URBAN RUNOFF POLLUTANT ADSORPTION AND FILTERING BY SELECTED NORTHERN GUAM SOILS AND LIMESTONE

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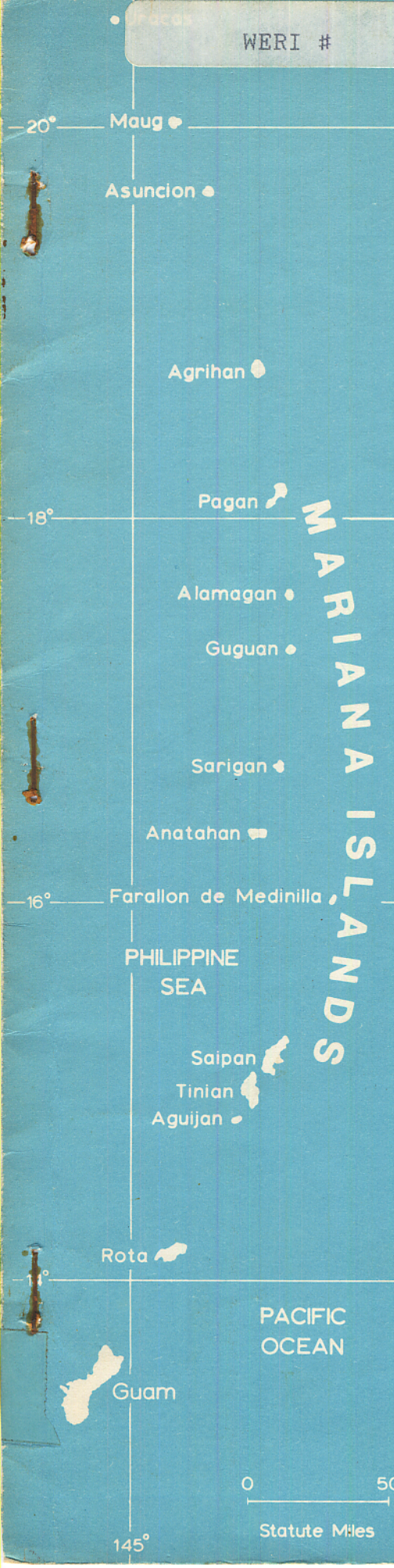

Water Resources Research Center

UNIVERSITY OF GUAM

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Partial Project Completion Report

for

EFFECTS OF INFILTRATION OF URBAN RUNOFF ON GROUND AND COASTAL WATERS IN LIMESTONE REGIONS OF NORTHERN GUAM

OWRT Project No. A-005-Guam, Grant Agreement Nos. 14-34-0001-6054,7023,7024

Principal Investigators: Reginald H. F. Young and Stephen J. Winter

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ABSTRACT

The concentrations of most pollutants in urban runoff percolating through lysimeter columns containing Guam soil and limestone were substantially reduced. This reduction by adsorption and/or filtration occurred after percolation through 3/4 meter of substrate. Pollutants showing a 70 percent or greater reduction in concentration included total and fecal coliform bacteria, orthophosphorus, and total phosphorus. Compared to limestone, soils generally showed greater removal of MBAS and oil and grease. The mean removal rate of MBAS for soils averaged 68 percent. Mariana limestone was particularly permeable to MBAS, generally removing less than 30 percent.

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INTRODUCTION

Guam is roughly divided into two hydrogeologic areas; a limestone northern plateau and volcanic southern upland. Although groundwater underlies all of Guam, only in the limestone plateau is it extensive enough to be developable on a large scale (Mink, 1976). Currently, the groundwater aquifer underlying the northern plateau is the principle source of drinking water. Due to increasing urbanization and agricultural development on northern Guam the available surface recharge area is diminishing. Mink (1976) in his study of groundwater resources of Guam identified urban storm water runoff as a potential contaminant of the groundwater resources. Mink asserted that the normally light pollutant load associated with this type of runoff posed minimal threat to the aquifer quality. However, in order to maintain this resource for future use, long term external pollutant sources must be determined as well as their potential impact.

The quality of urban runoff in northern Guam, either discharged into coastal receiving waters or ponded for groundwater recharge, was assessed by Zolan et al., 1978. This study determined that the urban runoff in the central and northern areas (primarily from residental developments) is lightly polluted, while the urban runoff from the commercial areas of Agana-Tamuning is lightly to heavily polluted. Since this commercial runoff is either discharged into coastal waters or allowed to infiltrate into the coastal recharge zone (Fig. 1), it does not pose a major threat to the aquifer quality.

Two soil types predominate on the northern plateau: Guam clay and Chacha clay (Fig. 2). Guam clay, a reddish latosal, comprises roughly 35 percent of the total island soil and 80 percent of the northern soil (Tracey et al., 1964). This shallow soil extensively overlies the Barrigada and Mariana limestones (Fig. 3). Chacha clays, a latosolic intergrading of up to three silty clays, are deposited, moderately deep to deep, in the central portion of the island on the Agana argillaceous member of the Mariana limestone.

This laboratory lysimeter study augments the study by Zolan et al. (1978) by assessing the quality fo urban runoff after percolation through Guam clay, Chacha clays, and Mariana limestone.

OBJECTIVE

The laboratory lysimeter studies were conducted to determine the filtering and adsorptive potential of predominant Guam soils and limestone for selected pollutants found in urban runoff.

SCOPE

Laboratory lysimeter tests were conducted to provide an assessment of the quality of urban runoff waters after percolation through soils and limestone. Each test consisted of repeated applications of urban runoff waters to lysimeters with selected water quality parameters analyzed prior to and after application to ascertain the adsorptive and filtering potential of the substrata. Repeated tests were conducted using the same substrata to determine short and long term behavior.

MATERIALS AND METHODS

Three lysimeter columns were constructed for the soil adsorption studies. Each column consisted of a 1 m section of clear polyvinyl chloride (PVC) pipe, inside diameter of 15 cm (6"), flanged at the lower end, and bolted to a plexiglass base plate. The base plate was drilled and fitted with a shut-off mechanism. Fine mesh plastic screen and glass beads or aquarium gravel were placed in the bottoms of the constructed columns to reduce substratum wash out. The lysimeters were placed in a wooden rack that provided ample space for sample collection (Fig. 4). See appendix A for detailed description of lysimeter design.

Two soils and a limestone common to northern Guam were selected for testing. A fixed volume, approximately 15 liters, and depth, 78-80 cm, of substratum was maintained for each lysimeter test series. The depth was choosen on the basis of obtaining the maximum loading capacity for the columns that still left space for application of two liters of sample water. Additionally, the loaded depth was reasonably representative of soil depths found on northern Guam. The 15 liter volume was used to standardize compaction of the loaded substratum.

The two soils used have tentatively been classified as Chacha or Chacha-Saipan clay and Guam clay based on description in Carroll and Hawthaway (1963) and soil maps from Military Geology of Guam, 1959. See appendix B for description and mineralogy of Guam clay and Chacha clay.

Both soil types were collected from Mt. Barrigada. The Guam clay was obtained from a large disturbed pile at the summit and the Chacha clay from a recently disturbed area on the lower north slope (Figs. 5 and 6). The Guam clay appeared to be typical of the soil type in the surrounding area. Additionally, it appeared similar to other moderately weathered Guam clay deposits typical of northern Guam. The Chacha clay was not typical of the area. It is suspected that the soil was transported into the area for agricultural purposes. This soil appeared similar in color and composition to deposits of Chacha-Saipan clay found in the vicinity of Barrigada Village.

The limestone used was Mariana limestone of a lagoonal or detrital origin. It was classified based on descriptions in Schlanger, 1964. See appendix B for description and mineralogy. The Mariana limestone was collected from tailings of a trench being dug for the northern area sewage system at Naval Communications Station, Dededo (Fig. 7). The limestone was collected from the top of the tailing pile. It was recently trenched material representative of the limestone 5-8 m below the surface.

In order to reduce column packing problems, the soils and limestone were sieved through a 2 cm mesh screen at the time of collection. This removed the coarse gravel to boulder size fraction. The sieved substrata were collected and stored in large, covered plastic vats (Fig. 8). Aliquots of these original collections were used in the lysimeter test series.

A standard procedure was devised for loading the substrata into the lysimeter columns. It was assumed that the substrata in the storage vats were already uniformily mixed. Therefore, a one liter lift was scooped directly from the vat and dumped into the column. This aliquot was tamped using 5-10 moderate to heavy blows. The tamper was a section of PVC pipe attached to a circular (10 cm diameter) plexiglass plate. The substratum near the edges of the column was packed hardest. This was done to prevent channeling of the sample water along the column walls. After 15 liters of substratum had been loaded, a fine mesh plastic screen was placed on top to minimize surface distortion and to trap organic debris.

Urban runoff water was collected from three locations. Residentially derived runoff was collected from Barrigada Heights ponding basin (Fig. 8). Commercially derived urban runoff was collected from the Airport Road drainage channel (Fig. 9) and the storm drainage ditch along Marine Drive at Camp Watkins Road. The Barrigada Heights and Airport Road collection sites are the same sites used in *Urban Runoff Quality in Northern Guam* (WRRC Tech. Rept. No. 5). In terms of pollutant concentrations, residential runoff was designated by the above report as being high quality runoff and commercial runoff as lower quality runoff. Runoff from the residential source was utilized more extensively since residentially derived runoff is the predominant runoff type on the northern plateau (Zolan et al., 1978). The Marine Drive-Camp Watkins site was selected as a commercial source of runoff waters when it was observed to contain heavy loads of oil and grease and a foaming agent.

The water was collected in a cleaned bucket and transferred to a chemically cleaned 40 liter ice chest for transport to the laboratory. Only water collected in the ice chest was utilized. It was noted that the oil and grease adhered to the ice chest during transport. Therefore, the initial oil and grease concentrations determined in the laboratory are lower than actual field conditions.

Preapplication water samples were taken from the ice chest immediately upon return to the laboratory. Two liter applications were siphoned from the ice chest and added to the columns. Usually 10 liters of sample water were added per column per test run. The infiltration time and flow rate, for the first liter passing, were recorded (Figs. 11 and 12). This information was used as a check on the substratum compaction and to determine if channeling was occurring.

In the initial lysimeter test the bottom valves of the columns were closed. The soil was saturated with 5 liters of water before removal for analyses. Free percolation was allowed for all subsequent test runs. The columns were allowed to drain between test runs, leaving only interstitial water. This was done to reduce cross-over contamination between test runs.

Pollutant parameters in urban runoff water that potentially could pose a hazard include coliform bacteria, oil and grease, MBAS (detergent compounds), total phosphorus, and nitrate-nitrogen. As a result, these parameters were emphasized. Table 1 lists the parameters and the method used for analysis.

A percolate collection order was devised. Each parameter sample was collected from roughly the same volume passing in each test run. The order was, for the most part, arbitrarily assigned. The nitrate-nitrogen sample was collected first since it was known to rapidly leach out. The collection order was as follows: nitrate and nitrite-nitrogen; BOD; turbidity and specific conductance; hardness; pH; oil and grease; total and ortho phosphorus; MBAS; and total and fecal coliform bacteria.

RESULTS AND DISCUSSION

This study indicates that Guam clay, the most common surface soil in northern Guam (80%), will adsorb or filter out from 50 to 70 percent of most urban runoff pollutants within one meter of the surface. Due to the fact that greater compaction of Guam clay exists in the field than could be obtained in lysimeter columns, residence time and percolation rates are probably longer under field conditions. Hence, the removal values obtained in the laboratory study are rough indications only. It is probable that the adsorption values obtained are conservative if they differ from actual field adsorptive and filtering capacity of similar soil depth.

Comparatively, both Mariana limestone and Chacha clay were superior to Guam clay as adsorptive and filtering media. This lower rating of Guam clay is due to its lower removal rates of Total Phosphorus, BOD and coliform bacteria (Tables 2 and 3).

Pollutants which permeate most readily through the substrata are nitrate, MBAS, and oil and grease. Most urban runoff on Guam is derived from residential or light commercial areas. Quantities of these least adsorbed pollutants are usually low in this runoff (Zolan, et al., 1978). The lysimeter data indicates that substrata filtering and adsorption of the measured parameters is sufficient to remove the danger of groundwater contamination from residential runoff. High levels of oil and grease and MBAS can be found in runoff from the central commercial district in Tamuning-Agana. Lysimeter tests with runoff containing high MBAS and oil and grease show substantial concentrations in the percolate. Based on the lysimeter results, discharge or runoff containing high oil and grease and MBAS should not be allowed to pond in the critical resource and conservation zones of northern Guam (Fig. 1). Commercial development of Guam currently is situated along the western coast away from groundwater recharge areas. As a result, commercial urban runoff is discharged into coastal waters or ponded on the periphery of the groundwater recharge zone.

Individual test results of the 20 lysimeter tests run with urban runoff are presented in Table 4. The following is a discussion of results obtained for each pollutant parameter.

Orthophosphorus

Orthophosphorus was the most readily removed parameter from urban runoff. The soils and limestone generally removed over 90 percent of the orthophosphorus in runoff water (Fig. 2). No decrease in removal capabilities was noted at higher concentrations (<.8 mg/l). The standard deviation from mean removal rates was less than 6 percent.

The removal of phosphate ions by Guam clay and similar clays can be attributed to their nature as lithosolic latosols. One characteristic of lateritic soils is a tremendous ability to fix phosphate ions. Two agents of fixation occur in Guam soils: an abundant amount of hydrated oxides of aluminum and iron and a large amount of exchangeable calcium. At the slightly alkaline conditions of Guam clay, calcium exchange is probably the main source of phosphate fixation (Demeterio, 1978).

