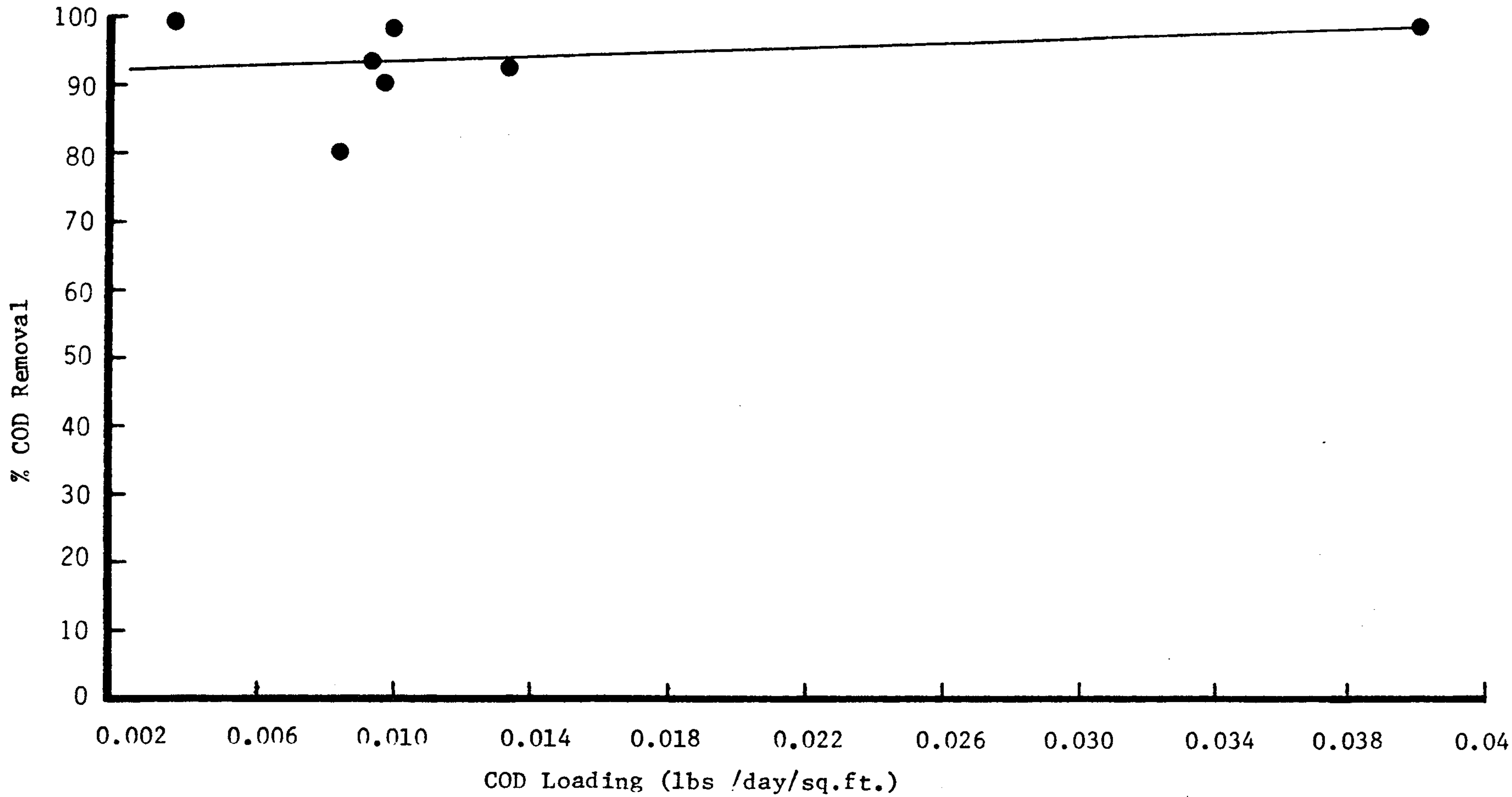

FIGURE 19 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 8 (Depth: 18 inches, Size: passed number 4 sieve)

