PROTRACTED RECHARGE OF TREATED SEWAGE INTO SAND

Part I: Quality Changes in Vertical Transport Through the Sand

by

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ABSTRACT

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When the Lake George Village sewage treatment plant was put into operation in 1939, it was described as a "complete treatment" plant. This was because the treated effluent is discharged onto natural delta sand seepage beds which are "at least 25 feet deep."

Studies were made to determine the removal efficiency in the sand beds of coliforms, BOD, chlorides, and the nitrogen and phosphorus compounds.

It was found that when beds were dosed, they were no longer saturated with water at 15 feet. Ten feet of sand were found to remove coliforms by 99% and BOD by 96%. However, nitrates, phosphates, and chlorides remained in significant concentrations after filtration through 10 feet of sand. Phosphate removal in an infrequently used sand bed was greater than in a continuously used bed.

PROTRACTED RECHARGE OF TREATED SEWAGE INTO SAND

PART I: Quality Changes in Vertical Transport Through the Sand

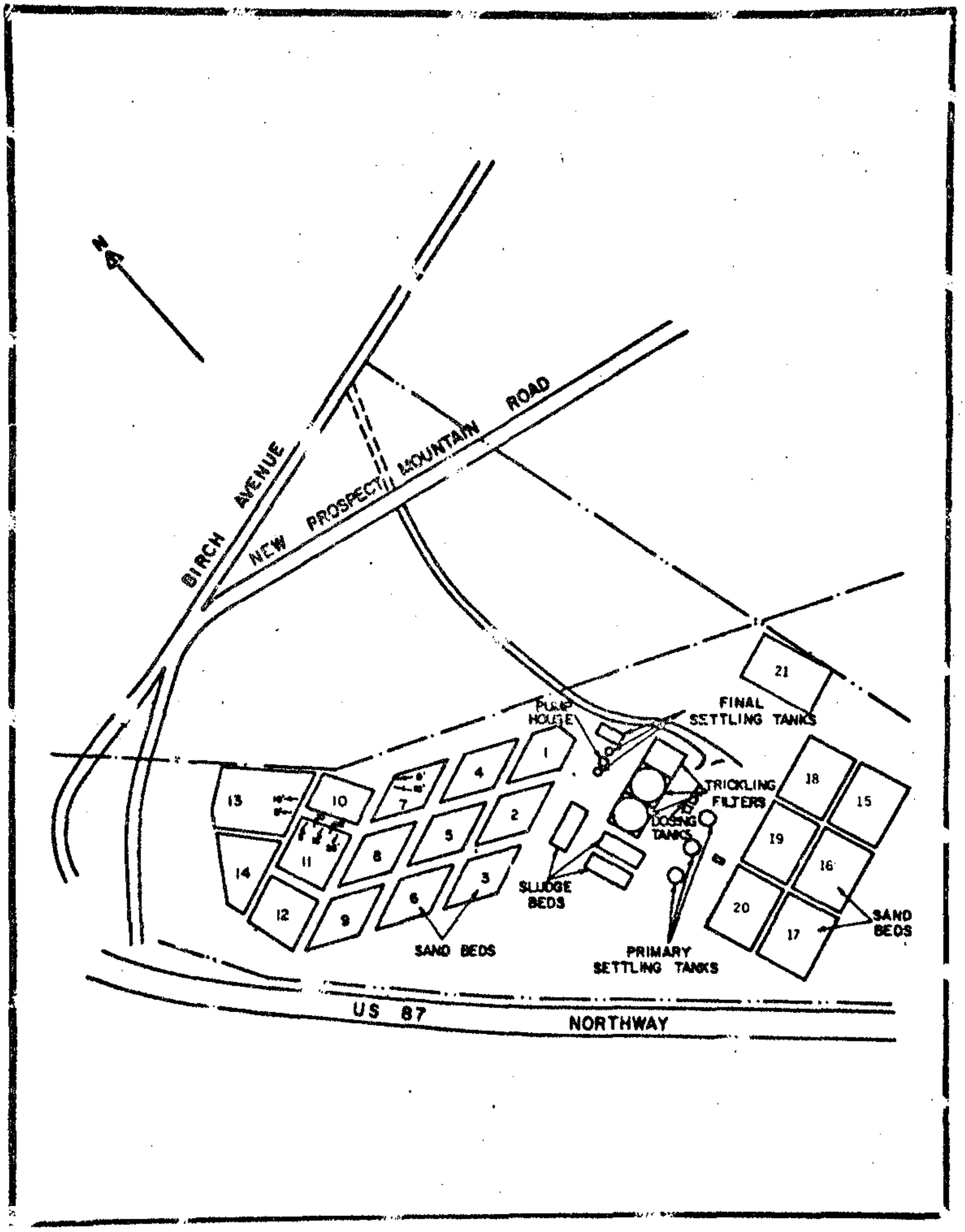
INTRODUCTION

Lake George is a beautiful recreational lake located in northeastern New York within the southeast boundary of the Adirondack Park. It is a desirable tourist area with most of the population centered around the southwestern shores of the lake. In order to preserve the purity of the lake, regulations (N.Y. State Public Health Law) prohibit the discharge of any sewage effluent, no matter how well treated, into Lake George or any tributary thereof. The Town of Lake George is served by the Lake George Village sewage treatment plant and the Town of Bolton is served by the Bolton sewage treatment plant. The remainder of the lake depends upon septic tanks for disposal of domestic water-carried wastes.

When the Lake George Village sewage treatment plant began operation in 1939, it was described as a "complete treatment" plant (Vrooman, 1940). This is because the effluent after secondary treatment by trickling filtration followed by secondary sedimentation is discharged onto natural delta sand seepage beds which are "at least 25 feet" deep (Vrooman, 1940).

Figure 1 shows the general layout of the treatment plant and the location of the sand beds and sampling wells. The plant consists of three primary settling and digestion tanks of the Imhoff type; three dosing tanks; three trickling filter beds, one rectangular with fixed nozzles which is covered in winter, and two circular with rotating arms; two circular and two rectangular secondary settling tanks; twenty-one natural sand seepage beds; a sludge pump house; and three sludge drying beds. The effluent from

FIGURE 1



Lake George Village Sewage Treatment Plant the secondary settling tanks is not chlorinated before discharge onto the sand beds.

When the original treatment plant was designed and constructed, the population estimates for the area varied from approximately 1500 persons in winter to about 5000 at the peak of the summer season. In order to allow for this approximately threefold change in population, the treatment system was built essentially in triplicate using one-third of the system for the winter-time flows and the entire plant for summer-time flows. The present population estimates (Aulenbach and Clesceri, 1973) being served by the treatment system are 2100 persons in winter and 12,300 in summer. Initially, there were 6 sand beds with a total area of approximately 72,000 sq ft (6,690 sq m). Presently, there are 14 sand beds in the area where the original 6 were located and an additional 7 sand beds at a higher elevation above the primary settling tanks. The total area of these combined beds is 6.4 acres (2.6 hectares).

In order to determine the fate of substances remaining in the treated effluent, wells were installed in beds 7, 11, and 13 (see Figure 1) at depths of 5, 10, 15, 20, and 25-ft (1.5, 3, 4.6, 6.1, and 7.6 m). Bed 7 was an extremely slow bed and took up to a week to dry. Bed 11 was a fast bed in that the water percolated away in a day or two. Bed 13 was chosen because it had had only limited use since the plant was built due to the fact that the control valve for this bed is accessible only through a manhole. Valves for the other beds are operated from above the ground.

It was found that no sample could be secured from bed 7 and that samples could be secured from the wells in beds 11 and 13 at the 5 and 10-ft depths only. It was considered that the securing of samples at the 5 and 10-ft depths indicated a continuous water column to these depths, but that by the time the water percolated 15-ft down into beds 11 and 13, the water became dispersed and could not be pumped directly.

After well points had been installed and a filter bed flooded, the wells were developed to remove the fine sand from the area around the point. This was accomplished by pumping the wells at the maximum rate for about 60 minutes.

Samples were collected by pumping a well at its maximum rate (approximately 4.5 gpm for a 5-ft well and 1.3 gpm for a 10-ft well) for about 10 minutes and then collecting the sample in a clean polyethylene gallon bottle. The collection of samples had to be incorporated with the daily operation of the treatment plant. Normally the beds were used only once a week and sometimes only once every two weeks. Cooperation of the treatment plant personnel was obtained so that bed 11 was flooded from June 14 through July 1, and both beds 11 and 13 from July 18 through July 25.

