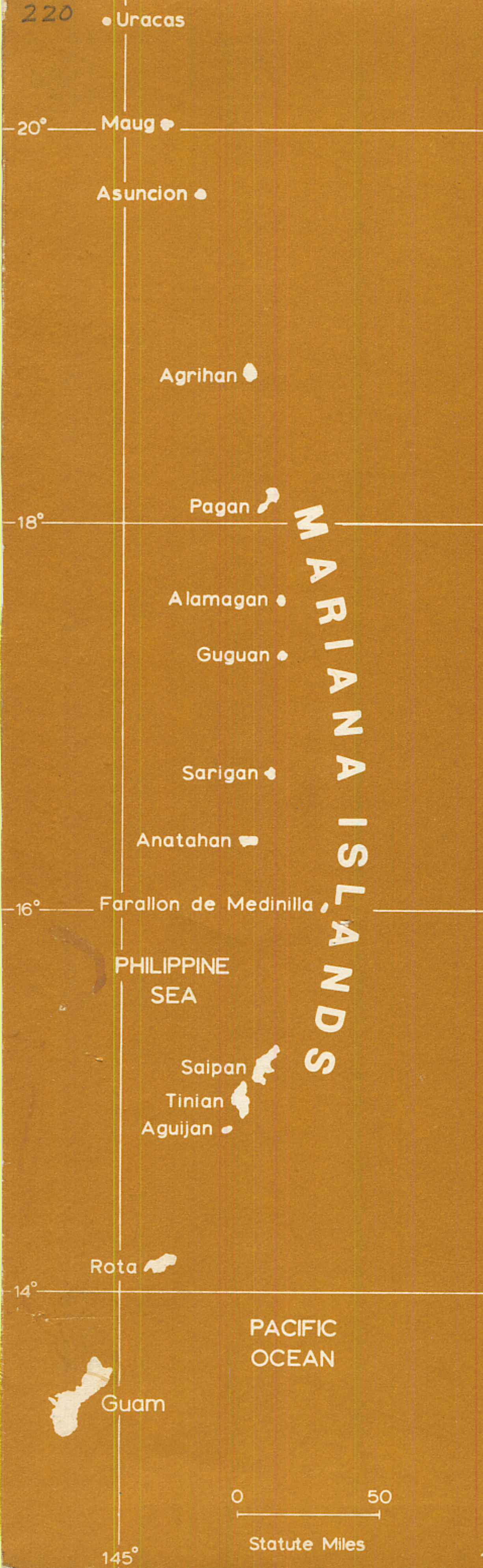

URBAN RUNOFF QUALITY IN NORTHERN GUAM

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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. 14-34-001-6054, 7023, 7024

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

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ABSTRACT

The purpose of this study was to obtain qualitative information on urban runoff in northern Guam. To accomplish this, runoff was collected over an 18 month period from ponding basins and storm drains and analyzed for common water quality parameters.

Results indicate that pollutant concentrations in ponding basins are relatively low in comparison to levels measured in other communities in the United States. Moderate to high concentrations of oil and grease and soaps are occasionally measured at storm drain outlets emptying into ponding basins. Coliform bacteria levels are generally low with geometric means of 900 total coliform per 100 ml and 215 fecal coliform per 100 ml. However, counts range from near zero to several hundred thousand (total coliform) per 100 ml depending on rainfall occurrence and basin sampled.

Urban runoff being discharged into coastal waters is generally low in pollutants with the exception of nitrate-nitrogen and coliform bacteria. Counts of bacteria in excess of the Guam Water Quality Standards established for Agana Bay shore waters were observed on most samplings. Groundwater seepage and tap water sources are the suspected source of the high nitrate-nitrogen concentrations (ranging up to 3.4 mg/l) which also exceed Guam Water Quality Standards.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

INTRODUCTION

Background

Guam is a small tropical island in the western Pacific. Its capital, Agana, is located at 13°30'N, 144°45'W. The area of Guam is 212 square miles. It is 30 miles long and has a width that varies from 4 to 11.5 miles, the longer axis being oriented in a NE-SW direction.

Guam is warm throughout the year but, nevertheless, has distinct wet and dry seasons. The average daily temperature is usually between 80 and 85°F about which the daily maximum and minimum seldom vary by more than 10°F. Depending on location, mean annual rainfall can vary from 85 to 115 inches. However, yearly variations can be quite large and droughts are common. About two thirds of the annual rainfall occurs during the rainy season from July through November. January through May is the dry season; the months of June and December are transitional.

The island is divided into two nearly equal geologic/hydrologic areas. The northern half of Guam is an undulating limestone plateau which is so permeable that there is no significant stream drainge pattern. Rainwater moves quickly downward to a zone of saturation, and aquifer, which generally occurs as a lens of fresh water floating on sea water. The southern half of Guam consists primarily of a rough terrain of volcanic origin which is relatively impermeable compared to the limestones of northern Guam. A mountain range parallels the west coast with drainage occurring primarily to the east and west by means of numerous rivers and streams.

Water Resources

The average monthly water production on Guam for 1976 was 28.8 mgd (U.S. Geological Survey, 1976). 61.5% of this total (17.7 mgd) was the result of groundwater pumpage from the aquifer underlying the northern half of Guam. The Bureau of Planning (1977) has projected that Guam's present civilian population of 84,701 will double shortly after the year 2000. It is probable that Guam's fresh water supply requirements will undergo a comparable increase. Mink (1976) has conservatively estimated that up to 50 mgd is available from Guam's northern aquifer. This amount is probably adequate to supply Guam's needs to the year 2000 although it may be more feasible to develop southern surface water sources to supply the needs of that area. In any event, the northern aquifer will probably remain Guam's most important source of fresh water for the forseeable future.

In 1976, Mink recommended that conservation and low density areas be established in certain undeveloped areas overlying portions of the northern aquifer. The purpose of this recommendation was to insure that all rain falling in the reserved areas would be retained for the purpose of recharging the lens and, furthermore, that the recharge waters would be subjected to minimum contamination. Unfortunately, these recommendations have not been strictly followed.

The Water Pollution Control Act of 1967 empowered the Guam Environmental Protection Agency (GEPA) to "formulate standards of water purity and classification of water according to the most beneficial uses of such water." The Water Quality Standards promulgated by GEPA on September 25, 1975 designate Mink's conservation and low density areas as groundwater conservation zones, containing approximately 3764 hectares. Resource and recharge zones are also indicated in the GEPA Water Quality Standards. The locations of these zones is indicated in Figure 1. However, the exact boundaries have not yet been delineated. According to GEPA, further development in conservation zones is prohibited.

The Department of Public Works (1969) requires ponding basins where the natural seepage into the ground is decreased due to development. On northern Guam they are an effective means of insuring that runoff from developed areas is used to recharge the groundwater aquifer. Ponding basins are also an excellent means of flood control. However, no data exists describing the quality of runoff entering into ponding basins and no estimates have been made of the influence of this runoff on groundwater quality.

The coastal waters of Guam bordering urban areas, particularly between Adelup Point and Amantes Point (Fig. 2), also receive considerable runoff from developed areas. Here too, no data exists describing the quality of the runoff and no estimates have been made of the influence of this runoff on coastal waters and the marine life that inhabits these waters.

OBJECTIVES

The objectives of the urban runoff study were to characterize the quality of urban runoff discharged into:

a. ponding basins, and
b. coastal receiving waters on northern Guam.

SCOPE

In an effort to achieve these objectives, a monitoring program consisting of analyses of selected water quality parameters was undertaken in December 1975. The study period covered 18 months, included seasonal rainfall variations (although somewhat atypical) as well as super-typhoon, Pamela. Urban runoff discharged into both selected ponding basins and coastal storm drains was included. In an attempt to determine the source of potential hazards, a distinction was made between commercial and residential runoff. In order to establish the quality of the urban runoff, comparisons were made with the GEPA Water Quality Standards, Guam ground and well water, and urban runoff quality as recorded for Hawaii and other United States communities. The established qualities of runoff parameters were then utilized to characterize the ponded runoff designated for groundwater rechrage in both conservation and resource zones. In the case of coastal discharge, potentially hazardous parameters were determined.

Site Selection Criteria

Since it was impractical to monitor all the ponding basins and coastal storm drains, representative sites that would provide the desired data base were selected. The following rational was utilized in the selection of the ponding basins and coastal storm drains.

Ponding Basin Sites.

1. were located in both conservation and resource zones as designated by the GEPA Water Quality Standards.

2. reflected the different limestone formations (Fig. 3) and soil types found on northern Guam. The quality and rate of infiltration of recharge water entering the groundwater aquifer is dependent on the type of limestone formation through which it percolates. Additionally, soils are known to play an important role in the removal of pollutants from runoff waters, the amount of removal being dependent on the soil type.

3. reflected input from the residential, commercial, or mixed residential-commercial sources.

4. received runoff from substantially large, representative, drainage areas.

5. contained a sufficient quantity of ponded water to assure that routine sampling could be conducted.

6. were accessible at all times.

7. included an obviously polluted body of water which could be utilized for comparative purposes.

Coastal Storm Drain Sites.

1. had either a continual flow or ponded water that could be sampled prior to discharge into the coastal waters.

2. reflected heavy runoff from a large drainage area. This was based on the size of the reef flat sediment delta produced by the storm drain discharge.

3. reflected input from commercial or mixed commercial-residential sources.

4. were accessible for routine monitoring.