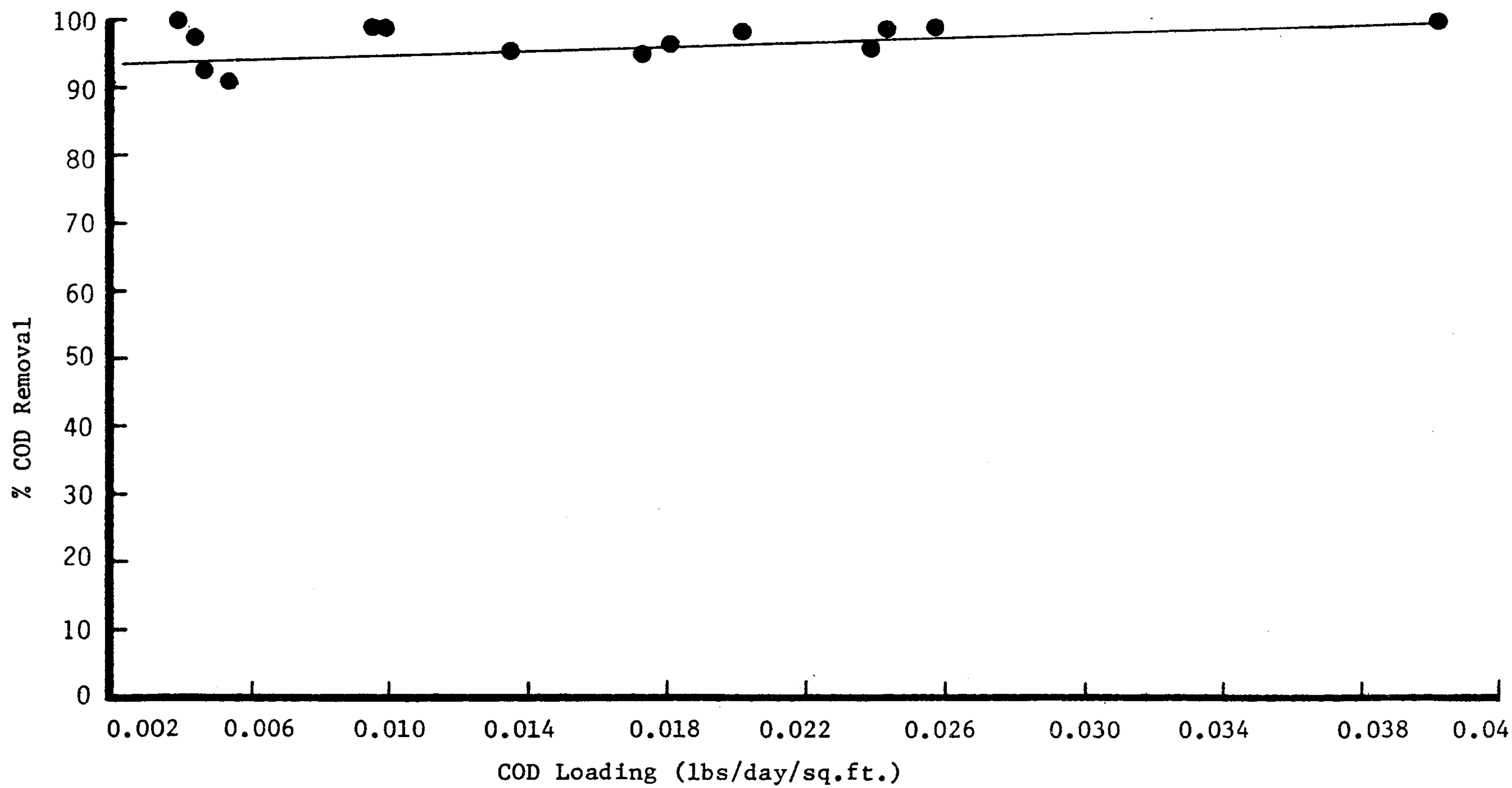

FIGURE 20 RELATIONSHIP OF COD LOADING TO COD REMOVAL FOR LYSIMETER 7 (Depth: 24 inches, Size: passed number 4 sieve)

number 4 sieve respectively, again demonstrate an increase in removal with an increase in loading for both lysimeters. Removals for each are between 90% and 100% with identical loading ranges, 0.0038 lbs/day/sq.ft. to 0.040 lbs/day/sq.ft. It appears from these last four figures that depth plays a less important role in finer material than it does in coarser material.

A visual comparison of COD removal with time for lysimeters of equal depth but different sieve size material is presented in Figure 21 through Figure 24.

The first figure in this series, Figure 21, shows a far more efficient COD removal capacity for lysimeter 5 than lysimeter 13. Each lysimeter is six inches deep but number 13 holds material passing a 3/8 inch sieve and number 5 contains material passing a number 4 sieve. Dosing of lysimeter 13 started long before that of lysimeter 5; consequently, more data points were available for it.

