

LABORATORY APPLICATION OF SECONDARY SEWAGE EFFLUENT TO ARGILLACEOUS LIMESTONE

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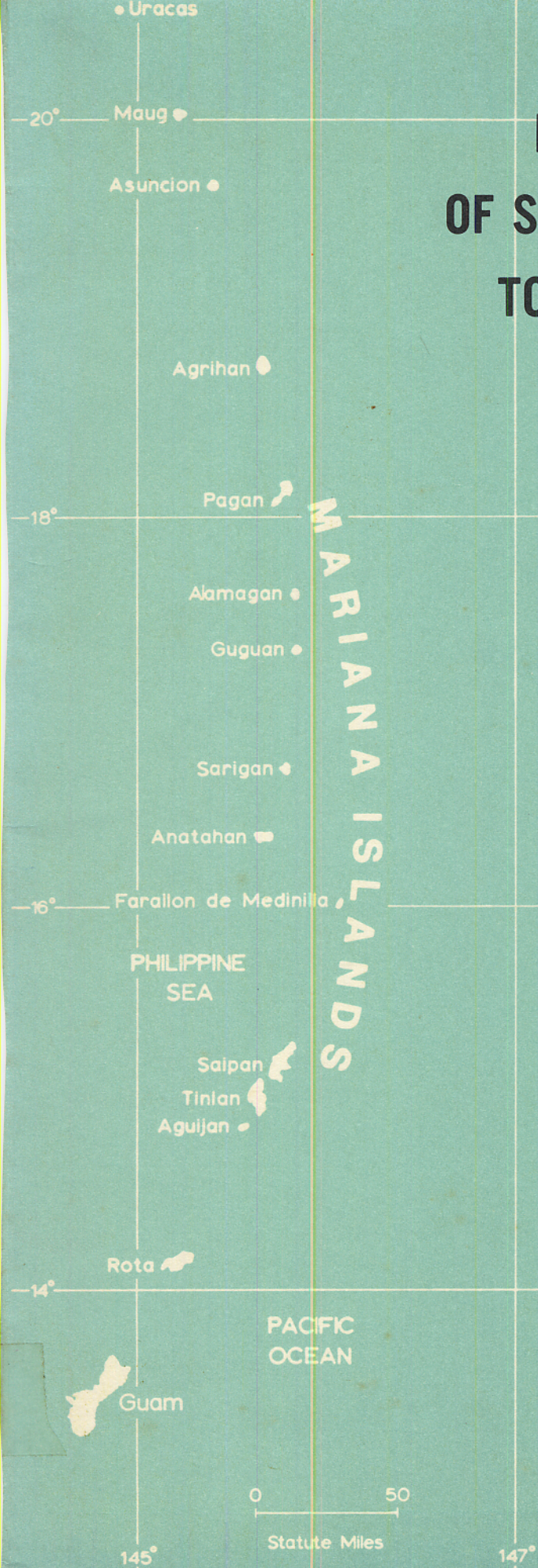
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*Water Resources
Research Center*

UNIVERSITY OF GUAM

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ABSTRACT

Secondary sewage effluent and river water (control) were applied to a series of laboratory lysimeter columns containing argillaceous limestone. Nitrates naturally deposited in the limestone were leached after semi-continuous water loading. Mass balance data of river water percolate with low nutrient input levels showed nitrogen removal and phosphorus release. Phosphorus release was attributed to fine particulate matter flushed from the lysimeters. River water leachate was generally high quality. Sewage effluents with high nitrate concentrations leached through the limestone media yielding mean percolate concentrations of 8.0 ± 0.4 and 14.3 ± 8.7 mg/l at a depth of 2.74 m. The limestone was unable to remove nitrogen. Phosphorus was initially stripped from the sewage effluent with 76 to 90% removal after percolating through 2.74 m of limestone media. Phosphorus breakthrough occurred in the top 0.91 m of limestone after 70% of water loading. The estimated phosphorus adsorption capacity was low at 0.011 kg P/m³. Coliform bacteria removal efficiencies in the sewage runs were >95% at the 0.91 m depth and >99% at the 1.83 m depth. In relation to the limestones' inability to remove nitrogen and phosphorus, the limestone infiltration/percolation system was concluded to be a disposal option and not a treatment alternative.

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INTRODUCTION

Potential sources of environmental water pollution should be managed to minimize and eventually eliminate any adverse effects. Point and non-point sources of pollution have been identified for Guam in a recent "208" study (GEPA, 1978). A majority of the point sources are storm drains (85 of 105 significant point sources). However, in terms of public health and environmental protection, the nine sewage discharges on Guam represent major obstacles to successful compliance with the Federal Water Pollution Control Act (FWPCA) of 1972 (P.L. 92-500) and with the revised national water policy presented in the Clean Water Act (CWA) of 1977 (P.L. 95-217). Relative to these laws, the upcoming decade (1980-1990) has two target dates: 1983 for *fishable and swimmable* waters; 1985 for *zero discharge* into waterways.

Emphasis for compliance with these goals (on Guam, in Micronesia and at many mainland sites) should be directed away from the conventional advanced wastewater treatment approach and center upon innovative and alternative (I/A) options for best practicable waste treatment technologies. Two general reasons for rejection of conventional approaches are escalating construction costs and substandard performance levels. The added constraints of high operation and maintenance costs and the necessity for energy conservation are overriding factors which must be realistically accounted for in this area of the world. The alternative investigated for compliance with the *goals* of the 80's is land application (LA). The innovative portion of the I/A approach addresses the use of limestone as a treatment medium for discharges from municipal sewage point sources.

Guam is an island (540 square kilometers) in the western Pacific Ocean which has the unique distinction of having obtained significant political and social development while at the same time having no heavy industry (the only major industry is tourism) nor meaningful agricultural economic development. The sources of pollution are self generated (autochthonous) with the operational sewage treatment plants and solid waste disposal sites representing a major portion of the pollutorial potential. Most of the commercial establishments and approximately 75% of Guam's population are located on the northern half of the island. This relatively flat northern limestone plateau contains a well developed groundwater lens. Potable water is pumped from this groundwater aquifer to supply a large portion of the freshwater consumptive needs of the population. Continued residential and commercial development in this area can potentially limit aquifer recharge by rainwater sources.

The water quality aspects of proposed groundwater recharge utilizing storm drain runoff have been addressed in previous studies; however, no work has been performed on Guam relative to the prospect of utilizing treated secondary (2°) sewage effluents. Although the primary goal of this study is to evaluate the LA alternative to conventional advanced wastewater treatment systems and therefore prevent surface water pollution, the secondary goals of groundwater recharge and evaluation of groundwater pollution potential are implicit in such an alternative.

OBJECTIVES

Land application (LA) of treated sewage effluents consists of many options, three of which are: irrigation of crops, overland flow and infiltration/percolation (I/P). Design considerations for such systems include analyses of hydraulic as well as influent water quality characteristics. The purpose of the study is to evaluate a portion of the water quality aspects of the I/P option. Actual design factors relative to limestone sites on Guam are relegated to future research.

Since the geology of the southern portion of Guam is impermeable volcanic bedrock overlaid by relatively impermeable clay soils, the only possible locations for I/P sites would be in the permeable limestone northern plateau. Land application options for southern Guam would include slow rate irrigation and overland flow. Specific water quality objectives for I/P systems consisting of a limestone medium include:

- i. evaluate the fate of nitrogen;
- ii. quantify the removal capacity relative to coliform bacteria;
- iii. determine the sorption capacity for phosphorus compounds;
- iv. evaluate the I/P option as an alternative to conventional advanced wastewater treatment processes;
- v. make preliminary estimates as to the viability of utilizing secondary sewage effluent for groundwater recharge.

LITERATURE REVIEW

The intent of water pollution control legislation is to maintain or establish quality water resources which pose no threat to public health or the environment. The Federal Water Pollution Control Act (FWPCA) of 1972 (P.L. 92-500) set forth national policies which stressed the design and construction of conventional wastewater treatment plants

(Jewell and Seabrook, 1979). Although land disposal of sewage effluents was considered, programs were funded, and billions of dollars were appropriated and spent for conventional systems. Concern has now arisen as to the adequacy of such technology because of escalating costs of conventional systems, substandard performance of systems once operational, and lack of recycle and reuse options (Alleman and Price, 1980). Young and Carlson (1975) pointed out that physical/chemical processes of conventional advanced wastewater treatment systems require large amounts of chemicals, highly skilled operators and considerable energy. Given these constraints, revisions of the FWPCA were formulated and presented in the Clean Water Act (CWA) of 1977 (P.L. 95-217). The land disposal concept was replaced by one of land treatment (Jewell and Seabrook, 1979). Properly designed and managed LA systems offer viable alternatives to conventional systems and incorporate recycling and reclamation concepts. The soil mantle can provide physical, chemical and biological treatment of applied wastewaters which is comparable to advanced wastewater treatment technologies (Pound and Crites, 1975, Malhotra and Myers, 1975; Hadeed, 1978; Thomas and Reed, 1980; Lance et al., 1980). The CWA specifically includes LA as a best practicable waste treatment technology.

Wastewater discharged to land treatment systems would be directed away from surface waters. However, the resultant decreased potential for surface water pollution would be offset by possible groundwater contamination. After implementation of the FWPCA, States began requiring unnecessarily stringent preapplication treatment requirements for LA systems (Jewell and Seabrook, 1979). Minimum pretreatment requirements included use of secondary sewage treatment with the State of California requiring tertiary treatment in some cases (e.g. Water Factory 21, Orange County). Environmental Protection Agency (USEPA) Administrator Costle (Memo, 3 October 1977) officially advocated use of land treatment processes to renovate and reuse wastewater:

- i. materials should be cycled to return them to where they were generated;
- ii. land treatment is capable of achieving levels of removal comparable to the best available advanced wastewater treatment techniques;
- iii. applicants who do not utilize land treatment must justify the rejection of the land treatment alternative;
- iv. wastewater treatment facilities required to provide excessive LA pretreatment will not be funded by the USEPA (wastewater input to LA systems is not required to meet secondary standards).

The primary goal of these new policies remains to protect groundwater resources since effluent from LA sites must meet primary drinking water standards (Thomas and Reed, 1980).

Sewage treatment technology in the two decades preceding 1970 was directed towards two basic discharge concepts: the solution to pollution is dilution; the assimilation capacities of rivers and streams (Phelps, 1944). Mixing zones were established as areas at and below outfall sites where water quality standards were not strictly enforced (Emrich, 1978). Sewage effluents were and are still discharged into the nation's waterways under the guise of effluent standards or stream standards (Nemerow, 1971) with the idea of utilizing the dilution and the biological treatment (assimilation) potentials of these surface waters. These same concepts apply to land treatment system: groundwater dilution factors; assimilatory capacity of the soils overlying the groundwater resource; mixing zone concept in areas below LA site.

The CWA has initiated a major redirection in the wastewater engineering industry by including policies which advocate the development of innovative and alternative (I/A) technologies (Alleman and Price, 1980). A three year period of authorization (FY 1979-FY 1981) of I/A options of wastewater treatment has been established with the following goals (goals which are critically relevant to Guam and Micronesia):

- i. recycle and reuse;
- ii. energy conservation;
- iii. cost reduction (construction as well as operation and maintenance costs).

Even though I/A technology includes options other than LA, it is evident that LA of wastewaters will play an important role in the future of water pollution control programs. This is primarily because LA fulfills criteria for being an inexpensive, simple and functionally reliable treatment technology (Alleman and Price, 1980). Given these criteria, it appears that LA (or some other I/A option) offers a possible technology for attainment of the *zero discharge* goal scheduled for 1985 implementation.

The direct beneficial aspect of LA is the return of nutrients to the soil (Pound and Crites, 1975). There are three general types of LA for wastewaters: irrigation, overland flow and infiltration/percolation (I/P). The method pertinent to the study reported herein is the I/P option; however, the crop irrigation option is similar due to the fact that both options are applicable to permeable soils. Typical hydraulic conductivities for argillaceous limestone range from 6 to 60 m/day with

other types of limestone having conductivities as high as 600 m/day (Mink, 1976). The overland flow method is applicable to relatively impermeable soils and is therefore a possible option for southern Guam. The most efficient method of wastewater reclamation is the irrigation option. Nutrient uptake by the cover crop supplements the wastewater renovation achieved in the soil mantle. The use of the irrigation option poses specific problems including: the presence of aerosols (if spray irrigation is utilized); the build-up of salts; accumulation of heavy metals; presence of toxic material. These problems must be investigated (relative to the quality of the influent wastewater, the crop planted and the type of soil at the site) prior to any large scale irrigation operation. Information reviewed in this study deal with the water quality aspects of nutrient (nitrogen and phosphorus) and bacterial (total and fecal coliform) components of a limestone I/P system. Detailed information on other aspects of LA methodology may be obtained by referring to the yearly literature review presented in the Journal of the Water Pollution Control Federation (JWPCF).

Since groundwater is the premier water resource on Guam (Mink, 1976), every effort must be made to protect its integrity. Rainwater infiltrates the porous limestone and recharges the groundwater lens. The estimated annual rainfall on Guam is between 2.2 and 2.5 m which represents an average daily input of 3.4 billion liters (GEPA, 1978). Even assuming that only 25% of this rainwater input falls on undeveloped northern areas of Guam, it is doubtful that future application of sewage effluents will have any significant effect relative to the groundwater supplies on Guam. Conversely, rainwater inputs plus groundwater supplies offer infinite dilution capabilities should LA be selected as an alternative to conventional advanced wastewater treatment.

The "208" study (GEPA, 1978) identified 105 significant point sources of pollution. Only 17 point discharges were in northern Guam and these were all coastal discharges. Northern discharges, located within 610 m of the shoreline in the mixing zone, present minimal potentials for groundwater pollution. Since I/P systems should be located (ideally) in areas where groundwater moves away from the aquifer (Malhotra and Myers, 1975), the 610 m wide mixing zone seems a perfectly suited zone for LA sites. Non-point sources of pollution were classified from five types of activities: construction; agriculture; urban runoff; solid waste disposal; sewage disposal. Rating these non-point sources utilizing *pollutional potential points*, urban stormwater runoff was concluded to have the largest negative impact (GEPA, 1978).

Zolan et al. (1978b) characterized urban runoff water quality for central and northern Guam (areas excluding Agana and Tamuning) as only lightly polluted. Urban runoff lysimeter studies evaluating the filtering and adsorption capacities of Guam clay, Chacha clay and

Mariana limestone media (Zolan et al., 1978a) quantified: nitrate-nitrogen ($\text{NO}_3\text{-N}$) removal in only Marianas limestone; orthophosphate-phosphorus ($\text{PO}_4\text{-P}$), total phosphorus (TP), total coliform (TC) and fecal coliform (FC) removals in each medium. When secondary (2°) sewage effluents are applied to land, typical LA treatment removal efficiencies are: N, 0-80%; P, 8-96%; coliform bacteria, 98-100% (Pound and Crites, 1975).

Cationic ammonium ion (NH_4^+) sorbs to soil particles and anionic nitrate ion (NO_3^-) leaches through the soil mantle (Lance, 1975; Fenn and Kissel, 1976; Sikora and Corey, 1976; Freeze and Cherry, 1979; Uradnisheck and Corcoran, 1979). Reactions and processes pertinent to the fate of N in soil systems (Schmidt, 1974; Ardakani et al., 1975; Smith and Myott, 1975) are listed below with estimates of major and minor importance in I/P systems:

- i. sorption (a function of the cation exchange capacity of the soil) - major;
- ii. nitrification, $\text{NH}_4^+ \xrightarrow{\text{Nitrosomonas}}$ nitrite (NO_2^-) $\xrightarrow{\text{Nitrobacter}}$ NO_3^- (aerobic biological process involving obligate autotrophs) - major;
- iii. Denitrification, $\text{NO}_3^- \longrightarrow$ nitrous oxide (N_2O) \longrightarrow N gas†(N_2) (anaerobic biological process involving facultative heterotrophs) - major;
- iv. volatilization of ammonia (NH_3), requires considerable air/water contact - minor;
- v. chemodenitrification, requires $\text{pH} < 5$ and high $\text{NO}_2\text{-N}$ concentration - minor;
- vi. assimilation, incorporation of N into soil microbes - minor.

The principal N component of 2° sewage effluents is NH_4^+ . Efficient removal of N from land applied 2° effluents requires the sequential processes of sorption, nitrification and denitrification. Nitrification is a biological process in which 4.6 mg oxygen (O_2) are consumed per mg N oxidized. A source of organic carbon (Org C) is necessary for denitrification to proceed in the presence of denitrifying bacteria. Depending upon the carbon source, this process requires approximately 1 mg Org C per mg $\text{NO}_3\text{-N}$. Various hydraulic management schemes have been developed to increase N removal in LA systems (Lance and Whisler, 1972; Lance et al., 1976).