5. could potentially stress the reef flat environment, including associated flora and fauna.

Site Descriptions

Abbreviated site descriptions are given below. Detailed descriptions are given in the Appendix. Refer to Figure 2 for site locations and Table 1 for ponding basin and coastal discharge site characteristics.

Barrigada #1 (Ble; B2c)

This ponding basin (Fig. 4) is located in Barrigada Village at the junction of Routes 8 and 10, behind the Esso Service Station. This places it in the resource zone as designated by the GEPA Water Quality Standards.

Two sampling sites were monitored within the basin: the northern storm drain discharge region (Blc); and the southern natural drainage introduction region (Ble).

This basin was selected as a study site based on the following considerations:

1. it consisted of almost exclusively commercial runoff at the storm drain outlet with mixed residential-commercial runoff at the southern end.

2. it contained a large, continuously ponded body of water.

3. it could be easily monitored at both the northern and southern ends, with inherently different runoff water qualities.

4. it is located in the Agana argillaceous member of the Mariana Limestone which does not underlie any other study site.

5. it was constructed in an extensive deposit of Chacha-Saipan clay, which reduces infiltration and potentially influences water quality.

Barrigada #2 and #3 (B2d; B2w; B3)

This basin system (Fig. 5 and 6) is located at the southwest base of Mt. Barrigada. It borders the northern edge of a large, open, savanna-like field near a sharp bend in Route 16. This basin system receives runoff from the Barrigada Heights subdivision and its surrounding areas, which includes most of the western slopes of Mt. Barrigada. Mt. Barrigada has been designated a conservation zone by the GEPA Water Quality Standards, with the basin area located at the boundary of resource and conservation zones. Clearance for construction of this subdivision was granted prior to enactment of the GEPA Water Quality Standards. As a result, a large portion of the western Mt. Barrigada water shed has been disrupted to urbanization.

Two sites were monitored in Barrigada #2: at the northern storm drain outlet (B2d); and at a weir (B2w) separating the upper channel from the lower infiltration basin. The lower basin, Barrigada #3 (B3), was monitored in the southeast corner.

Selection of this basin system was based on the following considerations:

1. it receives runoff from a drainage basin encompassing a large portion of the Mt. Barrigada conservation zone.

2. the drainage area at over 1 km^2, is comparatively large in relation to other drainage areas.

3. its primary source of runoff is from a residential development.

4. its underlying limestone formation is Mariana limestone, veneered by Guam clay.

5. within the basin system, there was one and usually two sample sites containing sufficient ponded water to assure routine monitoring.

6. it was easily accessible at all times.

Latte Estates #2 and #3 (L2; L3)

The Latte Estates (Fig. 7 and 8) residential subdivision is situated on the north western slopes of Mt. Barrigada. This places is on the northern edge of the Mt. Barrigada conservation zone as designated by GEPA Water Quality Standards. Since the conservation zone boundaries are not clearly defined, this subdivision may be partially in the resource zone.

At L2, samples were taken in the pond, unless the sampling day coincided with rain conditions, in which case samples were taken at the base of the principle drain. No distinction was made between these different sources. At L3, samples were taken at what ever point happened to be the deepest at the time of sampling.

L2 and L3 3 were selected as study sites based on the following considerations:

1. the subdivision and ponding basins are located in a conservation zone.

2. the underlying limestone is Barrigada Limestone with a surrounding soil type of Guam clay.

3. L2 represents exclusively residential runoff.

4. L3 represents residential runoff mixed with some minor agriculture runoff.

5. originally there were sufficiently large ponds at both sites to assure routine sampling.

6. concentrations of flora and fauna were relatively low at both sites.

7. both sites were easily accessible.

Dededo

The Dededo ponding basin is located north of Dededo village across from the Dededo Junior High School on Santa Monica Street. This study area has been designated as a resource zone by the GEPA Water Quality Standards.

Samples were obtained from a low relief area in the vicinity of the eastern storm drain. The ponding ability of the basin was altered as a result of super-typhoon Pamela. As a result, this basin was dropped from routine sampling in August 1976.

Dededo ponding basin was selected as a study site based on the following considerations:

1. it receives runoff from a large drainage area.

2. its runoff waters are derived from a wide variety of land use types.

3. it originally contained a large body of continually ponded water.

4. the drainage area was reasonably representative of residential development found in the resource zone.

5. the underlying limestone formation was Barrigada Limestone with a modified Guam clay veneer.

6. it was easily accessible for routine monitoring.

Perez Acres

The Perez Acres subdivision is located 1.0 km south of the Yigo Baptist Church, on the east side of Marine Drive. This places is in the resource zone as designated by the GEPA Water Quality Standards. It is a relatively small, isolated, residential development, with a total drainage area of .08 km^2. Runoff waters draining into the ponding basin, located on the northern boundary, are exclusively from the development.

Sampling was conducted at the storm drains. Samples were usually taken just east of the drains, at a point that appeared to be a representative mixture of the two drainage waters. When the sampling day coincided runoff, samples were taken at the drains. At low ponding levels the lower drain was sampled and a high ponding levels the upper drain was sampled.

Perez Acres ponding basin (Fig. 9) was selected as a study site based on the following considerations:

1. it reflects exclusively residential runoff waters.
2. it has a well defined drainage area.
3. it contains a sufficiently maintained pond allowing for routine monitoring.
4. the ponded water always appeared to be highly turbid.
5. the underlying limestone formation is Barrigada Limestone.
6. the drainage area contains a possibly different soil type, Agat-Asan-Atate clays.
7. it was easily accessible for routine monitoring.

Mariana Terrace (MT)

The Mariana Terrace residential subdivision is located in Yigo Village, 0.8 km east of Marine Drive, on the Northern side of the Yigo road. This 0.5 km^2 subdivision is situated at the base of the western foothills of Mt. Santa Rosa, placing it in the resource zone as designated by the GEPA Water Quality Standards.

Initially, samples were obtained from either the central western storm drain outlet or in the northern pond. During routine monitoring samples were obtained from the storm drain site. No distinction was made between the sites. It was noted that on several occasions raw sewage was flowing into the monitored storm drain. A sewage treatment plant occasionally discharges into the basin.

The MT ponding basin was (Fig. 10) selected as a study site based on the following considerations:

1. it reflected input from residential development and discharge of raw and/or secondary sewage.

2. it receives runoff from a comparatively large drainage area.

3. it contains sufficient quantities of ponded water, at several locations within the basin, to assure routine monitoring.

4. the underlying limestone formation is a transition zone between Mariana and Barrigada Limestone.

5. the drainage basin contains a variety of soil types including Chaca Saipan, Saipan-Yona-Chaca and Guam clays.

6. the flora and fauna are extremely diversified and abundant, exceeding that found at all other study sites.

7. it was reasonably accessible for routine monitoring.

Airport Road Runoff Channel (AP)

Runoff from the Guam International Airport (including the building complex, airplane parking aprons, and parking lots) is channeled into a concrete lined drainage ditch which runs west along Airport Road to the base of the upper plateau adjacent to Mendiola Apartments. At this location it merges with a north-south drainage system, either man-made or natural, that discharges into the Harmon Sink, a natural Mariana limestone infiltration area.

Ponding of Airport runoff waters occurs at the junction of the two channels. Since the bottom of the ponding site is concrete lined, the ponded water can be completely replaced during periods of moderate to heavy runoff. The quality of ponded water is dependent on the source channel. The north-south channel receives natural storm runoff, thereby influencing the quality during storm runoff periods. The Airport channel has greater influence during non-runoff periods, a result of maintenance activities at the Airport.

The AP ponding site (Fig. 11) was selected for study based on the following considerations:

1. it represents drainage from a large, specific commercial enterprise.

2. there were frequently heavy concentrations of oil-grease, a foaming agent, and a creamy white substance (possibly paint) in the airport runoff waters.

3. a detectable petroleum odor was associated with the ponded water during periods of non-storm runoff.

4. it is a low water quality site which was utilized for comparison with urban runoff at the ponding basin and storm drain sites.

5. organisms were rarely observed (primarily dragon fly nymphs). *Bufo* egg masses were observed but no tadpoles developed.

East Agana Bay (EAB)

The East Agana Bay storm drain discharge site is located 0.5 km south of the Marine Drive-Camp Watkins Road intersection. This drain discharges runoff associated with commercial developments along Marine Drive, starting at the Camp Watkins Road intersection and ending just south of the discharge site. Samples were obtained at storm drain outlets adjacent to the Marine Drive.

The EAB storm drain (Fig. 12) was selected for study based on the following considerations:

1. a substantial body of continuously ponded water occurs prior to the coastal discharge location.

2. it has a well defined commercial drainage area.

3. there were always observable quantities of oil-grease and man-made debris.

4. a large sediment delta is maintained on the adjacent reef flat.

5. there is a large diversity of fauna surviving in the ponded water.

6. it was easily accessible for routine monitoring.

Naval Air Station (NAS)

The Naval Air Station storm drain discharge site (Fig. 13) is located 0.6 km south of the Marine Drive-Camp Watkins Road intersection. The storm runoff originates from the Naval Air Station residential development and the adjoining commercial runway situated on the plateau immediately above the discharge site. Additionally, a substantial continuous flow is discharged from the storm drain that is brackish basal lens water. Apparently during construction of the lower section of the drain, a deliberate channeling of naturally occurring seepage was incorporated into the system. As a result, the primary discharge during non-runoff periods is brackish water similar in quality to the Tumon Bay seepage.