The analyses for coliforms, BOD, chloride, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and orthophosphate were performed in accordance with Standard Methods (APHA et al., 1965). The method used in the determination of total phosphate and polyphosphate is described on page 719 of International Journal of Air and Water Pollution (Lee, Clesceri, and Fitzgerald, 1965).

EXPERIMENTAL RESULTS AND DISCUSSION

The number of samples analyzed did not allow for a comprehensive statistical analysis. Some sample analyses showed a wide range of variation and the mean value would not give a true representation of the data. It was felt that the median value (the magnitude of the middle observation of an array) would be the most representative value in making comparisons and drawing conclusions.

A. Coliform Removal

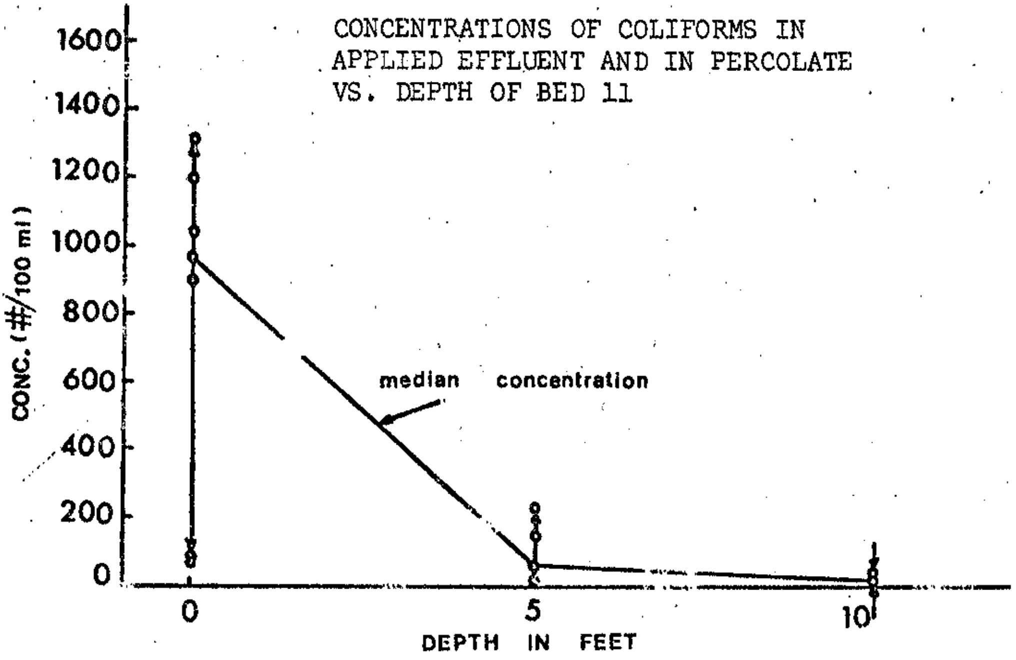
The results of the coliform analyses are summarized in Figure 2. The median coliform concentration dropped off rapidly in the first 5-ft of sand. In bed 11 the coliform reduction was from 970 to 46/100 ml, while in bed 13 the reduction was from 1260 to 20/100 ml. Bed 11 which is used routinely, removed 95.3% of the coliforms in 5-ft. Bed 13 which is used rather sparingly, removed 98.4% of the coliforms in the first 5-ft. Although bed 11 had slightly less capacity for coliform removal in the first 5-ft, its over-all removal in 10-ft approached that of bed 13, with both beds having greater than 99% removal.

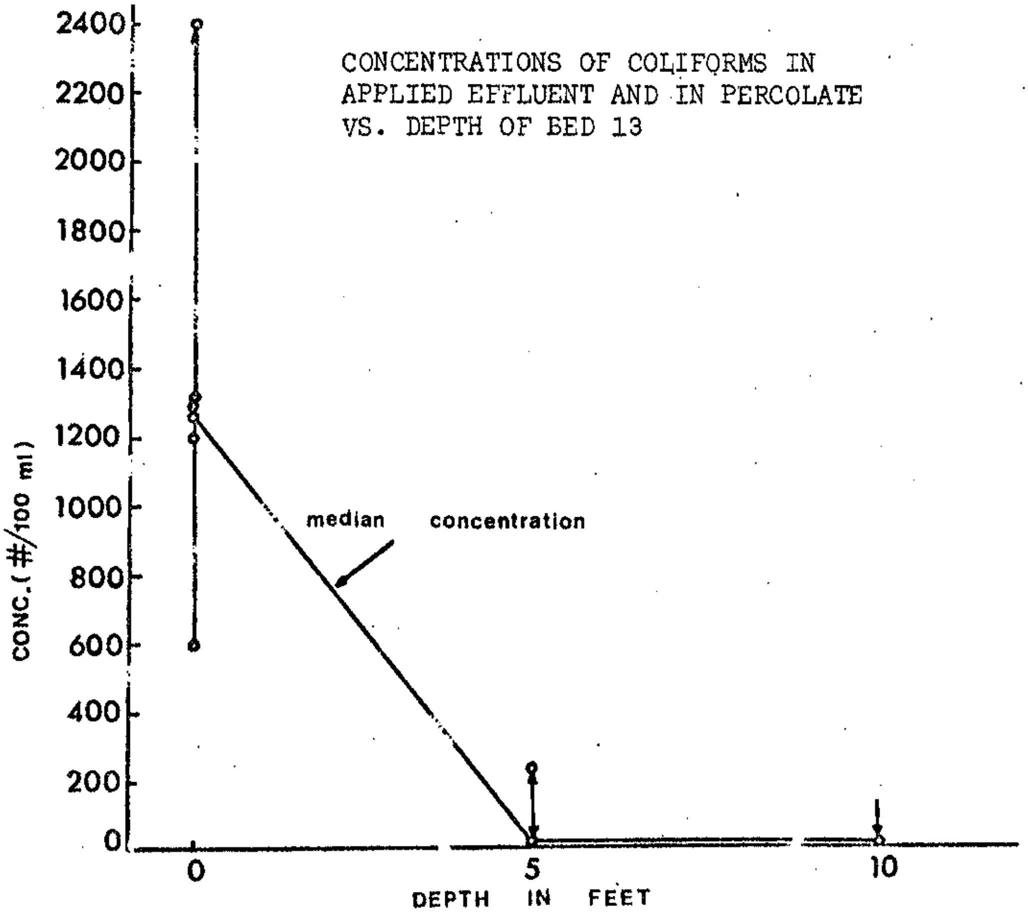
The results here agree with similar findings by Calaway, et al. (1952), who showed that the greatest numbers of coliforms occurred in the surface level of the sand, with this being best explained by the character of the sand at this level. The surface sand screens out the larger organic particles during filtration and this organic matter forms a matted layer which acts as a highly retentive filter and aids in coliform removal. However, in addition to this mat that forms, the sand filtering capacity itself has an appreciable effect on coliform removal.

There appears to be no appreciable effect on the over-all coliform removal efficiency when a bed is used for extended periods of time. Bed 11 was in continued use from June 14 through July 1 with the efficiency being 98% for the July 1 sample. Bed 13 was used continuously from July 18 through July 25 and the removal efficiency remained greater than 99%.

Almost all coliform organisms were removed from the percolate in the vertical travel through 10-ft of sand. The applied effluent was not chlorinated which demonstrates that a sand bed removes coliforms very well and

FIGURE 2


CONCENTRATIONS OF COLIFORMS IN
APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH OF BED 11


CONCENTRATIONS OF COLIFORMS IN
APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH OF BED 13