Dugan et al. (1976) evaluated the fate of N in chlorinated 2° effluents applied to laboratory soil (Oxisol) columns in Hawaii under continuous and intermittent hydraulic loading schedules. Mass balance and removal summaries were calculated from the Dugan et al. (1976) data (Table 1). Continuous and intermittent results were similar; decreases in NH_4^+ (sorption), organic N (Org N), and NO_2^- . The fate of $\text{NO}_3\text{-N}$ differed between the two types of loading. Anaerobic conditions (continuous) suppressed nitrification and promoted denitrification with subsequent $\text{NO}_3\text{-N}$ removal. The decrease in the N content of the column effluent became more pronounced with time. A total of 2281.8 mg N was deposited in the column given an input of 3106.3 mg N. Aerobic conditions (intermittent) promoted nitrification which produced $\text{NO}_3\text{-N}$ from sorbed NH_4^+ . The increase in column effluent nitrogen (mostly $\text{NO}_3\text{-N}$) relative to the column influent occurred throughout the intermittent experiment. An excess of 102.8 mg N came from the N pool present in the column prior to commencement of the run. The highest percolate $\text{NO}_3\text{-N}$ concentrations measured were 12.5 mg/ℓ and 73.5 mg/ℓ for the continuous and intermittent runs respectively.

Field experiments were performed with the same soil type utilized in Dugan et al. (1976) and groundwater pollution potential was quantified when chlorinated 2° municipal sewage effluents were applied to sugarcane acreage (Lau, 1979). The median LA influent concentrations were 20 mg N/ℓ (largely $\text{NH}_3\text{-N}$ with some Org N and $\text{NO}_3\text{-N}$) and 11 mg P/ℓ. The corresponding percolate at times had N in excess of 10 mg N/ℓ while P was effectively removed.

The fate of phosphorus in wastewater effluents applied to soils depends upon the P fixing capacity (sorption and precipitation) of the soil medium (Schneider and Erickson, 1972; Enfield and Bledsoe, 1975; Reneau and Pettry, 1976; Sikora and Corey, 1976; Reynolds et al., 1980). Whenever sorption is a primary removal mechanism, the possibilities of saturation of the sorption sites and subsequent breakthrough must be evaluated. Degrees of phosphorus adsorption capacity are listed in Table 2. Burton et al. (1979) reported a phosphorus adsorption capacity value of 0.176 kg/m³ (medium capacity) for a site at the Water Quality Management Project (WQMP: Michigan State University). Once P loading exceeds this level, no further P sorption will occur and applied P will percolate through the soil mantle (breakthrough). An equally important P removal mechanism is related to the formation of insoluble phosphate compounds of Al (aluminum), Fe (iron) and Ca (calcium). Due to significant sorption/precipitation/filtration processes in soil systems, soluble $\text{PO}_4\text{-P}$ was concluded to be the best indicator of groundwater P pollution (Reneau and Pettry, 1976).

Studies at Pennsylvania State University (Kardos and Hook, 1976) quantified <3% of the P applied at four sites irrigated with 2° effluents for periods of 9 to 11 years leached through the soil mantle. Reynolds

Table 1. Nitrogen mass balances and per cent removal data (from Dugan et al., 1976).

Hydraulic Loading	NH ₃ -N	Org N	NO ₂ -N	NO ₃ -N	Total N
	mg N				
Continuous					
Influent	1718.8	546.0	60.7	780.8	3106.3
Effluent	58.1	167.0	10.0	589.4	824.5
Removal (%)	97.	69.	84.	25.	73.
Intermittent					
Influent	528.7	151.8	12.9	49.3	742.7
Effluent	13.2	31.4	0	800.9	845.5
Removal (%)	98.	79.	100.	--	--
Increase (%)				1525.	14.

Table 2. Phosphorus adsorption capacities (from Schneider and Erickson, 1972).

Classification	Phosphorus Adsorption Capacity
	(kg/m ³)
Very high	>0.249
High	0.199 - 0.249
Medium	0.162 - 0.199
Low	0.124 - 0.162
Very Low	<0.124

et al. (1980) concluded that no serious harmful effects to groundwater occurred as a result of long term wastewater irrigation at a Tooele (Utah) site.

Factors affecting the survival of enteric bacteria in soil systems (Gerba et al., 1975) include: soil moisture, pH, temperature, and the presence of organic matter. Bacteria survive longer and travel farther into the soil under saturated flow conditions (high soil moisture). Bacterial survival was found to be 4 - 7 days in sandy soils and > 42 days in loamy soils (Gerba et al., 1975). Indicator organisms and potential pathogenic bacteria were almost completely removed after short travel distances (30 cm lateral and 8 cm vertical) through unsaturated soils (Hagedorn and McCoy, 1979). Specific removal mechanisms are straining and adsorption. The resultant decreases in bacterial concentrations of leachates are exponential with increasing depths of filtration where 97 - 100% removals have been measured at existing LA sites (Gerba et al., 1975).

The use of chlorinated sewage effluents decreased biological activity (Petty and Peterson, 1979) and aided in the destruction of enteric bacteria (Baumann et al., 1962). However, caution must be exerted because chlorination of wastewaters having high $\text{NH}_3\text{-N}$ concentrations will lead to the formation of chloramines (AWWA, 1979). In LA systems, such prechlorination is not necessary due to the high removal efficiencies of pathogenic bacteria from the wastewater as it percolates through the soil.

MATERIALS AND METHODS

Lysimeter Column Design

Clear polyvinyl chloride (PVC) lysimeter columns similar in design to ones used in Zolan et al. (1978a) were utilized in the present lysimeter studies. PVC pipe measuring 1 m high with an inside diameter of 15 cm was PVC welded to a bottom-flange. A plexiglass baseplate with a PVC gate valve was bolted and glued (silicone cement) to the flange. A bottom filter was placed in the bottom of a column. The filter consisted of 2-3 cm of limestone (1.0-1.5 mm) sandwiched between 1.25 mm mesh plastic screen. This filter prevented clogging of the shutoff valve and reduced the silt/clay load in the percolate. The 8 lysimeters were placed on a table constructed to provide ample space and ease in sample collection.

Limestone/Soil Media

The limestone tested was the Agana argillaceous member of the Mariana limestone. The characteristics and distribution of this limestone are presented in Tracey et al. (1964). Carroll and Hathaway (1963) determined the grain-size distribution, pH, chemical composition,

organic carbon, free iron oxide, ion exchange capacity and mineralogy of the overlying soil type (Chacha clays) which also intermixes with the argillaceous limestone. The petrology of the limestone was analyzed by Schlanger (1964).

The Agana argillaceous member is located on the southwestern portion of the northern limestone plateau and along the southeast coast (Figure 1). It is a lagoonal deposit of detrital and molluscan facies contaminated with fine mud and silt eroded from the adjacent volcanic highlands. The amount of clay incorporated into the limestone is low. However, there can be an extensive amount of clay deposition in cavities of weathered limestone. The Chacha clay which developed on the argillaceous limestone (Figure 1) tends to have a lower pH (5.5 to 6.9) and less effective leaching. These clays are a yellowish brown, firm plastic lithosolic clay intergrading with firm red clay (Saipan) and a brownish clay (Yona). Chacha clays have very high clay content, averaging 93 percent, with consequent low silt content, averaging 3.9 percent. In chemical composition it averages 41 percent SiO_2 , 36 percent Al_2O_3 , 19 percent Fe_2O_3 , and 1 percent TiO_2 . The free iron oxide is low, averaging 5.9 percent. The principal iron oxide is goethite, which is probably due to a shorter period of soil formation. The organic carbon content of the surface soil averages 2.2 percent. The average ion-exchange capacity is 12.7 milliequivalents per 100 grams. There are practically no heavy minerals, traces of magnetite and feldspar, contained in the insoluble residue of the limestone (Schlanger, 1964).

The 500 ℓ of argillaceous limestone used in this study was collected from a recently cut bank in the Maina area (Figure 1). The yellowish limestone which contained numerous fossil molds was interspersed with pockets of fine yellowish-brown to red clays. The gravel component larger than 1.27 cm ($\frac{1}{2}$ inch) was removed by screening prior to collection.

The collected limestone/soil was stored in covered 200 ℓ plastic vats. The moisture content (dried at 105°C) of the stored material averaged 12% at the time of column loadings. The specific gravity of limestone loaded into columns averaged $2.55 \pm .09$. The porosity of loaded columns averaged $.389 \pm .04$ based on 112 1- ℓ lifts with an average final compacted total lift volume of $898 \pm 57 \text{ cm}^3$ and a soil lift volume of 549 cm^3 . The organic content was low, generally less than 2%.

The argillaceous limestone was sieved before and after the river test series. Limestone samples were taken from the top, middle and bottom of 8 tested lysimeters, well mixed and subsampled for sieve analysis. The initial batch limestone had an average component breakdown of 15% gravel, 64% sand and 21% silt/clay. The tested limestone samples averaged 18% gravel, 58% sand and 24% silt/clay. The sand and silt/clay size percentages were statistically different ($p=0.5$) after the test series with a t-test (Table 3). There was a smaller sand percentage and greater silt/clay content after water loading. Fine sediment input and removal as a result of water loading could be discounted as the source of variation. Therefore, there was mechanical and possibly some chemical breakdown of the sand fraction in the loaded lysimeters.

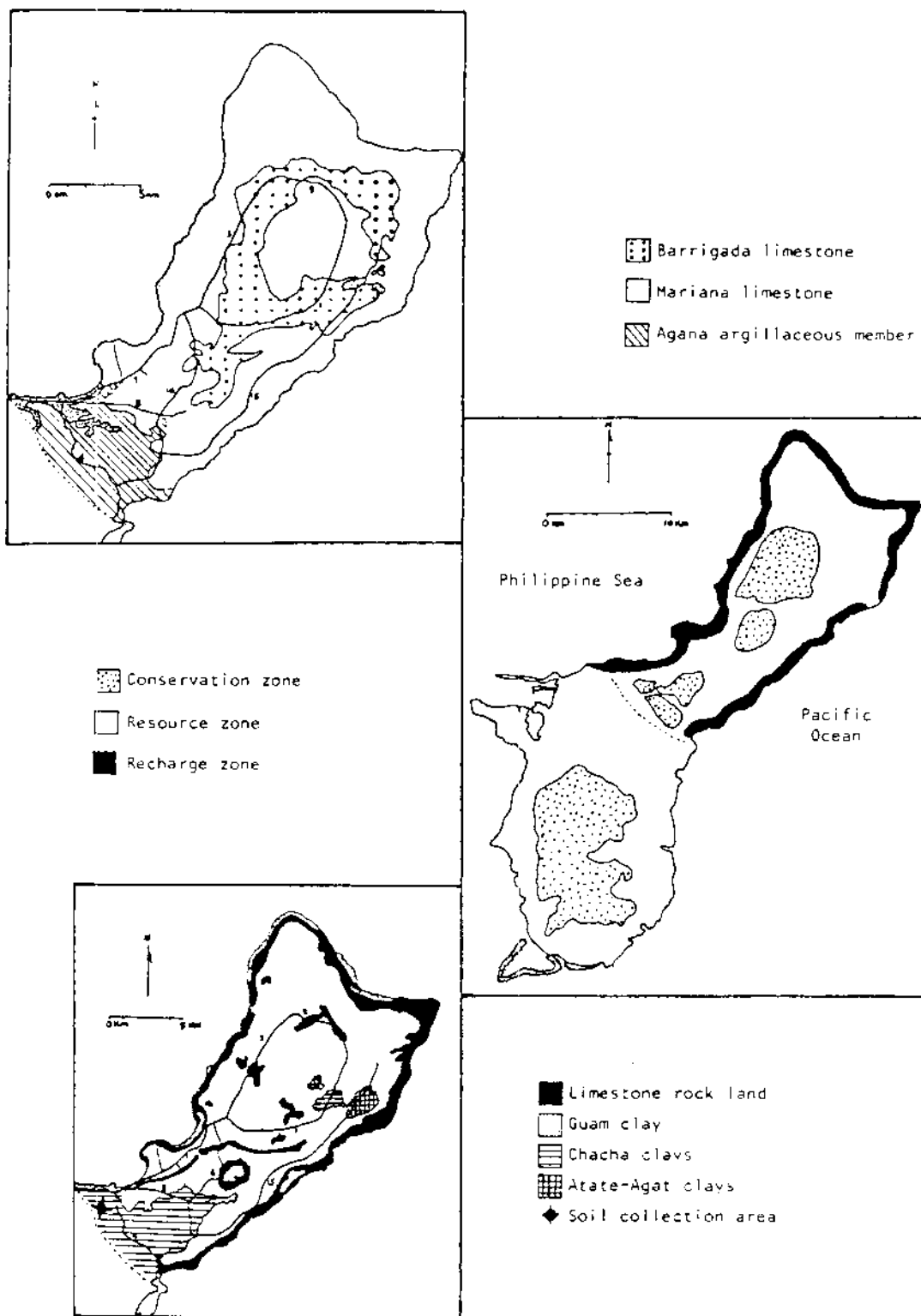


Figure 1. Water zonation of Guam, limestone formations and soil classification of Northern Guam.

Table 3. Size classification percentages of limestone before and after river water series.

	Gravel >5mm	Sand 5mm. to 75 μ m	Silt/Clay <75 μ m
Before	14.9 \pm 4.0	64.2 \pm 3.8	20.9 \pm 1.2
After	18.2 \pm 1.6	57.6 \pm 0.7	24.0 \pm 0.9
t_s .05 = 2.447	n.s.	t = 3.36*	t = 4.15**

n.s. = not significant
 * = significant @ .05
 ** = significant @ .01

Water Sources

River and secondary sewage effluent waters were tested in the lysimeter studies. River water was obtained from the Ylig river potable-water pumping and filtering station. The water was sampled at the pump before it entered the filtering system. The larger floating organic matter was screened at the pump site. The secondary effluent was collected at the Baza Garden sewage treatment plant. The water was taken in the effluent drain after chlorination. The treatment plant utilizes an extended aeration process. It generally receives .07 MGD with a design capacity of 0.6 MGD. In regards to nitrogen, the Baza effluent is not typical secondary effluent. The concentration of ammonia-nitrogen is low with elevated nitrate-nitrogen levels.

The river and effluent waters were collected in acid-washed (10% HCL) 50-l jugs and returned to the laboratory for physical, chemical and bacteriological water analyses. Lysimeter water loading began 4-5 hours after sampling.

The Baza effluent was dechlorinated in accordance with *Standard Methods* (1975) for BOD analysis. An experiment was conducted to ascertain if dechlorination with either sodium thiosulfate or aeration would affect the physical and chemical effluent qualities. Four 2-ℓ glass jars were filled with effluent that had a chlorine residual of 1 mg/ℓ. The effluent was left stagnant, aerated, dechlorinated and dechlorinated/aerated for 24 hours. Physical and chemical water parameters were analyzed for the initial batch water and each of the experimental jars (Table 4). Aeration and dechlorination did not affect the specific conductance, chloride, total alkalinity, total hardness, phosphorus, and ammonia-nitrogen levels in the tested effluent. The nitrite-nitrogen and residue levels were consistently higher in all the test effluents as compared to the initial batch effluent. Aeration increased the pH and turbidity levels. The aerated, dechlorination and dechlorinated/aerated samples had increased nitrate-nitrogen levels with erratic TKN concentrations. Dechlorination of the effluent with sodium thiosulfate without the use of aeration was established as the method, since it minimized the changes in the water quality parameters.

Physical, chemical and bacteriological characteristics of the Baza effluent as recorded by PUAG for the period between March 1976 to August 1979 are presented in Table 5. The plant is regarded as an efficient secondary treatment facility since BOD removal averages $91 \pm 9\%$. Suspended solids removal ranges between 65 to 97% and settleable solids are usually negligible.

Soil/Water Loading Procedures

The lysimeters were loaded with argillaceous limestone to a uniform depth and similar compaction. The limestone was well mixed prior to loading. Lysimeters were loaded with $14 \pm \frac{1}{2}\%$ of limestone in 1ℓ lifts. Each lift was lightly tamped (10-15 light blows) with a 2 cm tamper and further packed with a rod to reduce voids. A 14 cm tamper was used to level the limestone surface and further compress the lift. The surface layer was lightly disrupted with a rod to eliminate a high density area between successive lifts. The tightest compaction was adjacent to the lysimeter walls. This was done to minimize channeling of percolating water down the column walls. The lysimeters were soil loaded 2 to 3 days before water loading.

The argillaceous limestone in each lysimeter was flushed with 10ℓ of deionized water. The first 5ℓ of water was used to saturate the limestone, requiring 30 to 45 minutes. The gate valve was opened to begin drainage after saturation with an additional 5ℓ of water percolated through the column. A percolation rate of 15 to 20 minutes per liter passing was maintained for flushing and subsequent percolation test runs.