The NAS storm drain was selected for study based on the following considerations:

1. its primary discharge is groundwater seepage with secondary discharge consisting of mixed residential-commercial runoff.

2. the primary discharge water volume exceeds all other storm drain sites.

3. a large sediment delta is maintained on the adjacent reef flat.

4. an assemblege of fish, attracted to the discharge site are caught by local fishermen.

5. it was easily accessible for routine monitoring.

West Agana Bay (WAB)

The West Agana Bay storm drain discharge site (Fig. 14) is located 0.4 km south of the Marine Drive-Route 4 intersection in Agana. This storm drain receives runoff exclusively associated with commercial development. Additionally, it was suspected that a portion of the effluent was a result of leakage from a water pipe discharging into the drainage system.

The WAB storm drain was selected as a study site based on the following considerations:

1. a small continuous discharge could be obtained directly from the drain pipe, except at high tide.

2. it reflected exclusively commercial runoff.

3. the discharge water appeared to restrict algal growth produce in the immediate surrounding area (primarily restricted to the inner delta).

4. it was easily accessible for routine monitoring.

Camp Watkins Road (CWR)

The Camp Watkins storm drain (Fig. 15) is located northwest of the Marine Drive-Camp Watkins Road intersection. It discharges into East Agana Bay at Alupang Cove. The primary sources of runoff are from commercial developments north of the intersection along Marine Drive. Additionally, there is input from residential sources and an unidentifiable fresh water source, possibly a basal lens leak.

The CWR storm drain was selected as a study site based on the following considerations.

1. it has a large volume flow with substantial ponding occurring prior to the coastal discharge location.

2. there were frequently observable quantities of oil-grease, foam, and man-made debris in runoff waters near the intersection.

3. an extensive sediment delta extended 150-200 m north of the discharge site.

4. the runoff reflects commercial development with minor residential input.

5. it was frequently reported by GEPA as being heavily polluted by fecal coliform bacteria.

6. this site was added late in the study when it was decided that additional data on the quality of coastal discharge was needed.

Tumon Bay (TB)

Brackish water seepage occurs along the coast (primarily the upper shoreline) along the entire 3.2 km stretch of Tumon Bay (Fig. 16). This seepage is basal lens water from the transition zone. Numerous locations along the bay are characterized by substantial and almost continuous discharge of this basal water. Since brackish water seepage is a common occurrence along the northern Guam fringing reefs, it was considered necessary to ascertain its basic quality.

Limited sampling of the following five major seepage sites was conducted: 50 m east of the Hilton Hotel storm drain; ca. 0.15 km and 0.16 km east of the Continental storm drain; below the Reef Hotel storm drain; and east of the Okura Hotel storm drain. Site selection was based on accessibility and volume flow. Sampling proved to be difficult as a result of the diffuse nature of the seepage and the requirement of low tides. When the water analyses provided consistent values sampling at these sites were discontinued.

The five sites were initially selected in order to establish:

1. the quality of basal lens water discharged onto the fringing reef environment.

2. the uniformity of basal lens water quality along a continuous stretch of shoreline in a contained drainage basin.

3. that high nitrate-nitrogen concentrations are characteristic of basal lens water entering coastal waters.

Field Monitoring Schedule

Preliminary monitoring of ponding basins and coastal discharges was initiated in December, 1975. During this study phase, nine ponding basin locations (Ble, Blc, B2w, B2d, B3, L2, L3, Dededo, MT) and four coastal discharge sites (Tumon Bay) were sporadically sampled. This initial phase was utilized to establish the most advantageous study sites as well as the sampling locations within the study sites. An attempt was made to sample study sites prior to, during, and shortly after periods of moderate to heavy storm runoff. The number of parameters analyzed during this phase were limited. Water samples were collected for the analyses of nitrate and nitrite nitrogen, ortho-phosphate, DO, pH, total and phenolpthaline alkalinity, turbidity, and specific conductance. Toward the end of this phase an additional five study sites (Perez, AP, EAB, NAS, WAB) were examined as potential study sites for the routine monitoring.

The second phase of study began in July of 1976 after restoration of island power, lost as a result of super-typhoon Pamela in May, 1976. This phase was a systematic monitoring of between twelve to thirteen sites (Ble, Blc, B2s, B2d, B3, L2, Perez, MT, AP, EAB, NAS, AT, CWR).

The CWR site was added toward the end of phase two since additional coastal discharge data was required. The sampling interval and number of samples per site is given in Table 2.

A monitoring schedule consisting of semi-monthly sampling was selected. This proved to be the most advantageous sample interval in terms of laboratory analyses times. Additionally, it provided sufficient data to establish the quality of urban runoff waters. When experience with new water analyses techniques was gained, these parameters were added for routine monitoring.

Sequential sampling was conducted at selected ponding basin sites during storm runoff. Samples were collected at short time intervals directly from the storm drain outlets, from the onset to the end of the discharge period. This was done in order to ascertain if changes in the quality of urban runoff could be detected during runoff.

Field Sampling Techniques

All water samples were collected in accordance with *Standards Methods, for Examination of Water and Wastewater* (1971). Sampling containers were treated to the degree necessary, dependent on the water sample. Water samples that required preservation were treated either in the field or immediately upon returning to the laboratory. Dissolved oxygen samples were always fixed at the site. Samples transported to the laboratory were either iced or kept in covered transport boxes.

A grab sampling technique was employed whenever feasible. A sufficient quantity of ponded water, to meet sampling requirements, was collected in a cleaned bucket. The bucket was rinsed two or three times with the ponded water. The water was then siphoned from the bucket into appropriate sample bottles. Care was taken to avoid contamination of sampling bottles. For DO samples the siphon was placed at the bottom of the bottle so a 300 to 400 ml flush could be made; this avoided oxygen introduction. For all other samples the siphon was not allowed to come in contact with the sample bottle.

A direct collection into the sampling bottles was employed at coastal sites with continuous discharge or when ponded levels became low. Since these were hand held samples, care was taken to avoid potential contamination.

An attempt was made to obtain sample water representative of the observed natural conditions. At basins with ponded water high in organic or faunal content, special precautions were taken. When the collected sample contained excessive settleable material, a 3 to 10 minute settling period was allowed prior to siphoning. Excessive fauna, mainly mosquito larvae, water striders, and snails, were occasionally collected. They tended to migrate to the surface of the collected water. In order to minimize distortion of the water quality, the siphon was maintained in the central portion of the collected water. This provided water samples that more realistically compared to the natural conditions.

The pH and temperature were obtained at the site. A portable pH meter, standardized with two standards, was used. Temperature measurements were taken with a 20-50°C thermometer.

Laboratory Techniques

Collected water samples were analyzed for the parameters listed in Table 3. All parameters listed except temperature and pH were measured in the Water Resources Research Center (WRRC) Laboratory.

All analyses were performed in accordance with techniques presented in *Standard Methods for the Examination of Water and Wastewater* (1971) with the exception of orthophophorus, nitrite-nitrogen, nitrate-nitrogen, MBAS and COD.

A rapid dichromate reflux technique for COD analysis (Jervis, 1967) was tested and found to yield results consistent with the standard dichromate reflux method. This method was used to save time.

The modified MBAS technique presented in *Journal of American Water Works Association* by L. Wang (1975) yields results consistent with the standard method. The method was utilized because it required less time and consumed less chloroform.

Techniques presented in *A Practical Handbook for Seawater Analysis* (Strickland and Parsons, 1971) were used to analyze orthophosphate, nitrite-nitrogen and nitrate-nitrogen. The Strickland and Parsons techniques are similar to those presented in Standard Methods and were used because they were familiar to lab personnel.

The number of parameter measurements varies because some parameters (sulfate, oil and grease) were measured on a non-routine basis. Also parameters were added to the list to be analyzed as the lab acquired the capability to perform them.

RESULTS AND DISCUSSION

Results of Chemical Analyses

In the analysis of the results, the data is broken down into two categories: urban runoff sampled from ponding basins reflecting runoff from mainly residential areas and runoff discharged into coastal receiving waters derived from of adjoining commercial areas of Marine Drive and vicinity.

Three sampling sites present distinguishing characteristics. Mariana Terrace ponding basin receives sewage and/or waters from a tap water source. NAS storm drain flows continuously with a high volume of water with groundwater characteristics. Airport Road drainage ditch receives runoff from aircraft maintenance operations, and was therefore more highly polluted with oil and grease and MBAS than other sampling sites. Mariana Terrace and NAS were treated individually in the analysis of the data. Airport Road drainage was included with other commercial area runoff discharge sites in determining mean values for commercial runoff.

Tables 4-11 present the mean, standard deviation and number of samples for all parameters measured at the sampling sites selected.

Temperature

Temperatures of runoff fluctuated between 25.4 and 35.7 degrees centigrade during the study. No temperature trends were noted except that effluent from storm drain mouths was usually 27-28 degrees centigrade. The mean temperature of all sampling locations was 29.3°C. The highest individual mean temperature (31.7°) was recorded at the Airport Road site, a result of the cement lined bottom.

Temperature measurements were only taken during sampling times, and therefore were restricted to daylight hours.