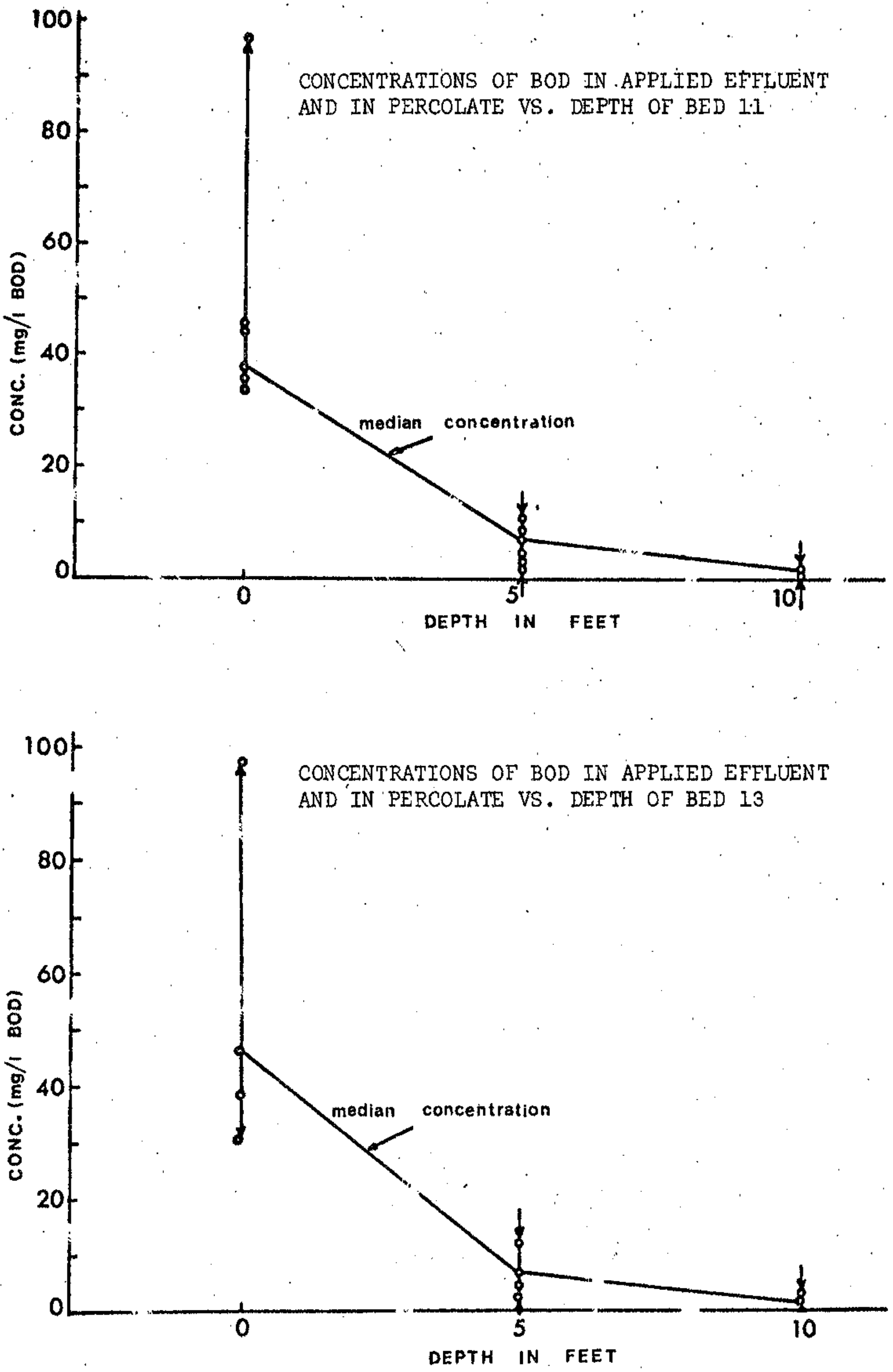
assumedly other bacteria of fecal origin also. In all probability, coliforms would be further removed by deeper percolation; therefore, the sand bed proves to be an effective method for removing coliform organisms.

B. BOD Removal

The results of the BOD analyses are shown in Figure 3. The median BOD concentration dropped sharply in the first 5-ft and continued to drop at a slower rate, in the next 5-ft. The decrease was 38.5 to 7.5 to 1.45 mg/l BOD in bed 11 and 46.0 to 6.8 to 1.2 in bed 13. Over-all removal in 10-ft is just about the same for both beds, namely 96% for bed 11 and 97% for bed 13. As in the case of coliform removal, there is no noticeable effect upon BOD removal due to continuous loading of the beds. Furman, et al. (1955) reported similar results. In their study they found that even though the organic loading rate was sufficient to clog the interstices of the surface sand, they were able to obtain 80 to 95% removal. Since there is no difference in degree of removal between the two beds studied, the bed efficiency is apparently not a function of their use over the past years.

Since BOD removal is primarily an aerobic process and the majority of BOD removal was in the upper layers of the filter bed, there must be a source of oxygen available. D.O. studies at depths of 2, 4, 6 and 8-ft at the Rio Hondo test basin (Wastewater reclamation...." 1966) on similar sand showed that oxygen was available in the percolate throughout the sampling depth. Although dissolved oxygen tests were not performed in this study, there are two possible sources of oxygen. One would be the initial D.O. of the effluent; the other would be the air in the bed before loading. Upon loading, the air is dissolved by the water and becomes available for the organisms to use in their metabolism. Since the beds were not saturated

FIGURE 3



CONCENTRATIONS OF BOD IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 11

CONCENTRATIONS OF BOD IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 13 with water at 15-ft and below, there is some supply of air available to move upward into the upper water-saturated area. This air may possibly come underground from adjacent beds which are not being loaded. It would also enter the beds when they are not being dosed, thereby indicating the desirability of alternate dosing and resting of the beds. Thus the void spaces between sand grains are essential to air movement. To prove the above hypothesis, D.O. determination should be made at various depths to determine the D.O. levels.

C. Chloride Concentrations

The results of the chloride analyses shown in Figure 4 show that the median chloride concentration varied only slightly as the percolate moved through the filter beds. There was no distinguishable difference between beds 11 and 13 with respect to chloride concentration at the 5 and 10-ft depths.

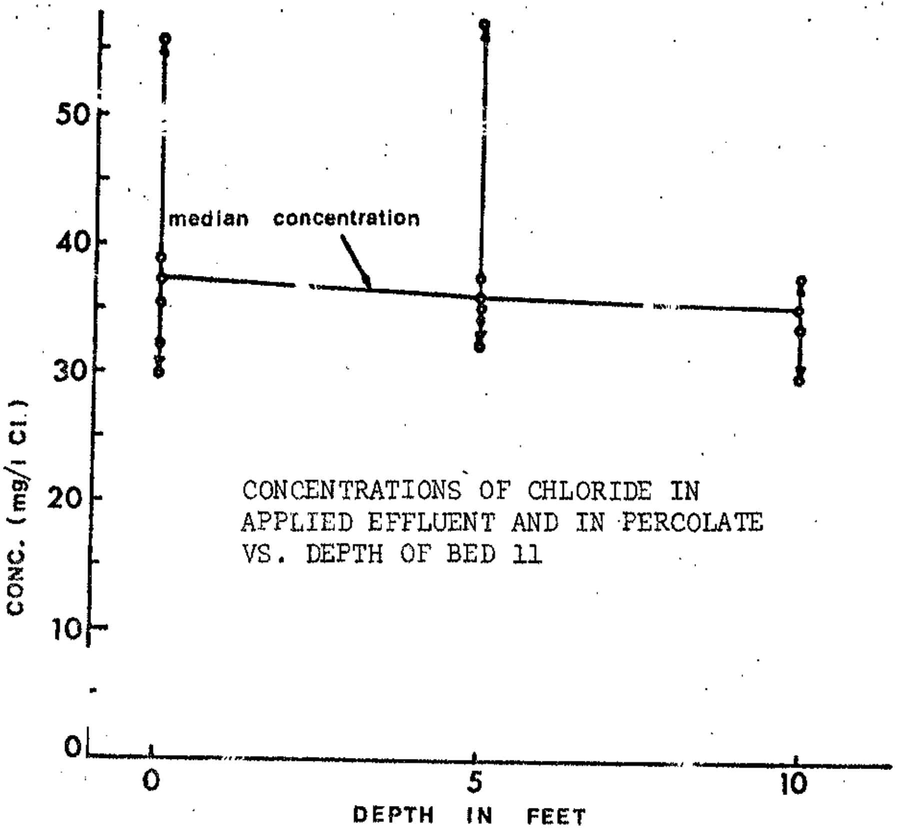
These results confirm those of others (Pennypacker, *et al.*, 1967 and "Field investigations..." 1953), namely that chlorides are not removed from water that percolates through soil or sand. Where vegetation is present, one can expect some chloride removal by absorption through the roots of vegetation (Pennypacker, *et al.*, 1967). However, there is no vegetation present in these sand beds.