Table 4. Effect of aeration and dechlorination on secondary sewage effluent. The units are in mg/l unless otherwise specified.

	pH	Turbidity NTU	Specific conduct. $\mu\text{mhos/cm}$	Total nonfiltrable residue	Total filtrable residue	Chloride	Total Alkalinity mg/l @CaCO ₃	Total Hardness mg/l @CaCO ₃
Initial water	7.58	2.4	705	9	492	74.5	190	219
Control	7.80	1.8	715	4	604	71.0	208	219
Aeration	8.30	5.0	700	5	652	76.3	192	215
Dechlorination	7.68	1.8	713	1	652	71.0	180	217
Dechlorination/Aeration	8.30	3.5	700	4	676	76.3	184	209
	TKN	NH ₃ -N	NO ₂ -N	NO ₃ -N	Total Phos.	Total Soluble Phos.	Ortho- Phos.	
Initial water	.65	.09	.51	10.9	4.86	4.31	4.12	
Control	.16	.10	1.71	10.8	4.54	4.62	4.41	
Aeration	.11	.07	1.74	12.3	3.92	4.00	4.41	
Dechlorination	.64	.10	2.03	12.3	4.46	5.15	4.63	
Dechlorination/Aeration	.31	.11	1.71	12.5	4.58	4.62	4.41	

Table 5. Discharge monitoring data for Baza Gardens sewage treatment plant. These data were supplied by the Public Utility Agency of Guam (Government of Guam, PUAG, Monitoring Reports for 1976-1979).

Date Sampled	Flow (MGD)	pH	Dissolved Oxygen (mg/ℓ)	Settleable Solids (mg/ℓ)	Suspended Solids (mg/ℓ)	COD (mg/ℓ)	BOD ₅ (mg/ℓ)	Fecal Coliform (Cts/100mℓ)	Chlorine Residue (mg/ℓ)
8/5/79	-	8.1	5.9	0.0	8.5	19.6			
6/6-7/79	0.4	7.9	5.4	0.0	8.9	15.6	22.5	0	1.6
5/25-26/79	0.28	7.8	N/S	0.0	10.0	51.9	9.4	0	
4/22/79	0.15	8.2	6.1	0	9.5	19	3.0	0	
3/25/79	0.07	7.8	4.7	Trace	7.5	15.9	1.5	0	
2/24-25/79	0.08	8.0	5.8	200	4.8	17.5	.05	0	
1/18-19/79	0.14	7.8	4.8	0.0	39.1	25.0	2.6	0	1.5
10/12/78		7.9	6.0	0.0	41.3	23.3	3.6	0	
10/5-6/78		7.8	5.3	0.0	10	23.7	1.2	0	
9/20/78		8.0	6.2	0.3	12.3	46.2	-	0	
7/26/78		8.2	5.9	2.0	19.2	N/S	58.9	0	0.5
4/1/78-6/30/78		7.9		0.1	9.1		19.2	60	
1/1/78-3/31/78		7.9		0	9.6		31.2	N/S	
10/1/77-12/31/77		7.4		0.2	6.3		15.4	0	
7/1/77-9/30/77		7.6		0.0	5.1		5.4	5	
6/1/77-6/30/77		7.6					23.4	125	1.2
3/1/77-5/31/77		7.5					2.3	3	2.3
12/1/76-2/29/77		7.8					3.0	7	1.6
9/1/76-11/30/76		7.7					5.8	8	1.8
6/1/76-8/31/76		8.5							
3/1/76-5/31/76		7.7					1.9	0	1.3

The columns were allowed to drain for a period of 20-30 hours. This initial flushing helped remove most of the silty-clays which had accumulated in the bottom filter as a result of the loading procedure. There was a 2 to 5 cm compaction of the limestone column at the end of the flushing.

A second 10% flushing was done just before initiating a test run series. River water was used for flushing in the river water test. The water was passed through a fine mesh screen (20-30 mesh) to remove small floating organic matter. Double deionized water was used for flushing the sewage test runs. Lysimeters were not allowed to completely drain before beginning the testing sequence. The flush water was not analyzed for water quality.

Lysimeters were sequentially loaded with water in a test series. Water passing the first column was transferred in 2ℓ aliquots to the top of the second column which in turn was transferred to the third column and so forth. Water samples for physical, chemical and bacteriological analyses were taken from the bottom of a column after a 10% volume of water had been passed through the lysimeter. The 2ℓ volume of analyses water was not accounted in subsequent column water loadings. As a result, the lysimeters had greater quantities of water percolated than the liters passing indicate. However, the water sampling sets between columns were still obtained at 10% intervals. All glassware was acid-washed (10% HCl) between water transfers and sampling sets.

The river and sewage test series were essentially continuous water loadings. Lysimeters were not allowed to completely drain once a test series was initiated. River and Sewage I test series, which had 8 and 7 lysimeters respectively in a sequence, were left saturated for periods up to 10 hours between water loadings. Sewage II test series with 3 lysimeters was continuously water loaded over a 3-day period. The River series was water loaded and analyzed until at least 50% had passed 7 lysimeters in the series. The Sewage I series was stopped when 50% had passed and been analyzed from the first column with the sixth and seventh columns analyzed only at 10% passing. This series was interrupted as a result of an extended power outage and subsequent air conditioner failure. The Sewage II series was stopped when 70, 60 and 50% had passed the first, second and third columns respectively.

Water Parameter Analyses

The physical, chemical and bacteriological parameters were analyzed in accordance with *Standard Methods for the examination of water and wastewater*, 14th ed. (1975). Techniques presented by Strickland and Parson (1971) were used to determine orthophosphate phosphorus, nitrate

and nitrite-nitrogen. The indophenol technique (Solorzano, 1969) was used to determine ammonia-nitrogen. Table 6 presents the methods of analysis used for each parameter and the parameters examined in each of the test series (River, Sewage I and Sewage II).

All water quality parameters from the lysimeter sets were analyzed within 12 hours after collection. Bacteriological samples were usually filtered and placed in the incubators within the first 10 minutes. The pH, specific conductance, turbidity, residue, chloride, total alkalinity and hardness, and ammonia-nitrogen samples were analyzed in the following hour. The remaining water parameters were analyzed in larger batches toward the end of a loading sequence, approximately 8 to 10 hours.

RESULTS AND DISCUSSION

The primary objective of this research was to make a preliminary evaluation of the land application (LA) option of infiltration/percolation (I/P) as an advanced wastewater treatment alternative. Secondary (2^o) sewage effluent was applied to a set of laboratory lysimeter columns containing an argillaceous limestone medium. Wastewater treatment performance was monitored with respect to specific physical, chemical and bacteriological parameters. The fate of nitrogen (N), phosphorus (P), total coliform (TC) and fecal coliform (FC) was analyzed due to the importance of these constituents relative to potential groundwater pollution. Prior to the two sewage experiments (Sewage I and II), a control experiment was performed utilizing river water. This control permitted evaluation of N and P flux under conditions of low level inputs. The control provided a basis for comparison and facilitated assessment of potential adverse groundwater impacts of applying sewage effluents to I/P systems.

Column influent was applied semi-continuously (River and Sewage I) and continuously (Sewage II) with effluent water quality parameters measured at 10ℓ intervals. Relative to the laboratory column, a loading of 10ℓ represented 56 cm of applied water or wastewater; therefore, a 70ℓ load to Column I in the River and Sewage II experiments represented a loading of 4 m of influent. Quantification of hydraulic variables (loading and application rates) was not attempted in this study. Analytical frequency (every 10ℓ) and maximum loading (70ℓ) were selected due to time and manpower constraints; therefore, the wastewater treatment evaluations presented below describe systems receiving large quantities of sewage in short periods of time (high application systems).

Water quality data for the River, Sewage I and Sewage II experiments are listed in Appendix A. Mass balances calculated from these data are presented in Appendix B. The mass balance calculations include simplifying assumptions and therefore only estimate the nutrient and bacterial fluxes.

Table 6. Physical, chemical and bacteriological parameters and methods used in analysis. All standard methods of analyses were performed according to the 14th edition (1975). 5

PARAMETER	RIVER TEST		SEWAGE TEST		METHOD	REFERENCE
	I	II	I	II		
PHYSICAL.						
pH	x	x	x	x	pH specific ion meter/combination electrode	Orion
Specific Conductance	x	x	x	x	Wheatstone bridge/probe	Standard Methods
Turbidity	x	x	x	x	Nephelometer (NTU)	Standard Methods
Total Nonfiltrable Residue	x	x	x	x	Glass fiber filtration	Standard Methods
Total Residue	x	x	x	x	Evaporation at 105°C	Standard Methods
Total Filtrable Residue	x	x	x	x	Calculation	Standard Methods
CHEMICAL.						
Chloride					Specific ion meter/Cl probe	Orion
Total Alkalinity	x	x	x	x	Potentiometric titration/HCl	Standard Methods
Total Hardness	x	x	x	x	EDTA Titration	Standard Methods
Total Kjeldahl Nitrogen	x	x	x	x	Digestion/distillation/nesslerization	Standard Methods
Ammonia-Nitrogen			x	x	Indophenol	Solorzano, 1969
Nitrite-Nitrogen	x	x	x	x	Photometric	Strickland and Parson, 1971
Nitrate-Nitrogen	x	x	x	x	Cadmium reduction	Strickland and Parson, 1971
Total Phosphorus	x	x	x	x	Persulfate digestion/ascorbic acid reduction	Standard Methods
Total Soluble Phosphorus	x	x	x	x	Filtration/digestion/ascorbic acid reduction	Standard Methods
Orthophosphate-Phosphorus	x	x	x	x	Ascorbic acid reduction	Standard Methods
BACTERIOLOGICAL						
Total and Fecal Coliform Bacteria			x	x	Membrane filtration	Standard Methods

Any inconsistencies in the mass balance data between successive 0.91 m layers of limestone are primarily due to the inadequacy of these assumptions. Influent parameter concentrations were measured for batches of collected water and wastewater. The concentration of the entire volume of a particular water batch was assumed to be constant. Effluent parameter concentrations were assumed to apply for the entire preceding 10ℓ volume (River experiment last volume was 20ℓ):

- i. influent mass = influent concentration * volume loaded;
- ii. effluent mass = effluent concentration * volume of percolate.

Mass balances were calculated (effluent mass - influent mass) where positive values indicated release (effluent mass > influent mass) and negative values represented removal (effluent mass < influent mass).

The control (River) and 2° sewage effluent (Sewage I and II) experiments are presented separately. Tabular summaries of mass balances are presented in tables 7-9 with graphical representations of pertinent water quality parameter concentrations versus depth of medium presented in figures 2-14. In these figures: inverse relationships indicate removal (decrease in percolate concentration with depth); direct relationships indicate release (increase in percolate concentration with depth); infinite slope (vertical line) identifies no change in percolate concentration with depth (conservative substance).

River Water

Mass balance summaries and mean influent concentrations for N and P are listed in Table 7. The influent ammonia-nitrogen concentration ($[\text{NH}_3\text{-N}]$) was <0.010 mg/ℓ for the first 4 batches of river water loaded to the column; therefore, this analysis was discontinued. The erratic total Kjeldahl nitrogen (TKN) values were due to the lack of precision and accuracy of the analytical technique at low concentrations of organic N (Org N) and $\text{NH}_3\text{-N}$; these data are suspect. The consistent results relative to the N/P fluxes in the control experiment were: low orthophosphate-phosphorus ($\text{PO}_4\text{-P}$) and nitrite-nitrogen ($\text{NO}_2\text{-N}$) concentrations in the influent and leachate (conservative substances at low concentrations); nitrate-nitrogen ($\text{NO}_3\text{-N}$) input was low and increased with depth. The release of $\text{NO}_3\text{-N}$ was due to the flushing effect that the river water had upon the limestone. Even though the columns were rinsed with deionized water (10ℓ) and river water (10ℓ) prior to the filtration experiment, the N present in the limestone medium at the time of collection (N deposited under natural conditions) was not leached out until 30ℓ of control experiment river water had percolated through the soil column (Figure 2).

Table 7 . Mass balance summary - River water (Balance = Effluent-Influent)

Nitrogen, mg N (+) Release; (-) Removal

<u>Layer</u>	<u>Depth, m</u>	<u>NO₃-N</u>	<u>NO₂-N</u>	<u>TKN^a</u>	<u>Total N^b</u>
I	0.91	+2.35	-0.02	-12.42	-10.09
II	1.83	+1.69	-0.05	+ 1.91	+ 3.55
III	2.74	+1.21	0	- 4.53	- 3.32
IV	3.66	+2.28	-0.03	+22.11	+24.36
V	4.87	+1.53	+0.04	-20.01	-18.44
VI	5.49	+0.66	-0.02	+23.85	+24.49
VII	6.40	+2.78	0	-26.66	-23.88
Totals:		+12.50	-0.08	-15.75	- 3.33
Mean Influent N, mg/ℓ		0.013	0.002	0.346	0.361
± Standard Deviation		±.006	±.001	±.358	±.357
(7 Data Points)					

Phosphorus, mg P

<u>Layer</u>	<u>Depth</u>	<u>PO₄-P</u>	<u>TSP^c</u>	<u>PART P^d</u>	<u>Total P^e</u>
I	0.91	+0.39	+0.62	+2.61	+3.23
II	1.83	-0.19	-0.30	-1.72	-2.02
III	2.74	+0.42	+1.74	+2.28	+4.02
IV	3.66	-0.15	-0.59	-1.81	-2.40
V	4.87	+0.16	-0.85	+0.98	+0.13
VI	5.49	-0.21	+0.89	+1.77	+2.66
VII	6.40	0	-0.63	-1.83	-2.46
Totals:		+0.42	+0.88	+2.28	+3.16
Mean Influent P, mg/ℓ		0.003	0.031	0.013	0.044
±Standard Deviation		±.004	±.062	±.016	±.076
(7 Data Points)					

a TKN = Total Kjeldahl Nitrogen

b Total N = (NO₃-N) + (NO₂-N) + TKN

c TSP = Total Soluble Phosphorus

d Part P = Particulate P

e Total P = TSP + Part P

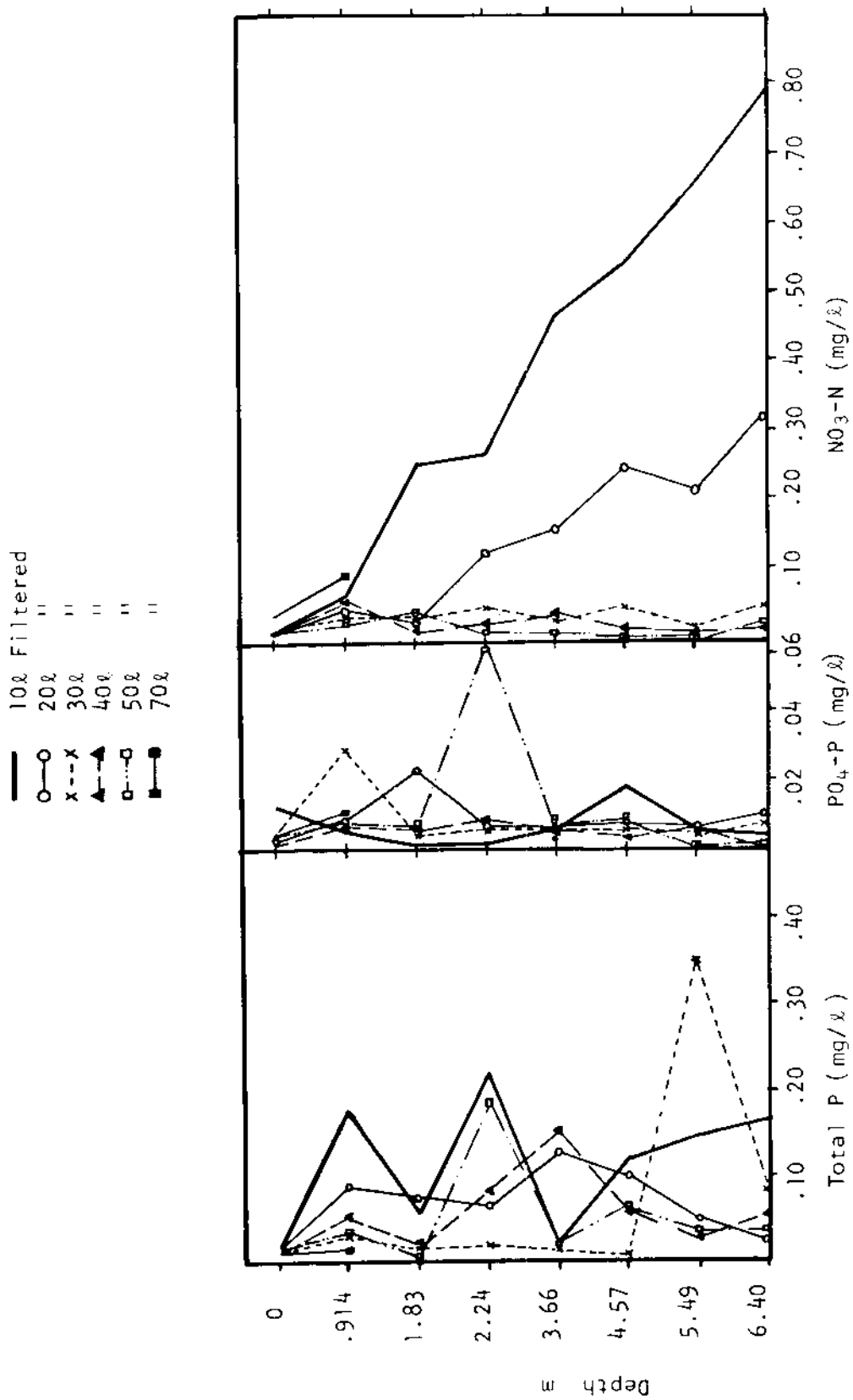


Figure 2. River; Total P, PO₄-P and NO₃-N percolate concentrations as a function of depth.