Again in Figure 22, the superiority of the finer material (passing a number 4 sieve) over material passing a 3/8 inch sieve is demonstrated. Lysimeter 6 and 14 which are each twelve inches deep are compared for COD removal. The lysimeter containing the fine material was established later than the one containing the coarse material. Even so the initial removals are much greater for the finer material and remain so for the lifetime of the lysimeters.

Figures 23 and Figure 24 demonstrate the decreasing importance of material size with increasing depth. The eighteen inch lysimeters in Figure 3.3 have per cent COD removals nearer to one another than the six inch and twelve inch soil columns. However in Figure 24 COD removals for lysimeter 7 (24 in.: no. 4), lysimeter 3 (24 in.: no. 4) and lysimeter 15 (24 in.: no. 4) are quite similar even though removals for number 15

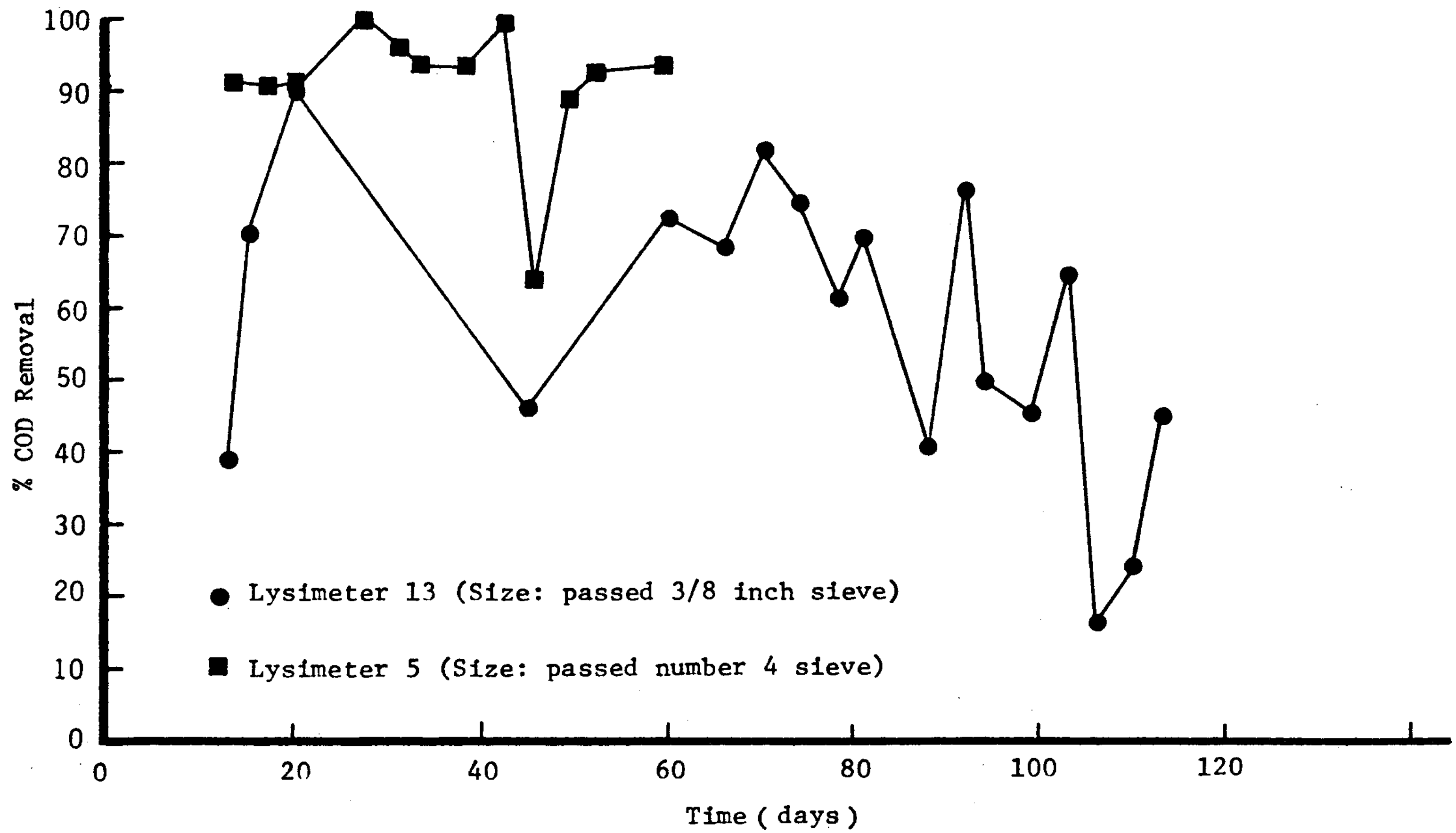

FIGURE 21 RELATIONSHIP OF COD REMOVAL TO TIME FOR LYSIMETERS OF SIX INCH DEPTH

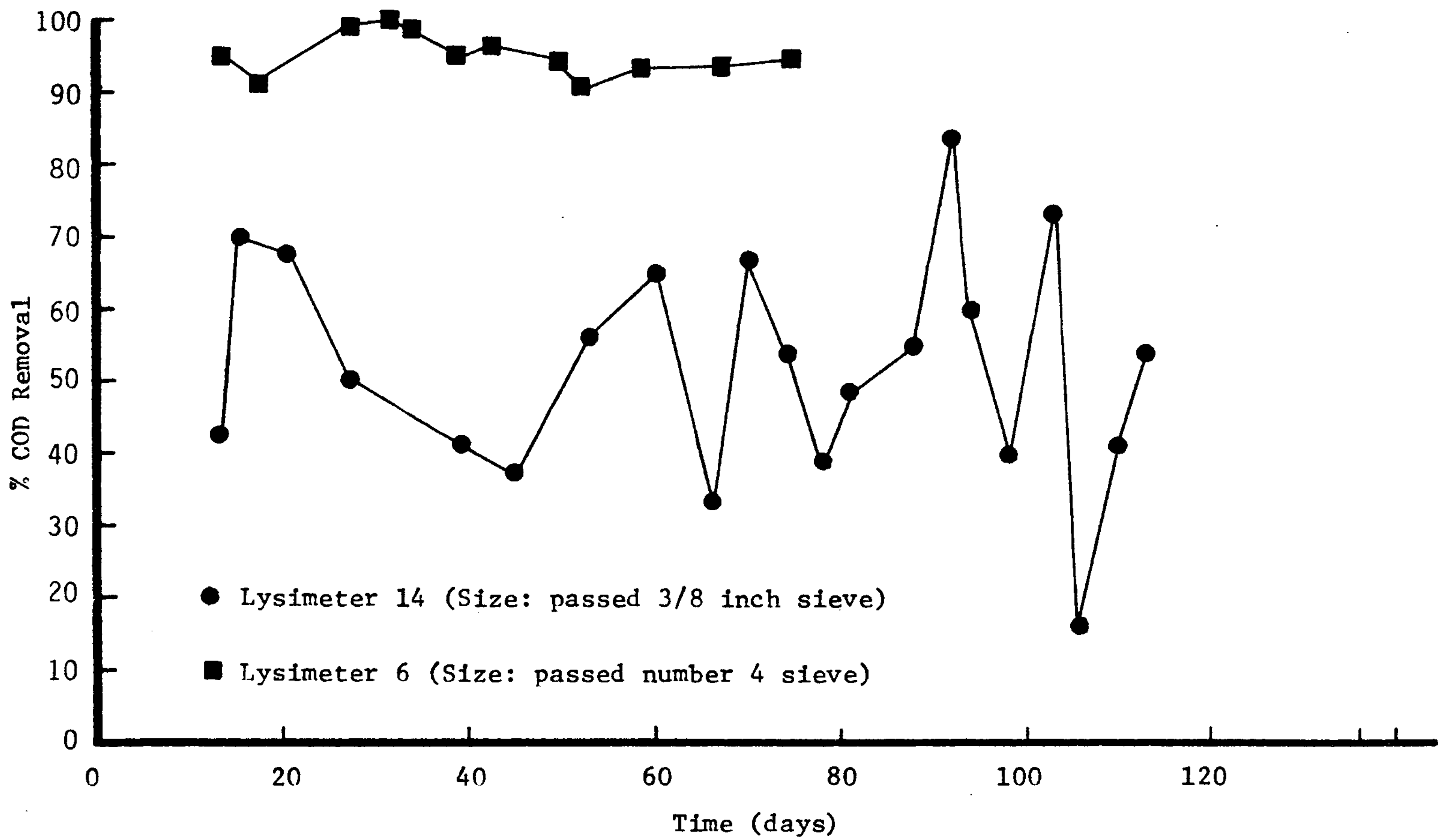

FIGURE 22 RELATIONSHIP OF COD REMOVAL TO TIME FOR LYSIMETERS OF TWELVE INCH DEPTH