D. Nitrogen Analyses

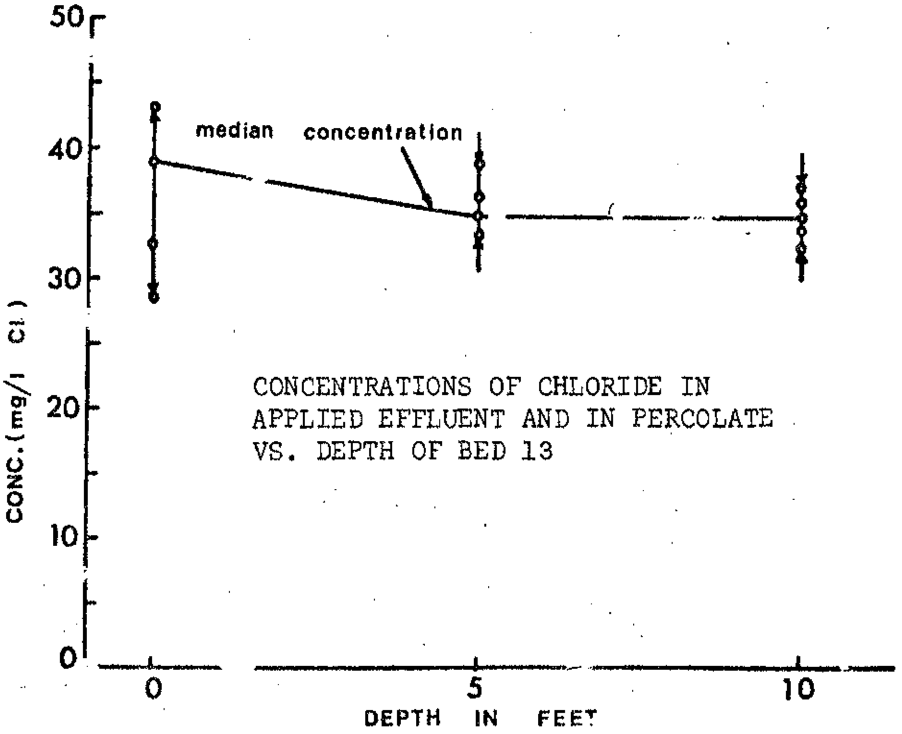
Figure 5 shows that organic nitrogen was effectively removed in the top 10-ft of the sand beds. In the upper 5-ft of sand in both beds 11 and 13, more than 82% removal was indicated, whereas further percolation to 10-ft increased the total median percent removal to 100%.

Figure 6 shows the reduction in ammonia nitrogen in the two beds. The reduction was more than 19.5% in percolation through the upper 5-ft of

FIGURE 4.

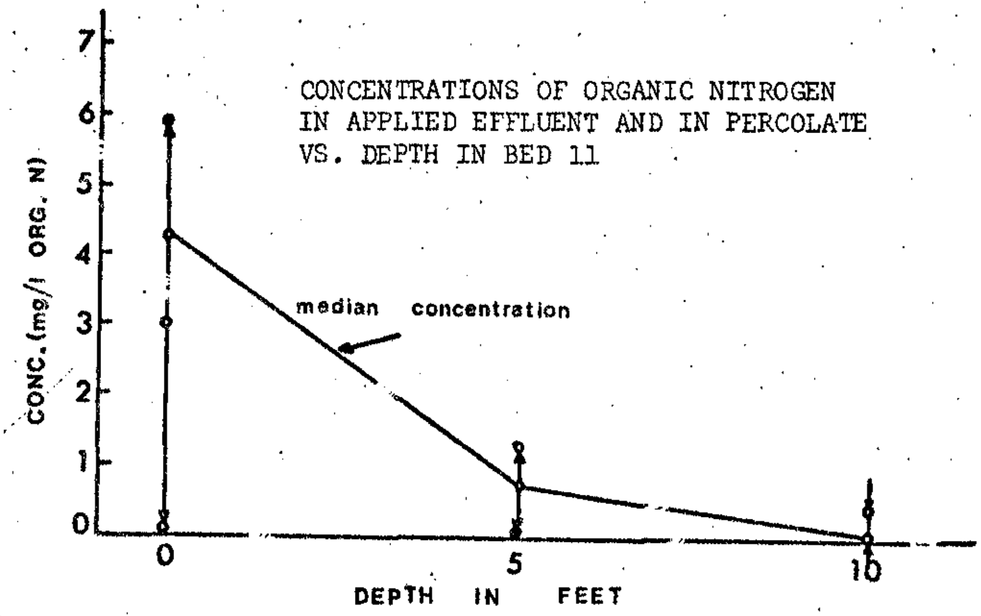


CONCENTRATIONS OF CHLORIDE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 11



CONCENTRATIONS OF CHLORIDE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 13

FIGURE 5


CONCENTRATIONS OF ORGANIC NITROGEN
IN APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH IN BED 11
median concentration
CONC. (mg/l ORG. N)
0
1
2
3
4
5
6
7
0
5
10
DEPTH IN FEET

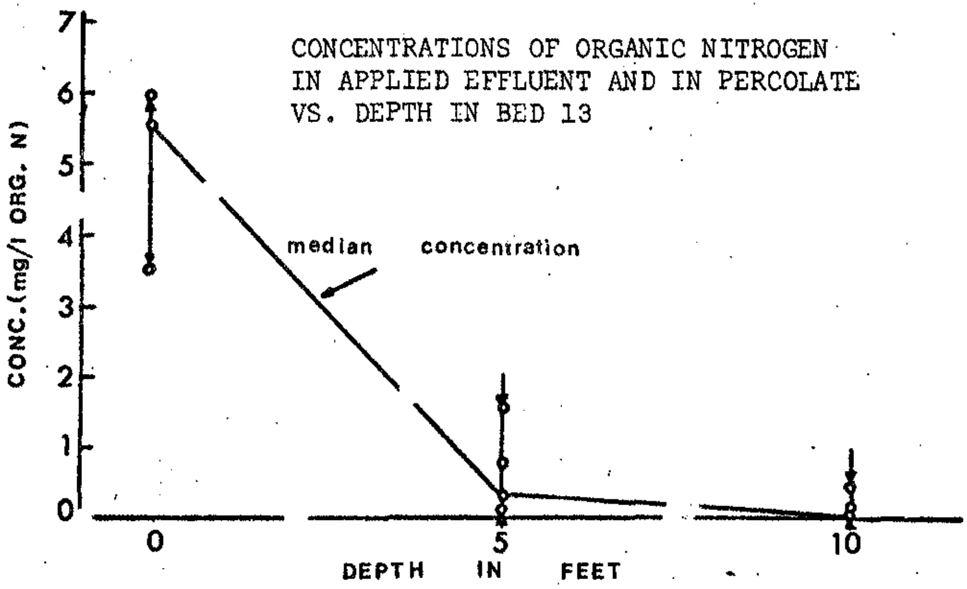
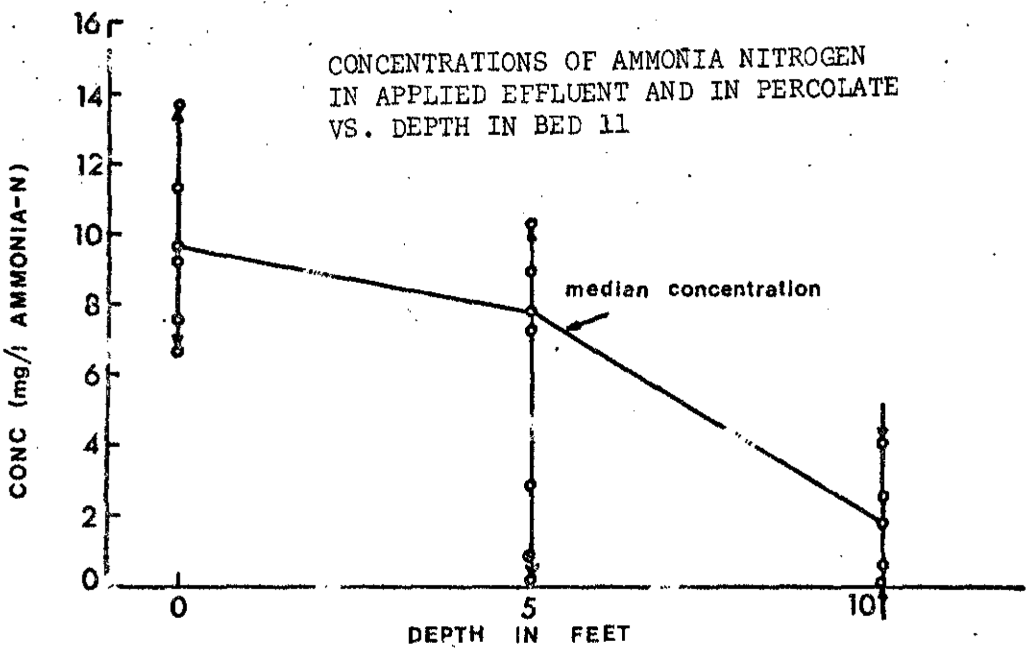
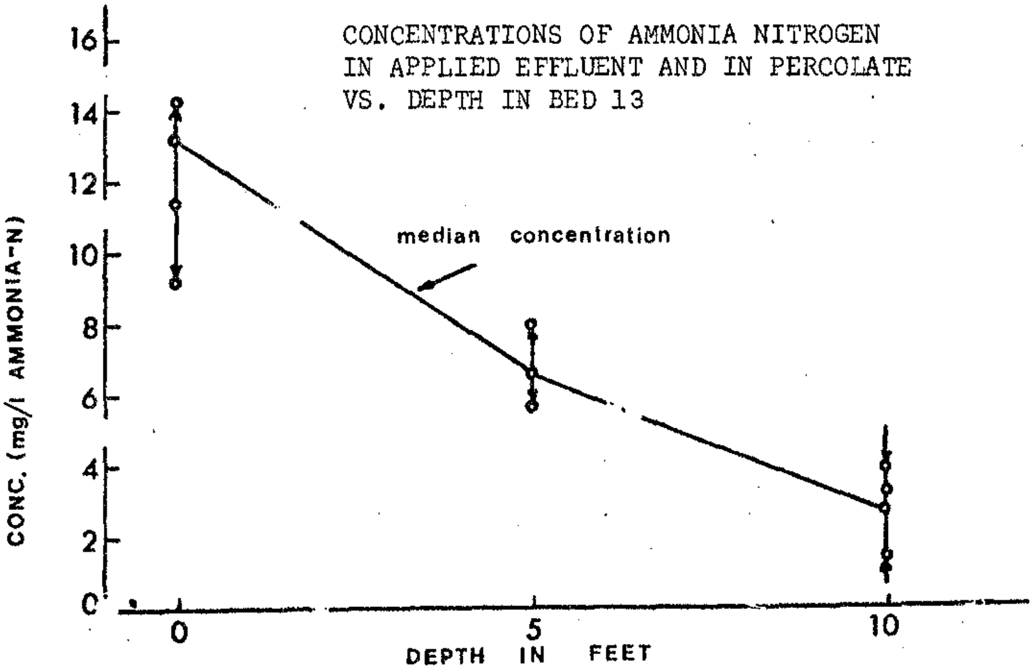