The variability of total phosphorus (Total P) leached was attributed to the washing out of fines (Figure 2). This inconsistent leaching of effluent fines was reflected in turbidity variations (Figure 3). Specific conductance (Ec), pH, chloride ion (Cl^-), total alkalinity and total hardness (Figure 3) parameters were invariant (conservative substances). It was concluded that river water would have no adverse impact upon groundwater resources.

Sewage Effluent

Secondary (2°) sewage effluent was collected from the Baza Gardens (extended aeration) sewage treatment plant. The plant, designed for 0.6 MGD hydraulic loading capacity, received approximately 0.07 MGD during the test period. Residence times were, therefore, an order of magnitude greater than those specified in the design, and plant effluent was not "typical" 2° effluent with respect to N species. Mean total N content (10 mg/l) had as its major components the oxidized forms of N ($\text{NO}_3\text{-N}$: 83%; $\text{NO}_2\text{-N}$: 13%) with only minor reduced N components ($\text{NH}_3\text{-N}$: 0.6%; Org N: 3.4%). Effective N removal from typical 2° wastewaters applied to land systems require sequential processes of sorption (NH_4^+), nitrification ($\text{NH}_4^+ \rightarrow \text{NO}_3^-$) and denitrification ($\text{NO}_3^- \rightarrow \text{N}_2\uparrow$). Nitrogen removal from the non-typical 2° effluent tested required only the denitrification process since the major N components were in the oxidized state. Semi-continuous (Sewage I) and continuous (Sewage II) application precluded contact between the limestone medium and the atmosphere which created the opportunity for anaerobic conditions (favorable to denitrification). Potential N removal limiting factors were: inadequate populations of denitrifying bacteria; insufficient organic carbon (energy source) in the wastewater; presence of dissolved oxygen in the applied sewage.

Nitrogen mass balance summaries and mean influent N concentrations for the sewage experiments are listed in Table 8. Total N flux in the Sewage I phase was dominated by the $\text{NO}_3\text{-N}$ flux which was variable (Figure 4). These large differences were due to the high $[\text{NO}_3\text{-N}]$ measured (column I at 40%, column II at 30% and column III at 20%) in the percolate (Appendix A, Table A-2). Positive $\text{NO}_3\text{-N}$ fluxes (release) were quantified in both sewage experiments (Table 8). Although the total $\text{NO}_2\text{-N}$ mass balance indicated release of $\text{NO}_2\text{-N}$ in the first sewage experiment (Table 8), it was hypothesized that different stages of the nitrification process occurred throughout the experiment (Figure 4):

- i. first 20% applied — $\text{NO}_2\text{-N}$ was converted to $\text{NO}_3\text{-N}$ with resultant decrease in $[\text{NO}_2\text{-N}]$ with depth;
- ii. next 10% applied — $[\text{NO}_2\text{-N}]$ remained constant with depth;

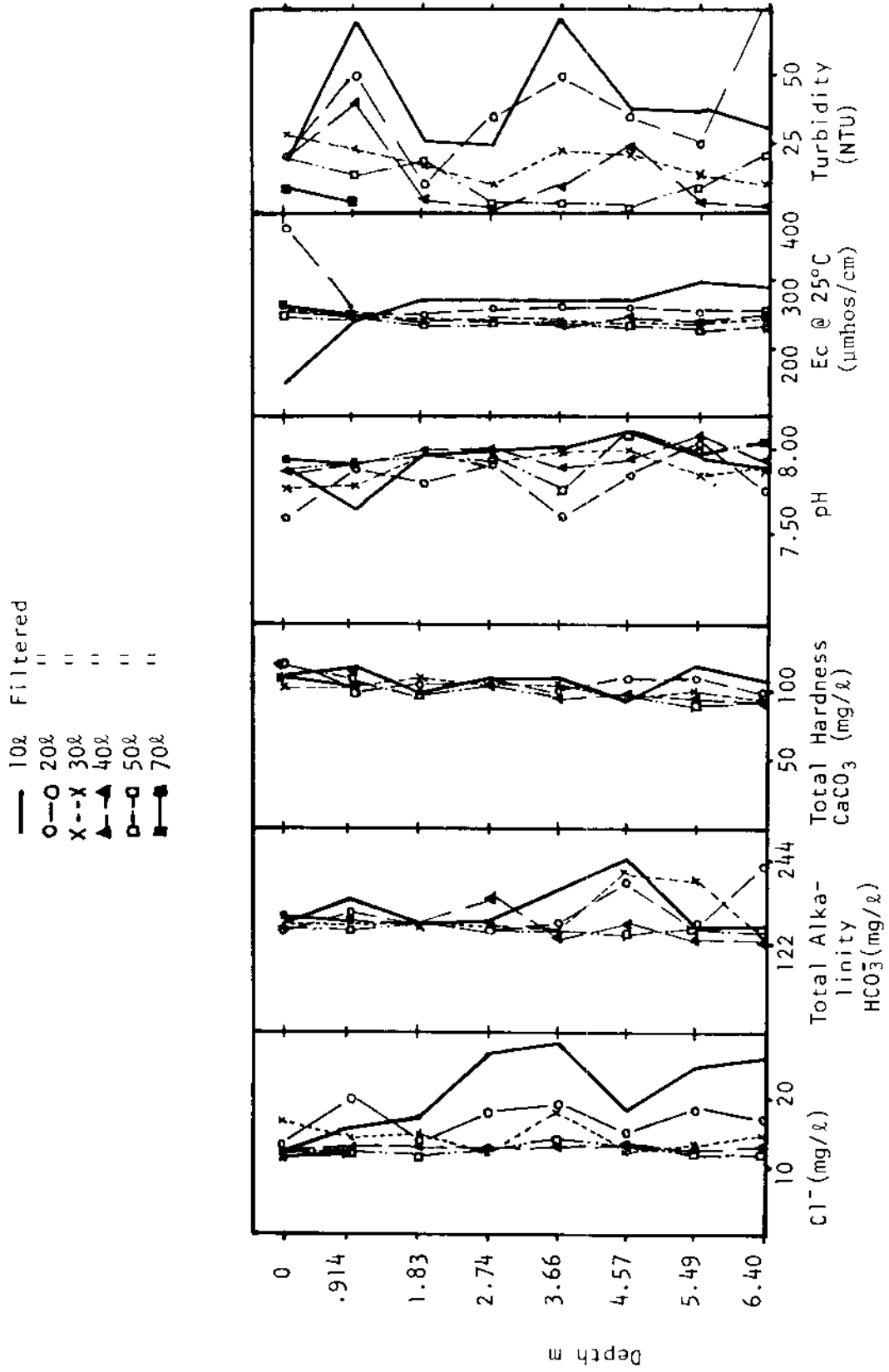


Figure 3. River; Cl⁻, Total Alkalinity, Total Hardness, pH, Ec and Turbidity percolate concentrations as a function of depth.

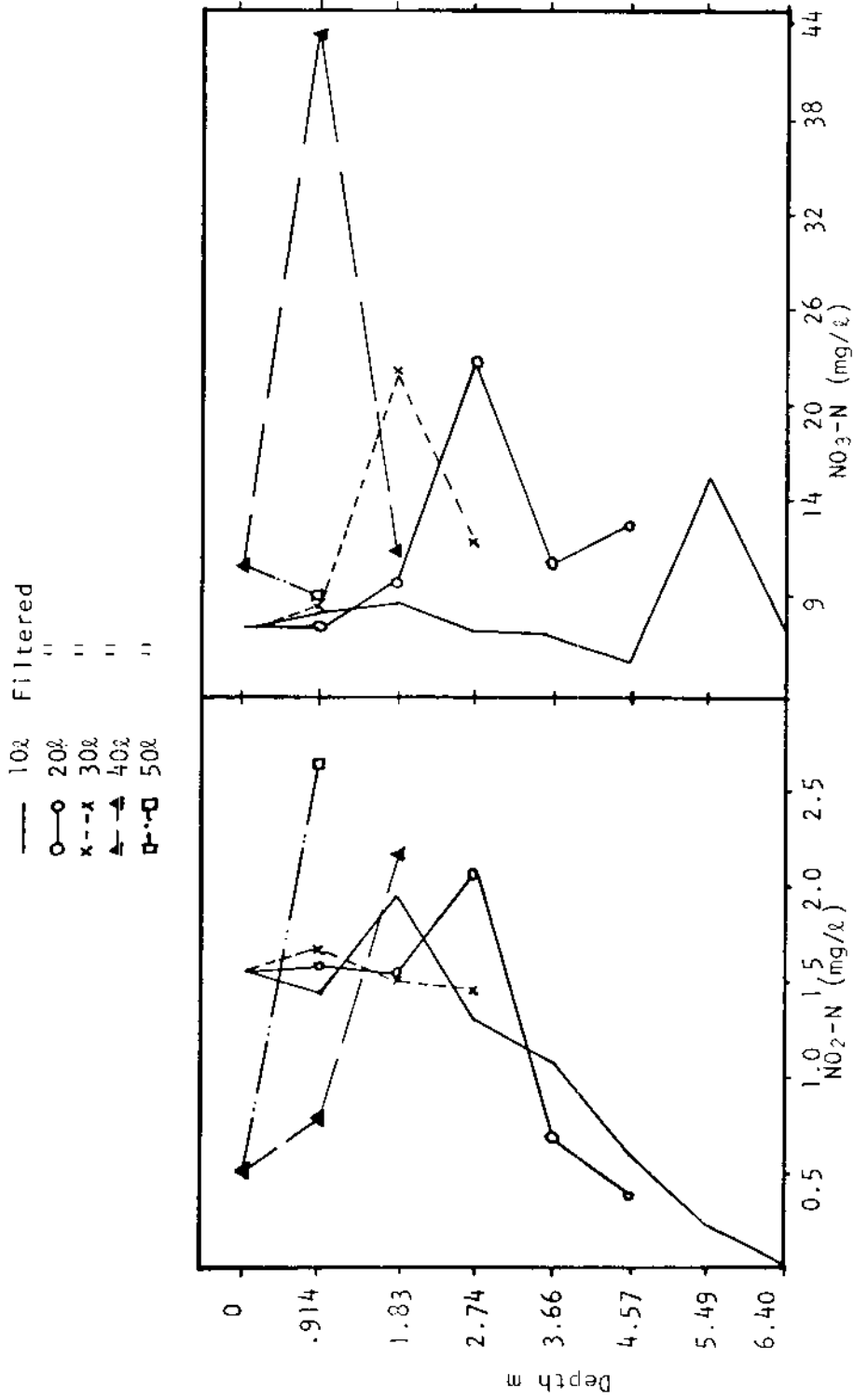


Figure 4. Sewage l; NO₂-N and NO₃-N percolate concentrations as a function of depth.

Table 8. Nitrogen mass balance summary - Secondary sewage effluent (Balance = Effluent-Influent)

Nitrogen, mg N (+) Release; (-) Removal

Sewage I

<u>Layer</u>	<u>Depth, m</u>	<u>NO₃-N</u>	<u>NO₂-N</u>	<u>NH₃-N</u>	<u>Org N</u>	<u>Total N^a</u>
I	0.91	+342.7	+24.5	-1.20	+0.44	+366.44
II	1.83	-143.5	+17.0	-2.00	-6.50	-135.00
III	2.74	+ 11.3	- 1.9	-0.60	-0.90	+ 7.90
IV	3.66	-129.5	-16.1	-0-	-1.02	-146.62
V	4.87	+ 8.2	- 8.0	-0-	+7.78	+ 7.98
VI	5.49	+117.0	- 3.7	-0-	-0-	+113.3
VII	6.40	- 93.6	- 2.0	-0-	2.43	- 93.17
Totals:		+112.6	+ 9.8	-3.80	+2.23	+120.83

Sewage II

Layer

I	0.91	+ 10.	-11.2	-1.52	-7.29	- 10.01
II	1.83	+ 12.	- 9.7	-0.51	+3.64	+ 5.43
III	2.74	+ 8.	- 7.2	-0.07	+5.19	+ 5.92
Totals:		+ 30.0	-28.1	-2.10	+1.54	+ 1.34

Mean Influent N,mg/ℓ	8.1	1.28	0.06	0.35	9.8
± Standard Deviation ±	1.9	± .53	± .02	± .18	± 1.5
(Number of Data Points)	(4)	(4)	(5)	(5)	(4)

a Total N = (NO₃-N) + (NO₂-N) + (NH₃-N) + Org N

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- iii. final 20ℓ applied — previously sorbed NH_4^+ was converted to $\text{NO}_2\text{-N}$ with resultant increase in $[\text{NO}_2\text{-N}]$ with depth.

Dissolved oxygen in the influent wastewater sustained aerobic conditions favoring nitrification and inhibiting denitrification. The biological oxidation of $\text{NO}_2\text{-N}$ to $\text{NO}_3\text{-N}$ was confirmed in the Sewage II experiment where $\text{NO}_2\text{-N}$ losses approximated $\text{NO}_3\text{-N}$ increases (Table 8, Figure 5).

The decrease in $\text{NH}_3\text{-N}$ concentration with depth of percolation was reflected in both sewage runs (Table 8) and is graphically displayed in the inverse relationship between $[\text{NH}_3\text{-N}]$ and depth (Sewage II: Figure 6). Organic N flux indicated release in both sewage experiments (Table 8); however, these results were variable. In the second sewage experiment, $[\text{Org N}]$ decreased in column I and increased in columns II and III (Figure 6). The sources of excess $\text{NO}_3\text{-N}$ (Sewage I and II) and $\text{NO}_2\text{-N}$ (Sewage I) were NH_4^+ sorbed during the experiments and the N pool present in the limestone when it was collected.

Whereas the N data were variable, the phosphorus (P) data were consistent and indicated removal of this potential algal growth stimulating nutrient. Mass balance summaries and mean influent P concentrations are presented in Table 9. Phosphorus stripping, an important goal of advanced wastewater treatment, was exhibited in the laboratory I/P system; therefore, percent P removal was included in Table 9. Removals were greater in the Sewage I experiment; total P removals were 90% (Sewage I) and 76% (Sewage II) through 2.74 m of limestone medium. Essentially all of $\text{PO}_4\text{-P}$ and Total P removal (Figure 7) occurred in the top 1.83 m of limestone in the Sewage I experiment. There was no indication of failure (breakthrough of P) after 50ℓ of sewage leached through the Sewage I laboratory columns. In the second sewage experiment, the percolate $[\text{PO}_4\text{-P}]$ increased with increased loading up to 60ℓ leached at the 1.83 m depth (Figure 8). Only column I percolate was analyzed at 70ℓ leached, and the $[\text{PO}_4\text{-P}]$ at 0.91 m depth decreased. Percolate $[\text{Total P}]$ increased with increased loading (Figure 8) and was mostly $\text{PO}_4\text{-P}$ for the first 50ℓ leached. Subsequent increased $[\text{Total P}]$ was mostly soluble organic and acid hydrolyzable phosphate. Influent $[\text{Total P}]$ was 3.77 mg/ℓ while column I percolate $[\text{Total P}]$ was 3.42 mg/ℓ (at 60ℓ) and 4.10 mg/ℓ (at 70ℓ). Since most of this P was soluble, breakthrough was concluded to occur between 60 and 70ℓ leached. Further experimentation is required to confirm breakthrough. Phosphorus adsorption capacity was estimated for column I:

- i. volume of limestone in column = 12.6 ℓ = $1.26 * 10^{-2} \text{ m}^3$;
- ii. mass of total P adsorbed while 60ℓ of sewage applied =
134 mg P = $1.34 * 10^{-4} \text{ kg P}$;

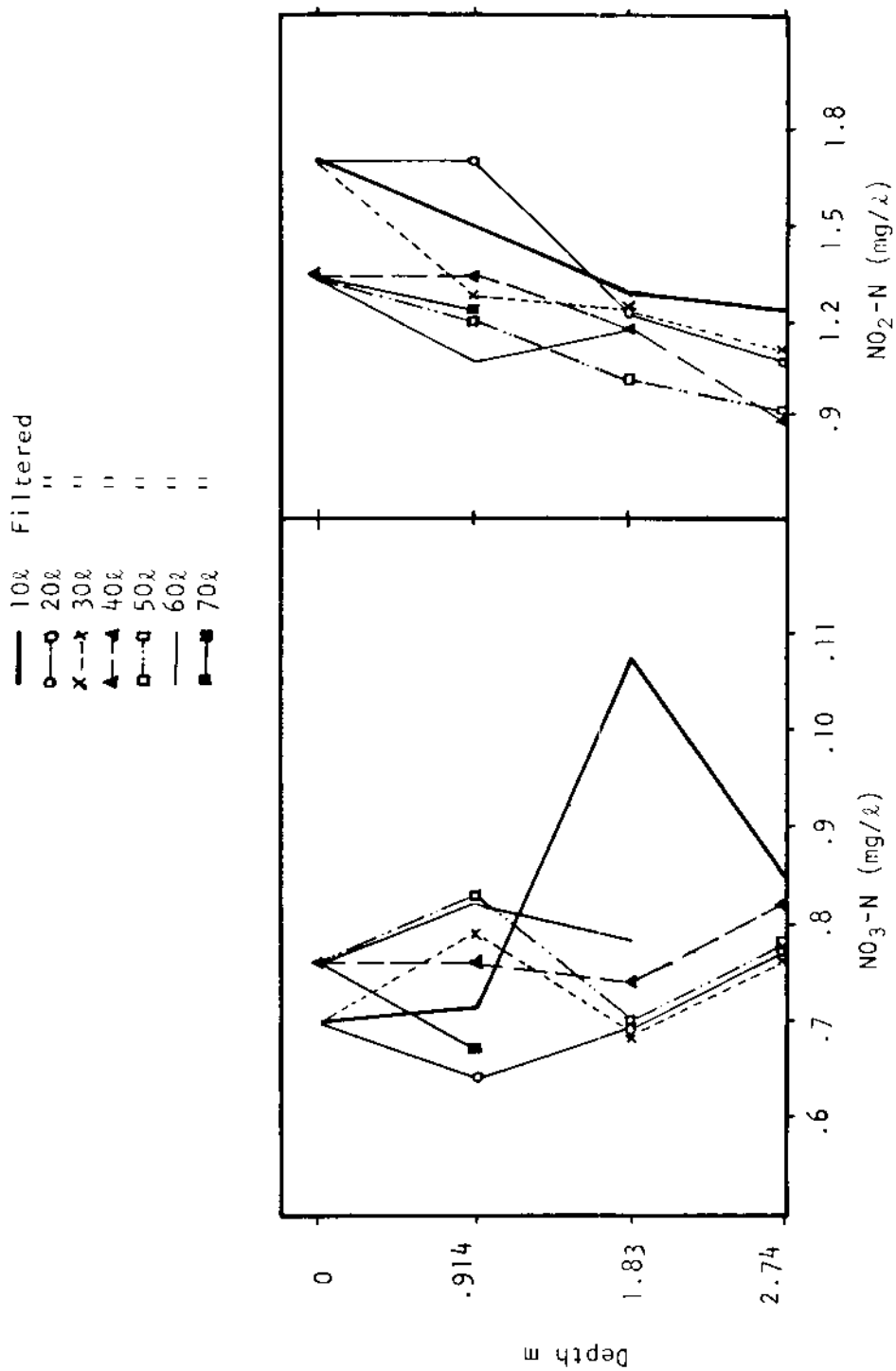


Figure 5. Sewage 11; NO₃-N and NO₂-N percolate concentrations as a function of depth.