Total Phosphorus

Total phosphorus removal was generally over 80 percent for Mariana limestone and Chacha clay (Fig. 13). Guam clay had lower removal rates with a mean removal of 68 percent. Increased permeability to total phosphorus occurs when MBAS compounds in urban runoff are high. The ability of MBAS compounds to percolate through soils more readily probably accounts for the decrease in total phosphorus adsorption.

Nitrite-Nitrogen and Nitrate-Nitrogen

Removal of nitrate ions was not generally observed with the exception of Mariana limestone. Runoff waters added to freshly loaded soils picked up large quantities of nitrate ions with resulting percolate nitrate-nitrogen concentrations ranging from 54.8 mg/l to 150.6 mg/l (Table 5). These high concentrations are believed to have resulted from increased aeration when the soil was collected. Since nitrification is a process of oxidation, any procedure that increases soil aeration serves to increase the conversion of the organic nitrogen pool to nitrate-nitrogen (Brady, 1974). This process probably occurred in the stored soils. Stored Guam clay showed a gradual increase of nitrate over time (6 months) to produce concentrations of over 150 mg/l nitrate-nitrogen. The maximum concentration for stored Chacha clay was 61 mg/l nitrate-nitrogen. The concentration of nitrate-nitrogen in the percolate dropped to between 1 and 10 mg/l after the initial 5-10 liters had passed. The level of leaching nitrate-nitrogen

remained at this level for the remaining tests (Table 4). These concentrations were maintained by nitrification and mineralization of the pooled organic nitrogen in the lysimeter between test runs.

The concentration of nitrate-nitrogen in the freshly loaded Mariana limestone was low, ranging from .039 to .380 mg/l. The extremely low organic content of Mariana limestone is believed to be responsible for the lower nitrogen available for nitrification to nitrate. Mariana limestone occasionally removed nitrates after the initial leaching of nitrate-nitrogen. However, its performance was unpredictable (Table 2) as evidencedfrom its low mean removal rate and high standard deviation.

An attempt was made to flush nitrate from the soils and substratum by passing 20-30 liters of demineralized water through the columns. Upon completing the flushing, the demineralized water contained .180 and .179 mg/l nitrate-nitrogen for Guam clay and Chacha clay respectively and .047 mg/l for Mariana limestone (Table 6). Immediately upon completion of the demineralized flushing, sample water containing 1.05 mg/l NO_3-N was added to the columns. The percolate concentration from Guam clay was .998 mg/l, from Chacha clay .775 mg/l, and from Mariana limestone .281 mg/l nitrate-nitrogen. This shows that temporary flushing of nitrates is possible and probably occurs readily during rainfall. Within two weeks of the flushing, surface soil levels of leaching nitrate returned to the normal greater than 1.0 mg/l concentration.

The concentration of organic nitrogen in Guam soils has been determined to be as high as 3000 ppm (Demeterio, 1978). Mineralization of this organic pool and nitrification results in a continual production of nitrate in the soil with subsequent leaching into percolating runoff waters. The values of nitrate-nitrogen from lysimeter percolate generally fall within the same range as groundwater pumped from beneath northern Guam (.5 to 5 mg/l nitrate-nitrogen).

Nitrite concentrations are usually quite low (<.010 mg/l) and therefore are not a pollution problem in urban runoff waters. However, sewage septic tank leakage may contribute large quantities of nitrite-nitrogen. No lysimeter tests were run with water containing high nitrite-nitrogen concentratons. Initial nitrite concentrations in freshly loaded soil ranged up to .5 mg/l nitrite-nitrogen. The concentration of nitrite fell to well below .010 mg/l by the time ten liters had percolated through the columns. The concentrations remained in at this level in subsequent test runs (Table 4).

Oil and Grease

On an average, 70 percent of the oil and grease compounds in urban runoff were removed by the clay soils. The limestone generally removed only 50 percent of the oil and grease compounds. Runoff containing high concentrations of oil and grease were added (up to

185 mg/l). At the higher concentrations the percentage of removal was greater (Fig. 10). It appears that the clay soils have a fairly high adsorptive capacity for oil and grease.

Large oil spills (fuel oil) occur with disturbing frequency in resources areas from rupturing fuel oil pipelines and fuel tank filling operations. Spills occurring from 1975 through 1977 resulted in a total exceeding several thousand gallons. These large fuel oil spills pose a major threat to groundwater quality.

Methylene Blue Active Substances

All three substrata varied in their ability to remove MBAS from runoff waters. Mariana limestone generally removed less than 30 percent of the MBAS in urban runoff. Guam clay generally removed less than 50 percent and Chacha clay removed less than 70 percent (Fig. 11). The percentage removed varied widely from zero to 95 percent. Considering the poor adsorption of MBAS by Guam clay and Mariana limestone, MBAS can potentially pose a threat to the groundwater quality. MBAS has been measured in some Guam groundwater wells at nearly 20 percent of the limit established in United States Environmental Protection Agency drinking water standards.

Total and Fecal Coliform

Mariana limestone showed superior filtering of coliform bacteria with almost 100 percent removal of fecal coliforms and over 90 percent removal of total coliforms (Figs. 12 and 13). The standard deviation of the mean removal rate for Mariana limestone was comparatively low, 3.9 percent for fecal coliform and 15.5 percent for total coliform bacteria (Table 2).

The clay soils showed wide variation in coliform bacterial filtering, although on an average Guam clay removed over 70 percent of the total and fecal coliform bacteria and Chacha clay removed over 80 percent.

Despite the high filtering percentage of fecal and total coliform, the concentrations in the percolate were high (in comparison to groundwater), with values ranging up to the thousands per 100 ml (Table 4). Also, other types of bacteria (not identified) were noted in the percolate.

BOD

Biochemical oxygen demand serves as a indication of overall filtering/adsorption capability since BOD depends upon both biological and chemical quality of the percolate. In removal of BOD, Chacha clay was the most effective, removing a mean of 79 percent. However, removal values ranged widely (Table 4). Both Mariana limestone and Guam clay removed roughly 50 percent of the BOD (Fig. 14). Despite the good bacteria filtering capacity of Mariana limestone, its permeability to organic compounds results in higher percolate BOD.

Turbidity

Filtration of material producing turbidity was observed in columns once initial flushing of columns occurred. Mariana limestone acted as a very good filter usually reducing runoff turbidities to below drinking water standards (<1 NTU). The precolate from the clay soils had higher turbidities (approximately 5 NTU) as a result of clay suspension. In all cases turbidity filtering improved with column use (Table 4).

Specific Conductance

Leaching of ions from the soil resulted in a substantial increase in the specific conductance of the percolate (Table 4). The mean specific conductance of urban runoff was 136 umho/cm. The mean specific conductance of percolate from Mariana limestone was 218 umho/cm, from Guam clay 344 umho/cm, and from Chacha clay 359 umho/cm. When runoff water of 1443 umho/cm specific conductance was tested, specific conductance dropped to 1005 umho/cm in Mariana limestone percolate, 1075 in Guam clay percolate, and 387 umho/cm in Chacha clay.

pH

The pH of sample runoff water ranged from 7.07 to 8.35 with a mean of 7.54. This pH range is typical of runoff found in the *Urban Runoff Quality in Northern Guam* (1978). Percolate water ranged from 7.48 to 7.84 (Table 4). The clay soils produced similar mean pH values: 7.67 and 7.65 for Guam clay and Chacha clay, respectively. Mariana limestone produced a slightly higher mean pH of 7.75. These pH values fall within the range of groundwater pH (7.4 to 7.9).

In the neutual to alkaline soils of northern Guam, hydrogen and aluminum ions are bound (in the form of gibbsite) and replaced by exchangeable bases (calcium). Percolating water in contact with the alkaline soil produces free calcium and hydroxyl ions, increasing both hardness and pH.

Total Hardness

Urban runoff percolating through the lysimeter columns increased appreciably in hardness. All three substrata contain a considerable calcium fraction. Urban runoff usually contained less than 50 mg/l hardness. After percolation through Mariana limestone the hardness increased by 30 to 40 mg/l. The increase in hardness after percolation through the clay soils ranged from 50 to 100 mg/l (Table 4). The final hardness concentrations generally ranged from 100 to 150 mg/l for soils and usually fell below 100 mg/l for Mariana limestone. The surface soils of Guam have a high ion exchange capacity (5.8 to 35 mg/100 ml, Carroll and Hathaway, 1963). This, coupled with the slightly alkaline native of the soils, facilitated the leaching of calcium into percolating runoff water. Additionally, runoff pH

values are almost always greater than 7.0 which increases the calcium leaching process.

Soil Adsorption/Filtration and Guam Urban Runoff Quality

As found in the *Urban Runoff Quality in Northern Guam* (1978), Guam urban runoff quality varies according to its source area. Runoff from predominately residential areas or developments is lightly polluted. This type of urban runoff comprises most runoff waters. More heavily polluted runoff with high concentrations of oil and grease and MBAS is usually characteristic of commercially developed areas along Marine Drive in the Agana-Tamuning area. (Generally, oil and grease concentrations in the commercial area exceed 15 mg/l and MBAS concentrations exceed .5 mg/l).

Based on the lysimeter tests, it appears safe to assume that soil adsorption and filtration is removing pollutants to acceptable levels in ponded urban runoff. If the quality of urban runoff in residential areas is allowed to deteriorate and become similar to runoff from Marine Drive or Airport Road then a threat of groundwater contamination might exist.

Future commercial development of Northern Guam or high density residential development can be expected to result in increased pollutant concentrations of both storm and non-storm related runoff.

RECOMMENDATIONS

1) Continued use of ponding basins as a means of retaining storm runoff waters from residential developments for groundwater recharge.

2) Inclusion of ponding basin water quality monitoring in the Guam Environmental Protection Agency water monitoring program.

3) A determination of MBAS and oil and grease concentrations in all groundwater wells to determine their current concentrations for future reference and to determine if problem areas exist.

4) Enforcement of the Guam Environmental Protection Agency Water Quality Standards regarding resource and conservation zones to maintain the current quality of runoff waters in northern Guam.

5) Determination of heavy metal concentrations in urban runoff and the adsorption capacity of northern Guam soils for heavy metals.

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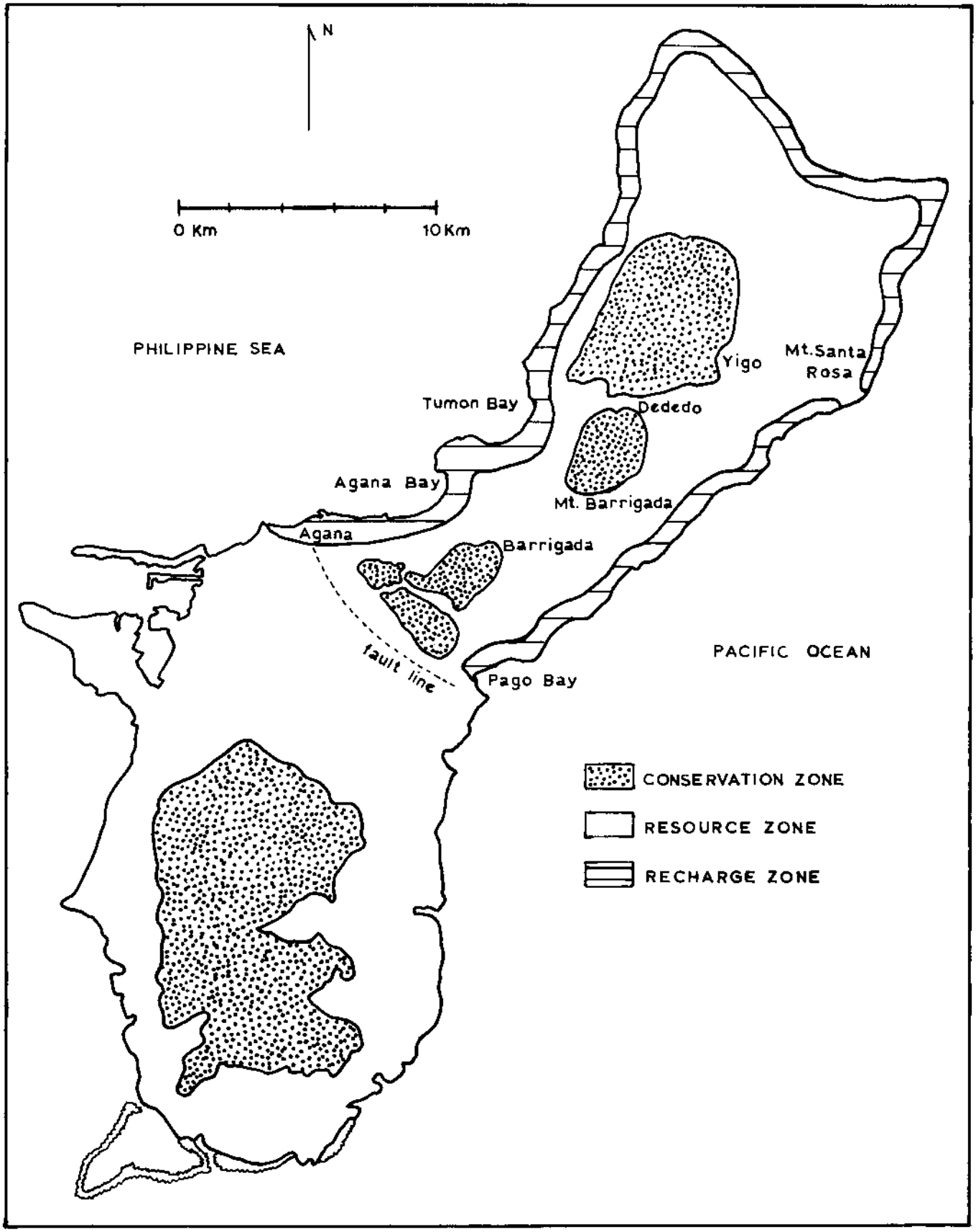

Fig. 1. Water conservation, resource and recharge zones as designated by the Guam Environmental Protection Agency (1975).