CONCENTRATIONS OF ORGANIC NITROGEN
IN APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH IN BED 13
median concentration
CONC. (mg/l ORG. N)
0
1
2
3
4
5
6
7
0
5
10
DEPTH IN FEET

FIGURE 6


CONCENTRATIONS OF AMMONIA NITROGEN IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH IN BED 11


CONCENTRATIONS OF AMMONIA NITROGEN IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH IN BED 13

sand, and further percolation to 10-ft increased the total median removal to 79%.

Nitrite nitrogen concentrations were determined as shown on Table I. The values were very low and can be considered insignificant throughout the depth of sampling.

The results of the nitrate nitrogen analyses are plotted in Figure 7. The nitrate content varied appreciably from day to day. Although on several days there was a decrease of nitrate nitrogen through the upper 5-ft of sand, especially in bed 11, nitrification was the predominant effect in percolation from the 5 to 10-ft depth. As there is no measurable increase in ammonia nitrogen, it can be assumed that nitrification is the dominant effect.

The decrease in concentration of nitrate nitrogen through the upper 5-ft of sand could be due to the presence of anaerobic conditions within this saturated portion of the sand beds, resulting in denitrification with the subsequent reduction of some of the nitrate to nitrogen gas. Adsorption could also help in the decrease of nitrate in this zone. The over-all decrease of organic and ammonia nitrogen with the subsequent increased concentrations of nitrates through the 5 to 10-ft zone could be due to the existence of aerobic conditions in this zone. Unfortunately, DO measurements were not made in this study.

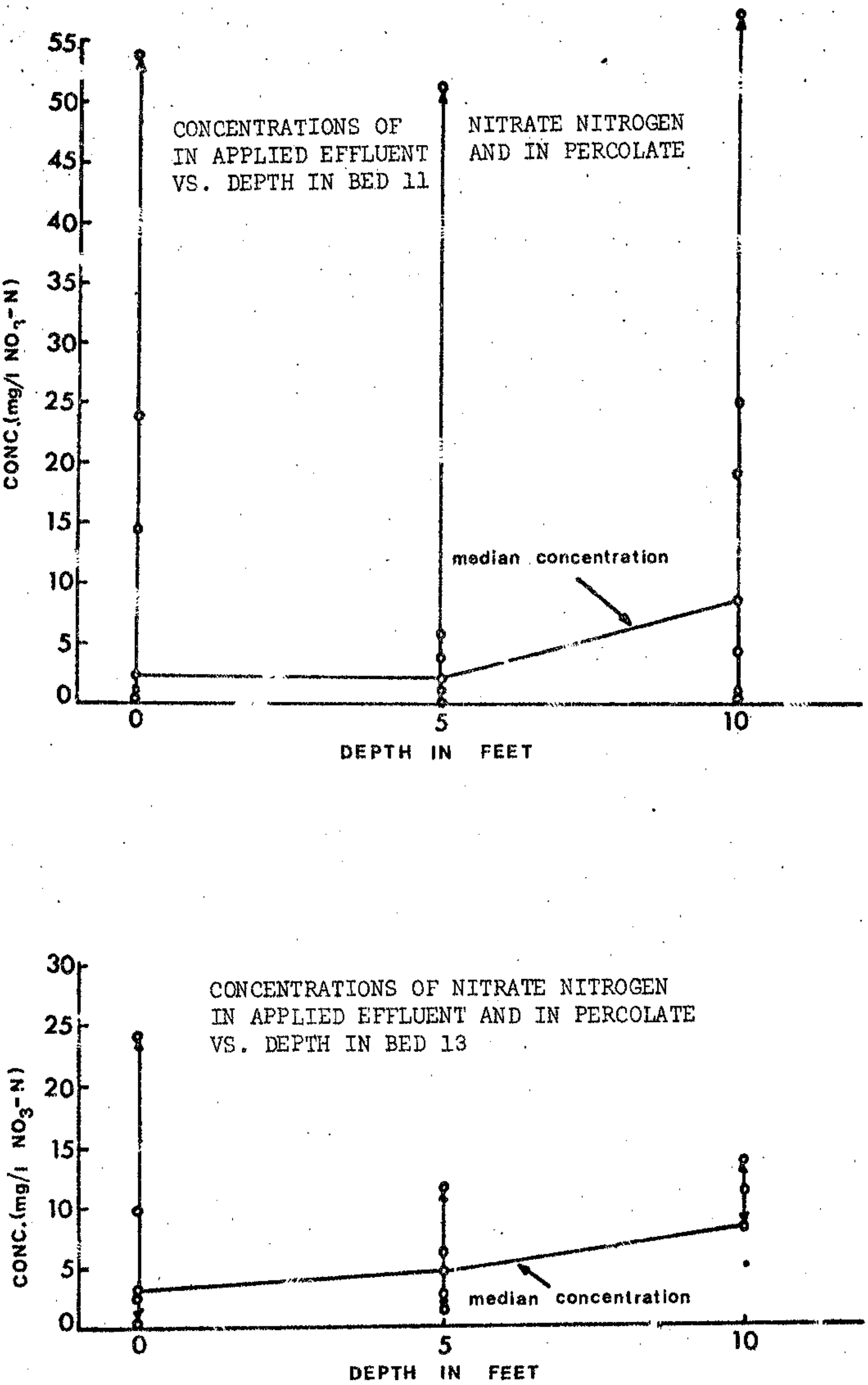
Organic nitrogen can be converted to ammonia by the action of bacteria under both aerobic and anaerobic conditions (Sawyer and McCarty, 1967). Ammonia is oxidized to nitrite and nitrate by nitrifying bacteria. Other authors (Bailey, 1968; "Field investigations..." 1953; Furman et al., 1955; Greenberg and Thomas, 1954; Preul, 1966; Sawyer and McCarty, 1967; "Wastewater reclamation...." 1966) have shown that soil does not have the