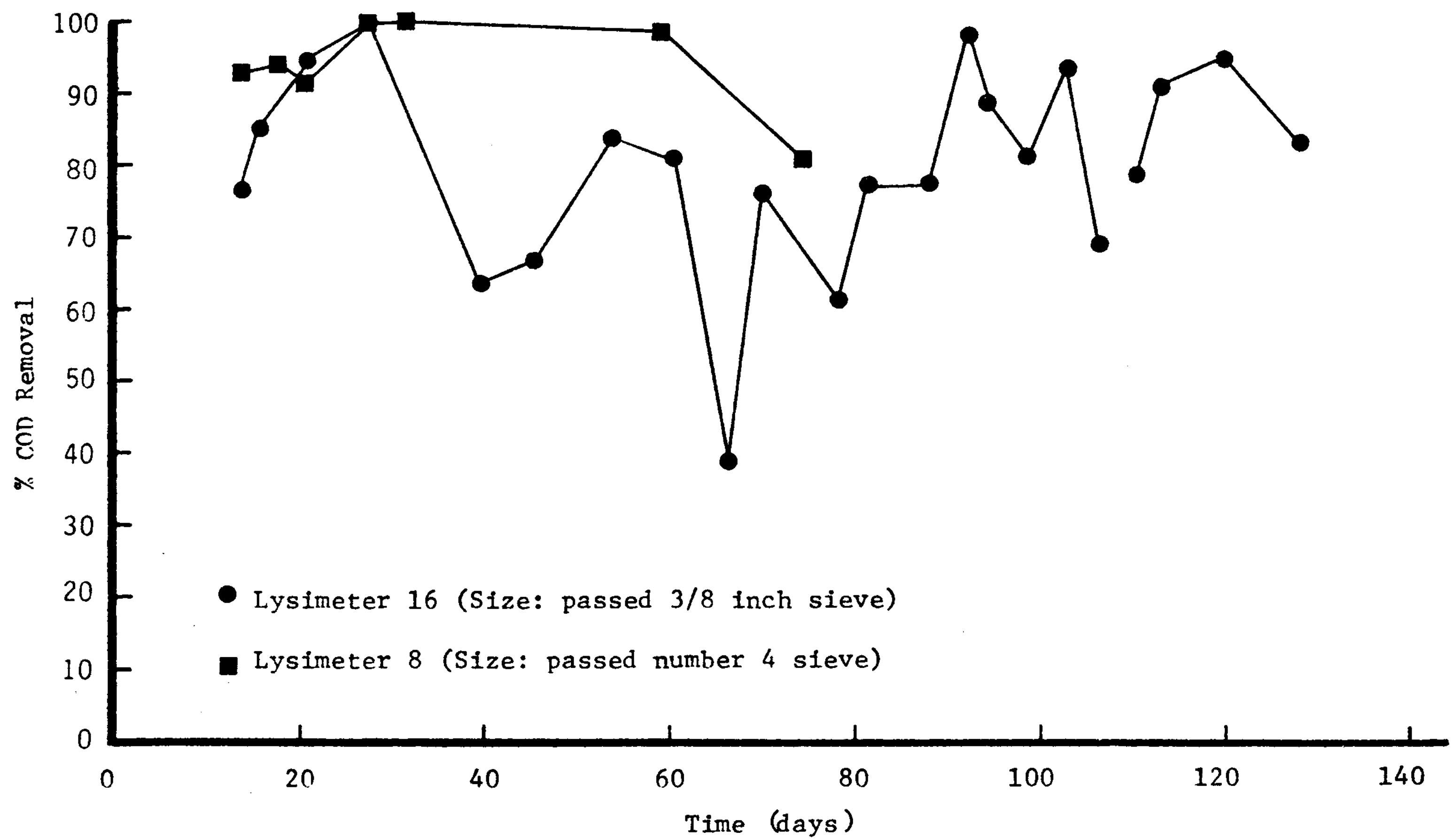

FIGURE 23 RELATIONSHIP OF COD REMOVAL TO TIME FOR LYSIMETERS OF EIGHTEEN INCH DEPTH

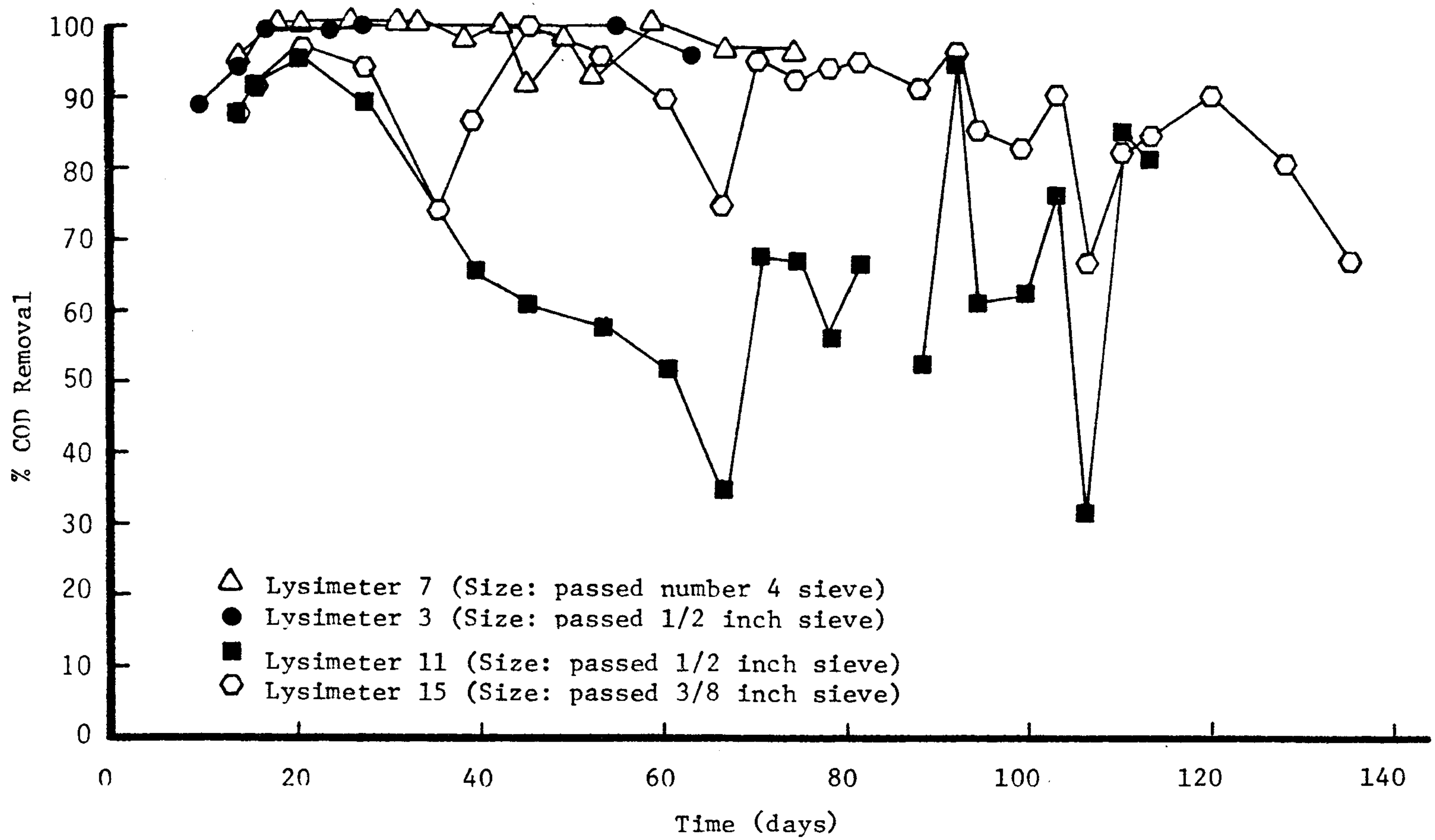

FIGURE 24 RELATIONSHIP OF COD REMOVAL TO TIME FOR LYSIMETER OF TWENTY-FOUR INCH DEPTH

are slightly more erratic than those of the other two. Lysimeter 11, which has material the same sieve size and depth as lysimeter 3, has a distinctly lower removal than the other twenty-four inch soil columns.

4. DISCUSSION OF RESULTS

The purpose of this study was to determine the biodegradation capacity of various sizes and depths of washed river gravel. In the following section the results of the laboratory analysis of influent and effluent wastewater is discussed as it relates to the establishment of the most efficient biodegradation size and depth of the column. The biodegradation capacity of each lysimeter was evaluated in terms of COD removal, total inorganic nitrogen removal and phosphate removal in relation, to dosage rates, loading rates and pH. This section gives an interpretation of the results obtained during the study as presented in the previous section.