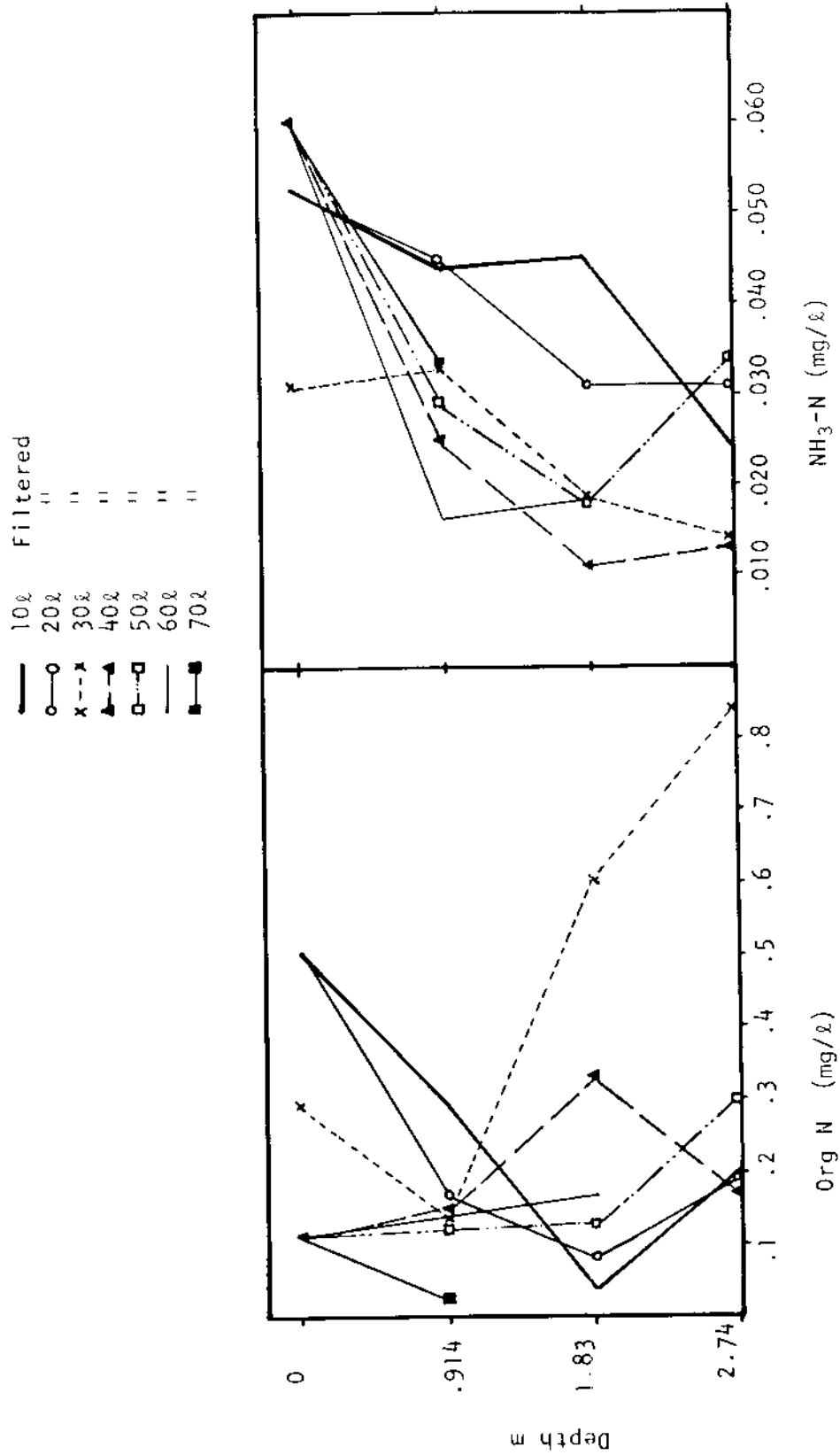


Figure 6. Sewage II; Org N and NH₃-N percolate concentrations as a function of depth.

Table 9. Phosphorus mass balance summary - Secondary sewage effluent
(Balance = Effluent-Influent)

Phosphorus, mg P (+) Release; (-) Removal

Sewage I						% Removal Total P with respect to Column Influent
<u>Layer</u>	<u>Depth, m</u>	<u>PO₄-P</u>	<u>TSP^a</u>	<u>Part P^b</u>	<u>Total P^c</u>	
I	0.91	-172.04	-199.67	+9.20	-190.47	78.4
II	1.83	- 14.43	- 18.74	-8.51	- 27.25	11.2
III	2.74	- 0.15	- 0.11	-0.53	- 0.64	0.3
IV	3.66	+ 0.03	- 0.08	+0.21	+ 0.13	(0.1)
V	4.87	- 0.06	- 0.02	+0.19	+ 0.17	(0.1)
VI	5.49	- 0.01	- 0.01	-0.56	- 0.57	0.2
VII	6.40	+ 0.01	+ 0.01	-0.31	- 0.30	0.1
Totals:		-186.65	-218.62	-0.31	-218.93	90.0

Sewage II

Layer	Depth, m	PO ₄ -P	TSP ^a	Part P ^b	Total P ^c	% Removal Total P with respect to Column Influent
I	0.91	-178.86	-135.82	+5.62	-130.20	49.0
II	1.83	- 52.95	- 52.65	+5.41	- 47.24	17.8
III	2.74	- 10.79	- 21.16	-2.59	- 23.75	8.9
Totals:		-242.60	-209.63	+8.44	-201.19	75.7

Mean Influent P, mg/l	3.9	4.2	0.1	4.4
± Standard Deviation	±.2	±.5	±.2	±.6
(4 Data Points)				

a TSP = Total Soluble Phosphorus

b Part P = Particulate Phosphorus

c Total P = TSP + Part P

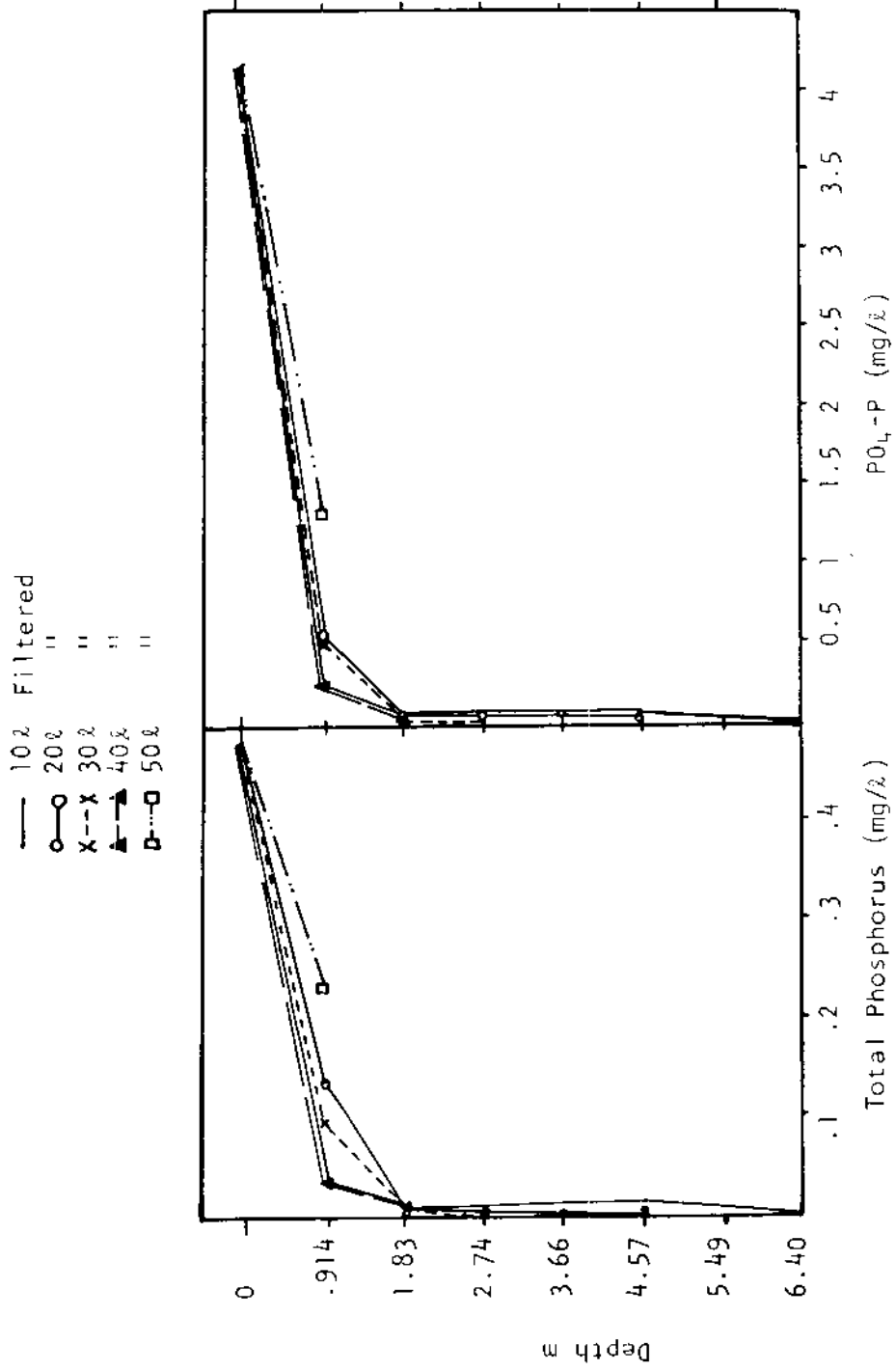


Figure 7. Sewage 1; Total Phosphorus and P₀₄-P percolate concentrations as a function of depth.

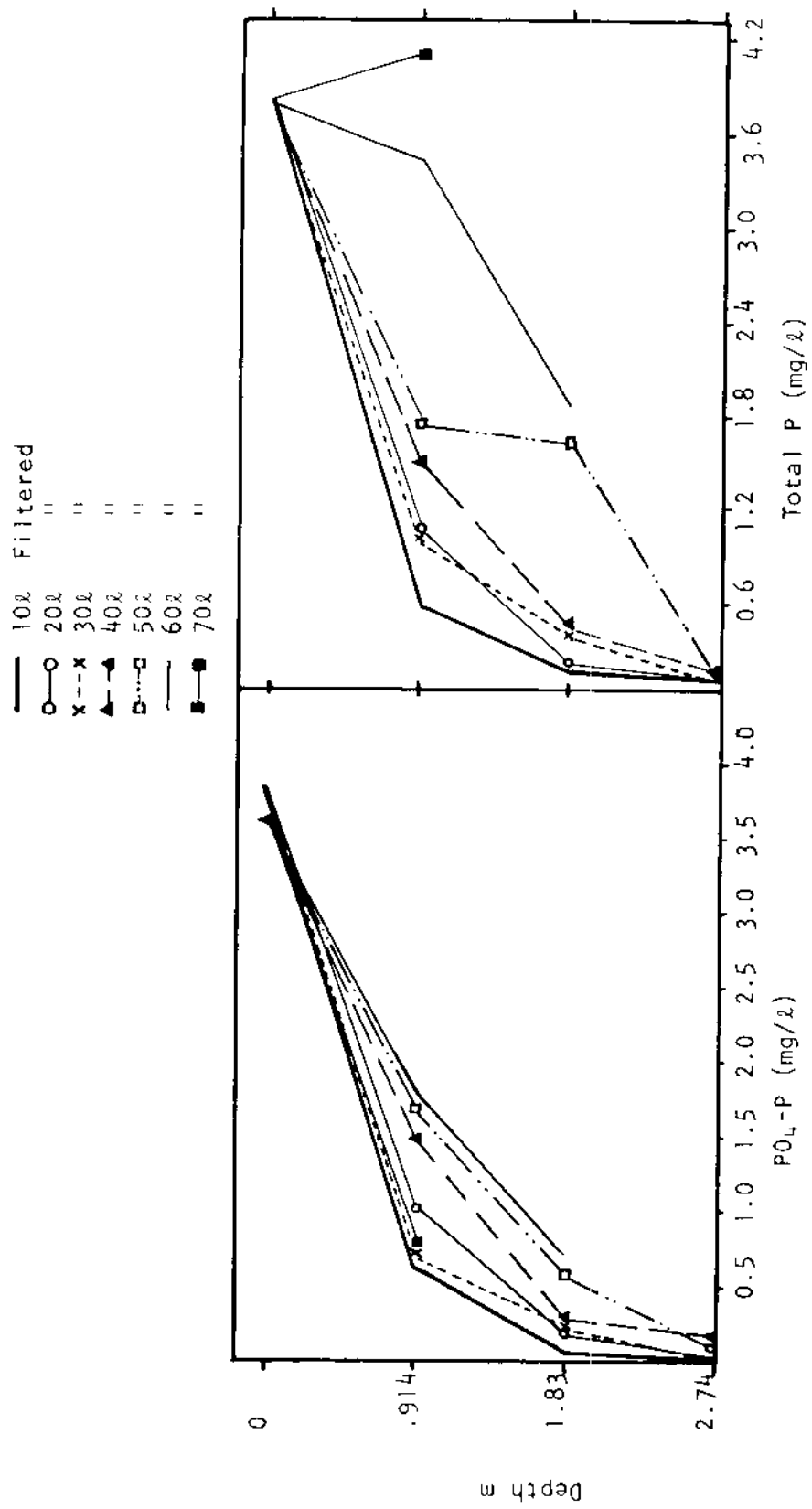


Figure 8. Sewage 11; PO₄-P and Total P percolate concentrations as a function of depth.

iii. phosphorus adsorption capacity = 0.011 kg P/m^3 .

This preliminary estimate of adsorption capacity of the tested limestone was negligible (Table 2).

Coliform bacteria removal efficiencies in the sewage runs were >95% at the 0.91 m depth and >99% at the 1.83 m depth. Coliform balances, geometric mean coliform inputs and per cent removal data are listed in Table 10. Sewage I initial total coliform (TC) results were variable below 1.83 m (Figure 9); however, logarithmic decrease in coliform bacteria occurred with increased depth of percolation in both experiments (Figures 9 and 10). Geometric mean percolate bacterial densities were 188 TC/100 ml (Sewage I) and 59 TC/100 ml (Sewage II) at the 1.83 m depth. The corresponding geometric mean percolate fecal coliform (FC) densities were 6 FC/100ml at 1.83 m in both experiments. Since the laboratory experiments were performed under conditions of high soil moisture (conditions which favor bacterial survival), lack of high percolate bacterial densities indicated removal and not die-off. The limestone medium tested provided removals comparable to typical LA systems.