TABLE I

Nitrite Nitrogen Concentration (mg/l NO_2-N) and Percent Removal

Sample Date	Bed No.	Influent	5-ft Depth	Percent Removal	10-ft Depth	Total % Removal
6/17	11	0.39	0.14	64.0	0.04	89.7
6/20	11	1.10	0.11	90.0	0.09	92.0
6/26	11	0.63	0.02	96.7	0.01	98.5
7/1	11	0.02	0.12	-500.0	0.05	-150.0
7/8	11	0.39	0.01	97.5	0.01	97.5
7/23	11	0.01	0.01	0	0.04	-300.0
7/25	11	0.02	0.02	0	0.04	-100.0
(Median)		0.39	0.02	94.9	0.04	89.5
7/8	13	0.39	0.03	92.3	0.03	92.3
7/15	13	0.02	0.03	-50.0	0.06	-200.0
7/19	13	0.33	0.12	63.7	0.07	78.8
7/23	13	0.01	0.39	-3800.0	0.10	-900.0
7/25	13	0.02	0.05	-150.0	0.09	-350.0
(Median)		0.02	0.05	-150.0	0.07	-250.0

FIGURE 7


CONCENTRATIONS OF NITRATE NITROGEN IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH IN BED 11

CONCENTRATIONS OF NITRATE NITROGEN IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH IN BED 13 ability to retain nitrates. Under anaerobic conditions, nitrates and nitrites are both reduced either to ammonia or nitrogen gas. Since there was no measurable increase in ammonia nitrogen, nitrification appears to be the dominant phenomenon in the over-all reduction of organic and ammonia nitrogen. Due to the extreme variations in the nitrate content of the applied treated sewage, it was difficult to establish a nitrogen balance which would confirm any reduction to and loss of nitrogen gas as the result of anaerobic reduction of nitrates and nitrites.

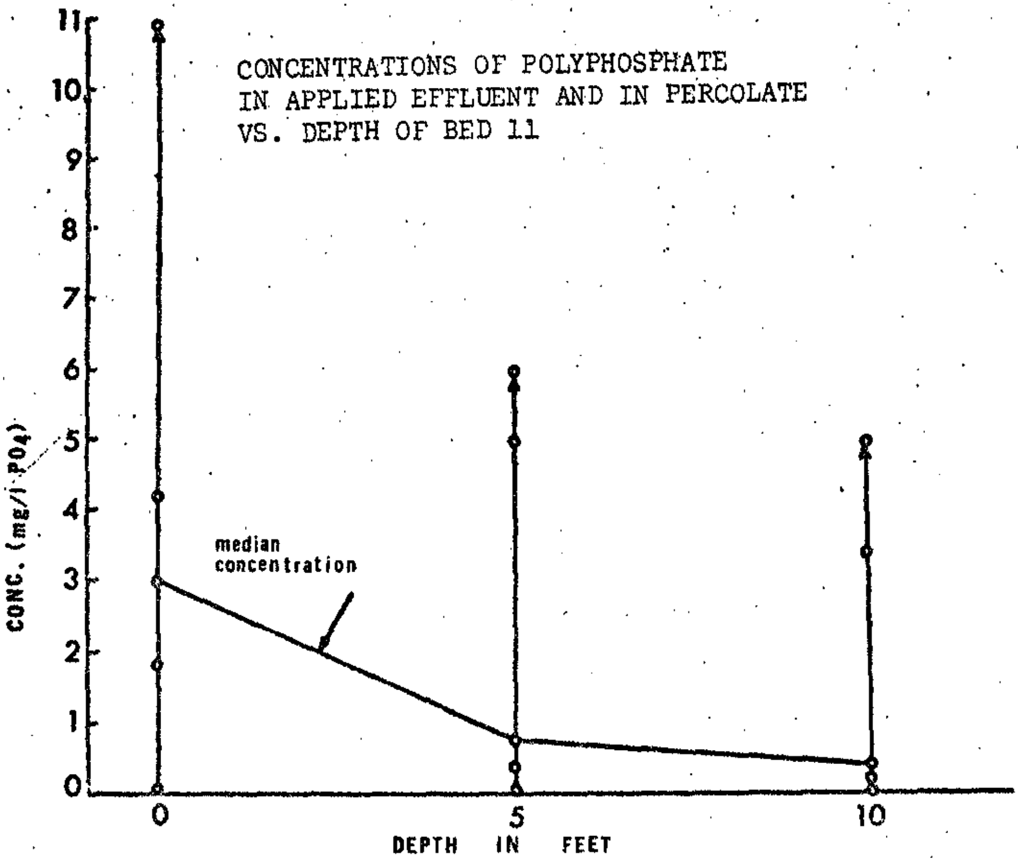
E. Phosphorus Analyses

Graphs showing the comparison of beds 11 and 13 with respect to the concentrations of poly, ortho, and total phosphate vs. depth of bed are shown in Figures 8, 9, and 10, respectively. Since over 85% of the influent total phosphate was composed of orthophosphate and since the ratio of ortho to total phosphate was fairly constant, comparison of beds 11 and 13 is made on the basis of the total phosphate.

It is immediately apparent that the two beds differ greatly. Bed 11 which has been used regularly over the years showed a slight increase in the median total phosphate concentration from 0 to 5-ft (25.4 to 33.4 mg/l PO_4). The concentration then dropped off to a value of 27.5 mg/l at 10-ft. On the other hand, bed 13 which has been used only sparingly showed 72% removal of total phosphate (25.8 to 7.2 mg/l PO_4) in the first 5-ft of sand. The concentration then increased slightly to a value of 10.0 mg/l in the next 5-ft so that the over-all removal in 10-ft was to 61%.

At first glance it appears that the relatively unused sands of bed 13 had a high capacity for phosphorus removal in the initial 5-ft, whereas the same portion of bed 11 had lost its removal capacity (assuming it once had it). However, why there was no further decrease in the total phosphate

FIGURE 8


CONCENTRATIONS OF POLYPHOSPHATE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 11