4.1 COD Removals

Comparing Figures 1 and 2, which relate per cent COD removal to time for lysimeters 3 and 11, it can be seen that COD removal by number 3 is much more efficient than that of number 11. These lysimeters contain the same depth and sieve size material, but the material in lysimeter 3 has a C_u of 30 and a D_{10} of 0.4 mm. while lysimeter 11 has a C_u of 3.3 and a D_{10} of 4.2 mm. The material in lysimeter 3 came from Clear Creek and the material in lysimeter 11 came from Westfork White River. According to Matthews (5) the higher COD removals occur in soils with higher coefficients of uniformity and removal progressively decreases with decreasing C_u. Generally, soils with a higher C_u have lower permeabilities and therefore offer a longer contact time for the waste. The initial increase in removal in each lysimeter probably reflects a building up of organic material in the upper part of the soil column which increases adsorptive capacity, contact time and biological activity. However, it appears that lysimeter 11 could not maintain even an 80% COD removal for a long period of time. Its waste assimilative capacity was exceeded at the 1.29 GPD/sq.ft. dosing rate. The decrease in dosing to 0.97 GPD/sq.ft. improved over all COD removal but removal in lysimeter 11 still did not approach an acceptable level.

A step like increase in COD removal with time as depth of soil increases can be demonstrated for lysimeters 13, 14, 15 and 16 in Figures 3, 4, 5 and 6 respectively. This soil in all four lysimeters is the same size and has the same D_{10} and C_u; therefore, the improvement in removal can best be explained by increased contact time. Each of these four lysimeters displayed an initial increase in COD removal similar to the two lysimeters previously discussed. The same explanation is appropriate. An accumulation of organic matter in the top portion of the soil columns increased the contact time, adsorptive capacity and biological activity. Lysimeter 13 ponded after twenty-four days probably because of an excessive accumulation of organic matter, but after a two week rest, again exhibited the initial increase in removal. However, the removal capacity of lysimeter 13 which was six inches deep was gradually exhausted over the remaining period of time even with a decrease in dosage rate from 1.29 GPD/sq.ft. to 0.65 GPD/sq.ft. as seen in Figure 3.

Removal in lysimeter 14 which was twelve inches deep was erratic and never reached an acceptable level. The decrease in dosage from 1.29 GPD/sq.ft. to 0.97 GPD/sq.ft. slightly improved removal even though it remained erratic. Twelve inches still provided insufficient contact time.

The eighteen inch lysimeter in this series shows better removals than that level necessary for efficient treatment. Analysis was discontinued too soon after an 88% dosage decrease to determine its effect on removal.

A periodic drop in removal occurs in Figure 6 for lysimeter 15 (24 in.: 3/8 in.). The drop can probably be attributed to a breakthrough or sloughing of the organic matter accumulated in the soil. This cycle is repeated even after the dosage rate is raised from 1.29 GPD/sq.ft. to 1.89 GPD/sq.ft. Because of this increase in rate on day 92, COD removals in general declined.

COD removal with time appears to be less dependent on depth in lysimeters 5, 6, 8 and 7 than in lysimeters 13, 14, 16 and 15. The soil in the former passed a number 4 sieve and has a higher C_u than the latter. This means the soil is finer and less permeable, thereby offering more contact time with less depth. No significant increase in removal after the initial analysis is seen in Figures 7 through 10, indicating sufficient contact time was provided by the soil itself rather than by an accumulation of organics.

The steep drop in COD removal in Figure 7 midway through the second dosage rate probably reflects a breakthrough followed by accumulation of organic material again.

No particular difference in COD removal with time can be detected as dosage rate is doubled in Figures 8 and 10. Removals remained above 90% all the time. The decrease in recorded removals in Figure 9 reflects a decrease in permeability in lysimeter 8 as the dosage rate was increased. For this reason the dosage was reduced from 1.89 GPD/sq.ft. to the original dosage rate of 1.29 GPD/sq.ft. This decrease of COD removal in the eighteen inch depth without corresponding decrease in the twelve inch depth indicates that a dosage rate of 2.58 GPD/sq.ft. may not be accepted at all times.