Turbidity

Turbidity ranged from a low of .13 NTU at NAS storm drain to a high of 200 NTU at B2d (Fig. 17-28). Residential runoff had a mean of 16 NTU. Coastal discharge and Airport Road drainage had a mean turbidity of 17 NTU. Figures 17, 18, 19, and 20 show that ponding basin sampling sites near drain locations had higher turbidity levels than sampling sites in the same basin located away from the drain outlets. The higher turbdities at the drain outlets are a result of low to heavy concentrations of silts and clays in runoff waters. Reduced turbidity away from the drain is usually a result of vegetation in the vicinity of the drain acting as a silt screen as well as settling and dilution.

pH

pH measurements ranged from a low of 6.60 at Mariana Terrace ponding basin to a high of 10.35 at Perez Acres ponding basin (Fig. 29-40). The mean pH of ponded residential runoff was 8.67. The longer and more extensive ponding, limestone contact, and increased temperatures may account for the high pH in ponding basins. L2 had a mean pH of 9.22 based on 23 readings. Figures 34, 35, and 36 present pH data versus date for L2, Perez acres, and MT.

The pH of coastal discharge sites and Airport Road runoff was lower than observed in residential runoff with a mean of 7.65. Camp Watkins Road had the lowest mean pH, 7.02. The pH values at the coastal sites are similar to the values measured in groundwater seepage and well water.

Total and Phenolpthalein Alkalinity

Total alkalinity of coastal discharge was much higher than noncoastal runoff reflecting the oceanic influence at these sites. Total alkalinity ranged from 11.8 to 436 mg $CaCo_3$/l at coastal discharge sites and Airport Raod (no oceanic influence). The mean total alkalinity of the coastal discharge sites and Airport Road was 154 mg $CaCo_3$/l compared to the 49.4 mg $CaCo_3$/l mean alkalinity of residential runoff in ponding basins.

Phenolpthalein alkalinity of coastal discharge effluent had a low mean of 1.25 mg $CaCo_3$/l with many samples yielding no phenolpthalein alkalinity. Figures 37, 38, and 40 present alkalinity concentrations versus date for Airport Road, EAB and WAB.

The NAS storm drain effluent had the highest mean total alkalinity (246 mg/l) of any sampling site due to oceanic influence. This value is consistent with values recorded in some Guam wells and at the Tumon Bay groundwater seepage sites. No phenolpthalein alkalinity was ever recorded there. Figure 39 shows alkalinity concentrations recorded at NAS versus date.

Total alkalinity of ponded water (excluding Mariana Terrace) ranged from a low of 27.8 mg $CaCo_3$/l at Perez Acres to a high of 148 mg $CaCo_3$/l at Blc. The phenolpthalein alkalinity ranged from 0 to 28 mg $CaCo_3$l/ with a mean of 5.9 mg $CaCo_3$/l. Based on mean values, the total alkalinity of ponded water exists in a rough porportion of 75% carbonate to 25% bicarbonate alkalinity. Figures 29, 30, 34, and 34 show alkalinity concentrations versus date for Ble, Blc L2, and Perez Acres.

Mariana Terrace ponding basin recorded high alkalinity (probably due to reception of ground or tap waters) ranging from 32.1 to 306 mg $CaCo_3$/l with a mean total alkalinity of 131 mg $CaCo_3$/l. Figure 36 shows Mariana Terrace alkalinity concentrations versus date.

Hardness and Calcium Hardness

Hardness analysis of runoff waters was conducted on two to four dates in the later portion of the study. Results indicate that coastal runoff water is very hard with a range of 46 to 330 mg $CaCo_3$/l. The groundwater discharging at NAS had even greater hardness with a mean reading of 412 mg $CaCo_3$/l. Airport Road drainage which represents commercial runoff not influenced by oceanic conditions had a mean hardness of 70.7 mg $CaCo_3$/l. Calcium hardness composed 59 to 88 percent of total hardness in commercial runoff. Figures 37, 38, and 39 show the hardness concentrations for Airport Road, EAB AND NAS.

Ponded runoff ranged from 28 to 91 mg $CaCo_3$/l with a mean of 50 mg/l. The calcium hardness composed 88 to 100 percent of the total hardness in ponded runoff. Figures 31, 32, 33, and 35 show hardness concentrations for B2d, B2w, B3, and Perez Acres.

Mariana Terrace ponded water had hardness ranging from 228 to 259 mg $CaCo_3$/l with calcium hardness comprising over 90 percent of the total hardness (Fig. 36).

Settleable Solids

Settleable solids in excess of 0.1 ml/l were periodically recorded for MT, EAB, WAB, and Ble. The highest volumes measured were at Ble (80 ml/l) and MT (3.0 ml/l). The settleable solids at Ble, consisting almost solely, of Hydrilla filaments and organic debris, became concentrated when the pond water volume decreased during a drought condition. The solids at other sites consisted of decayed organic material, plant detritus and associated fauna of the site. WAB recorded a reading of .15 ml/l during storm runoff. The dark color of the runoff and high turbidity suggested that organic and inorganic material was flushed out of a stagnated area in the storm drain system.

Ponded waters were generally free of settleable solids. However, no detailed sampling was obtained during the start of storm runoff conditions for most sampling sites.

Total Solids

Total solids data at coastal storm drains reflects the influence of shore waters and, or groundwater. All coastal discharge sites had high TS values (Figs. 26-28). The mean TS concentration for EAB, WAB, NAS, and Camp Watkins Road sampling sites were 1392, 675, 1371, and 1174 mg/l, respectively. The TS concentrations ranged from 13 to 5664 mg/l for the coastal discharge sites.

Airport Road drainage ditch (Fig. 25) had a mean TS concentration of 245 mg/l. Residential ponded runoff, due to its interior location, was not influenced by sea water. Total solids for ponded runoff (excluding Mariana Terrace) ranged from 13.5 mg/l to 836 mg/l (Figs. 17-22) with a mean of 130 mg/l. Perez Acres (Fig. 23) had the highest mean TS of residential runoff with 210 mg/l. B2w had the lowest mean TS with 87.5 mg/l. Figure 84 shows the total solids data for ponded runoff plotted on probability graph paper to eliminate effects of extreme values on the mean. The graph data yields a mean of 100 mg/l for ponded water.

Mariana Terrace ponding basin which received occasional sewage and/or tap water effluent and contained organic detritus had much higher TS concentrations than other residential ponding basin. Total Solids ranged from 123 to 2968 mg/l (Fig. 24) with a mean of 439 mg/l.

Total Dissolved Solids

The results of TDS analyses follow the same pattern as TS data revealing low TDS values for residential ponded runoff (Figs. 41-48) and high values for commercial, coastal discharged effluent (Figs. 49-52).

The mean TDS concentrations for EAB, WAB, NAS, and Camp Watkins Road sampling sites were 1302, 675, 1370, and 1174 (one sample only) mg/l, respectively. The TDS concentrations ranged from 13.0 to 5654 mg/l for all four coastal discharge sites.

Airport Road drainage had a mean TDS concentration of 220 mg/l. Total dissolved solids in ponded water ranged from 2.9 mg/l to 783 mg/l with a mean of 110 mg/l. Perez Acres ponding basin had the highest level of TDS with 185 mg/l.

Values of TDS at Mariana Terrace ponding basin ranged from 38.0 to 783 mg/l with a mean of 185 mg/l.

Suspended Solids

Suspended solids (SS) concentrations for coastal discharge and ponded water sampling sites ranged from 0.0 at NAS storm drain to 43 mg/l at Blc (Figs. 1-28). The mean SS of ponded runoff was 18 mg/l. Commercial runoff had a similar mean of 17 mg/l. The SS data was plotted on probability graph paper (Fig. 85). The resulting geometric means for residential and commercial runoff were 15.0 and 15.5 mg/l, respectively.

Mariana Terrace suspended solids concentrations exceeded the range of values for other ponded water with a range of 4.1 to 57.8 mg/l and a mean of 15.8 mg/l.

Volatile Solids and Volatile Suspended Solids

Volatile solids in ponding basin waters ranged from 1.7 to 173 mg/l with a mean of 51.2 mg/l. Volatile suspended solids in ponding basin water ranged from 1.0 mg/l to 98 mg/l with a mean of 8.7 mg/l. Roughly one half the total solids in ponded waters is volatile.

Volatile solids of commercial runoff ranged from 21 to 654 mg/l with a mean of 131 mg/l. Volatile suspended solids of commercial runoff ranged from 11 to 37 mg/l with a mean of 8.7 mg/l.

Specific Conductance

Specific conductance values of coastal discharge sites reflect sea water or groundwater intrusion. The mean specific conductance of these sites was 1503 umho/cm.

Airport Road drainage had the lowest specific conductance of commercial area runoff with a mean of 175 umho/cm.

For ponded runoff, the specific conductance values are much lower (Figs. 41-47). Specific conductance readings for ponded runoff ranged from 52 umho/cm to 362 umho/cm with a mean of 115 umho/cm. B1c had the highest mean specific conductance with 149 umho/cm.

Specific conductance values were consistent throughout the monitoring period of each ponding basin site shown by Figures 42, 46 and 47.

Mariana Terrace had a much higher level of conductance with values ranging from 73.9 to 615 umho/cm (Fig. 48) and a mean of 286 umho/cm, reflecting sewage and/or tap water input.

Chlorides and Sulfates

Chloride levels in ponded runoff ranged from .10 to 45.3 mg/l with a mean of 9.13 mg/l for the seven ponded runoff sites (Figs. 41-48). B1c had the highest mean chloride level at 12.5 mg/l. B3 had the lowest mean chloride concentration at 5.64 mg/l. Figures 42 and 45 show chloride levels versus date for the two above sites.