The remaining parameters (physical: specific conductance (E_c) and turbidity; chemical: pH; total alkalinity, total hardness and chloride) are graphically represented in Figures 11 and 12 (Sewage I) and in Figures 13 and 14 (Sewage II). Variable washing out of fines produced erratic percolate turbidities in both sewage experiments. Total dissolved solids, as indicated by E_c , decreased with depth of percolation. Chloride fluxes were totaled for all columns and removals were estimated to be -1768 and -519 mg Cl^- given mean influent concentrations of 108 and 71 mg Cl^-/ℓ for Sewage I and II respectively. Decreases in total hardness were quantified as -3690 and -3020 mg as CaCO_3 corresponding to mean influent concentrations of 231 and 230 mg/ ℓ as CaCO_3 for Sewage I and II. Although mass balances for total alkalinity were not calculated, decreases were estimated to be less than those quantified for total hardness; therefore, the removed portion of the total hardness appeared to be non-carbonate hardness.

CONCLUSIONS AND RECOMMENDATIONS

Secondary (2°) sewage effluent from the Baza Gardens sewage treatment plant (Guam) was applied to a series of laboratory columns (lysimeters) containing an argillaceous limestone medium. The nitrogen (N) content of this effluent was not typical of 2° effluents since it contained up to 96% oxidized forms. The dissolved oxygen content of 2° effluent created conditions favorable for nitrification. Nitrate ($\text{NO}_3\text{-N}$), the end product, leached through the limestone medium yielding mean percolate concentrations ($\text{NO}_3\text{-N}$) of $14.3 \pm 8.7 \text{ mg}/\ell$ (Sewage I) and $8.0 \pm 0.4 \text{ mg}/\ell$ (Sewage II) at the 2.74 m depth. There were increased nitrate concentrations with depth. Since the primary drinking water standard for $\text{NO}_3\text{-N}$ is 10 mg/ ℓ , it was concluded that the tested limestone system failed as a nitrogen removal method.

Table 10. Coliform balance- Secondary sewage effluent (Balance = Effluent - Influent) (+) Release (-) Removal.

Sewage I			% Removal with Respect to Column Influent	FC ^b	% Removal with Respect to Column Influent
Layer	Depth, m	TC ^a			
I	0.91	-1.49*10 ⁶	92.55	-7.77*10 ⁴	95.13
II	1.83	-8.00*10 ⁴	4.97	-3.55*10 ³	4.35
III	2.74	+1.90*10 ⁴	(1.18)	-1.90*10 ²	0.23
IV	3.66	-2.67*10 ⁴	1.66	-1.30*10 ²	0.15
V	4.87	+5.97*10 ⁴	(3.71)	+1.0 *10 ¹	(0.01)
VI	5.49	+6.82*10 ³	(0.42)	-2.0 *10 ¹	0.02
VII	6.40	-4.65*10 ³	0.29	-0-	-0-
Totals:		-1.51*10 ⁶	94.16%	-8.16*10 ⁴	99.87

Sewage II

Layer

I	0.91	-1.50*10 ⁶	98.83	-2.14*10 ⁵	98.25
II	1.83	-7.84*10 ³	0.51	-2.34*10 ³	1.07
III	2.74	-8.10*10 ²	0.05	-3.80*10 ²	0.17
Totals:		-1.51*10 ⁶	99.39%	-2.17*10 ⁵	99.49%

Geometric

Mean Influent Coliform

Densities, #/100m² 2.19*10⁴

3.77*10³

a TC = Total Coliform

b FC = Fecal Coliform

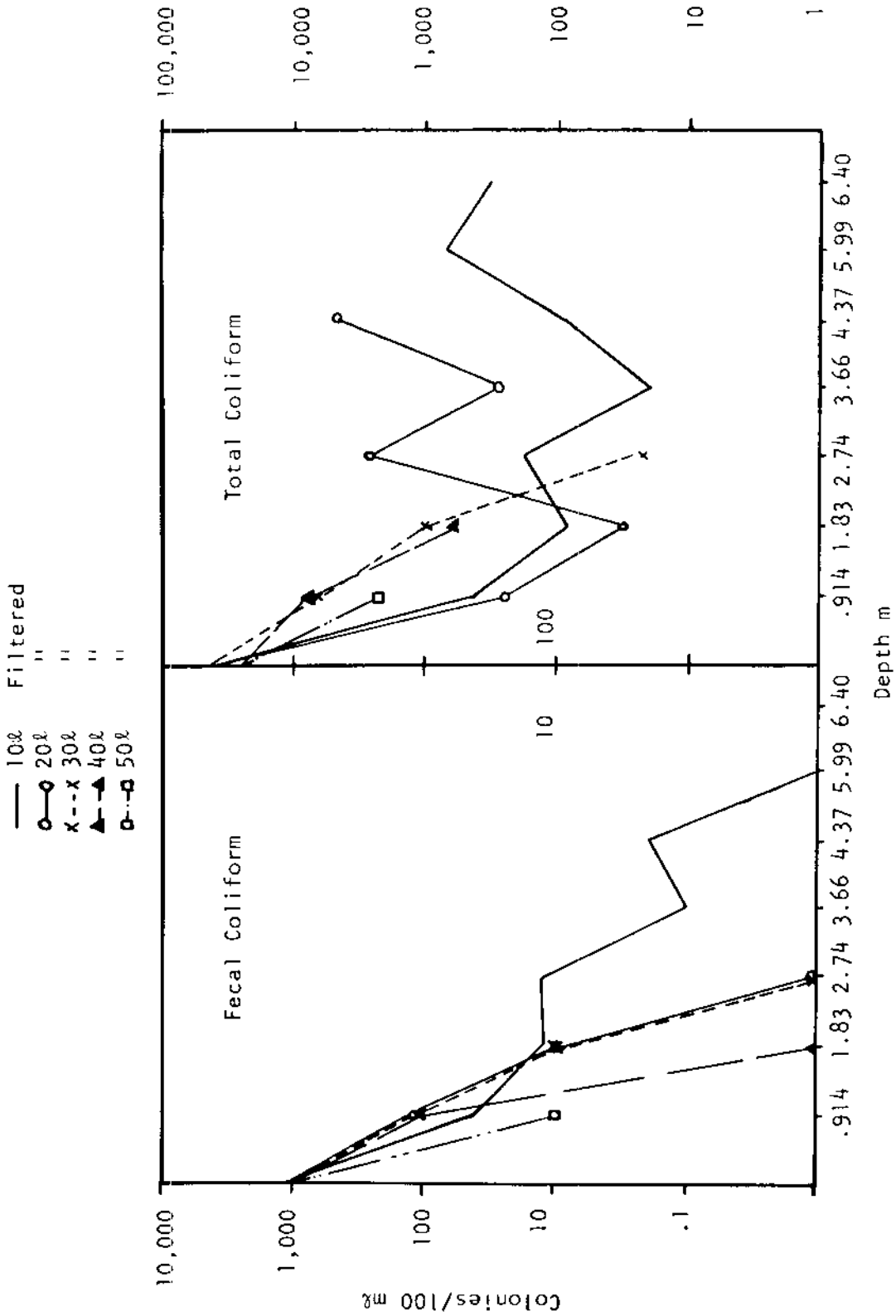


Figure 9. Sewage I; logarithmic decrease of percolate coliform density as a function of depth.

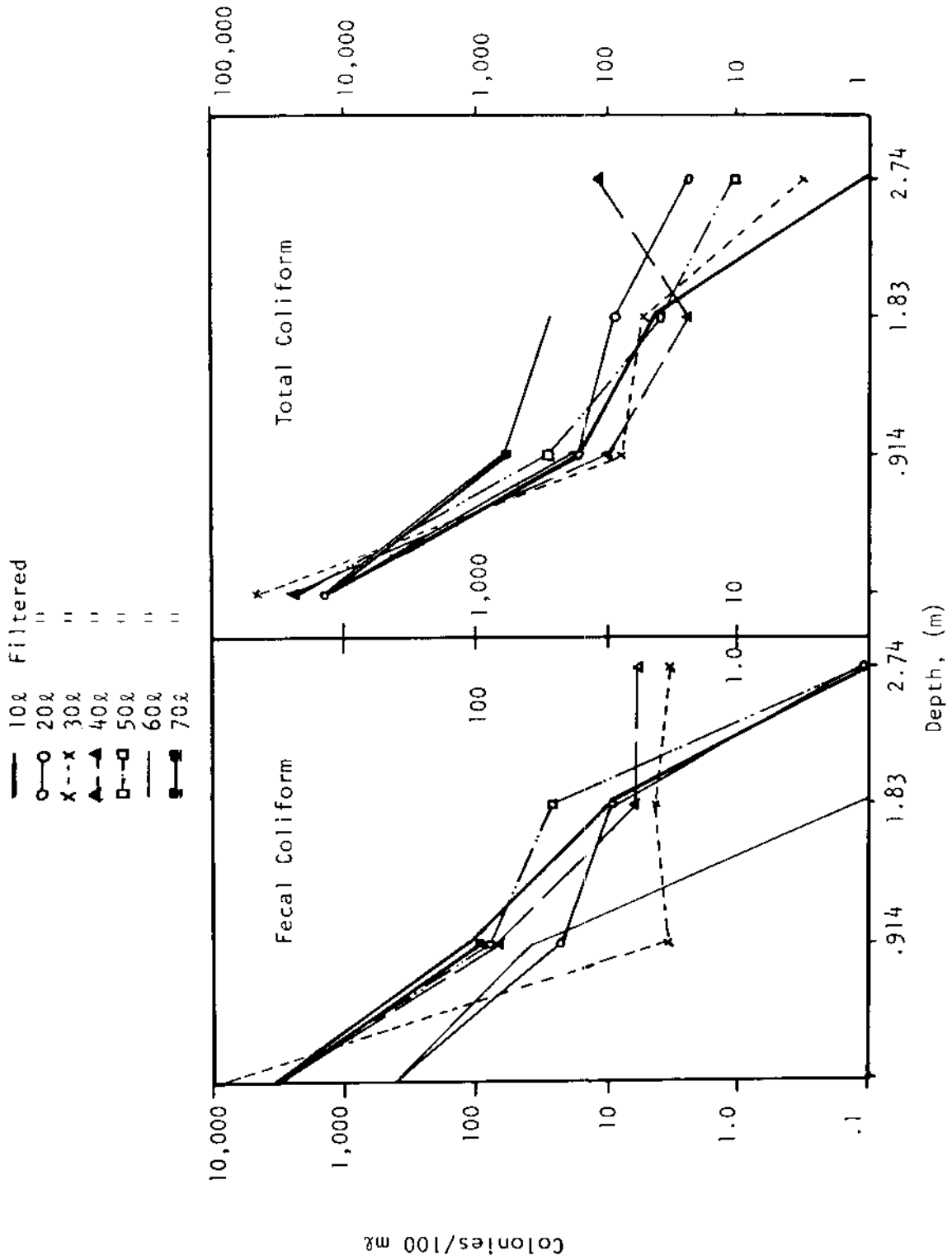


Figure 10. Sewage II; logarithmic decrease of percolate coliform density as a function of depth.

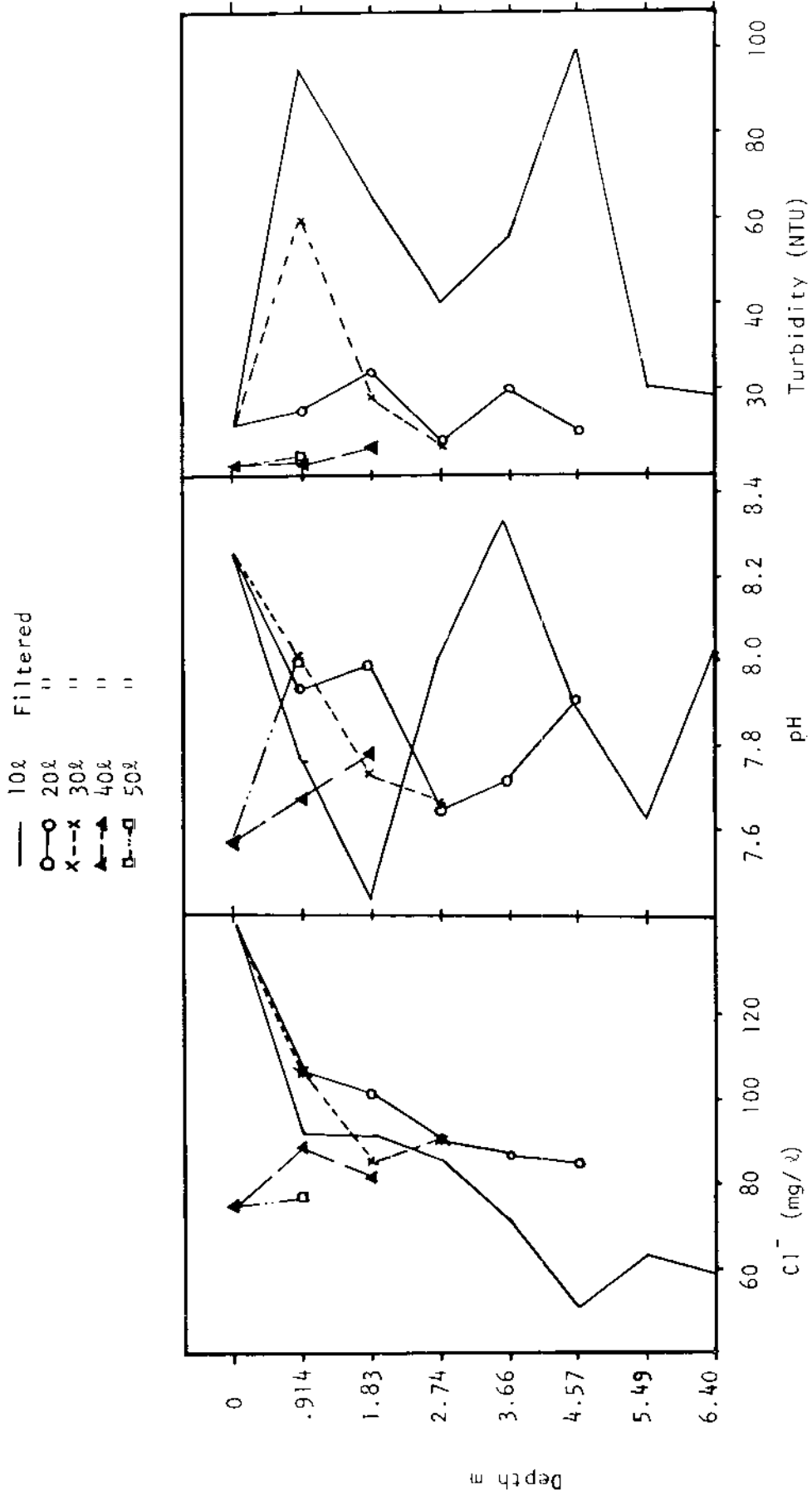


Figure 11. Sewage l; Cl⁻, pH and Turbidity percolate concentrations as a function of depth.

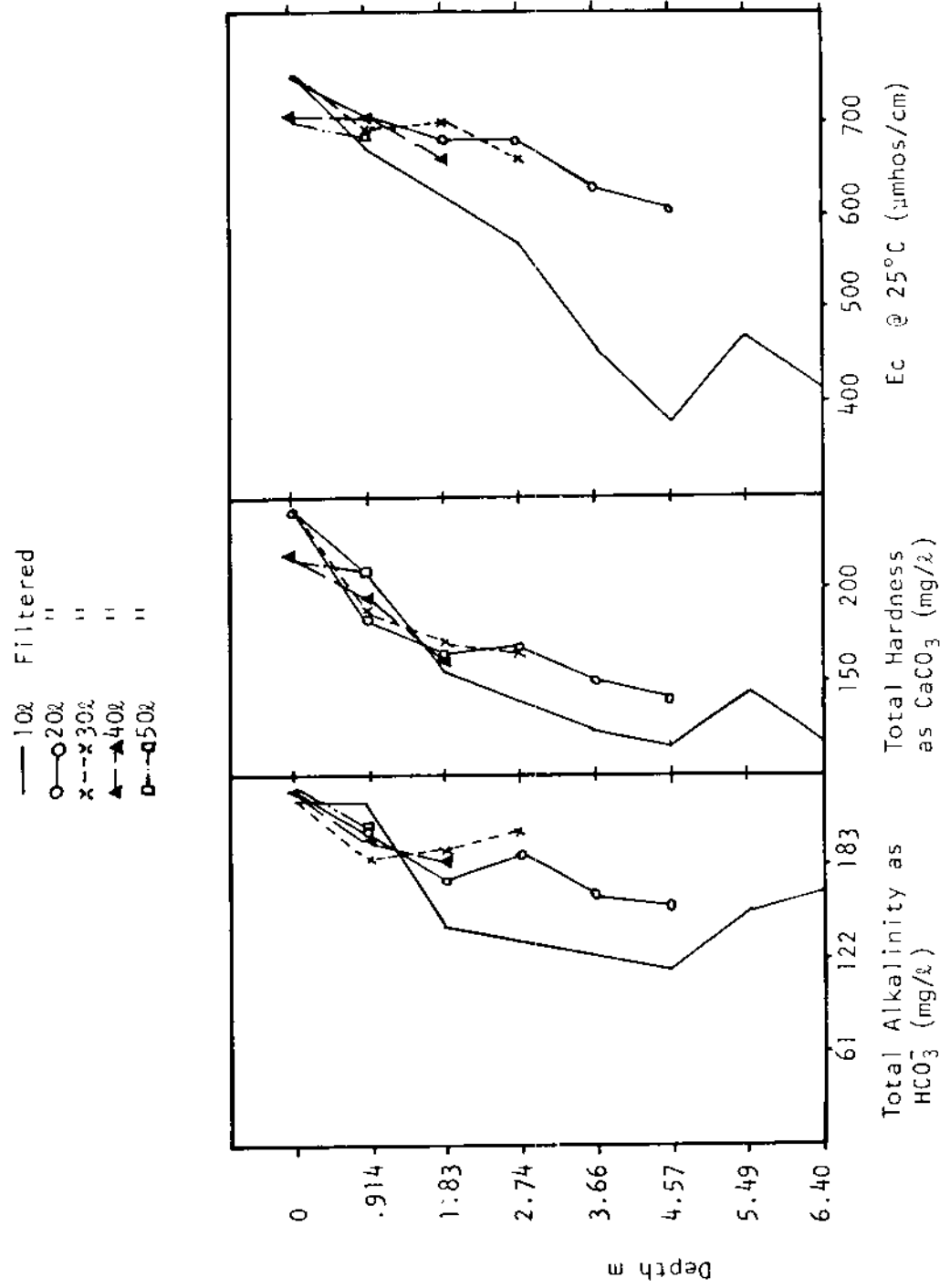


Figure 12. Sewage 1; Total Alkalinity, Total Hardness and Ec percolate concentrations as a function of depth.