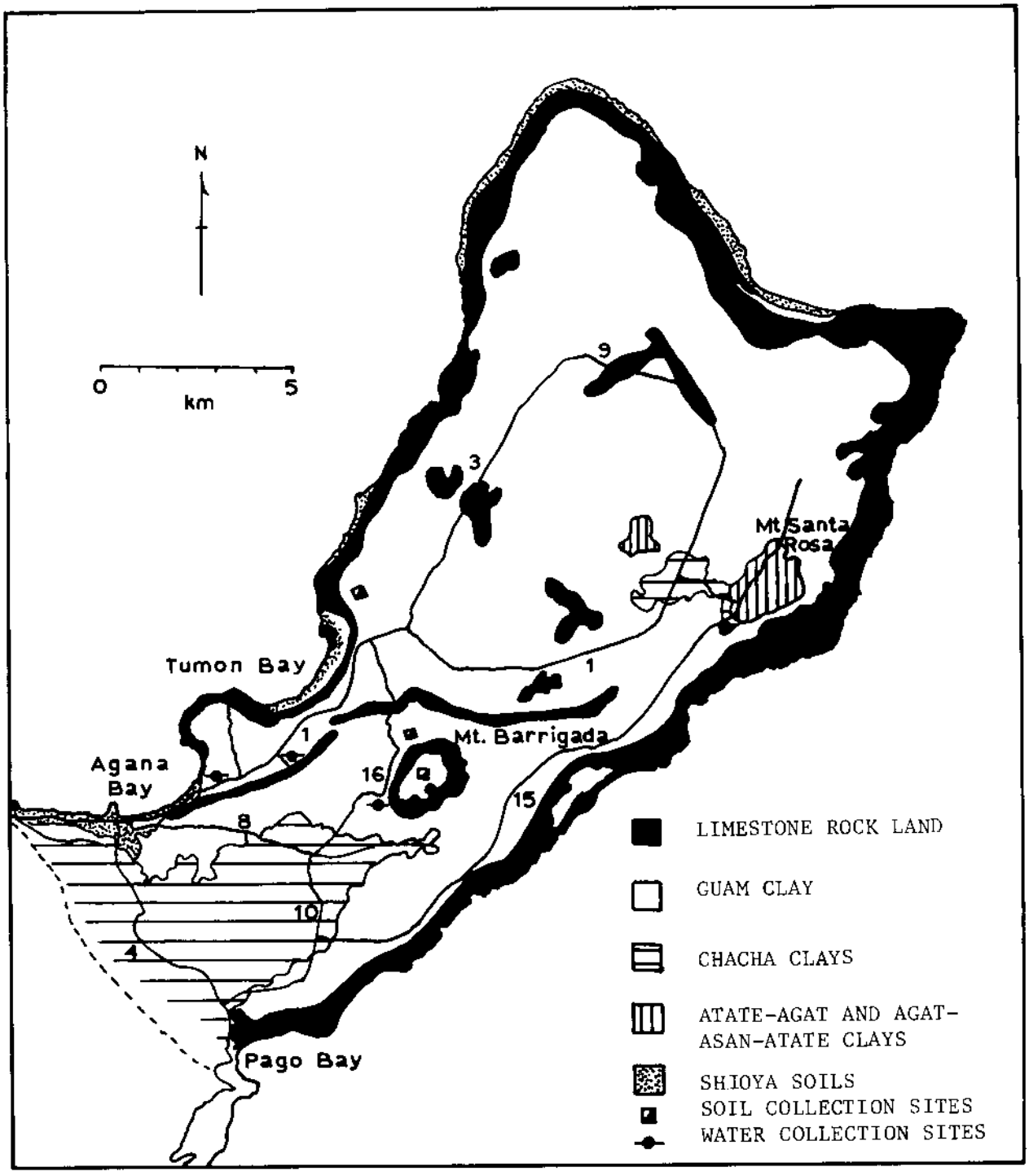

Fig. 2. Soil classification map of Northern Guam.

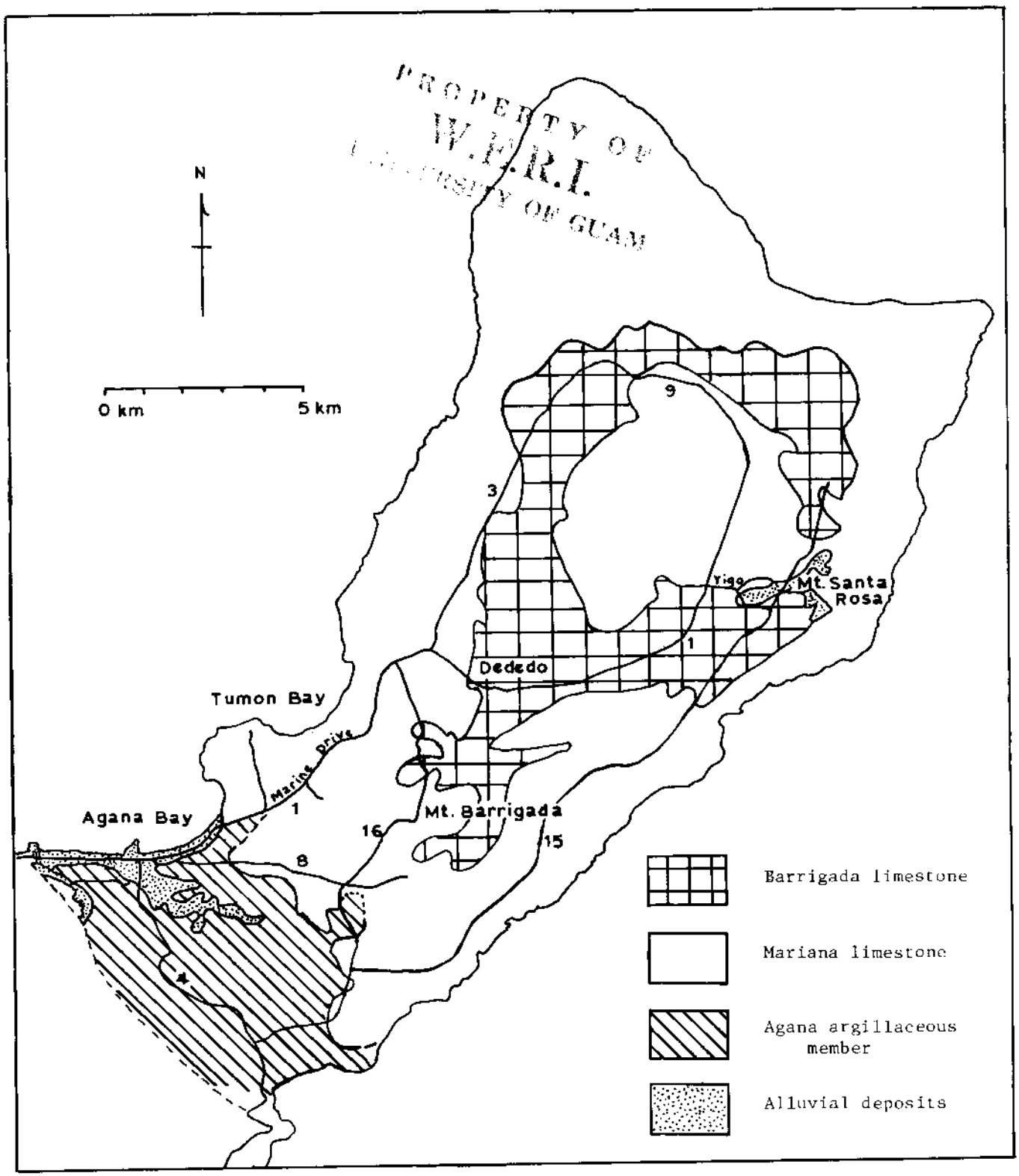

Fig. 3. Limestone formations of northern Guam

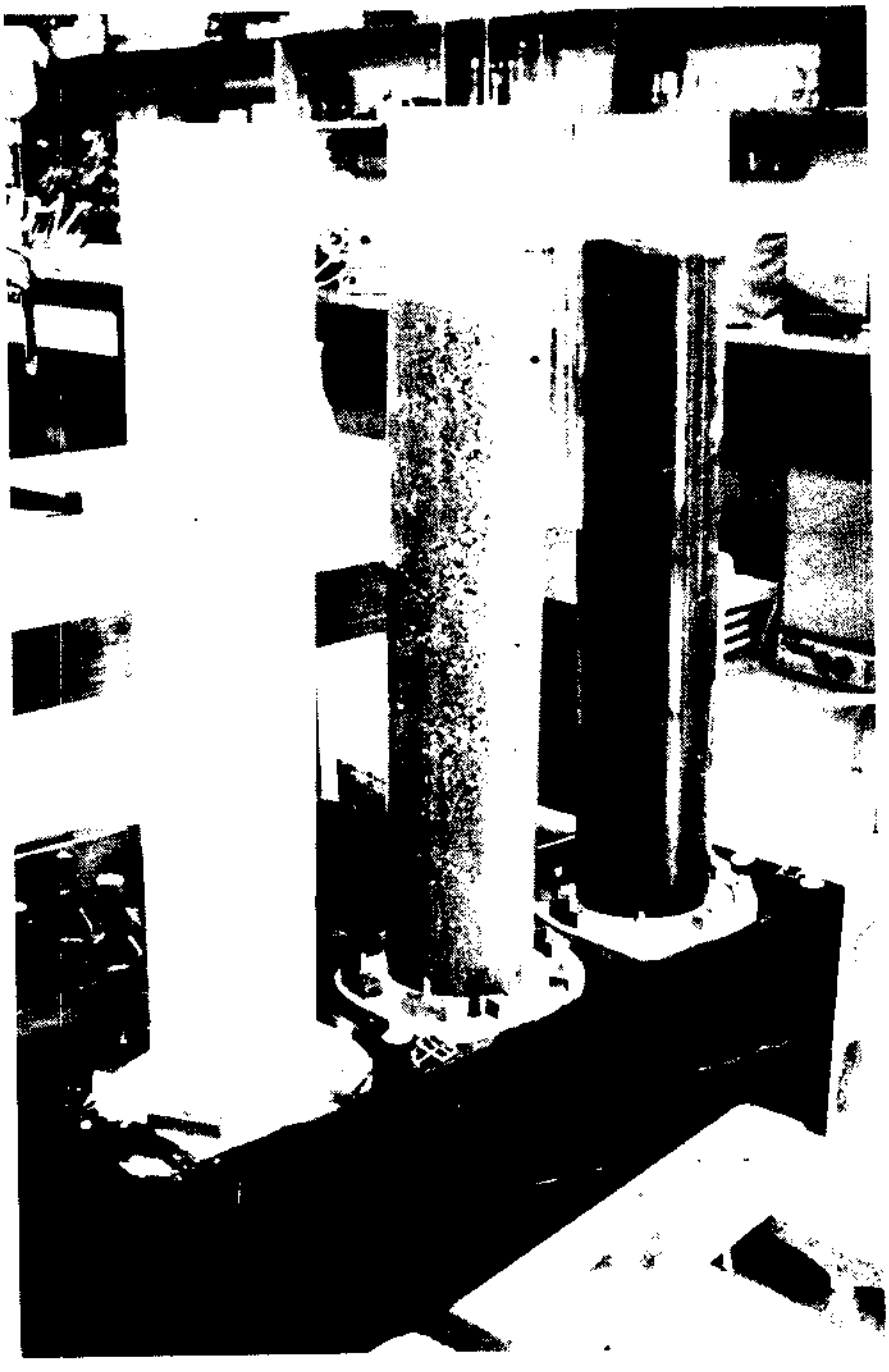

Fig. 4. Lysimeter columns. Mariana limestone, Guam clay and Chacha clay from left to right.

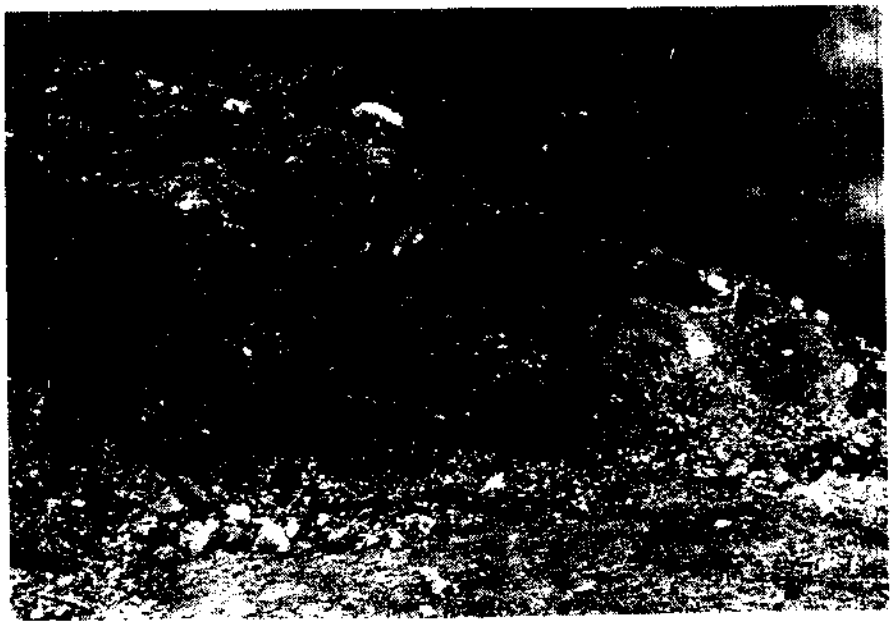

Fig. 5. Guam clay collection site atop Mt. Barrigada.