The relation of COD loading to COD removal is illustrated graphically in the second collection of figures. In Figures 11 and 12 lysimeter 3 shows a slight increase in removal with an increase in loading while lysimeter 11 shows a definite increase in removal with loading increase. These two lysimeters are identical in sieve size and depth of material, but again number 3 has a C_u of 30 and a D_{10} of 0.4 mm. while number 11 has a C_u of 3.3 and D_{10} of 4.2 mm. The over all removal in number 3 is much greater than that of number 11. The greater permeability of the material in lysimeter 11 accounts for the difference in removals. As organic matter was added to the soil column number 11 permeability decreased thereby increasing treatment potential due to increased biological activity, adsorptive capacity and contact time.

This same reasoning can be used to explain the direct relation of COD removal to COD loading in Figures 13, 14, 15 and 16 for lysimeters 13, 14, 16 and 15 respectively. As the depth of material passing a 3/8 inch sieve in this series of lysimeters increases in six inch increments from six inches to twenty-four inches, the COD removal increases. For this reason the increase in removal with increasing loading is less dramatic. Once again this set of figures demonstrates the importance of contact in COD removal. This contact time can be provided by depth or by decreased soil permeability from accumulation of particles in the soil column.

The soil that passed a number 4 sieve in lysimeters 5, 6, 8 and 7 again shows a general trend in improved COD removal with higher COD loadings. Figures 17, 18, 19 and 20 once more show COD removals of good quality at all loadings and for all depths, six inches through twenty-four inches.

Figures 21, 22, 23 and 24 comparing COD removal time for lysimeters of the same depth but different sieve size materials, reemphasize the preceding discussion. Figure 21 shows better COD removal for lysimeter 3 over lysimeter 11 due to the lower permeability reflected by its lower C_u. The same can be said about Figure 22 lysimeter 6 (12 in.: no.4) shows much higher and consistent COD removals than lysimeter 14 which has a higher permeability because it contains a coarser material passing a 3/8 inch sieve.

In Figure 23 COD removals for eighteen inch depth soil columns are presented. The removals are somewhat closer in value. The lower permeability with consequent longer contact time and better removal provided by the finer material in the soil columns can be approached by increasing the depth of soil columns containing coarser material.

The twenty-four inch deep lysimeters confirm that increased contact time and decreased permeability improve COD removal. Lysimeter 11 with the coarsest material and lowest C_u offers the lowest permeability and consequently the lowest COD removal, while lysimeter 7 with the finest material and highest C_u offers the best removal. Lysimeter 15 contains material finer than that of lysimeter 3 but a lower COD removal. This is probably because number 3 has a higher C_u of 30 and D_{10} of 0.4 mm. compared to a C_u of 3.3 and D_{10} of 4.2 mm. for number 11.

4.2 Nitrogen Removal

Figures 25 through 34 show the relationship of the ratio of effluent to influent inorganic nitrogen (NH_3 + NO_3) for the ten lysimeters studied. A high rate of nitrification is characterized by an increase in nitrate nitrogen concentration greater than one. Most of the total inorganic nitrogen measured was nitrate nitrogen indicating aerobic conditions and nitrification.

It appears from comparison of Figures 25 and 26 that nitrification

5. CONCLUSIONS

Based on the results of this study, the following conclusions can be made.

1. In lysimeters containing river gravel passing a 3/8 inch sieve, degradation as measured by COD, phosphate and nitrogen removal varied directly with increasing depth.
2. A higher degradation efficiency was achieved in lysimeters containing river gravel passing a number 4 sieve. The variation in COD removal in lysimeters of increasing depth is less pronounced for this fine material.
3. The significantly higher removals in lysimeter 3 with a C_u of 30 and D_{10} of 0.4 mm. compared to lysimeter 11 of identical depth and material passing a 1/2 inch sieve but having a C_u of 3.3 and a D_{10} of 4.2 mm. emphasize the importance of soil characteristics on waste absorption.
4. An absorption field with an addition of twelve inches of gravel passing a number 4 sieve with a C_u of 30 and a D_{10} of 0.4 mm., would provide COD removal of 90% or above at minimum dosage rates calculated according to Bulletin No. 9 by the Arkansas State Department of Health.

6. RECOMMENDATIONS

Consistently higher COD removals are obtained by lysimeters having a C_u of 30 and a D_{10} of 0.4 mm in comparison with those of identical depth and passing the same size sieve but having a C_u of 3.3 and a D_{10} of 4.2 mm. Additional investigations should be conducted to determine the optimal and minimal C_u and D_{10} values which would give consistently acceptable pollutant removals.

An investigation of actual field absorption systems employing this gravel percolation system should also be conducted.