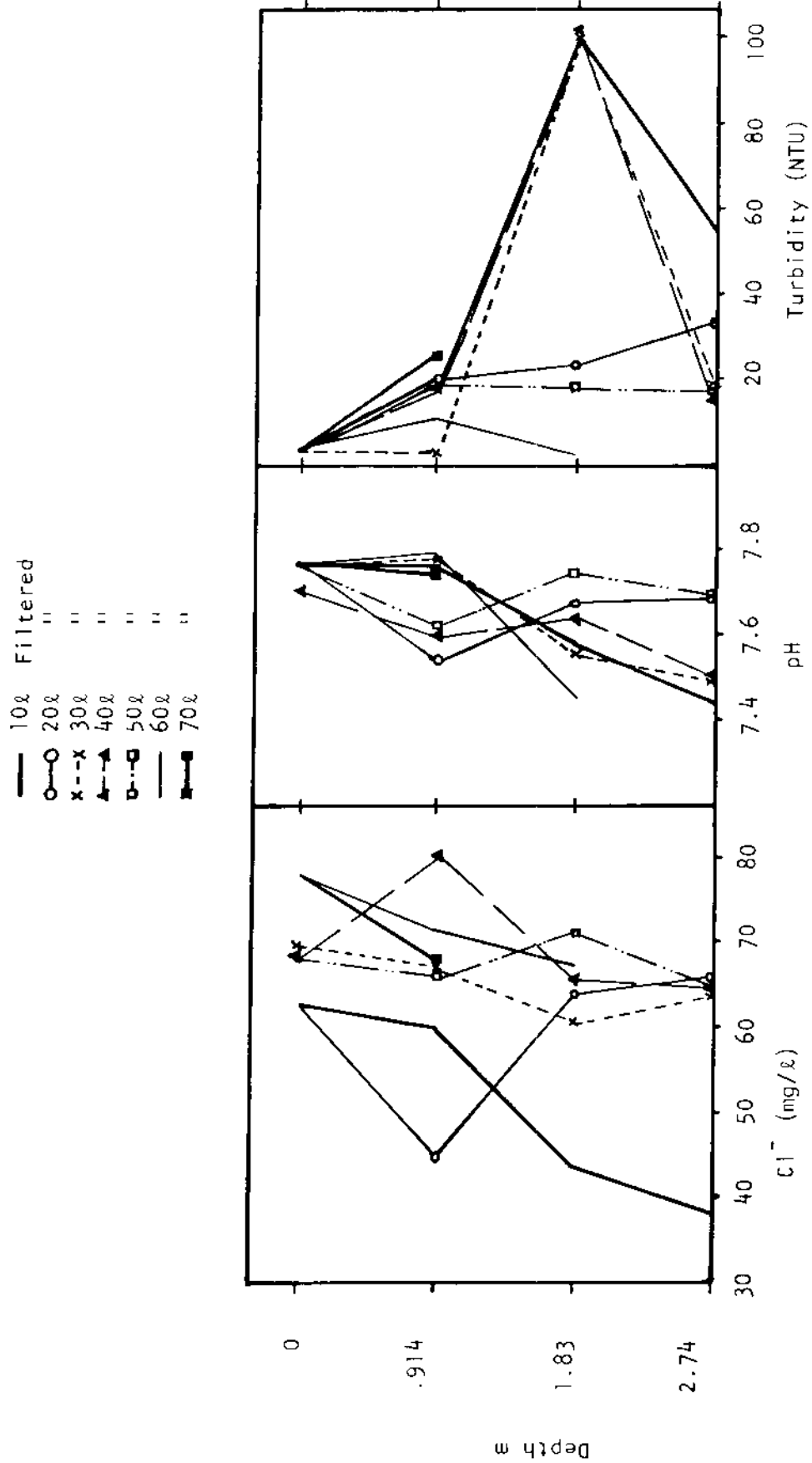


Figure 13. Sewage II; Cl^- , pH, and Turbidity percolate concentrations as a function of depth.

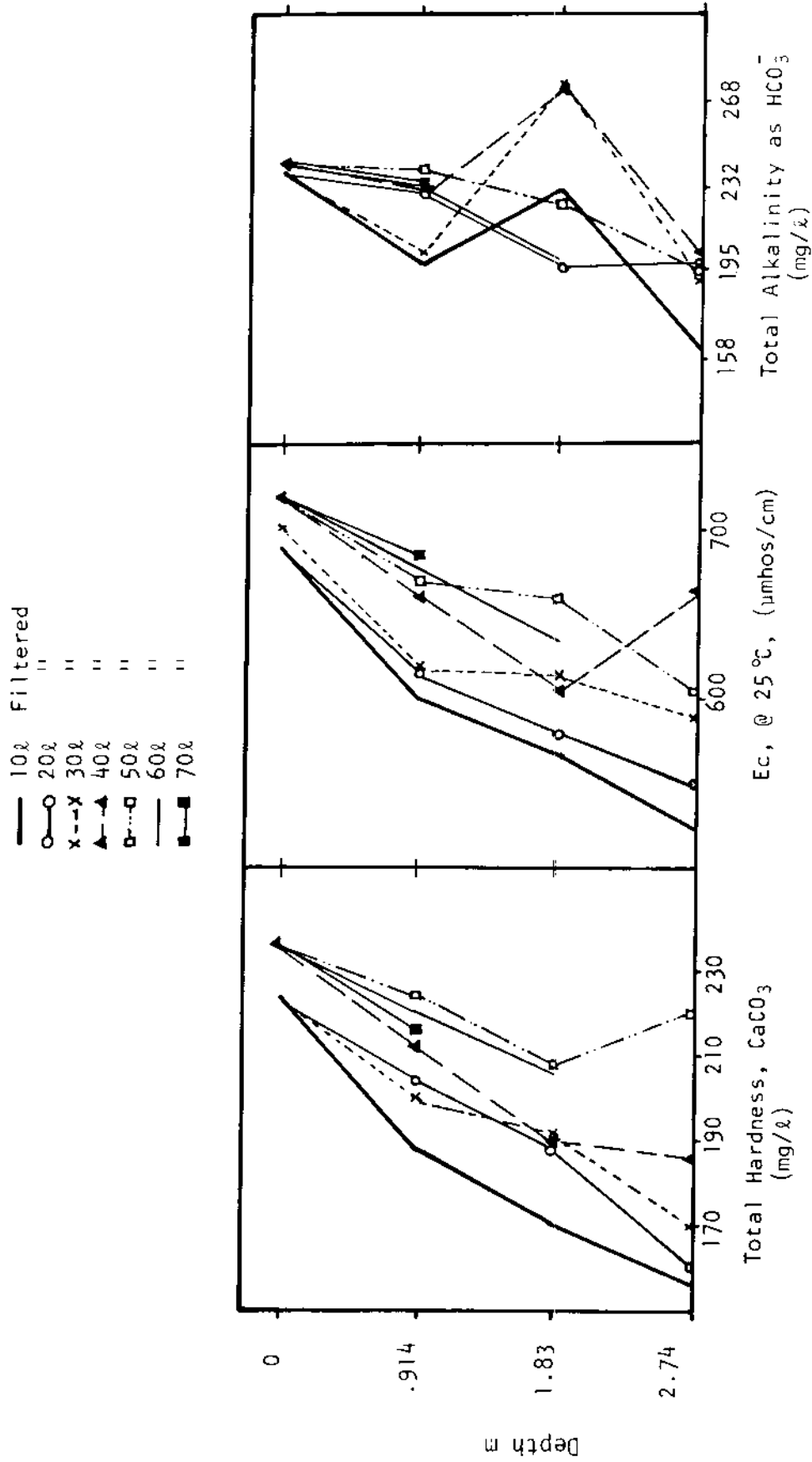


Figure 14. Sewage II; Total hardness, Ec and Total Alkalinity percolate concentrations as a function of depth.

Phosphorus adsorption capacity was estimated to be minimal (0.011 kg P/m³). Since the mean influent total phosphorus concentration was 4.4 mg/l, it was concluded that the tested argillaceous limestone could not maintain a significant phosphorus removal level. Relative to the advanced wastewater treatment goals of N and P removal, the tested limestone medium did not qualify as a treatment system. Further research is needed concerning evaluation of high expected dilution factors involving rainwater inputs and existing groundwater supplies. Dilution effects notwithstanding, application of wastewaters above Guam's groundwater lens is not recommended.

Coliform removal efficiencies were high (99-100%) after sewage percolated through 1.83 m of limestone; this high level of performance was typical of land application (LA) systems. The potential for bacterial contamination of groundwater sources was concluded to be minimal. This important characteristic of the tested limestone system (efficient coliform removal) coupled with the need to eliminate potential surface water pollution from sewage discharges, relegates the infiltration/percolation (I/P) option on Guam to the mixing zone (recharge zone; Figure 1). The limestone I/P system was concluded to be a disposal option and not a treatment alternative.

Additional I/A techniques which require investigation include:

- 1) nutrient stripping by over-land flow option of LA or aquaculture;
- 2) possibility of using aquaculture or overland flow as a pre-treatment for I/P systems;
- 3) Continuation of present study in order to test long term effects on limestone by increasing duration of filtration (add more sewage);
- 4) test hydraulic characteristics of system;
- 5) ascertain pertinent process variables by laboratory study and field testing.

Land application (LA) is a viable option for sewage disposal on Guam. The immediate benefit of LA is a reduction in surface water pollution by point sewage discharges. Although overland flow and aquaculture options were not tested, they offer potential nutrient stripping methods for sewage prior to discharge.

The I/P option of LA is not recommended for sewage treatment and/or disposal in resource or conservation zones (Figure 1). However, potential for discharge in the mixing or recharge zone remains a positive application of this innovative and alternate treatment scheme.

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Table A-1. River water quality data. Units in mg/l unless otherwise noted.

Col.	PH	S. COND		TURB	TMFR	TR	TFR	CHL	T. ALK.	T. HARD	TDN	NO ₂ -N	NO ₃ -N	TP	TSP	OP
		a	b													
Col. I	10A	7.65	240	27	188	161	15.4	153	117	651	.000	.060	.171	.015	.004	
	20B	7.88	250	39	207	168	19.9	135	103	101	.001	.029	.089	.022	.008	
	30C	7.78	250	23	124	105	14.2	129	103	.081	.005	.039	.029	.029	.029	
	40D	7.92	249	40	25	124	99	13.0	128	113	.057	.001	.028	.052	.014	
	50E	7.92	244	14	13	200	187	12.1	119	111	.172	.002	.015	.033	.018	
Col. II	10C	7.91	251	4	6	128	122	171	103	800	.000	.087	.015	.015	.007	
	20	7.97	270	26	25	272	247	128	99	.001	.001	.246	.057	.015		
	30	7.80	250	10	5	180	175	13.1	128	99	.001	.001	.023	.076	.013	
	40	7.97	248	18	7	164	162	14.6	109	109	.001	.022	.018	.009	.004	
	50	7.99	240	5	1	162	161	13.0	124	99	.253	.001	.008	.012	.012	
Col. III	10	7.93	241	19	14	156	142	11.4	123	107	.232	.001	.028	.009	.006	
	20	8.00	270	24	49	240	191	26.3	127	109	.283	.001	.265	.221	.014	
	30	7.91	258	34	40	23	173	17.8	118	105	.081	.002	.122	.066	.012	
	40	7.92	247	11	11	184	173	11.7	125	105	.354	.001	.041	.020	.012	
	50	7.94	240	3	4	165	161	12.6	120	109	.051	.000	.019	.082	.019	
Col. IV	10	8.01	270	70	124	356	232	27.9	163	109	.020	.001	.467	.019	.014	
	20	7.82	263	50	170	368	198	19.2	127	101	1.061	.000	.153	.128	.012	
	30	8.00	239	23	96	257	181	17.8	119	103	1.768	.000	.034	.015	.015	
	40	7.90	234	10	26	172	146	13.0	110	95	.031	.000	.032	.131	.124	
	50	7.76	238	4	2	162	160	14.0	119	97	.131	.000	.003	.021	.018	
Col. V	10	8.10	268	38	200	392	192	17.9	201	94	.020	.001	.535	.118	.049	
	20	7.86	262	34	165	341	176	15.1	175	111	.374	.002	.244	.101	.010	
	30	7.98	243	22	94	236	142	12.4	189	95	.192	.000	.042	.009	.009	
	40	7.95	248	24	101	252	151	13.0	124	99	.283	.001	.010	.057	.018	
	50	8.09	231	2	14	168	155	13.0	116	97	.141	.001	.001	.062	.012	
Col. VI	10	7.96	300	38	71	228	157	24.9	120	119	.202	.001	.657	.145	.012	
	20	8.04	255	26	94	216	132	18.6	120	111	.384	.001	.212	.050	.009	
	30	7.85	235	14	53	256	203	13.1	177	95	.051	.001	.012	.352	.132	
	40	8.09	234	4	34	100	126	12.8	109	85	2.071	.000	.007	.028	.025	
	50	7.98	227	9	17	152	135	12.4	122	91	.687	.000	.010	.037	.009	
Col. VII	10	7.89	290	30	23	214	191	25.6	120	107	.101	.003	.786	.164	.012	
	20	7.75	255	80	324	540	216	17.0	196	97	.071	.000	.322	.027	.014	
	30	7.89	245	10	40	205	165	14.8	109	95	.041	.000	.044	.082	.077	
	40	7.92	244	3	30	212	182	13.0	107	93	.463	.000	.011	.057	.012	
	50	8.03	241	21	36	252	216	12.2	114	95	.051	.000	.013	.037	.009	
Col. VIII	10	7.83	311	24	163	364	201	25.6	129	128	1.596	.001	.766	.076	.018	
	20	7.90	150	18	13	115	102	12.1	126	113	.101	.000	.008	.012	.012	
	30	7.60	302	20	55	308	253	13.0	117	119	.960	.001	.013	.015	.011	
	40	7.77	255	28	18	128	110	16.5	125	103	.737	.000	.015	.012	.006	
	50	7.88	250	20	4	216	212	12.2	123	119	.253	.003	.008	.012	.005	
Instatl River Water	A	7.94	255	13	10	204	194	11.4	129	111	.000	.002	.024	.009	.006	
	B	7.86	262	18	11	176	165	12.4	125	117	.202	.003	.006	.215	.171	
	C	7.86	262	18	11	176	165	12.4	125	117	.202	.003	.006	.215	.171	
	D	7.86	262	18	11	176	165	12.4	125	117	.202	.003	.006	.215	.171	
	E	8.05	163	90	25	135	110	8.3	72	74	.172	.002	.017	.036	.008	

a. pH units
 b. $\mu\text{mhos/cm}$ @ 25°C
 c. NTU
 d. as CaCO₃

Table A-2. Sewage I water quality data. Units in mg/l unless otherwise noted.