Fig. 6. Chacha clay collection site, Mt. Barrigada.

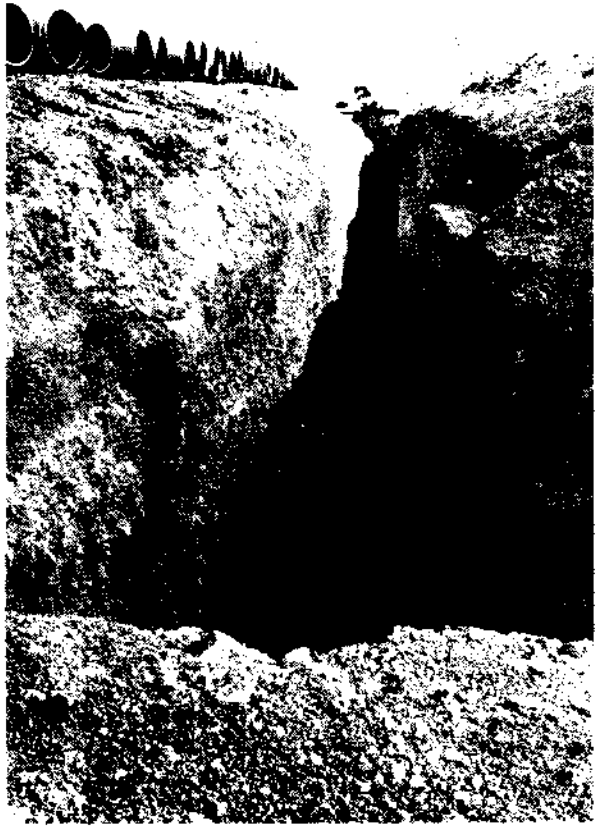

Fig. 7. Mariana limestone collection Site

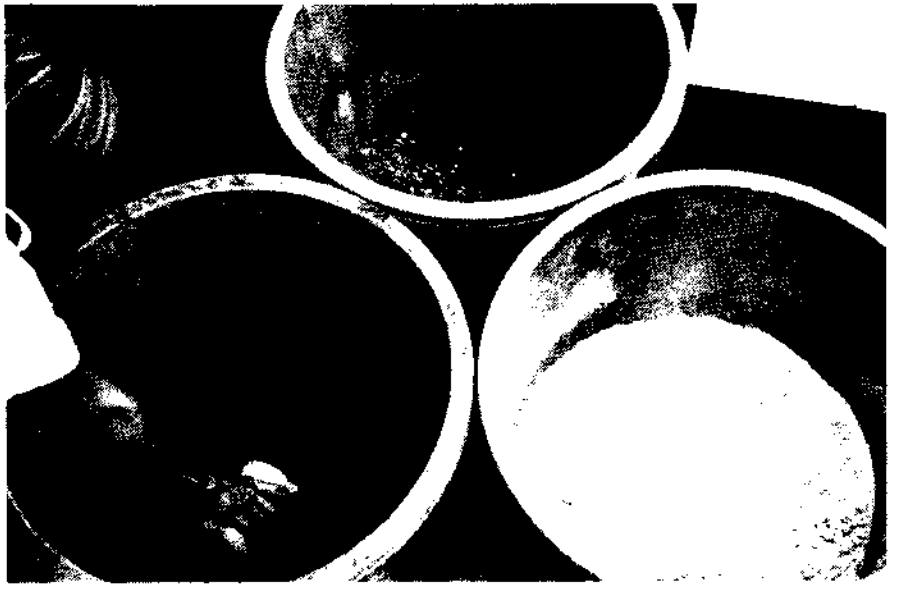

Fig. 8. Collected substrata in storage vats.

Fig. 9. Barrigada Heights storm drain, runoff collection site.

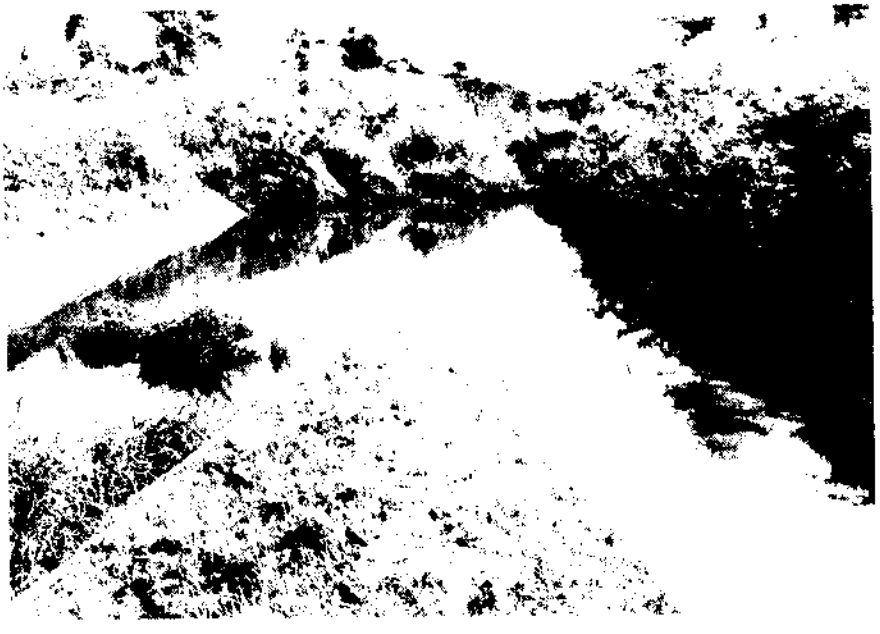

Fig. 10. Airport Road storm drainage channel runoff collection site.

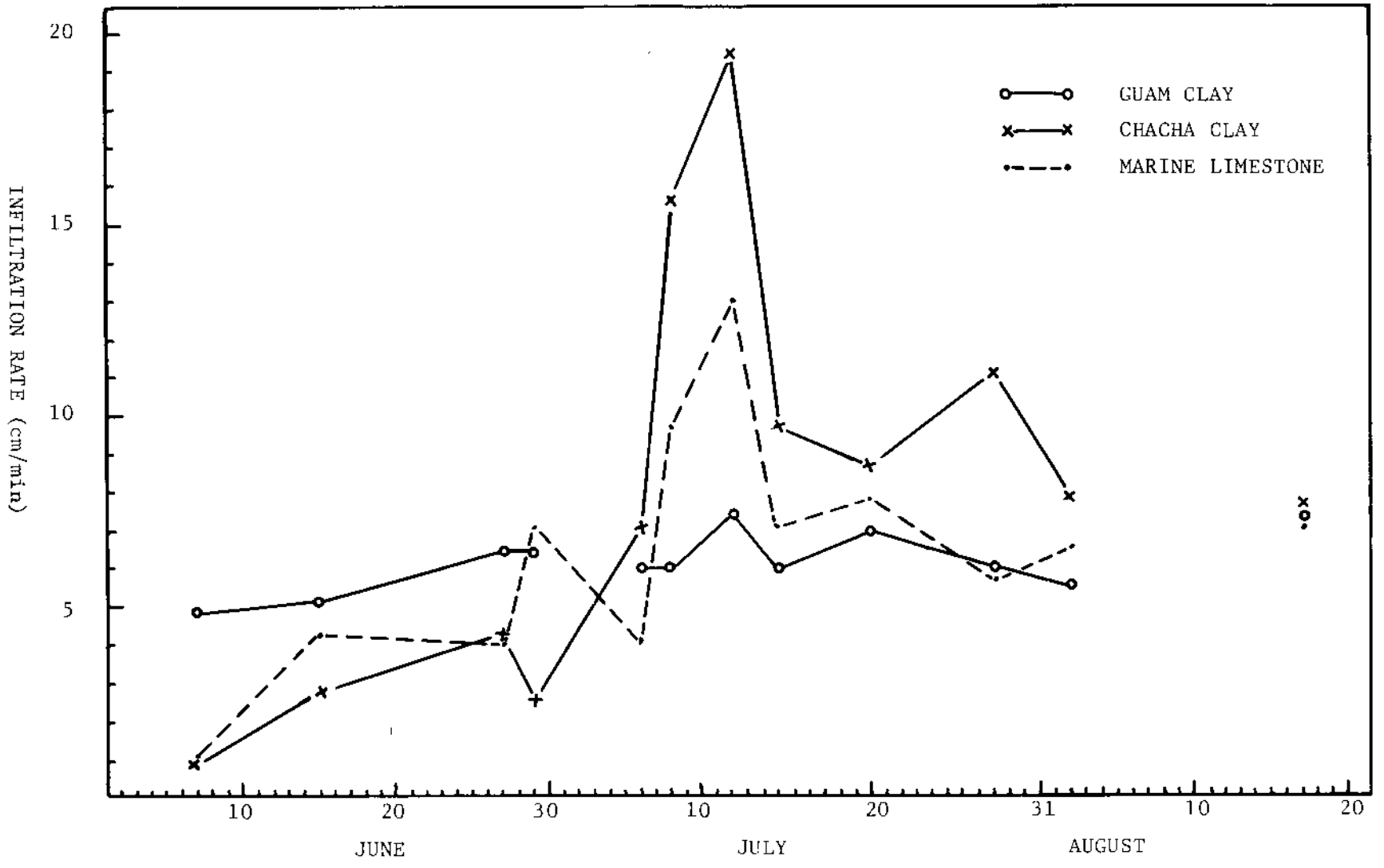

Fig. 11 . Infiltration rates of application water for tested substrata.

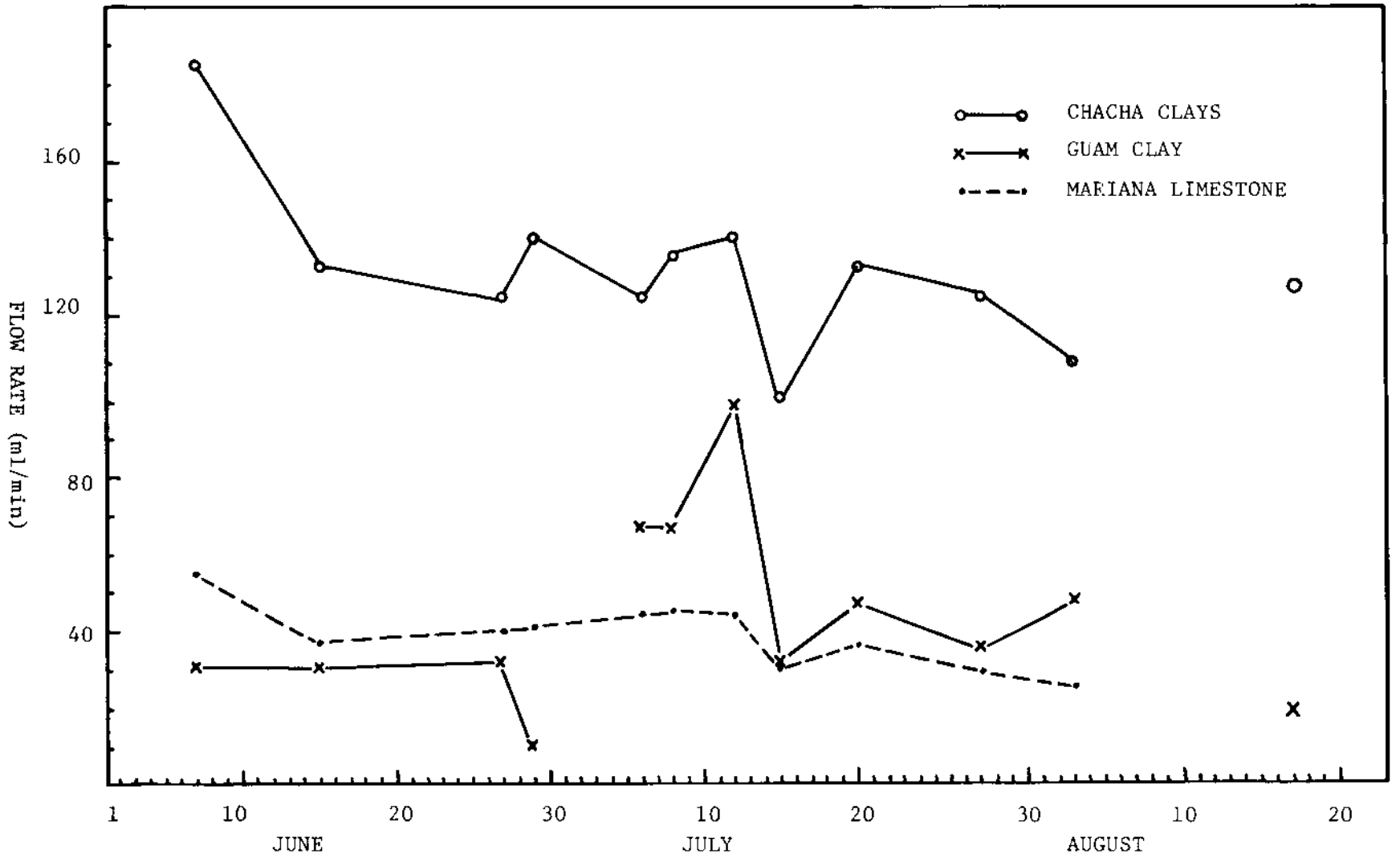

Fig. 12. Flow rate of percolate for first liter passing.