Coastal discharged effluent had very high chloride levels resulting from sea water or groundwater intrusion into coastal low lying areas. EAB, WAB, NAS, and Camp Watkins Road sampling sites reported chloride concentration means of 755, 217, 448, and 62.3 mg/l, respectively. Figures 50, 51 and 52 show chloride concentrations versus date for EAB, WAB, and NAS storm drains.

Sulfate values ranged from 2.1 mg/l to 13.7 mg/l for ponded runoff (Figs. 41-49). Mean sulfate concentration for ponded runoff was 3.0 mg/l.

Coastal discharge sites showed much higher mean sulfate concentrations, up to 158 mg/l at WAB storm drain.

Airport Road drainage had a mean sulfate concentration of 20 mg/l.

Dissolved Oxygen, Biochemical Oxygen Demand, and Chemical Oxygen Demand

Dissolved oxygen (DO) ranged from 0.00 to 18.2 mg/l (Figs. 53-64). Commercial runoff had a mean of 4.82 mg/l DO, while residential ponded runoff had a mean 7.97 mg/l. Levels of DO in ponding basins were usually at or above saturation levels. The shallow waters of L2 had the highest mean DO level for a sampling site, 10.51 mg/l. The EAB effluent had the lowest mean DO level at 4.22 mg/l.

Chemical oxygen demand (COD) concentrations for residential runoff ranged from 0.00 mg/l to 191 mg/l COD (Figs. 53-60). Commercial runoff COD values ranged from 0.00 to 693 mg/l COD (Figs. 61-64). The mean COD for residential runoff was 21 mg/l. For Commercial runoff, the mean COD was 43 mg/l. The Airport Road drainage ditch had the highest mean COD at 116 mg/l based on eighteen samples analyzed. B3 had the lowest mean COD with 13.1 mg/l. The NAS storm drain effluent which has groundwater characteristics, had a mean COD of 5.05 mg/l.

Biochemical oxygen demand (BOD) ranged from .16 mg/l to 17.2 mg/l for residential runoff (Figs. 53-60). Commercial runoff ranged from 0.00 to over 160 mg/l BOD. Residential runoff had a mean BOD of 2.98 mg/l. Commercial runoff had a mean BOD of 9.65 mg/l. As with COD, site B3 had the lowest mean BOD (2.00 mg/l) of any sampling site excluding NAS storm drain. Airport Road drainage also had the highest mean BOD with 30.0 mg/l. NAS storm drain effluent had a mean BOD of .54 mg/l.

When BOD and COD data are plotted on probability paper to eliminate the effects of extreme values on the means, the geometric means of both commercial and residential runoff are comparable (Figs. 86, 87, 88 and 89). The geometric mean BOD of commercial and ponding basin water falls to 2.45 mg/l and 2.00 mg/l BOD, respectively. The COD of commercial and ponding basin waters falls to 16.0 mg/l and 15.5 mg/l, respectively. The Airport Road drainage, because of extremely high values of BOD (160 mg/l) and COD (692 mg/l) accounted for the higher arithmetic means obtained for commercial runoff.

Phosphorus

Phosphorus concentrations in urban runoff were usually low with the exception of the Airport Road drainage ditch. Orthophosphate (PO_4-P) concentrations ranged from 0.00 mg/l to 3.75 mg/l (Figs. 65-76). The mean PO_4-P concentration for the seven ponding basin sites was .031 mg/l.

When the same data were plotted on probability paper to eliminate the influence of extreme values, the data yielded a mean of .021 mg/l PO_4-P (Fig. 90).

Commercial runoff showed a higher arithmetic mean of PO_4-P at .118 mg/l. When plotted on probability paper the data yielded a geometric mean of .019 mg/l, about the same value obtained for residential runoff (Fig. 91).

Airport Road drainage ditch had the highest mean PO_4-P level, .384 mg/l. Perez Acres ponding basin had the lowest mean PO_4-P concentration, .015 mg/l. Figures 73 and 71 show the results of PO_4-P analysis for these basins versus date.

Mariana Terrace ponding basin had a mean PO_4-P concentration of .049 mg/l, considerably higher than most other ponding basin surface waters.

Naval Air Station storm drain effluent, composed almost entirely of groundwater, had a mean PO_4-P level of .010 mg/l with a range of 0.00 to .017 mg/l. Figures 72 and 75 show the results of PO_4-P data collected versus date from MT and NAS.

Total phosphorus concentrations were much greater than orthophosphorus levels in urban runoff. Total phosphorus ranged from .001 to 8.28 mg/l T-P (Figs. 65-76). The mean concentration of total phosphorus in ponded water was .096 mg/l T-P. The mean concentration in commercial runoff was .510 mg/l. Airport Road drainage was again responsible for the higher concentrations measured and had the highest mean total phosphorus level at 1.80 mg/l. Excluding NAS, WAB had the lowest total phosphorus concentration at .028 mg/l.

Mariana Terrace had a range of .060 to .368 mg/l T-P and a mean of .133 mg/l.

The NAS storm drain effluent had a range of .002 to .020 mg/l T-P with a mean of .009 mg/l. The low amounts of phosphorus in these waters were entirely in the orthophosphorus forms.

Nitrite and Nitrate-Nitrogen

Nitrite-Nitrogen levels were barely measurable in urban runoff on many occasions with a range of 0.00 mg/l to .239 mg/l NO_2-N. The mean nitrite-nitrogen concentration for residential ponded waters (ex. Mariana Terrace) was only .003 mg/l NO_2-N. Commercial runoff had a higher mean of .019 mg/l NO_2-N. The EAB storm drain had the highest mean nitrite-nitrogen concentration at .047 mg/l. The lowest mean nitrite-nitrogen concentration was recorded at several ponding basins and NAS storm drain with a mean of .002 mg/l NO_2-N.

Mariana Terrace ponding basin had a mean nitrite-nitrogen concentration of .048 mg/l and a range of 0.00 to .239 mg/l.

Nitrate-nitrogen concentrations ranged from .001 to 4.56 mg/l NO_3-N (Figs. 65-76). The mean nitrate-nitrogen concentration for ponded water was .079 mg/l NO_3-N. Plotted on probability graph paper, the residential runoff data yielded a geometric mean of .033 mg/l NO_3-N (Fig. 92). Commercial runoff had a higher mean nitrate-nitrogen level with .634 mg/l. WAB had the highest mean nitrate-nitrogen concentration of individual sampling sites (excluding NAS storm drain) with 1.31 mg/l. B2w had the lowest mean concentration of .051 mg/l NO_3-N. Mariana Terrace had a mean nitrate-nitrogen concentrations of .349 mg/l and range of <.001 to 2.04 mg/l.

NAS storm drain effluent, composed mostly of groundwater, had a mean of 2.41 mg/l NO_3-N with a standard deviation of only .116 mg/l for 13 samples analyzed.

The nitrate-nitrogen levels in Guam's urban runoff are very low in comparison with nitrate levels measured in Guam's ground and tap water (Table 12). Guam's groundwater typically ranges from .5 to 4 mg/l NO_3-N (e.g. Mangilao tapwater ranges from 1.62 to 2.93 mg/l). The geometric mean of urban runoff from residential areas (.033 mg/l NO_3-N) is roughly 1/50 to 1/100 the concentration found in the groundwater, indicating a biological subsurface source for nitrate-nitrogen input.

The commercial runoff from storm drains discharging into Agana Bay, particularly WAB, are believed to contain tap waters from either tap line use or leakage. Thus, the higher nitrate-nitrogen levels of these waters may be due to the presence of groundwater and not to the effects of urbanization. The higher nitrate-nitrogen levels, regardless of source, are being discharged in concentration exceeding the GEPA Guam Water Quality Standards.

Methylene Blue Active Substances

Methylene blue active substances (MBAS) were found in measurable and occasionally high concentrations at a number of urban runoff sampling sites. MBAS (primarily soaps and detergents) concentrations ranged from .010 mg/l at NAS storm drain and WAB storm drain to 12.2 mg/l at the Airport Road drainage ditch. Residential runoff had a mean M3AS concentration of .241 mg/l (excluding Mariana Terrace runoff) and a range of .031 mg/l to 1.63 mg/l (Figs. 53-60). Commercial runoff had a mean MBAS concentration of 1.00 mg/l with a range of .010 to 12.21 mg/l (Figs. 61-64). Some positive interference in the MBAS technique used is probable for MBAS values measured at ponding basin sites, although no attempt was made to determine the types or amount of interference. Considerable positve interference at coastal sites could have occurred due to the high concentrations of chlorides, nitrate, and sulfate.

Ponding basins with higher mean levels of MBAS included L2 (.400 mg/l), MT(.270 mg/l), B2d (.386 mg/l), Blc (.379 mg/l). At the Barrigada Village and Barrigada Heights ponding basins, levels of MBAS were higher at sampling points located near the storm drain discharge points than at site removed from the storm drains. Blc and B2d had mean MBAS concentrations of .379 and .386 mg/l, respectively, compared to Ble and B2w concentrations of .178 and .169 mg/l, respectively.

Aircraft maintenance operations were observed to be a main source of MBAS entering the Airport Road drainage ditch, where concentrations of MBAS ranged from .677 to 12.2 mg/l. The drainage ditch usually contained (and is almost daily receiving water) considerable quantities of MBAS laden waters which percolate into the substrate north of the site. A paint-like substance was also observed in the airport runoff, suggesting that heavy metals might also be a pollutant problem there.