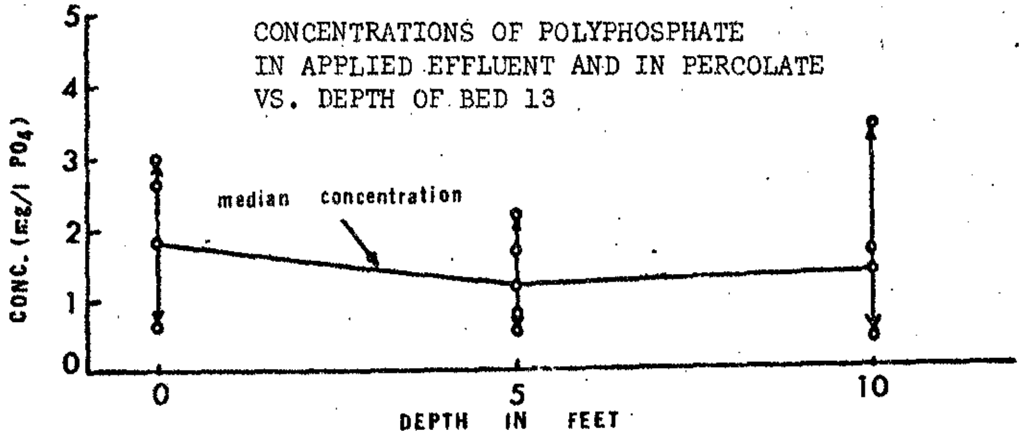
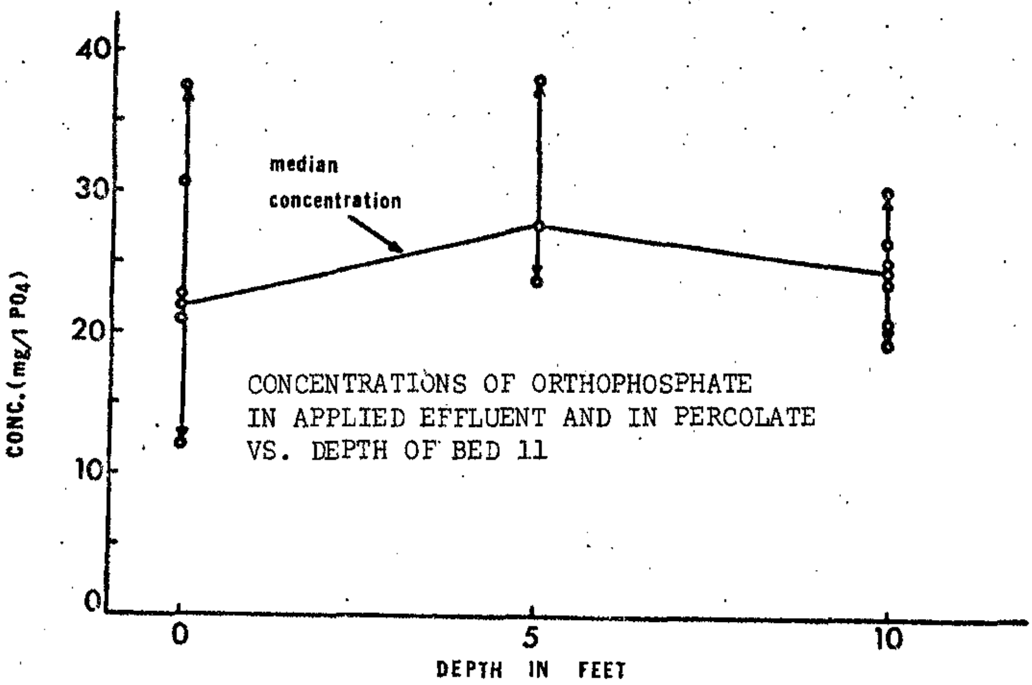
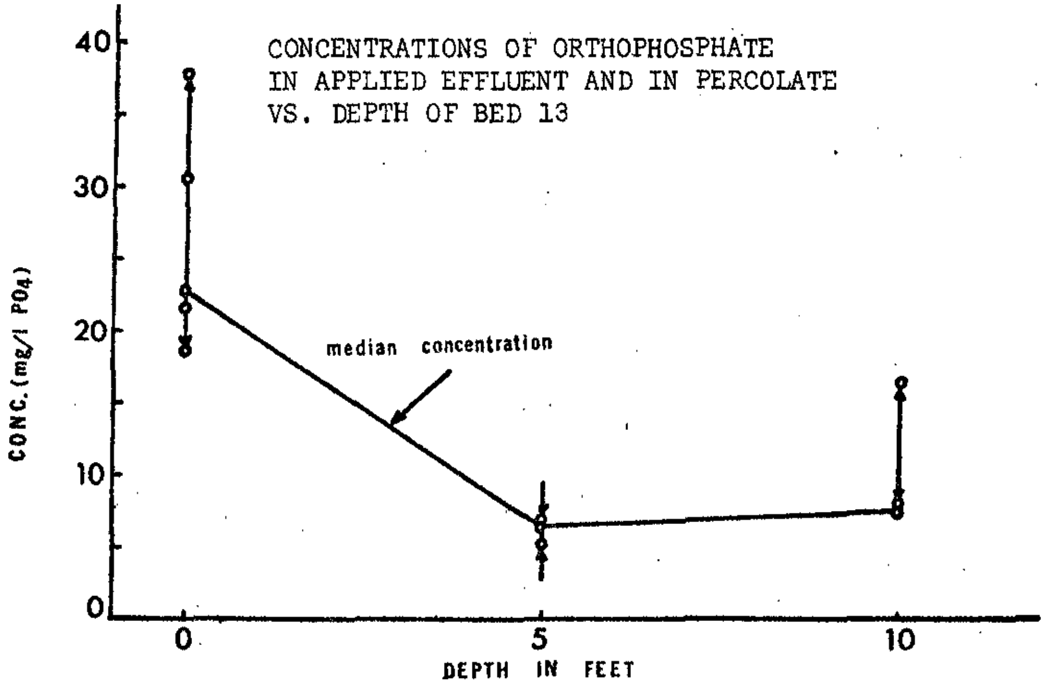

CONCENTRATIONS OF POLYPHOSPHATE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 13

FIGURE 9

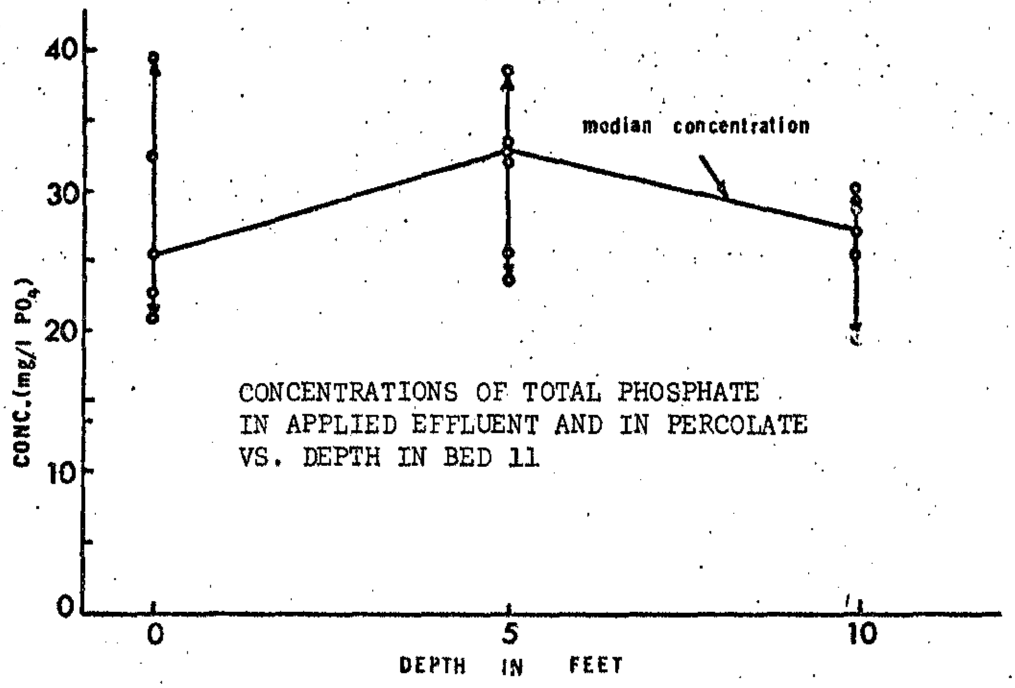


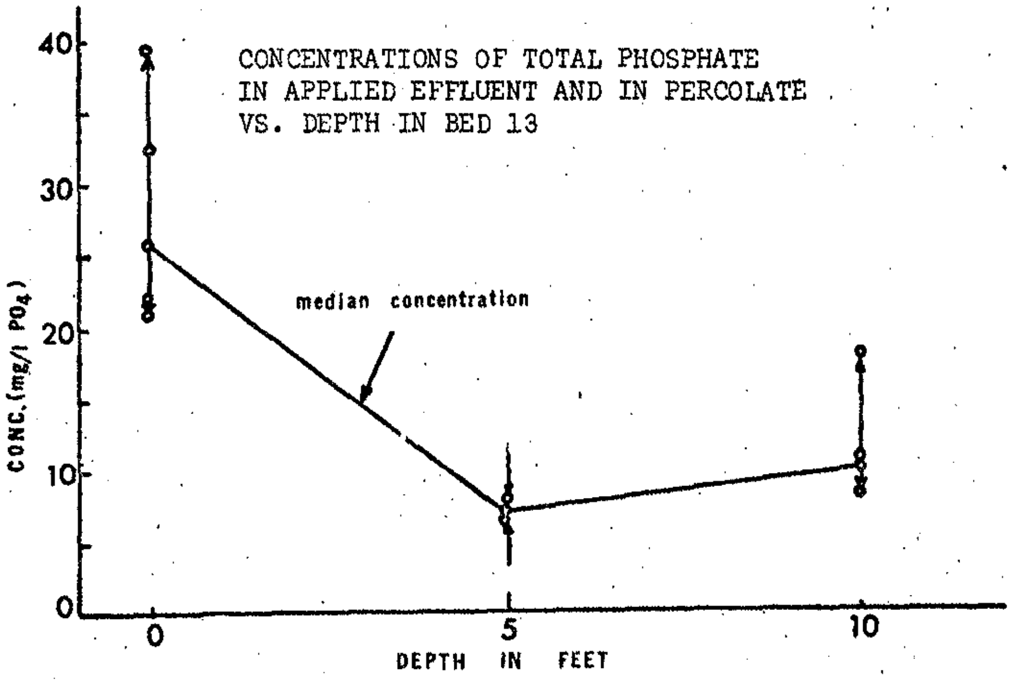
CONCENTRATIONS OF ORTHOPHOSPHATE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 11



CONCENTRATIONS OF ORTHOPHOSPHATE IN APPLIED EFFLUENT AND IN PERCOLATE VS. DEPTH OF BED 13

FIGURE 10


40
30
20
10
0
CONC.(mg/l PO_4)
median concentration
CONCENTRATIONS OF TOTAL PHOSPHATE
IN APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH IN BED 11
0
5
10
DEPTH IN FEET


40
30
20
10
0
CONC.(mg/l PO_4)
CONCENTRATIONS OF TOTAL PHOSPHATE
IN APPLIED EFFLUENT AND IN PERCOLATE
VS. DEPTH IN BED 13
median concentration
0
5
10
DEPTH IN FEET

from 5 to 10-ft in bed 13 is difficult to explain.