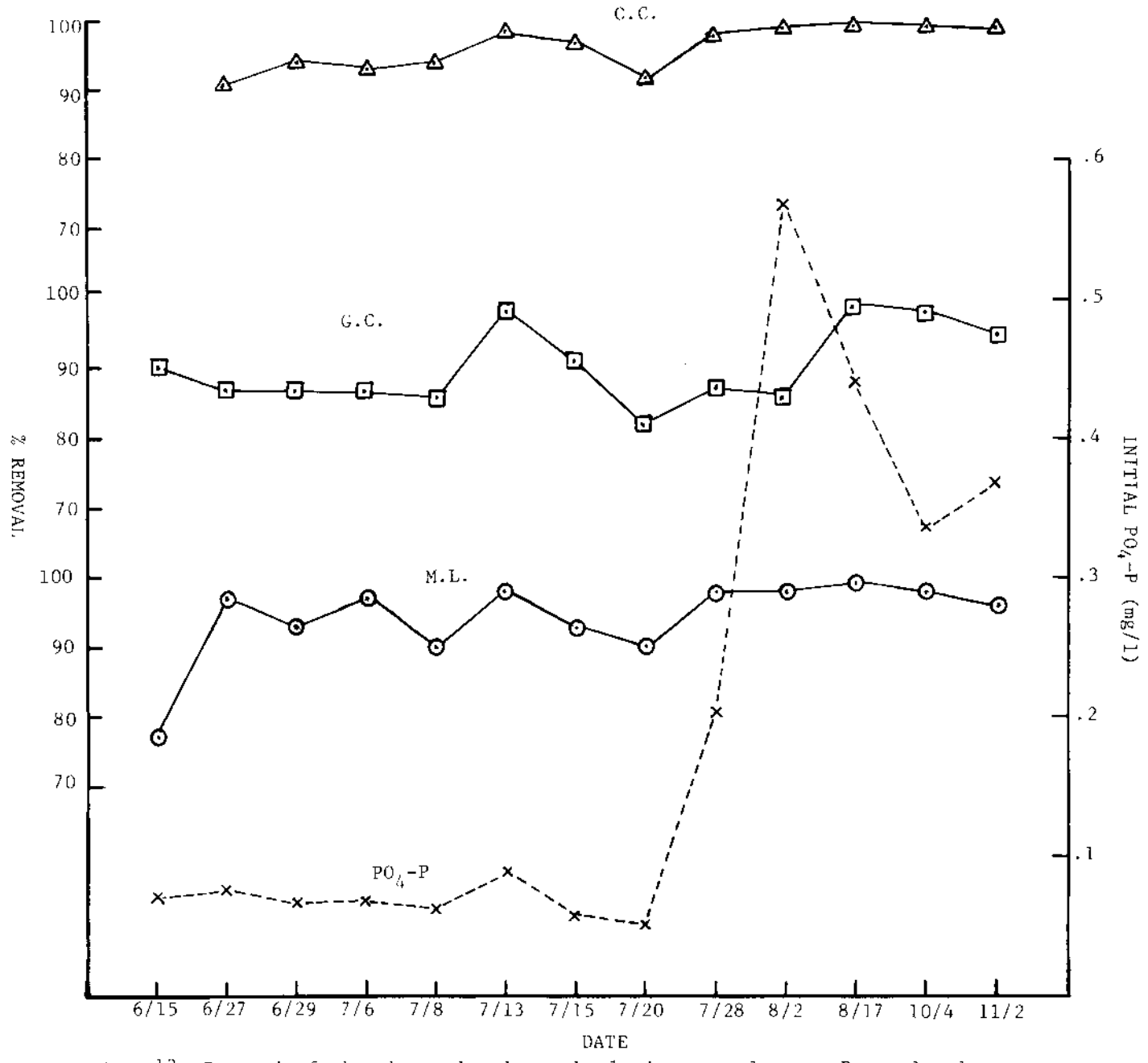

Fig. 13. Removal of phosphate-phosphorus by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

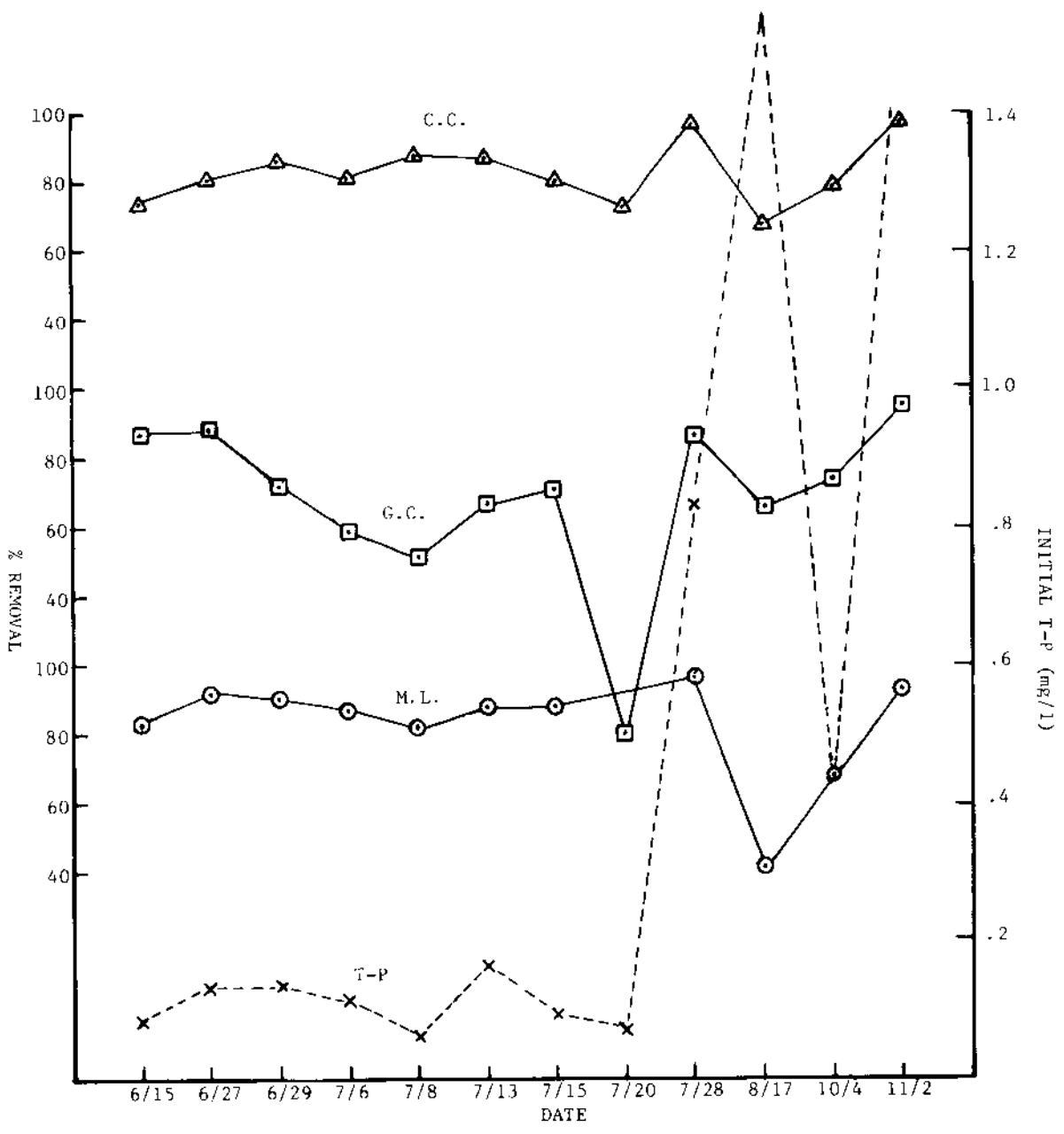

Fig. 14. Removal of total phosphorus by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

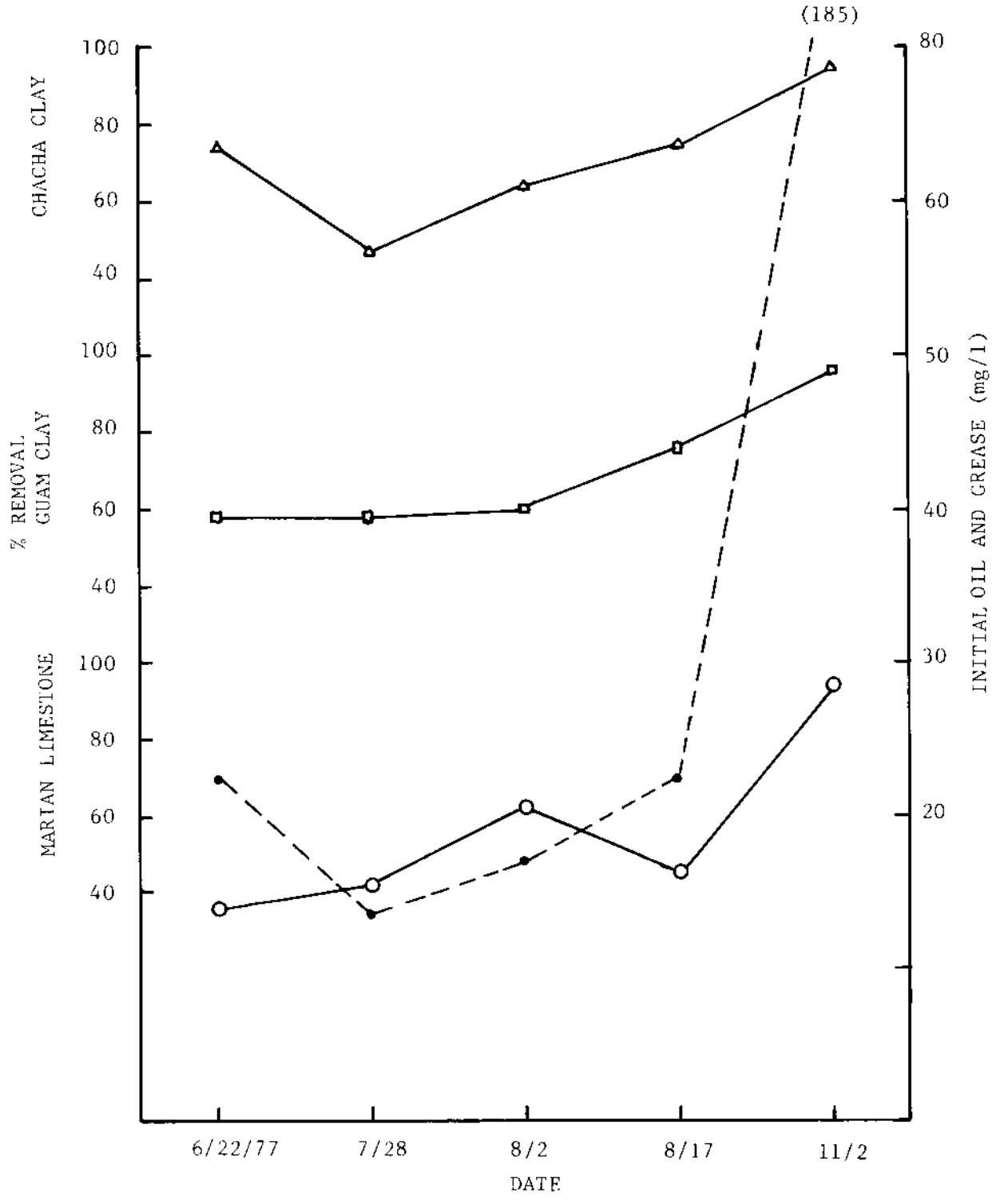

Fig. 15 Removal of oil and grease by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