Other commercial runoff was much lower in MBAS with mean concentrations of .172 mg/l at WAB and .360 mg/l at EAB. The mean MBAS concentrations of NAS effluent was .131 mg/l (Fig. 63) shows the MBAS data as collected versus time. This value may be higher than the actual concentration of MBAS due to chloride, nitrate-nitrogen, and sulfate interference.

Oil and Grease

Oil and grease concentrations ranged from 0 to 65 mg/l. Considerable oil and grease concentrations were noted at Barrigada Village, Barrigada Heights basins, L2, Airport Road and EAB sampling locations. Mean concentrations of oil and grease at ponding basin sites were similar with means of 13.1, 16.6 and 14.4 mg/l for sites Blc, B2d and MT. Perez Acres had the lowest mean concentration at 1.4 mg/l.

Runoff at Airport Road had the highest oil and grease concentrations. The mean oil and grease concentration of Airport Road drainage was 33 mg/l.

Other sites within the commercial area had much lower oil and grease concentrations than Airport Road drainage ditch. EAB had consistent oil and grease in its effluent with a mean of 10.6 mg/l. Camp Watkins Road drainage ditch had a mean oil and grease concentration of 15.6 mg/l. Values ranged from 2.5 to 18.0 mg/l at EAB storm drain and from 8.5 to 20.3 mg/l at Camp Watkins Road.

Oil and grease of NAS and WAB storm drains was low to non-existent due to the nature of the effluent. A reading of 0.7 mg/l oil and grease was obtained with one sampling of NAS effluent.

Sequential Sampling

Sequential samples were collected during or immediately after rainfall activity from Perez Acres, L2 and B2d, (Figs. 77-83).

Results indicate that levels of NO_3-N, PO_4-P, and TP input are low (Tables 13-16). Nitrate-nitrogen ranged from .001 to .415 mg/l with a mean of .047 mg/l for 39 samples. The median value was .008 mg/l. Orthophosphate data yielded similar results with a mean of .052 gm/l PO_4-P. The median value was .015 mg/l. Total phosphorus, measured during one shower at Perez Acres ranged from .050 to .115 mg/l.

Specific conductance was highly variable depending on runoff source with values ranging from 64 to 362 umho/cm.

Total alkalinity of storm runoff ranged from 15.4 to 73.7 mg/l $CaCo_3$.

Turbidity was moderately high at B2d, a result of clay suspension, with a range of 8.5 to 15.5 NTU. At Perez Acres flow from the top drain had a range of 2.0 to 6.2 NTU.

pH of runoff waters was high at Perez Acres with range of 8.68 to 9.63. pH was lower at B2d and L2 with a range of 7.89 to 8.25 for both sites.

The results of the 1/9/76 Perez Acres sequential sampling (Figs. 81 and 82) show that parameter concentrations increase with initial storm runoff flow then decrease thereafter. The data suggests that by the time of the third shower monitored the runoff area had been flushed of most (measured) parameters, particularly nutrients and suspendable solids.

Results of sequential sampling of B2d suggests that Turbidity decreases after the initial pulse of runoff water (Fig. 77). However, there is an increase in specific conductance and alkalinity over time (Figs. 77 and 78). The nitrogen data collected is inconclusive as to whether the concentrations increase or decrease.

The results of the sequential sampling can be considered characteristic of showers 30 minutes or less in duration which are nearly a daily occurrence on Guam. No sequential sampling was undertaken during any tropical depression or tropical storm when rainfall is continuous for hours at a time.

The quality of Guam's urban runoff can be expected to be fairly consistent due to the frequent shower activity which serves to prevent large accumulation of street debris, dirt and oil deposits. The results of the sequential sampling correspond with results obtained during the study of the ponded water quality.

Tumon Bay Groundwater Seepage

Natural groundwater seepage along the Tumon Bay shoreline (Table 11) was, as expected, very high in total solids (mean of 4200 mg/l), total dissolved solids (4195 mg/l) and chlorides (mean of 1933 mg/l). It was also high in nitrate-nitrogen (3.30 mg/l) which indicates that the near shore environment in many areas (Tumon, NCS, and other northern beaches) are under conditions of natural nitrogen enrichment. This enrichment, combined with other natural phenomena, may explain the blooms of Enteromorpha algae and phytoplankton blooms that occur in Tumon and Agana Bays.

Suspended solids, turbidity, BOD, COD and phosphorus are all very low with values similar to those obtained with ground or tap waters. These characteristics (particularly the high nitrate and consistency of water quality) led to the identification of NAS storm drain effluent as being groundwater derived and not surface water runoff. A spring-like upwelling beneath Marine Drive was later observed directly discharging groundwater into the storm drain pipe.

Comparison of Results of Chemical Analyses with Guam Water Quality Standards

The GEPA Water Quality Standards specify that coastal areas along Agana Bay are "A" primarily recreational waters. Discharges must be controlled to the degree necessary to protect the waters for their specified recreational uses. Discharges violate the Water Quality Standards as stated in the general criteria section when the discharges:

1. Cause visible floating materials, debris, oils, grease, scum, foam, or other floating matter;

2. Produce visible turbidity, settle to form deposits, or otherwise adversely affect desirable aquatic life;

3. Produce objectionable color, odor, or taste, directly or by chemical or biological action;

4. Are toxic or harmful to humans, animals, plants, or desirable aquatic life;

5. Induce the growth of undersirable aquatic life.

The five general criteria of the Water Quality Standards are violated in varying degrees by all coastal discharge sites. However, obvious chronic violation of criteria is restricted to criteria 2, 3, and 4.

Extensive sediment deltas have developed at the mouths of all discharge sites. The largest deltas occurs at NAS and Camp Watkins Road drainage ditch. These deltas extend from 50 to 100 m from shore. Upon exposure during low tides, deltas produce obnoxious odors which are unpleasant to users of the surrounding area and passersby. They also restrict and change water current direction thereby influencing conditions governing the establishment and propagation of aquatic life.

Bacteria analysis of effluent waters indicate (EPA monitoring as well) that substantial bacterial contamination can and does occur in shore areas surrounding storm drains. The presence of such discharges is inherently detrimental to public and environmental health. Thus, they violate general water quality criteria No. 4.

In regards to the Specific Criteria for Water Quality in "A" recreational waters, no data base currently exists to support the criteria chosen for Guam's near shore environment. The time and manpower were not available to accomplish this as part of this urban runoff study. Various factors have to be considered in determining the "Ambient" water quality of inner reef flat waters on Guam. Among them are: 1) Considerable amounts of groundwater naturally and continuously seep into shore areas and even compose substantial portions of urban runoff effluent in some locations. 2) since groundwater contains high concentrations of nitrate-nitrogen and possess other characteristics of freshwater, near shore areas of Guam naturally experience conditions of nutrient enrichment and reduced salinities. 3) Such parameters as suspended solids and turbidity in particular are greatly affected by tidal height, surf conditions, and wind direction and velocity. 4) because (marine) near shore areas are highly dynamic with continuous change, the probability of producing duplicate samples of 5% consistency is reduced.

A comprehensive study is needed to determine near shore water quality at a number of locations around Guam under the wide range of naturally occurring phenomena. Until then, the selection of specific water quality criteria remains of dubious value.

No specific numerical criteria were established for groundwater Ib-II) or surface waters in the limestone region of Guam destined to become groundwater. General criteria specify that no discharges are permitted in Ib-I conservation zones. In the resource zone that comprises most of the northern limestone area, pollutant discharges must be treated to the degree necessary to protect "Ia" waters. Since the sampled discharges were in place prior to the Water Quality Standards enactment they are exempt from the standards.

Current discharges should be compared to Ia drinking water standards to determine potential danger to drinking water quality. To determine the possible affects of urban runoff on drinking water quality, comparisons of urban runoff to groundwater quality are useful.

Mean concentrations of NO_3-N, and phosphorus compounds are low in Guam's urban runoff (Table 12 for comparisons to other urban community runoff studies). Nitrate concentrations in runoff are usually less than .1 mg/l, 1/100 that allowed in drinking water. Ground and tap water nitrate concentrations of nitrate-nitrogen are much higher than typical runoff nitrate concentrations, ranging past 4 mg/l NO_3-N to nearly 50% of the amount allowed (10 mg/l) by the GEPA Water Quality Standards for drinking water.

Phosphorus concentrations are not limited by specific numerical criteria for drinking waters. A limit of .10 mg/l total phosphorus is established by the Guam Water Quality Standards for standing waters in basins that are used as drinking water resources. The mean concentration of phosphorus is ponded water is .096 mg/l.

No specific pH units are specified for drinking waters. Guam tap waters usually range from 7.3-7.8 pH units. Due to the limestone substrate, runoff pH frequently ranges past 9.0 in northern Guam.

The GEPA Guam Water Quality Standards specify that surface, standing waters considered drinking water resources are not to be decreased in DO in increased in suspended solids other than that due to natural conditions. No natural pond of standing water exist in northern Guam with which to compare urban runoff ponding basins standards. Water in ponding basins is usually found near or at saturation. A DO concentration of 7.00 mg/l for ambient ponding basin conditions is suggested by the study results.

Turbidity limits for drinking water have been established at 1 NTU. No turbidity limit exists for groundwaters. Turbidity of urban runoff, frequently high, is removed by filtration through the two hundred or more feet of limestone prior to reaching groundwater level used for drinking water. Measured turbidity in groundwater is usually well below 1 NTU.