	pH	S. COND.	TURB.	TMR	TR	TFR	CHL.	T. ALK.	T. HARD.	TKN	NH ₃ N	NO ₂ N	NO ₃ N	TP	TSP	OP	FECAL COL.	TOTAL COL.
	a	b	(NTU)				C	C	C								d	d
Col. I	10 A	7.77	670	95	186	306	91.6	183	207	.667	.08	1.44	8.01	.332	.242	.212	37	390
	20 A	7.94	705	15	396	371	106.5	168	183	.313	.08	1.59	7.13	1.35	.769	.529	124	245
	30 A	8.02	690	60	424	382	106.5	154	189	.596	.10	1.68	8.38	.923	.692	.529	--	--
	40 B	7.68	705	2.7	4	428	88.7	162	195	.162	.00	0.78	44.48	.330	.240	.206	110	7700
	50 B	8.01	685	3.0	2	143	141	76.3	209	.495	.01	2.66	9.80	2.31	1.29	1.29	10	2300
Col. II	10 A	7.44	620	65	288	64	91.6	116	155	.212	.04	1.96	8.62	.071	.031	.012	13	75
	20 A	8.00	680	24	73	360	101.2	142	165	.242	.02	1.55	9.90	.058	.006	.005	10	28
	30 A	7.74	700	18	18	480	85.2	158	171	.242	.00	1.51	23.26	.049	.015	.006	10	1000
	40 B	7.79	660	6	49	273	81.6	152	163	.202	.00	2.17	11.87	.040	.017	.010	0	600
Col. III	10 A	8.01	570	40	63	300	85.2	110	139	.293	.00	1.30	6.69	.069	.012	.003	14	173
	20 A	7.65	680	8	6	436	90.5	156	169	.162	.00	2.08	23.79	.023	.015	.002	0	2800
	30 B	7.67	660	7	54	398	90.5	168	168	.091	.00	1.45	12.43	.022	.014	.003	0	25
Col. IV	10 A	8.33	455	55	193	300	107	102	125	.242	.00	1.08	6.46	.062	.012	.001	1	20
	20 A	7.72	630	20	23	408	87.0	134	151	.111	.00	0.69	11.07	.043	.007	.007	0	280
Col. V	10 A	7.90	375	100	248	72	50.4	94	115	.111	.00	0.59	4.88	.104	.007	.001	2	73
	20 B	7.91	605	10	18	301	85.2	128	141	1.02	.00	0.38	13.47	.018	.010	.001	0	6200
Col. VI	10 A	7.62	470	20	30	380	63.9	126	145	.111	.00	0.22	16.58	.047	.006	.000	0	755
	10 B	8.02	412	18	53	350	58.6	136	117	.354	.00	0.02	7.22	.017	.007	.001	0	290
Sewage I	A	8.27	750	11	4	564	142.0	186	243	.343	.07	1.56	6.95	4.86	4.86	3.91	1190	37000
	B	7.58	705	2.4	9	492	74.5	190	219	.646	.09	0.51	10.94	4.86	4.31	4.12	2300	25000

a. pH units

b. $\mu\text{mhos/cm}$ @ 25°Cc. as CaCO₃

d. counts/100 ml

Table A-3. Sewage II water quality data. Units in mg/% unless otherwise noted.

	pH	S. Cond.	Turb.	TNFR	Chl.	T. Alk.	T. Hard.	TKN	NH ₃ -N	NO ₂ -N	NO ₃ -N	IP	TSP	OP	Fecal Col.	Total Col.
	a	b	c			d	d								e	e
I	10a	7.76	600	11	59.6	164	188	.330	.044	1.50	7.2	.685	.628	.624	30	180
	20a	7.54	615	33	44.4	184	204	.211	.045	1.70	6.4	1.036	1.004	1.014	24	180
	30b	7.78	6.8	2	66.7	172	200	.167	.033	1.28	7.9	1.014	1.014	.728	3	74
	40c	7.60	660	18	34	184	212	.167	.025	1.34	7.6	1.495	1.495	1.495	64	100
	50c	7.62	670	19	186	200	224	.144	.029	1.21	8.3	1.747	1.703	1.69	70	240
	60d	7.79	675	10	34	188	220	.156	.016	1.07	8.2	3.421	3.295	1.78	100	500
	70d	7.75	685	25	28	190	216	.056	.033	1.24	6.8	4.103	3.786	.752	90	500
II	10	7.58	568	100	43.3	188	170	.078	.045	1.29	10.8	.134	.064	.054	0	40
	20	7.68	580	23	63.9	164	190	.111	.031	1.23	6.9	.225	.209	.184	9	84
	30	7.56	615	100	295	232	192	.622	.018	1.23	6.9	.396	.253	.231	4	54
	40	7.64	605	100	365	230	190	.344	.011	1.18	7.4	.454	.277	.278	6	26
	50	7.75	660	18	95	178	208	.144	.018	1.03	7.0	1.624	1.584	.578	28	36
	60	7.45	635	2	66.7	164	206	.189	.018	1.17	7.8	1.889	1.552	.713	10	250
III	10	7.44	525	54	106	138	156	.222	.024	1.23	8.5	.073	.017	.010	0	0
	20	7.69	550	33	102	168	160	.222	.031	1.08	7.7	.058	.021	.013	0	26
	30	7.49	590	18	155	156	170	.856	.014	1.11	7.6	.066	.028	.024	3	3
	40	7.50	665	15	28	172	186	.178	.013	0.90	8.2	.171	.135	.155	6	120
	50	7.69	605	17	10	162	220	.333	.034	0.92	7.8	.088	.063	.103	0	10
Sewage	a	7.77	690	2.0	6.6	62.1	224	.556	.053	1.70	7.0	3.93	3.93	3.84	400	16,000
	b	7.77	700		69.2			.322	.031						9,000	44,000
II	c	7.71	718	2.6	7.2	67.5	236	.167	.060	1.34	7.6	3.77	3.77	3.62	3,000	24,000
	d	7.7	720		77.4										12,000	14,000
	e				77.4			.178							3,000	11,000

- a. pH units
- b. $\mu\text{mhos/cm}$ @ 25°C
- c. NTU
- d. as CaCO₃
- e. counts/100 ml

Table B-6. Sewage 1 mass balance for total coliform, fecal coliform, Cl⁻ and total hardness.

UNIT	COLUMN I				COLUMN II				COLUMN III				COLUMN IV				COLUMN V				COLUMN VI				COLUMN VII										
	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE	NO.	UNIT	PERIOD	TO DATE			
TOTAL	10	1.7E+05	3.0E+02	5.6E+10	3.7E+10	1.5E+10	5.7E	5.2E	1.3E0	1.6E	1.6E	1.6E	1.3E0	1.3E0	1.8E	1.8E	1.1E0	1.0E	1.0E	1.0E	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0		
	20	3.1E+05	2.4E+02	6.0E+10	1.6E+10	1.6E+10	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	
	30	4.5E+05	3.8E+02	8.4E+10	2.2E+10	2.2E+10	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	
	40	5.9E+05	5.2E+02	1.08E+11	2.9E+10	2.9E+10	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	
	50	7.3E+05	6.6E+02	1.32E+11	3.7E+10	3.7E+10	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	
TOTALS			1.7E+11	1.2E+11	1.2E+11	6.5E4																													
DISPOSERS	10	2.4E+05	2.0E+02	4.0E+10	1.0E+10	1.0E+10	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E	1.0E		
	20	3.6E+05	3.0E+02	7.2E+10	1.5E+10	1.5E+10	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	1.5E	
	30	4.8E+05	4.0E+02	9.6E+10	2.0E+10	2.0E+10	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	2.0E	
	40	6.0E+05	5.0E+02	1.2E+11	2.5E+10	2.5E+10	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	2.5E	
	50	7.2E+05	6.0E+02	1.44E+11	3.0E+10	3.0E+10	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	3.0E	
TOTALS			1.7E+11	1.2E+11	1.2E+11	6.5E4																													
TOTAL	10	1.7E+05	3.0E+02	5.6E+10	3.7E+10	1.5E+10	5.7E	5.2E	1.3E0	1.6E	1.6E	1.6E	1.3E0	1.3E0	1.8E	1.8E	1.1E0	1.0E	1.0E	1.0E	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0		
	20	3.1E+05	2.4E+02	6.0E+10	1.6E+10	1.6E+10	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	
	30	4.5E+05	3.8E+02	8.4E+10	2.2E+10	2.2E+10	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	
	40	5.9E+05	5.2E+02	1.08E+11	2.9E+10	2.9E+10	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	
	50	7.3E+05	6.6E+02	1.32E+11	3.7E+10	3.7E+10	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	
TOTALS			1.7E+11	1.2E+11	1.2E+11	6.5E4																													
TOTAL	10	1.7E+05	3.0E+02	5.6E+10	3.7E+10	1.5E+10	5.7E	5.2E	1.3E0	1.6E	1.6E	1.6E	1.3E0	1.3E0	1.8E	1.8E	1.1E0	1.0E	1.0E	1.0E	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0	1.3E0		
	20	3.1E+05	2.4E+02	6.0E+10	1.6E+10	1.6E+10	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	1.6E	
	30	4.5E+05	3.8E+02	8.4E+10	2.2E+10	2.2E+10	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	2.2E	
	40	5.9E+05	5.2E+02	1.08E+11	2.9E+10	2.9E+10	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E	2.9E
	50	7.3E+05	6.6E+02	1.32E+11	3.7E+10	3.7E+10	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	3.7E	
TOTALS			1.7E+11	1.2E+11	1.2E+11	6.5E4																													

Table B-7. Sewage II mass balance data for nitrogen.

	COLUMN I				COLUMN II				COLUMN III			
	mg INF	EFF	MB PERIOD	TO DATE	mg EFF	MB PERIOD	TO DATE	mg EFF	MB PERIOD	TO DATE		
AMMONIA-NITROGEN												
10	.53	.44	- .09	- .09	.45	+ .01	+ .01	.24	- .21	- .21		
20	.53	.45	- .08	- .17	.31	- .14	- .13	.31	0	- .21		
30	.31	.53	+ .02	- .15	.18	- .15	- .28	.14	- .04	- .25		
40	.60	.25	- .35	- .50	.11	- .14	- .42	.13	+ .02	- .23		
50	.60	.29	- .31	- .81	.18	- .11	- .53	.34	+ .16	- .07		
60	.60	.16	- .44	-1.25	.18	+ .02	- .51					
70	.60	.33	- .27	-1.52	INF 1.92			INF 1.23				
TOTALS:	INF	3.77			EFF	1.41		EFF	1.16			
		EFF	2.25									
NITRATE-NITROGEN												
10	70	72	+ 2	+ 2	108	+ 36	+ 36	85	- 23	- 23		
20	70	64	- 6	- 4	69	+ 5	+ 41	77	+ 8	- 15		
30	70	79	+ 9	+ 5	69	- 10	+ 31	76	+ 7	- 8		
40	76	76	0	+ 5	74	- 2	+ 29	82	+ 8	0		
50	76	83	+ 7	+12	70	- 13	+ 16	78	+ 8	+ 8		
60	76	82	+ 6	+18	78	- 4	+ 12	INF 390				
70	76	68	- 8	+10	INF 456			EFF 398				
TOTALS:	INF	514			EFF	468						
		EFF	524									
NITRITE-NITROGEN												
10	17	15	- 2	- 2	12.9	- 2.1	- 2.1	12.3	- 0.6	-0.6		
20	17	17	0	- 2	12.3	- 4.7	- 6.8	10.8	- 1.5	-2.1		
30	17	12.8	- 4.2	- 6.2	12.3	- 0.5	- 7.3	11.1	- 1.2	-3.3		
40	13.4	13.4	0	- 6.2	11.8	- 1.6	- 8.9	9.0	- 2.8	-6.1		
50	13.4	12.1	- 1.3	- 7.5	10.3	- 1.8	-10.7	9.2	- 1.1	-7.2		
60	13.4	10.7	- 2.7	-10.2	11.7	+ 1.0	- 9.7	INF 59.6				
70	13.4	12.4	- 1.0	-11.2	INF 81.0			EFF 52.4				
TOTALS:	INF	104.6			EFF	71.3						
		EFF	93.4									
ORGANIC NITROGEN												
10	5.03	2.86	- 2.17	- 2.17	.33	- 2.53	- 2.53	1.98	+ 1.65	+ 1.65		
20	5.03	1.66	- 3.37	- 5.54	.80	- .86	- 3.39	1.91	+ 1.11	+ 2.76		
30	2.91	1.34	- 1.57	- 7.11	6.04	+ 4.70	+ 1.31	3.42	+ 2.38	+ 5.14		
40	1.07	1.42	+ .35	- 6.76	3.33	+ 1.91	+ 3.22	1.65	- 1.68	+ 3.46		
50	1.07	1.15	+ .08	- 6.68	1.26	+ 1.26	+ .11	2.99	+ 1.73	+ 5.19		
60	1.12	1.40	+ .28	- 6.40	1.71	+ .31	+ 3.64	INF 11.76				
70	1.12	.23	- .89	- 7.29	INF 9.83			EFF 16.95				
TOTALS:	INF	17.35			EFF	13.47						
		EFF	10.06									

Table B-8. Sewage II mass balance data for phosphorus.

	COLUMN I				COLUMN II				COLUMN III			
	mg INF	MB EFF	PERIOD	TO DATE	mg EFF	MB PERIOD	TO DATE	mg EFF	MB PERIOD	TO DATE		
SOLUBLE ORGANIC AND ACID-HYDROLYZABLE PHOSPHATE												
10	0	.04	+ .04	+ .04	.10	+ .06	+ .06	.07	- .03	- .03		
20	0	.50	+ .50	+ .54	.25	- .25	- .19	.08	- .17	- .20		
30	0	2.82	+ 2.82	+ 3.36	.22	- 2.60	- 2.79	0	- .22	- .42		
40	1.50	0	- 1.50	+ 1.86	0	0	- 2.79	0	0	- .42		
50	1.50	.01	- 1.40	+ .46	10.02	+ 9.92	+ 7.13	0	-10.02	-10.44		
60	1.50	15.2	+13.70	+14.16	8.37	- 6.83	+ .30	INF	10.59			
70	1.50	30.38	+28.88	+43.04	INF	18.66		EFF	.15			
TOTALS:	INF	6.00			EFF	18.96						
		EFF	49.04									
PARTICULATE PHOSPHORUS												
10	0	.52	+ .52	+ .52	.70	+ .18	+ .18	.56	- .14	- .14		
20	0	.40	+ .40	+ .92	.16	- .24	- .06	.37	+ .21	+ .07		
30	0	0	0	+ .92	1.43	+ 1.43	+ 1.37	.38	- 1.05	- .98		
40	0	0	0	+ .92	1.82	+ 1.82	+ 3.19	.36	- 1.46	- 2.44		
50	0	.40	+ .40	+ 1.32	.40	0	+ 3.19	.25	- .15	- 2.59		
60	0	1.20	+ 1.20	+ 2.52	3.40	+ 2.20	+ 5.40	INF	4.51			
70	0	3.10	+ 3.10	+ 5.62	INF	2.52		EFF	1.92			
TOTALS:	INF	0			EFF	7.91						
		EFF	5.62									
TOTAL PHOSPHORUS												
10	38.3	6.8	-31.5	- 31.5	1.34	- 5.46	- 5.46	.73	- .61	- .61		
20	38.3	11.0	-27.3	- 58.8	2.25	- 8.75	-14.21	.58	- 1.67	- 2.28		
30	38.3	10.1	-28.2	- 87	3.96	- 6.14	-20.35	.66	- 3.30	- 5.58		
40	37.7	15	-22.7	-109.7	4.59	-10.41	-30.76	1.71	- 2.88	- 8.46		
50	37.7	17.4	-20.3	-130	16.2	- 1.2	-13.96	.88	-15.32	-23.78		
60	37.7	34.2	- 3.5	-133.5	18.9	-15.3	-47.26	INF	28.54			
70	37.7	41	+ 3.3	-130.2	INF	94.5		EFF	4.56			
TOTALS:	INF	265.7			EFF	47.24						
		EFF	135.5									
TOTAL SOLUBLE PHOSPHORUS												
10	38.3	6.28	-32.02	- 32.02	.64	- 5.64	- 5.64	.17	- .47	- .47		
20	38.3	10.6	-27.7	- 59.72	2.09	- 8.51	-14.15	.24	- 1.85	- 2.32		
30	38.3	10.1	-28.2	- 87.92	2.55	- 7.57	-21.72	.28	- 2.25	- 4.57		
40	37.7	15	-22.7	-110.62	2.77	-12.23	-33.95	1.35	- 1.42	- 5.99		
50	37.7	17	-20.7	-131.32	15.8	- 1.2	-35.15	.63	-15.17	- 21.16		
60	37.7	33	- 4.7	-136.02	15.5	-17.5	-52.65	INF	23.83			
70	37.7	37.9	+ .2	-135.82	INF	91.98		EFF	2.64			
TOTALS:	INF	265.7			EFF	39.33						
		EFF	129.88									
ORTHOPHOSPHATE-PHOSPHORUS												
10	38.3	6.24	-32.06	- 32.06	.54	- 5.70	- 5.70	.10	- .44	- .44		
20	38.3	10.1	-28.2	- 60.26	1.84	- 8.26	-13.96	.13	-1.71	- 2.15		
30	38.3	7.28	-31.02	- 91.28	2.31	- 4.97	-18.93	.24	-2.07	- 4.22		
40	36.2	15	-21.2	-112.48	2.77	-12.23	-31.16	1.35	-1.42	- 5.64		
50	36.2	16.9	-19.3	-131.78	5.78	-11.12	-42.28	.63	-5.15	-10.79		
60	36.2	17.8	-18.4	-150.18	7.13	-10.67	-52.95	INF	13.24			
70	36.2	7.52	-28.68	-178.86	INF	73.32		EFF	2.45			
TOTALS:	INF	259.7			EFF	20.37						
		EFF	80.84									