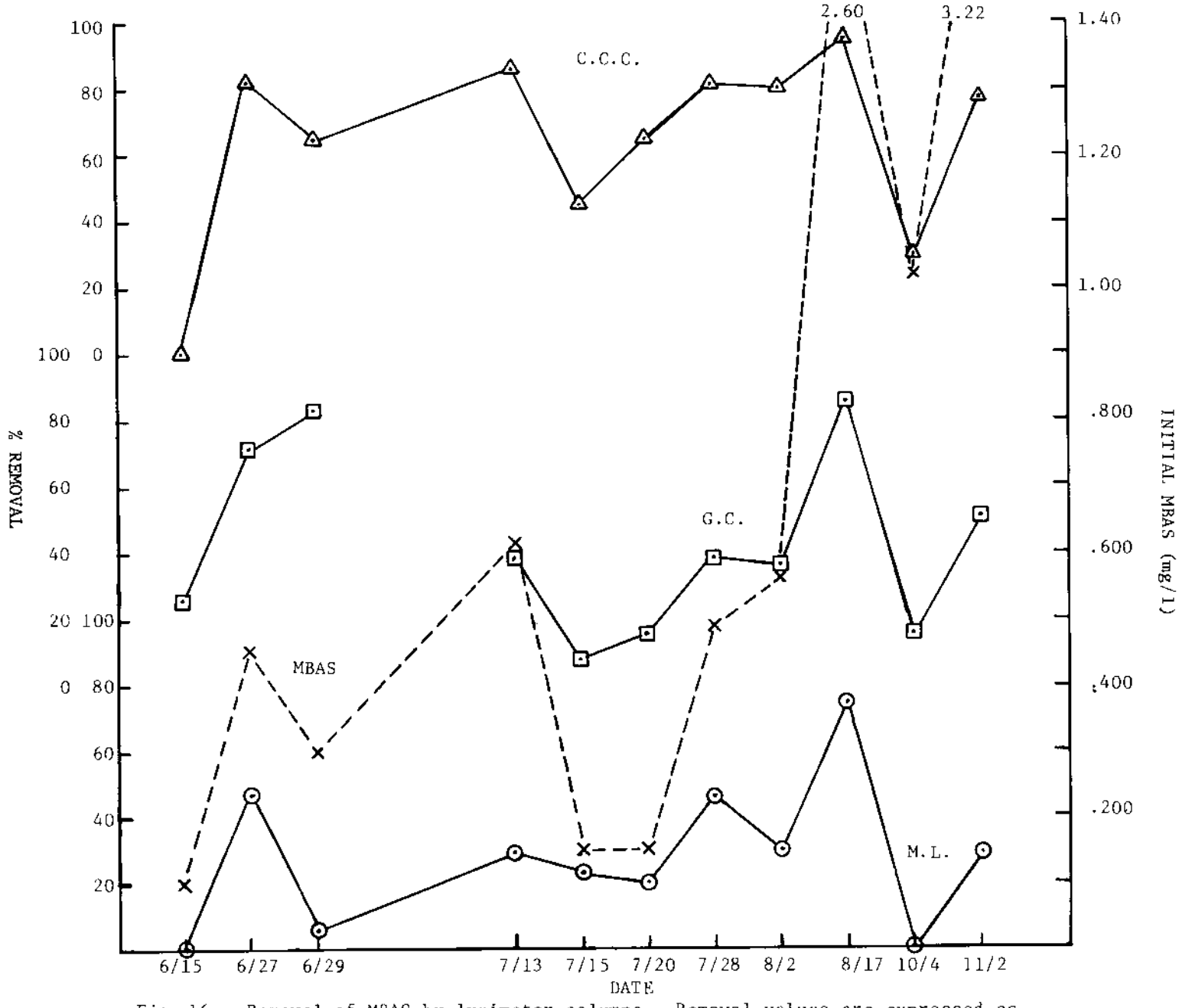

Fig. 16. Removal of MBAS by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

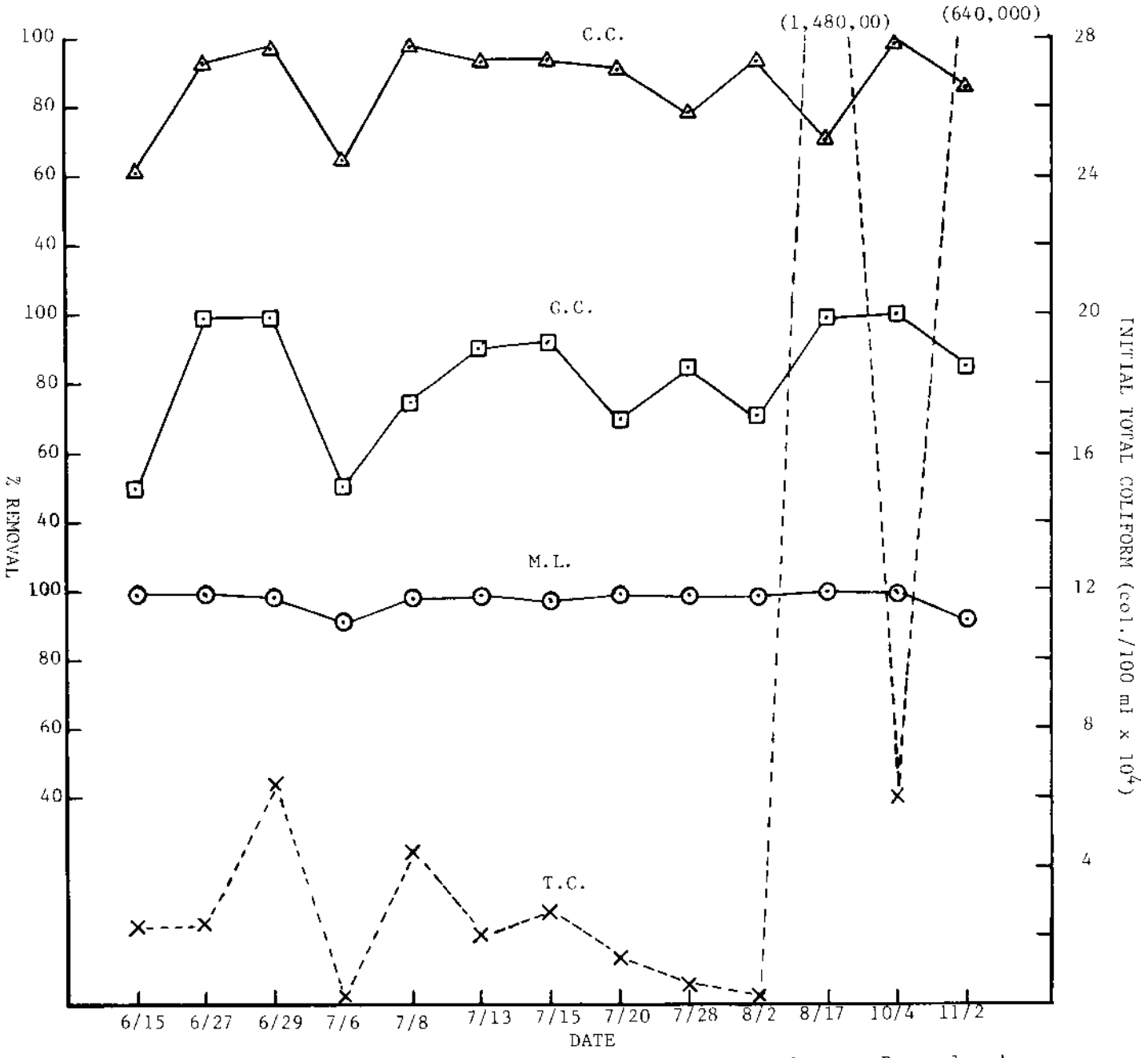

Fig. 17. Removal of total coliform bacteria by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

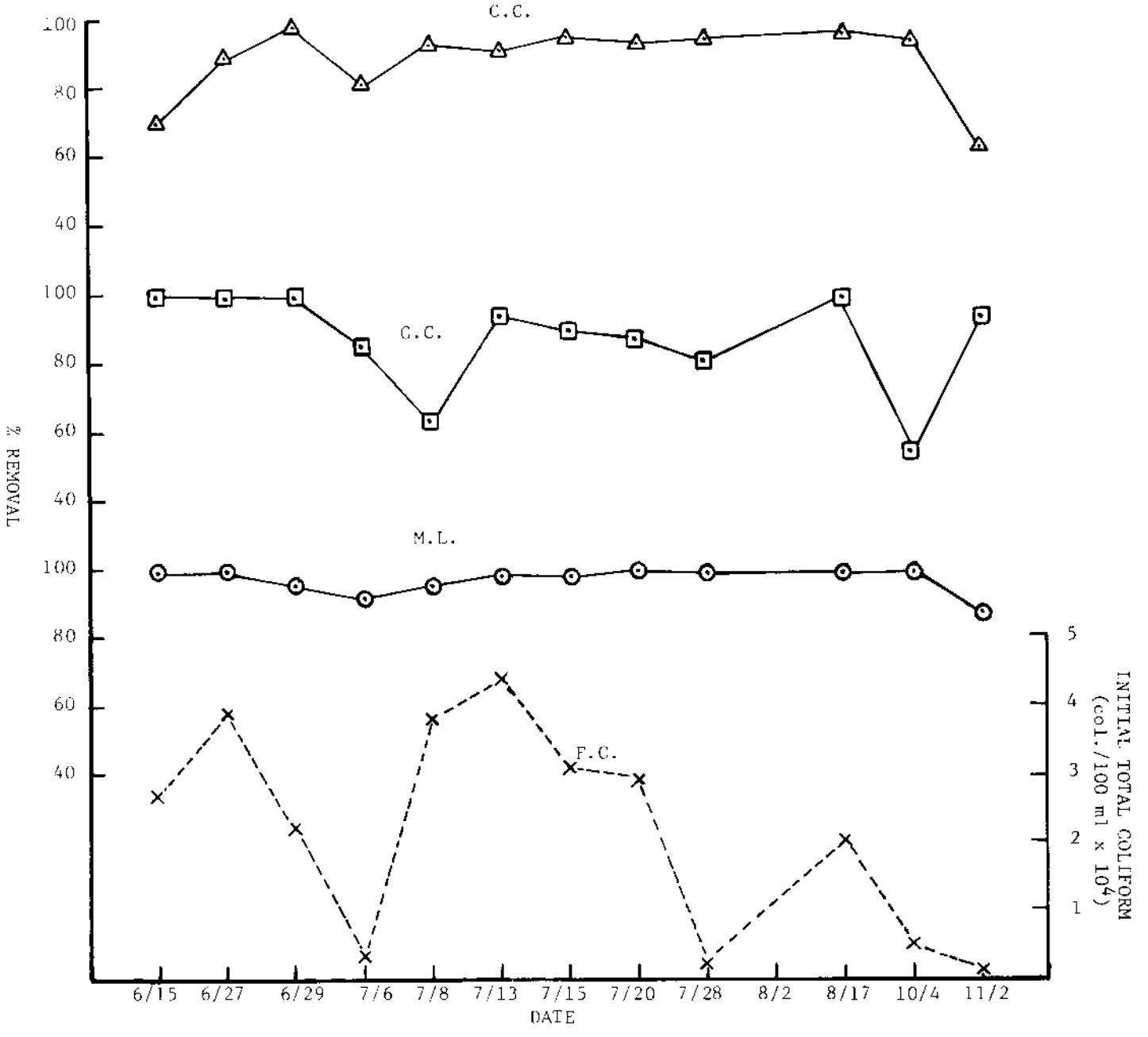

Fig. 18. Removal of fecal coliform bacteria by lysimeter columns. Removal values expressed as percentages of initial urban runoff concentrations.

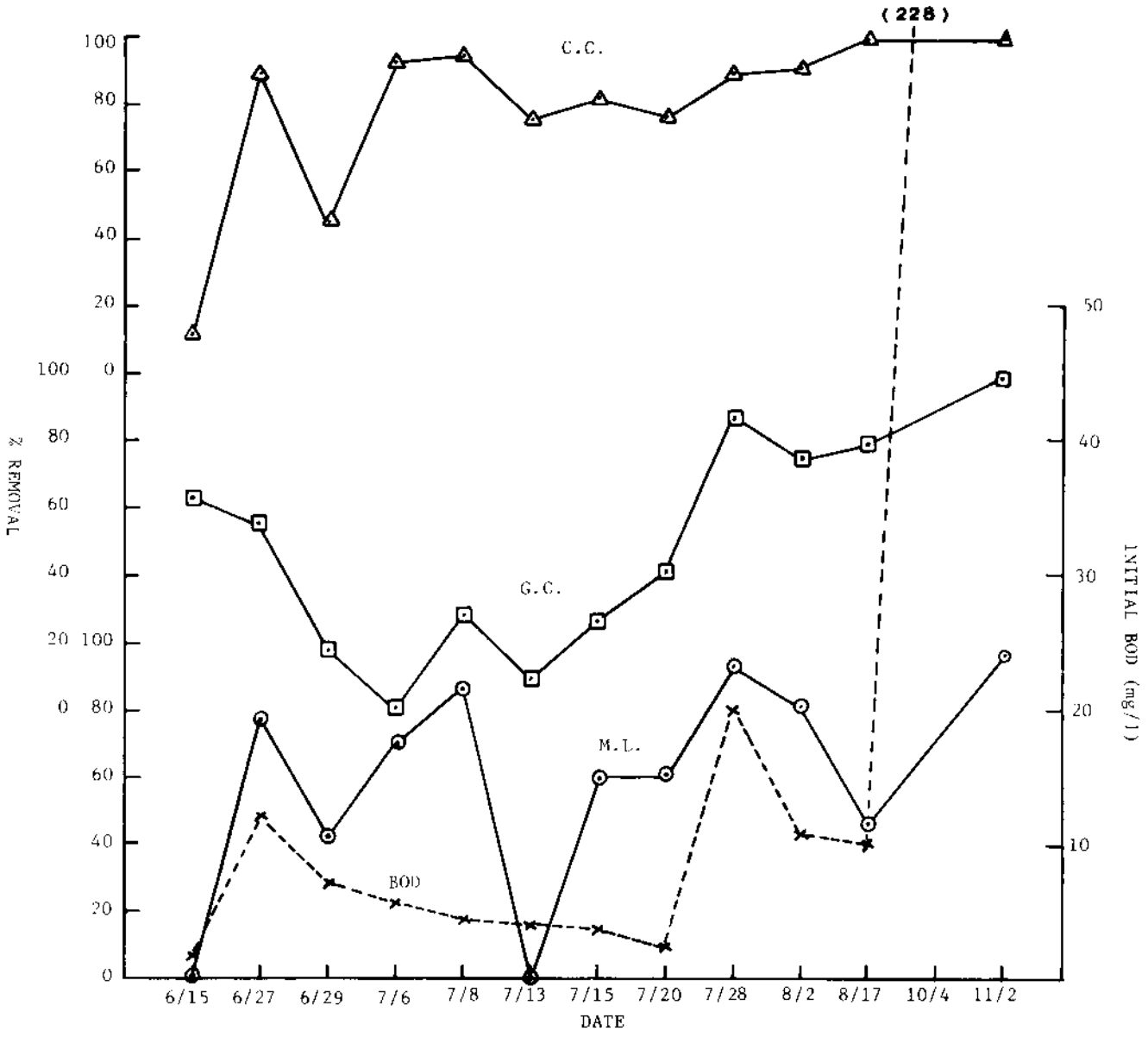

Fig. 19. Removal of BOD by lysimeter columns. Removal values are expressed as percentages of initial urban runoff concentrations.