Oil and grease concentrations were found to be present at all ponding basins. The Guam Water Quality Standards specify that any dectable film shown or discoloration of the surface or odor is a violation. All territorial waters are included. It seems highly improbably that any street runoff, commercial or residential will be free from oil and grease concentrations. The lowest mean oil and grease concentration observed was 1.4 mg/l at Perez Acres, which has the least drainage area and is the newest development (2 years).

MBAS concentrations were detected in all ponding basin waters. Drinking water standards specify a limit of .5 mg/l MBAS. Ponded waters ranged from .03 to 1.63 mg/l MBAS with mean of .241 mg/l. Since MBAS is known to infiltrate through soil more readily than other compounds, the concentrations of MBAS in surface runoff may be a greater threat to Guam's drinking water resource than realized. A monitoring of MBAS in surface runoff discharged into ponding basins should be included in groundwater monitoring programs on island. Also, periodic monitoring of MBAS levels in ponding basins should be undertaken.

Chloride concentrations of tap water in Mangilao, Guam, approach the 250 mg/l limit established by the Guam Water Quality Standards. Seawater intrusion into the groundwater lens presents a greater threat to the quality of Guam's drinking water resources than the concentration of chlorides in urban runoff. Concentrations of chlorides in urban runoff generally fall below 1/20 the concentration allowed by the GEPA Water Quality Standards.

Bacteriological Analyses

Tables 4-10 shows the arithmetic mean, standard deviation, range and number of samples for each of the twelve sampling sites. Total coliform values were generally very low with a range of 0 to 253,000 colonies/100 ml. Fecal coliform values ranged from 0 to 2,170,000/100 ml. However, if the Mariana Terraces ponding basin is excluded, the highest fecal count recorded was 44,000/100 ml. The Mariana Terrace ponding basin is situated in a natural sink area and it receives some raw sewage from sewer lines and a sewage treatment plant. The high count of 2,170, 000/100 ml was obtained during a rainfall when sewers flooded into the street storm drain system. Note the high fecal coloform to total coliform ratio (FC:TC) of 5.92. A ratio of .20 or higher indicates contamination from raw sewage water or domestic wastewaters [ORSANCO, 1971]. The NAS storm drain consistently had low total and fecal coliform counts with a range of 0 to 1460/100 ml for total coliform bacteria and 0 to 28/100 ml for fecal coliforms.

To compare the water quality of urban runoff from residential areas to that of commercial areas, the sampling sites were grouped according to type. Table 17 shows the arithmetic mean, standard deviation range, number of samples and FC:TC ratios for the sampling sites by type of runoff. Mariana Terrace and NAS are presented individually because of their unique nature. The ponding basin and storm drain waters, which may have been standing several days without input, reveal very low total coliform counts with a range of 0 to 20,000/100 ml and a fecal coliform range of 0 to 25,000/100 ml. These values should be compared to the Barrigada Heights storm drain counts from May-July 1977. During this time rainfall was more frequent and water samples reflect fresh (<12 hr.) input. These samples had a total coliform range of 0 to 640,000/100 ml and a fecal coliform range of 24 to 44,000/100 ml.

Commercial area urban runoff, shows much higher levels of total coliform bacteria with a range of 0 to 253,000/100 ml. Fecal coliform levels were more similar to those found in residential ponding basins with a range of 0 to 39,300/100 ml. All commercial runoff sampling sites, with the exception of Airport Road storm drainage, drain into coastal recreational waters. Also, commercial runoff sites continously contain water or are actively discharging into receiving waters. Table 12 compares the bacterial urban runoff quality of Guam with that of Hawaii and other U. S. communities.

The bacteriological data were plotted on probability graph paper to determine the frequency distribution and to eliminate the effects of extreme values on the mean values. These plots are shown in Figures 93-101 for the grouped data. The plots are linear enough to be assumed log normal. Table 13 presents the geometric mean and values exceeded 10 and 90 per cent of the time as derived from the graphs. When compared with the arithmetic means, the geometric means fall considerably, especially the Mariana Terrace site where occasional raw sewage contamination produced extreme values. Comparison of the geometric means reveals commercial urban runoff to be more highly contaminated by coliform bacteria than residential urban runoff with total coliform means of 17,500/100 ml versus 900/100 ml for residential runoff. Fecal coliform geometric means for commercial area was 1,140/100 ml versus the 215/100 ml for residential urban runoff. Both Tables 18 and 19 present FC:TC ratios. The ponding basins and storm drains leading to them show evidence of fecal contamination with a FC:TC geometric ratio of .24. The ponding basin sites which consistently showed higher levels of fecal contamination were L2, B2d, B3, and B1c. A group of ducks and other birds at B3 is the suspected cause of the higher FC:TC ratio. At other sites, domestic waste water, raw water from leaking cesspools (Barrigada Village), or sewer lines are probably responsible.

Comparison of Results of Bacteriological Analyses with GEPA Guam Water Quality Standards

The GEPA Guam Water Quality Standards specify, in regard to "A" waters "the median coliform bacteria content shall not exceed 70/100 ml sample during any 30 day period nor shall any sample exceed 230/100 ml at any one time." Sampling sites discharging into coastal waters were sampled 38 times with counts of 230/100 ml on 27 of the samplings. The only sampling site with a median coliform value lower than 70/100 ml was the NAS storm drain with a value of 62/100 ml. The other three sites, WAB, EAB and Camp Watkins Road accounted for 26 samplings of which 24 exceeded 230/100 ml.

Residential ponding basin sites lie in areas designated as 1B-1 or 1B-11 waters representing conservation and resource zones respectively. Both zones contain groundwater destined to become 1A (drinking) waters. Therefore ponded and discharge waters, being waters destined to become part of the groundwaters in these zones, should meet requirements of 1B-1 or 1B-11 waters. According to the Water Quality Standards, 1B-11 waters are to be kept free from pollutant discharges. 1B-11 resource zone waters are to be treated to the degree necessary to protect 1A waters. Microbiological requirements for these waters have not been established other than that they should not exceed ambient conditions. The data gathered in this study can be used to determine ambient bacteriological load levels for ponding basin waters. A geometric mean of 215/100 ml was found for ponding basin fecal coliform counts based on 73 samples at seven locations (B1e, B1c, B2d, B2w, B3, L2, Perez Acres).

CONCLUSIONS

Based on this study, the two parameters which may pose the greatest threat to Guam's groundwater quality are oil and grease and MBAS. There is a lack of sufficient data to determine if long term conditinuous addition of these pollutants, in low concentrations, will eventually affect groundwater quality. What is known, is that one drinking water well has been shut down due to oil and grease contamination (from World War II period oil spillage) and low concentrations of oil and grease and MBAS have been detected at other wells. Also, soil percolation tests indicate that oil and grease and MBAS percolate through the predominant soils of northern Guam more readily than other pollutants measured (Zolan, Clayshulte, and Winter, in progress). Thus, despite the fact that comparatively low concentration of MBAS, oil and grease are involved, they may pose a significant long term pollution problem.

Otherwise, the quality of collected urban runoff in conservation and resource zones that is allowed to pond and recharge the ground water is generally high. Based on the parameters analyzed during the study, the ponded water does not contain concentrations of pollutants which pose hazard to its use as recharge water. The ponded runoff water is comparable or better in quality than urban runoff water in Hawaii and other U.S. communities as it is comparatively:

1. low in solids and chlorides
2. low in organic content as determined by BOD and COD
3. low in nitrite-nitrogen, nitrate-nitrogen and phosphorus
4. low to high in total and fecal coliform depending on runoff source and rainfall occurrence
5. low to moderate in concentrations of oil and grease at all ponding basins, (this may pose the greatest threat to recharge water quality)
6. low in MBAS concentrations
7. high in dissolved oxygen with values close to saturation except at ponds of reduced volume and increased faunal populations

Each ponding basin has a narrow range of alkalinity, pH, and hardness values which are primarily dependent upon soil type and extent of limestone exposure.

All ponded runoff shows fecal contamination. The sources vary from sewage plant effluent (Mariana Terrace) to domestic pet feces.

Airport Road drainage regularly contains very high concentrations of oil and grease and MBAS derived from Guam International Airport operations. Although the runoff collecting basin is in a recharge zone, the large quantities and concentrations of pollutants involved makes the current discharge procedure undesirable.

Other airfields in northern Guam potentially present similar oil and grease and MBAS pollution problems. Indeed, the northern location of Naval Air Station, and Andersen Air Force Base with respect to groundwater resources requires that strict attention be paid to keeping oil spillage and aircraft washing effluent from entering the substrata.

Urban runoff discharged into coastal areas is generally comparable to ponded runoff with the exception of parameters influenced by the introduction of groundwater and seawater intrusion. The urban runoff discharged into coastal areas is characterized as follows:

1. it is high in solids and chlorides
2. it contains total and fecal coliform bacteria in quantities exceeding the GEPA Guam Water Quality Standards. This creates a public health problem since the near shore areas are heavily used for body contact recreation
3. concentrations of nitrate-nitrogen are far in excess of the nitrogen limit established by thw GEPA Guam Water Quality Standards for these near shore areas

In addition, near shore disposal of urban runoff via storm drains results in large sediment delta formation. These delta formation and storm drains have a number of effects on the near shore environment including:

1. the alteration of current flow and biological habitats by filling in portions of reef flat area normally submerged
2. the production of obnoxious odors upon tidal emergence, in excess of normal conditions. The odors result from anaerobic conditions and algal growth associated with the increased exposed area
3. increased algal growth (primarily Enteromopha) in the immediate vicinity
4. the reduction of the aesthetics of a near shore area

There are additional compounds in urban runoff and agricultural land use which pose potential hazards to groundwater quality. Organochlorine residues, other agricultural chemicals and heavy metal concentrations were not measured in this study. Also, levels of Kjeldahl nitrogen were not determined. Direct biological, physical and chemical impact of storm runoff waters on the reef flat environment has yet to be studied. A laboratory lysimeter study, dealing with the filtering effects of common Guam soils and substrates on runoff quality will be published in a subsequent report.