The literature contains many varied and conflicting reports with respect to the behavior of phosphorus in soils and sand. Preul (1966) conducted studies on the groundwater in the area of various waste stabilization ponds. Generally, the soil near these ponds was sandy or silty. Groundwater samples were taken from observation wells (usually less than 20-ft deep) up to 200-ft from the edge of the ponds. Generally the phosphates were reduced to less than 1.0 mg/l within 30-ft of the ponds. Initial concentrations varied from 4.0 to 21.5 mg/l, with a mean of 9.2. However, Preul (1966) noted one case of substantial increase in phosphates near a well 100-ft from a pond. This he could not explain except that it was due possibly to some localized effect in the soil. Preul indicates that phosphate removal is probably due to the strong affinity of phosphates for soil particles.

Pennypacker et al. (1967) conducted a study of renovation of wastewater effluent by irrigation of forest land. They found that 98.8 to 99.4% of the phosphorus was removed in the upper 12 inches of the soil. Groundwater concentrations of phosphorus were reduced to less than 0.07 mg/l P from an initial average concentration of 8.5. They attributed removal to the fact that phosphorus is fixed readily by soil colloids. Greenberg and Thomas (1954) in a study of sewage effluent disposal on sand loam basins (7.9% clay, 17.7% sand, and 74.4% silt), found that phosphate ions disappeared during the first foot of travel. This they felt was due to a replacement of the hydroxyl ions on the clay lattices, or more likely, to uptake by the micro-organisms developing in the soil.

On the opposite side of the ledger, studies conducted in California ("Field investigations...." 1953) on the percolating liquid from four sewage spreading basins, showed that phosphates disappeared during the first foot of vertical water travel in the period 1950-51, but in 1952 the concentration of phosphates increased, and even at a depth of 13-ft did not disappear. In another California study ("Wastewater reclamation..." 1966), a comparison was made between sewage disposed on soil at Whittier Narrows vs. Rio Hondo. At Whittier the soil consisted of 2-ft of highly organic soil, followed by thin discontinuous layers of silt and micaceous material. At Rio Hondo the soil was very homogeneous and composed mainly of a fine to medium sand (uniformity coefficient 2.36 and effective size of 0.139 mm). Phosphate removal varied greatly at the 2 sites. The concentrations of total phosphate (practically all in the ortho form) were fairly uniform in the surface waters at the two basins. At Whittier there was a decrease in phosphate concentration after 2-ft of percolation, a build-up at 4-ft, and finally almost complete removal in the percolate at 8-ft. At Rio Hondo Basin (somewhat similar to the Lake George Basin) there was no significant change in phosphate concentration with depth.

Bailey (1968) maintains that the pH of the soil is a dominating factor in phosphorus fixation and a minimum of phosphorus fixation occurs when the soil is "neutral," pH 6 to 7. In the present study analyses of influent to the bed, and 5 and 10-ft samples all showed a pH range of 6 to 7. Assuming that the sand is also in this same range, this helps explain why there was little phosphate removal through the 10-ft of sand. However, comparing beds 11 and 13, it appears that the sand of bed 13 does have some capacity for phosphate removal, namely 61% in 10-ft. Bed 11 has lost its capacity over the years. No explanation can be found for the reason why in bed 13 the total phosphate decreased over 72% in the first 5-ft, but failed to decrease further in the next 5-ft.

F. Sand Analyses

In Table II are shown the results of the sieve analyses performed on three sand samples. These samples were analyzed to get a general idea of the characteristics of the sands. The New York State Department of Health recommends an effective grain size between 0.3 and 0.6 mm, and the uniformity coefficient should be 3.5 or less for open sand filters. This natural filter bed sand is somewhat smaller than the recommended size range. However, the recommendations are for constructed sand filters where optimum percolation is desired.

SUMMARY

The results showed that coliforms, BOD, and organic nitrogen are essentially completely removed in the upper 10-ft of the Lake George Village sewage treatment plant sand beds. The ammonia nitrogen, on the other hand, was removed only to an extent of about 80% in the first 10-ft. Since the removal appears to be nearly linear, it may be estimated that nearly complete ammonia removal could be accomplished with an additional 5-ft of depth of sand or 15-ft total. Whereas the results of the nitrate determination varied considerably, the concentration did appear to increase slightly with depth. There was no quantitative balance between the reduction of ammonia and organic nitrogen and the increase in nitrate nitrogen. However, it may be concluded that there is an over-all oxidation process involved in converting organic and ammonia nitrogen to nitrate. There was no significant change in chloride concentration with depth. In all the above analyses, the results were similar in both beds, indicating no effects which could be attributed to prior use of a sand bed.

The phosphorus analyses were the only ones which showed a significant difference between beds 11 and 13. There seems to be some significant

TABLE II

Sieve Analyses - Bed 13

Sample Location	Effective Size	Uniformity Coefficient
Test boring hole 3 Approx. 30-33' depth	0.19 mm	2.6
Test boring hole 3 Approx. 10' depth	0.135 mm	3.4
Center of bed 13" below surface*	0.25 mm	3.6

*Sample collected and analyzed by New York State Department of Health reduction in polyphosphates in the first 5-ft of bed 11 but little further reduction between 5 and 10-ft. Bed 13 showed no significant change in polyphosphate concentration at any depth. The orthophosphate, on the other hand, showed no reduction with depth in bed 11 and even a slight increase at the 5-ft depth. In bed 13, which was little used, there was a significant reduction in the first 5-ft but no further reduction in the second 5-ft of bed depth. The total phosphate results are similar to those of the orthophosphate. It was concluded that, for the depths studied, bed 11, which had received considerable use, had reached saturation for adsorption of phosphorus, whereas bed 13, which had received little use, still had an active phosphorus adsorption capacity.

Based on these initial studies, further studies are being conducted both in the sand beds and in the area between the treatment plant and Lake George to determine any effects of this discharge on the quality of Lake George.

REFERENCES

A.P.H.A., A.W.W.A. and W.P.C.F. 1965. Standard methods for the examination of water and wastewater. Twelfth Edition.

Aulenbach, D. B. and N. L. Clesceri. 1973. Sources and sinks of nitrogen and phosphorus: water quality management of Lake George (N.Y.). WATER 1972. Gary F. Bennett, editor. AIChE Symposium Series No. 129, v. 69, pp. 253-262.

Bailey, G. W. 1968. Role of soils and sediment in water pollution control. U.S Dept. of the Interior, Federal Water Pollution Control Administration, Southeast Water Laboratory.

Calaway, W. T., W. R. Carroll and S. K. Long. 1952. Heterotrophic bacteria encountered in intermittent sand filtration of sewage. Sewage and Ind. Wastes. v. 24, p. 642.

Field investigations of waste water reclamation in relation to ground water pollution. 1953. Pub. No. 6, State Water Pollution Control Board, Sacramento, California.

Furman, T. S., W. T. Calaway and G. R. Grantham. 1955. Intermittent sand filters - multiple loadings. Sewage and Ind. Wastes. v. 27, p. 261.

Greenberg, A. E. and J. F. Thomas. 1954. Sewage effluent reclamation for industrial and agricultural use. Sewage and Ind. Wastes. v. 26, p. 761.

Lee, F. G., N. L. Clesceri and G. P. Fitzgerald. 1965. Studies on the analysis of phosphates in algal cultures. Int. Air Wat. Poll. v. 9, p. 715.

New York State Health Department. Standards for waste treatment works.

New York State Public Health Law. Article 12, Section 1153.

Pennypacker, S. P., W. E. Sopper and L. T. Kardos. 1967. Renovation of wastewater effluent by irrigation of forest land. Jour. Water Poll. Control Fed. v. 39, p. 285.

Preul, H. C. 1966. Underground movement of nitrogen. Jour. Water Poll. Control Fed. v. 38, p. 335.

Preul, H. C. 1968. Contaminants in groundwaters near waste stabilization ponds. Jour. Water Poll. Control Fed. v. 40, p. 659.

Sawyer, C. N. and P. L. McCarty. 1967. Chemistry for sanitary engineers. McGraw-Hill Book Co., Inc., New York.

Vrooman, M. 1940. Complete sewage disposal for a small community. Water Works and Sewage.

Wastewater reclamation at Whittier Narrows. 1966. Publication No. 33, California Water Quality Control Board.