Table 1. Parameters measured during the study.

PARAMETER	METHOD	SOURCE
pH	glass electrode method	Standard Methods
Turbidity	nephelometric method	Standard Methods
Specific Conductance	wheatstone bridge	Standard Methods
Hardness	EDTA titration	Standard Methods
Biochemical Oxygen	5 day incubation at 20°C	Standard Methods
Orthophosphorus	ascorbic acid reduction	Standard Methods
Total Phosphorus	persulfate digestion-ascorbic acid reduction	Standard Methods
Nitrite-Nitrogen	sulfanilamide diazotization	A Practical Method for Seawater Analysis
Nitrate-Nitrogen	cadmium reduction	A Practical Method for Seawater Analysis
Oil and Grease	partition-gravimetric method	Standard Methods
MBAS	methylene blue method	L. Wang, Journal of American Water Works Association
Total Coliform	membrane filter	Standard Methods
Fecal Coliform	membrane filter	Standard Methods
Total Solids	evaporation and drying at 105°C	Standard Methods
Suspended Solids	filtration and drying at 105°C	Standard Methods
Total Dissolved Solids	filtration and drying at 105°C	Standard Methods

Table 2. Percent removal of pollutants in urban runoff passed through lysimeter columns.

	MEAN % REMOVAL	STAN. DEV.	NUM.	INITIAL LOW CONC.	% REMOVAL	INITIAL HIGH CONC.	% REMOVAL
COLUMN I - MARIANA LIMESTONE							
PO_4P (mg/l)	94.4	5.9	14	.050	90	.814	97.7
T-P (mg/l)	85.0	10.1	12	.063	86	1.60	61,93
NO_3-N (mg/l)	41.4	31.4	16	.005	40	1.41	53.6
OIL & GREASE (mg/l)	51.8	23.8	5	13.6	42	185	94
MBAS (mg/l)	29.7	24.0	12	.100	0	6.32	62
TC (col./100 ml)	91.9	15.5	15	1,100	92	1,480,000	99.9
FC (col./100 ml)	97.1	3.9	13	0	--	44,000	98.4
BOD (mg/l)	57.1	33.8	16	1.9	0	228	97.0
COLUMN II - GUAM CLAY							
PO_4-P (mg/l)	90.2	5.4	13	.050	82	.568	86.0
T-P (mg/l)	68.9	19.5	13	.063	51	1.60	66,95
NO_3-N (mg/l)	(NO_3-N added to water)					1.41	0
OIL & GREASE (mg/l)	70.4	16.2	5	13.6	59	185	96
MBAS (mg/l)	46.8	30.2	12	.100	25	3.22	51
TC (col./100 ml)	71.1	31.0	18	20,000	50	1,480,000	99.7
FC (col./100 ml)	77.0	31.7	17	0	--	44,000	93.4
BOD (mg/l)	53.8	31.6	13	1.9	68	228	97
COLUMN III - CHACHA CLAY							
PO_4-P (mg/l)	94.6	6.0	13	.050	92	.814	98
T-P (mg/l)	82.8	9.0	12	.063	89	1.60	69,98
NO_3-N (mg/l)	(NO_3-N added to water)				0	1.41	0
OIL & GREASE (mg/l)	71.0	17.5	5	13.6	47	185	95
MBAS (mg/l)	66.8	28.6	12	.100	0	6.32	95
TC (col./100 ml)	85.2	13.1	14	18,000	93	1,480,000	70
FC (col./100 ml)	81.5	26.8	13	0	--	44,000	91
BOD (mg/l)	78.7	24.9	13	1.9	11	228	99.6

Table 3. Comparison of pollutant removal capabilities for substratum and soils tested.

Very Poor indicates < 30% removal
Poor indicates 30-50% removal
Fair indicates 50-70% removal
Good indicates 70-90% removal
Very Good indicates > 90% removal

	Mariana Limestone	Guam Clay	Chacha Clay
PO_4-P	Very Good	Very Good	Very Good
T-P	Good	Fair	Good
NO_3-N	Poor	Adds NO_3	Adds NO_3
MBAS	Very Poor	Poor	Fair
BOD	Fair	Fair	Good
OIL-GREASE	Fair	Good	Good
FECAL COLIFORM	Very Good	Good	Good
TOTAL COLIFORM	Very Good	Good	Good

Table 4. Lysimeter Test Results. Urban runoff was passed through 70 cm (2½ ft) of soil. Three soils and substrates were used; Mariana Limestone (M.L.), Guam clay (G.C.), and Saipan-Chacha clay (S.C.C.). Initial concentrations of parameters is presented first. Flow rate in ml/min.

SAMPLE SOURCE AND SOIL TYPE	DATE	TEST NUMBER	FLOW RATE	SP.COND umho/cm	TDS (mg/l)	TURB (NTU)	SS (mg/l)	TS (mg/l)	HARD (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	PO_4-P (mg/l)	T-P (mg/l)	MBAS (mg/l)	OIL GREASE	BOD (mg/l)	TC col/100 ml	FC col/100 ml
BAR.HT. RUNOFF	4/20/77	1[1]		226	174		1.0	174		.001	.244					4.1	1,000	24
G.C. (Dist.H_2o)				354	431		50	431		.157	6.18					4.4	85	0
G.C. (Runoff)				434	593		361	593		.157	24.8					3.1		25
G.C. (Runoff)				570	740		190	740		.418	28.6					>8.5		10
BAR.HT. RUNOFF	4/26/77	2		299	318		18.2	336		.090	.011						37,000	3,050
G.C. (Dist.H_2o)					275		19.4	294			1.31						136,000	0
G.C. (Runoff)				450			440	432		.049	1.95						18,000	600
G.C. (Runoff)				422	245		171	416		.118	3.66						17,000	200
BAR.HT. RUNOFF	5/ 2/77	1[1]		321	211		10.8	222		.015	.034					5.0		
S.C.C. (Dist.H_2o)				223	263		5.7	269		.078	75.4					25.9		
S.C.C. (Runoff)				663	639		14.7	654		.510	59.2					>29.8		
S.C.C. (Runoff)				745	655		13.3	668		.398	54.6					>29.5		
BAR.HT. (RUNOFF)	5/11/77	2		412	283		13.2	296		.007	.006					10.7	22,500	2,500
S.C.C.				318	203		3.2	206		.506	2.37					15.0	260,000	0
S.C.C.				425	263		5.0	268		.208	8.25					14.5	430,000	90
S.C.C.				399	229		10.4	239		.101	2.74					9.2	800,000	60
BAR.HT. RUNOFF	5/17/77	1[1]		683	430		3.6	434		.045	.195		.615			3.0	109,000	15,100
M.L.			109	786	972		14.8	987		.038	.064		.078			6.4	37,000	10
S.C.C.			113	1059	577		12.8	590		.159	3.7		.251			34.6	140,000	1,600
S.C.C.			95	1044	558		13.2	571		.448	1.66		.212			27.6	145,000	995
AIRPORT RUNOFF	6/ 3/77	2		329		70			124	.000	.058	.814	2.07	6.32		158	110,000	0
M.L.				597		60			142	.001	.013	.019		2.39		63.0	60,000	0
S.C.C.				843		2.7			332	.472	17.3	.015		.315		12.0	30,000	65
BAR.HT. RUNOFF	6/ 7/77	1[1]		137						.010	.210	.112	.135					
M.L.				228						.010	.320	.000	.034					
G.C.				1043						.006	121	.000	.034					
S.C.C.				725						.004	58.4	.000	.151					
BAR.HT. RUNOFF	6/15/77	2		144		15			32.6	.002	.058	.070	.089	.100		1.9	240,000	27,500
M.L.			37	179		9.5			111	.001	.006	.016	.015	.104		4.0	300	<100
G.C.			30	285		0.7			123	.076	3.58	.007	.012	.075		0.6	120,000	<100
S.C.C.			133	275		14.0			121	.008	.350	.016	.023	.100		1.7	90,000	8,300
BAR.HT. RUNOFF	6/27/77	3		112		10			39.8	.005	.042	.078	.135	.451	22.3	12	240,000	39,000
M.L.			40	421		0.52			76.5	.002	.013	.002	.011	.238	14.3	2.7	1,850	275
G.C.			32	362		0.82			175	.002	1.06	.010	.016	.132	9.1	6.6	<100	<10
S.C.C.			125	270		5.8			126	.004	.110	.007	.026	.079	5.9	2.5	17,900	4,000
BAR.HT. RUNOFF	6/29/77	4		94		20			31.6	.002	.082	.067	.136	.297		6.7	640,000	22,000
M.L.			41	205		.95			61.2	.002	.022	.005	.014	.278		3.9	12,450	1,085
G.C.			12	264		2.6			127	<.001	3.57	.009	.039	.051		5.5	400	<10
S.C.C.			140	270		4.8			163	.039	2.09	.004	.019	.104		3.7	1,400	70
BAR.HT. RUNOFF	7/ 6/77	5[2]		133		7.8			42.9	.003	.019	.069	.116			5.7	20,000	3,800
M.L.			44	175		1.5			64.3	.001	.012	.002	.015			1.7	1,800	330
G.C.			67						228	.014	96.3	.009	.048			12	10,000	600
S.C.C.			125	297		1.8			137	.003	.010	.005	.022			0.5	7,200	725

[1]Results of initial water pass through columns, no preflushing

[2]Fresh Guam clay soil (test number)

Table 4. Continued.

SAMPLE SOURCE AND SOIL TYPE	DATE	TEST NUMBER	FLOW RATE	SP.COND. umho/cm	pH	TURB (NTU)	HARD (mg/l)	NO_2-N (mg/l)	NO_3-N (mg/l)	PO_4-P (mg/l)	T-P (mg/l)	MBAS (mg/l)	OIL GREASE	BOD	TC col./100 ml	FC col./100 ml
BAR.HT. RUNOFF	7/ 8/77	6		76		25	23.2	.004	.072	.063	.063			4.2	350,000	38,000
M.L.			45	143		25	76.8	.034	.928	.006	.009			0.6	7,250	1,800
G.C			67	192		105	67.7	.003	5.06	.009	.031			3.0	90,000	14,200
S.C.C.			136	276		3.7	137	.001	.032	.004	.007			0.2	7,400	2,800
BAR.HT. RUNOFF	7/13/77	7		157		30	42.4	.011	.124	.087	.166	.635		4.0	200,000	44,000
M.L.			44	216		2.2	70.7	.001	.022	.002	.020	.446		4.6	3,700	725
G.C.			98	294		20	118	.014	7.02	.002	.054	.391		3.6	19,000	7,600
S.C.C.			140	275		8.6	134	.002	2.20	.002	.022	.087		1.0	13,000	3,800
BAR.HT. RUNOFF	7/15/77	8		103		55	31.0	.005	.091	.058	.092	.147		3.6	270,000	31,000
M.L.			30	162		2.4	61.0	.005	.117	.004	.011	.113		1.4	7,000	565
G.C.			32	238		25	86.0	.004	4.34	.005	.027	.135		2.6	22,000	3,550
S.C.C.			100	313		5.6	137	<.001	1.16	.002	.018	.081		0.7	19,000	1,620
BAR.HT. RUNOFF	7/20/77	9		128		30	48.0	.004	.052	.050	.073	.155		2.4	130,000	29,600
M.L.			36	189		.88	76.0	.003	.039	.005		.139		1.0	1,900	105
G.C.			47	214		25	92.0	.003	1.82	.009	.058	.131		1.4	40,000	3,900
S.C.C.			133	306		3.6	141	<.001	1.95	.004	.020	.054		0.6	12,000	1,960
MARINE DRIVE	7/28/77	10		222	7.62	70	61.0	.006	.098	.204	.834	.492	13.6	20	50,000	2,100
M.L.			29	292	7.70	0.68	94.0	.002	.045	.005	.030	.274	7.9	1.5	700	10
G.C.			35	313	7.70	80	116	.001	1.50	.026	.106	.306	5.6	2.3	6,100	420
S.C.C.			125	318	7.65	5.8	142	<.001	3.00	.005	.023	.093	7.2	2.1	10,900	120
MARINE DRIVE	8/ 2/77	11		1443	8.35	8.9	138	.093	1.27	.568		.560	17.2	10.8	18,000	
M.L.			25	1005	7.75	0.43	109	.053	.900	.012		.393	6.5	2.05	400	
G.C.			48	1075	7.65	11	151	.031	1.78	.080		.365	6.7	2.66	5,400	
S.C.C.			110	387	7.68	1.8	172	.001	2.26	.005		.113	6.2	1.06	1,200	
AIRPORT ROAD	8/17/77	1		180	7.12	55	70	<.001	.034	.441	1.60	2.60	22.5	9.96	1.48×10^6	20,000
M.L.			15	187	7.69	0.36	78	<.001	.082	.006	.630	.641	12.4	3.28	<1,000	<10
G.C.			19	250	7.57	2.8	96	<.001	1.85	.005	.549	.355	5.1	2.09	4,000	20
S.C.C.			125	465	7.48	2.8	183	.001	1.09	.005	.495	.117	5.6	.08	450,000	700
AIRPORT ROAD	10/ 4/77	2		152	7.07			<.001	.005	.337	.447	1.02			60,000	4,800
M.L.				214	7.84			<.001	.003	.008	.138	1.12			500	30
G.C.				333	7.62			<.001	4.47	.009	.116	.830			< 100	2,200
S.C.C.				520	7.78			<.001	10.12	.003	.092	.713			950	295
MARINE DRIVE	11/ 2/77	3						.008	1.41	.369	1.60	3.22	185	228	640,000	1,000
M.L.			32					.009	.654	.016	.117	2.30	10.3	5.72	60,000	125
G.C.			64					.002	4.09	.018	.077	1.59	8.1	3.17	100,000	80
S.C.C.			125					.001	8.69	.005	.034	.748	9.3	0.98	96,667	380

Table 5. Initial nitrate-nitrogen concentrations of freshly loaded substratum with percent reduction of nitrate-nitrogen after second application of sample water. The leached nitrate-nitrogen values are the concentrations in excess of the initial application water.