RECOMMENDATIONS

1. Increase the nigrate-nitrate concentration allowed by the GEPA Guam Water Quality Standards in coastal discharge waters to a figure as high as natural groundwater seepage into the same area (i.e. 3-4 mg/l).
2. A detailed monitoring study is needed of near shore environments to determine the ambient conditions for all parameters covered in GEPA Guam Water Quality Standards.
3. All current coastal storm drains should be phased out when

possible. This recommendation is based primarily on public health considerations and the reduction of aesthetics that occurs as a result of storm drains.

4. Large effluent discharges of oil and grease and/or MBAS (e.g. Airport Road drainage) containing water should not be allowed in areas where percolation of such water into the soil could result in contamination of groundwater.
5. Initiate a yearly ponding basin maintenance program to dredge the bottoms of silt and plant growth which reduces the water recharge rate.

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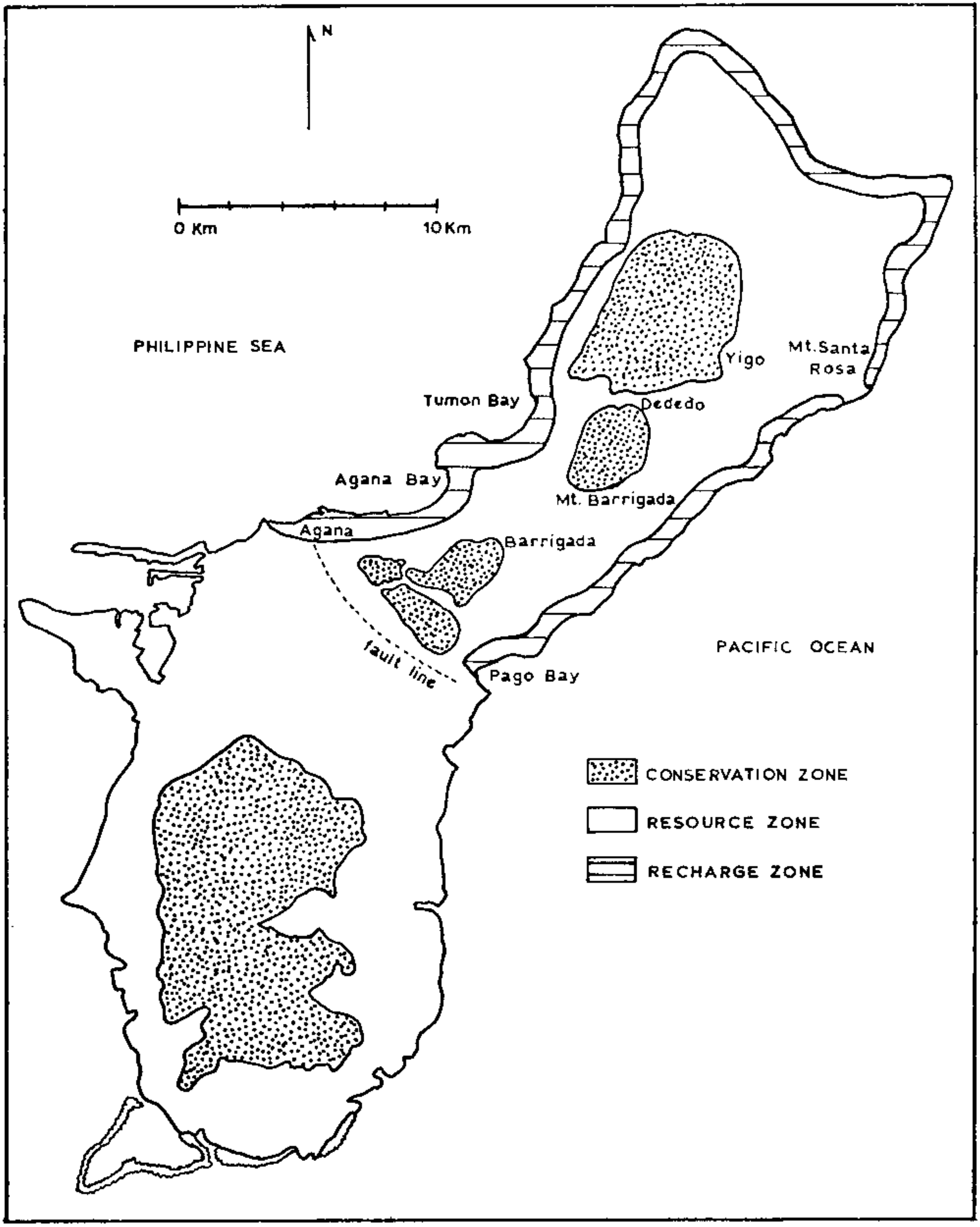

Figure 1. Conservation, resource, and recharge zones of Guam. [The fault line roughly separates northern and southern Guam. The figure is adopted from Mink (1976) and GEPA Water Quality Standards, 1975.]

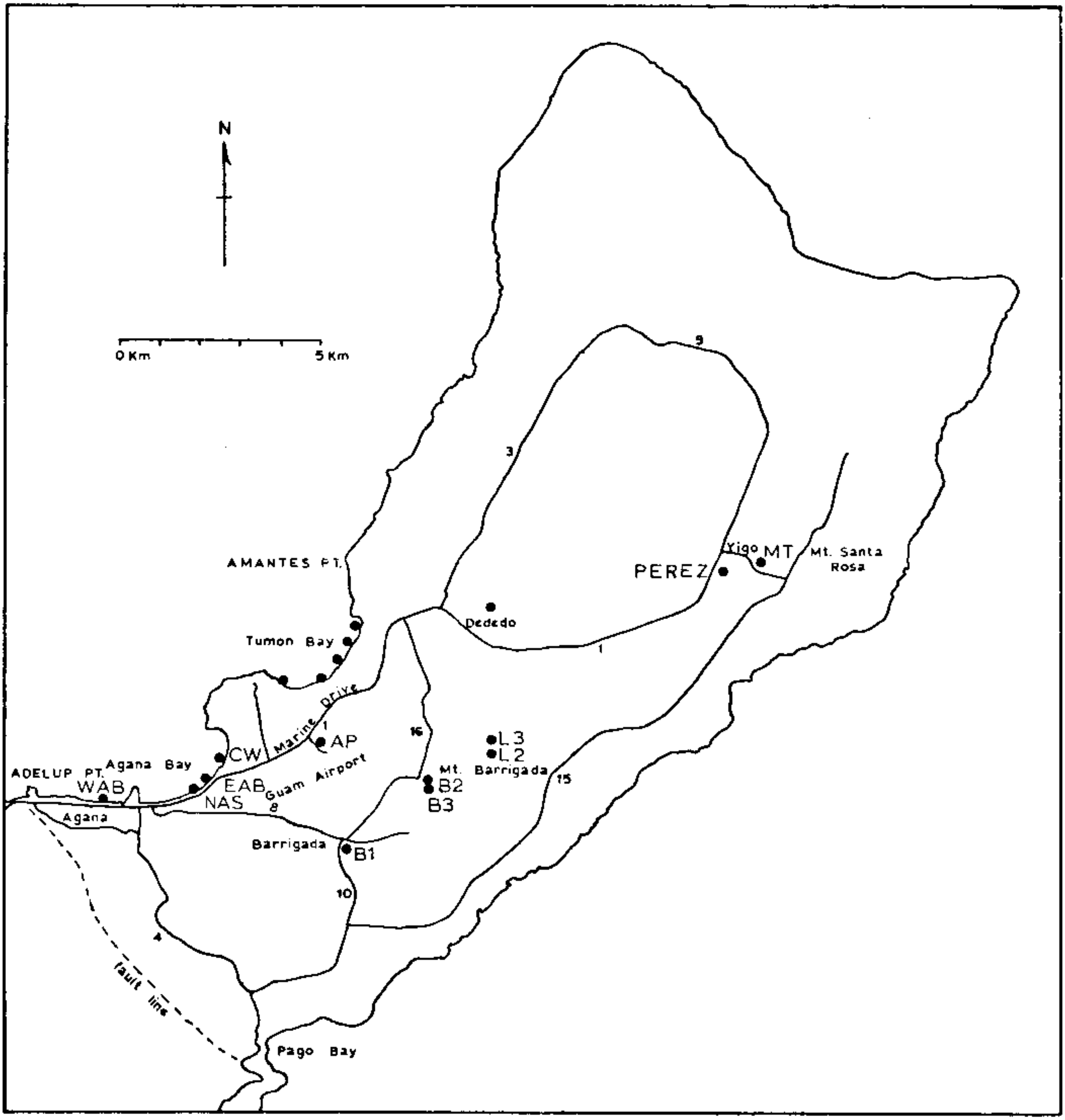

Figure 2. Sampling site ponding basins and coastal storm drain discharge locations.