DATE	SUBSTRATUM TYPE	LEACHED NO_3-N (mg/l)	VOLUME PASSED (l)	SECOND APPLICATION PERCENT REDUCTION
4/20/77	Guam Clay	6.18	12 days/10[1]	78.1
	Guam Clay	24.6	2 days/10[1]	92.1
	Guam Clay	28.4	2 days/10[1]	87.1
5/ 2/77	Chacha Clay	75.4	10	99.2
5/ 3/77	Chacha Clay	59.2	6	86.0
	Chacha Clay	54.6	6	95.0
5/16/77	Limestone	.039	8	100[2]
	Guam Clay	75.1	8	96.0
	Chacha Clay	61.0	8	97.6
6/ 7/77	Limestone	.110	10	100[2]
	Guam Clay	120.7	10	99.9
	Chacha Clay	58.2	10	99.9
7/ 6/77	Guam Clay	96.3	10	94.7
8/16/77	Limestone	.380	19	99.2
	Guam Clay	150.2	19	96.9
	Chacha Clay	74.0	19	98.4

[1]Number of days water was held in columns before being withdrawn for analysis.

[2]Nitrate ions taken up by soil.

Table 6. A comparison of the mean initial nitrate-nitrogen concentrations and percent reduction for Guam clay and Chacha clay.

	LEACHED NO_3-N mg/l			PERCENT REDUCTION OF LEACHED NO_3-N	
	MEAN	STAN. DEV.	NUM.	MEAN	STAN. DEV.
Chacha Clay	63.9	8.82	6	96.0	5.19
Guam Clay*	110.8	32.44	4	96.9	2.21

*Excluding 4/20/77 data.

Table 7. Quality of Lysimeter percolate after flushing columns with 20-30 liters of demineralized water. Prior and following Lysimeter tests with the same sample of urban runoff presented for comparison of adsorption capacity.

	DATE	Sp.COND.	HARD	NO_2-N	NO_3-N	T-P	PO_4-P
MARINE DRIVE	8/ 2/77	1443	138	.093	1.27		.568
M.L.		1005	109	.063	.900		.012
G.C.		1075	151	.031	1.78		.080
S.C.C.		387	172	<.001	2.26		.005
DEMIN H_2O	8/ 3/77	2.0	0.0	.000	.001	.000	
M.L.		194	57	.000	.047	.032	
G.C.		153	62	.002	.180	.049	
S.C.C.		296	55	.002	.179	.038	
MARINE DRIVE	8/ 3/77	1443	138	.092	1.05	.568	
M.L.		1070	91	.060	.715	.039	
G.C.		1121	128	.015	.997	.155	
S.C.C.		561	124	.001	.281	.022	

APPENDIX A

Lysimeter Column Design and Specifications

Clear polyvinyl chloride (PVC) lysimeter columns (Fig. 20) are recommended because they make it possible to assess:

a) the uniformity of substrata compaction both in and between columns,

b) the degree of channeling (unavoidable with lysimeter design),

c) if substrata settlement or bulking is occurring,

d) and the percolation charcteristics of the sample water.

The following materials are required for lysimeter construction:

a) clear PVC pipe (length and diameter variable). A possible design modification to reduce channeling problems would be the attachment of narrow (5 mm or less), circular, horizontal ribs in the column.

b) a bottom flange. The flange is PVC welded to one end of the column for stability and attachment of base plate.

c) base plate with shutoff mechanism. A hole is drilled in the center of the plate and fitted with a short section of PVC pipe which is either PVC welded or glued (silicon cement). Tygon tubing and clamp, rubber or cork stopper, or a PVC gate valve can be used as a shutoff mechanism. This base plate is bolted (8 bolts) and glued (silicon cement) to the flange.

d) a bottom filter. A fine mesh plastic screen, placed in bottom of column, is covered with 2 to 3 cm of inert sand-like material (20 to 30 mesh) and topped with a second screen. This filter prevents clogging of the shut-off mechanism and reduces the silt load of the percolate.

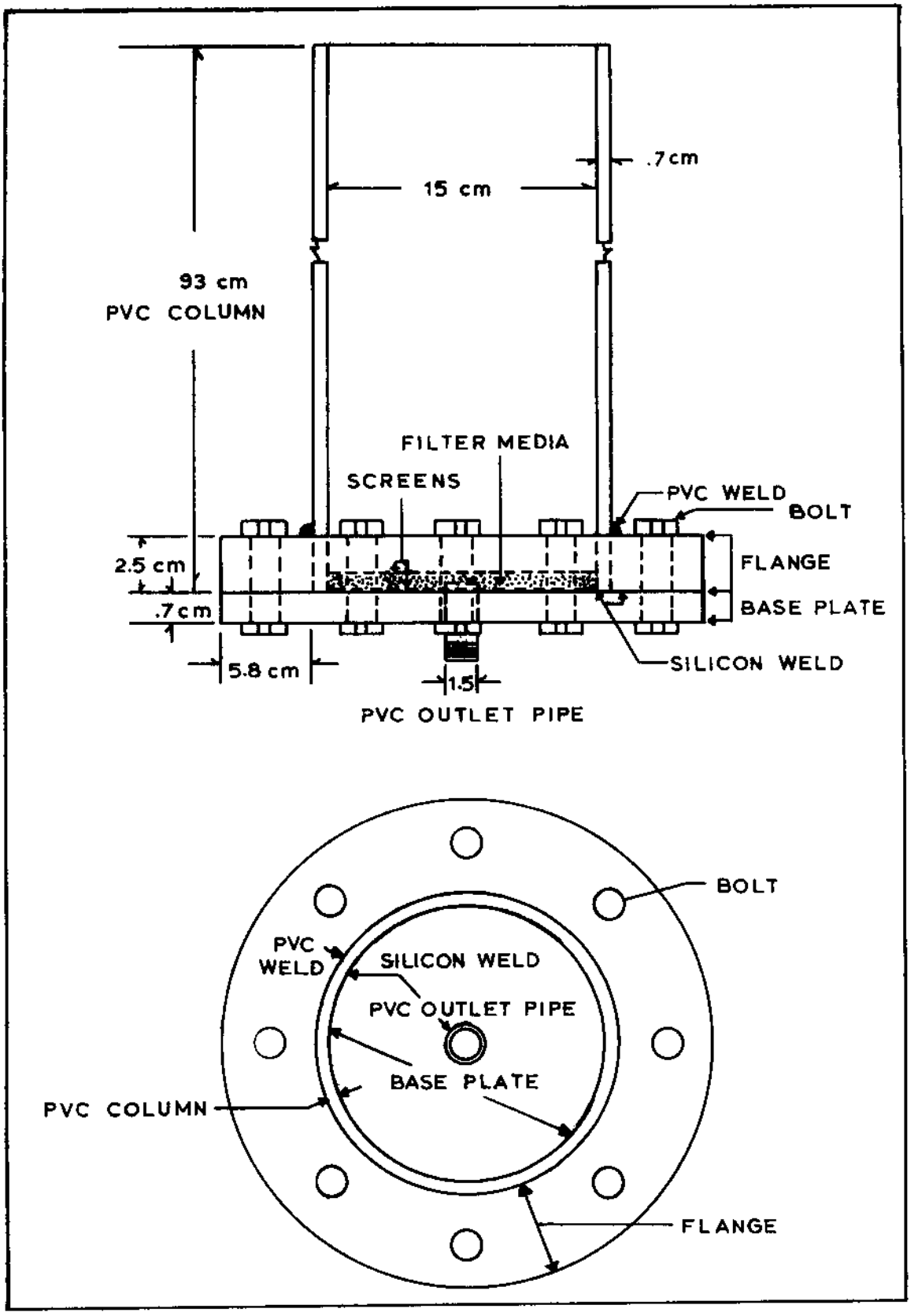

Fig. 20. Lysimeter column design.

APPENDIX B

Carroll and Hathaway (1963) determined the grain-size distribution, pH, chemical composition, organic carbon, free iron oxide, ion exchange capacity, and mineralogy of Guam clay and Chacha clays. Guam clay is a reddish, granular, friable, permeable lithosolic latosol that averages 59 percent clay, 33 percent silt, and 9 percent sand. In chemical composition it averages 1.4 percent SiO_2, 39.1 percent Al_2O_3, 20.9 percent Fe_2O_3, and 2.0 percent TiO_2. The main mineral constitutents are gibbsite, hematite, magnetite, quartz, and traces of halloysite. It has the highest pH of Guam soils at 7.4. The free oxide is high, ranging from 16.8 to 20.4 percent with an average of 18.07 percent. The organic carbon ranges from .1 to 5.9 percent with an average of 2.7 percent which is equivalent to approximately 5.8 percent organic matter in the upper 15 cm. This surface soil has a high ion-exchange capacity, 35.2 milliequivalent per 100 grams. The average for soil without organic matter is 5.8 milliequivalents per 100 grams. The phosphate averages 1.65 percent. This can probably be best explained as a residual constitutent of the limestones that is not removed by leaching at pH 7 and therefore accumulates in the soils.

Chacha clays are a yellowish brown, firm, plastic lithosolic clay intergrading with firm red clay (Saipan) and a brownish clay (Yona). The Chacha clays have very high clay content, averaging 93 percent, with consequent low silt content, averaging 3.9 percent. The surface of this soil is lower in clay content (86 percent) than the remainder of the soil profile, but it has more coarse sand than the average soil. In chemical composition it averages 32.1 percent SiO_2, 28.5 percent AL_2O_3, 16.1 percent Fe_2O_3, and 0.87 percent TiO_2. The dominant mineral constituents are halloysite, goethite, quartz, and traces of hematite. The pH ranges from 5.5 to 6.9 with an average of 6.3. 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 milliequivalent per 100 grams.

The origin of Guam clay is probably due to the almost complete desilication of volcanic ash released from the limestone by solution and weathered under conditions of strong leaching and relatively high pH. The Chacha clay developed on the Agana argillaceous member of the Mariana limestone contains an erosional or weathered assemblage at a lower pH. This soil is subjected to less effective leaching, due to either an abundance of clay which tightly compacts or to the density of the underlying limestone. As a result, removal of silica takes place slowly. Silica goes into solution at all pH values.

The organic detrital content of the Guam clay and Chacha clay used in the lysimeter study were determined by incinerating a dried soil sample (110°C) at 550°C for 1/2 hour. The organic content of the Guam clay averaged 2.9 percent, which is comparable to the findings of Carroll and Hathaway (1963). The Chacha clay was higher, averaging 7.6 percent.

The description of the Mariana limestone is adapted from Tracey et al. (1964) and the mineralogy from Schlanger (1964). The Mariana limestone forms approximately 80 percent of the exposed reef-associated limestones of Guam. It is the predominate limestone of the northern plateau. There are to members: the main body of the Mariana limestone, uncontaminated by clay and volcanic detritus, and the Agana argillaceous member near the central older volcanic uplands. The main body of the Mariana is composed of four reef-associated facies: the reef facies, the detrital facies, the molluscan facies, and the fore-reef facies. The detrial and molluscan facies represent lagoonal deposition. Each facies of the main body of the Mariana comprises several subfacies or biofacies characterized by a dominant faunal assemblage.

The limestone used in the lysimeter study was a detrital limestone similar to a lagoon margin deposition. The detrital facies was selected for study since it covers extensive areas of the northern plateau. This facies ranges from coarsely granular limestone containing scattered coral heads to fine-grained, almost sublithographic, limestone containing scattered molds of mollusks. Six subfacies are recognized which grade into one another laterally and vertically. An intergrading of the detrital foraminiferal and the detrital coral-molluscan subfacies was used for the lysimeter study. This fine to coarse-grained limestone contains molds of both coral and mollusks as well as scattered foraminifera tests.

The insoluable residue in Mariana limestone ranges from 0.6 to 16.4 percent by weight and is essentially a silt and clay fraction. The mineral constituents of the residue include apatite, montmorillonite, quartz, heulandite, gibbsite, geothite, halloysite, magnetite, augite, hypersthene, zeolite, and feldspar. The presence of augite in some Mariana limestone indicates a possible occurrence of volcanic ash additions, although both augite and magnetite persist as stable minerals in some of the soils and therefore could be detrital.

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Page 6 Orthophosphorus, Line 3 from heading
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Page 8 Methylene Blue Active Substances, Line 4 from heading
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"alkaline nature" not native