WETLANDS RESOURCES IN THE UGUM WATERSHED GUAM

A General Description and Preliminary Functional Assessment of a Palustrine-Riverine Wetland System

Technical Report 76

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WERI
WATER AND ENERGY RESEARCH INSTITUTE
OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

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A General Description and Preliminary Functional Assessment of a Palustrine-Riverine Wetland System

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ABSTRACT

Three permanent palustrine wetlands in the Ugum Watershed with a combined drainage area of about 55 hectares and nearly 1,500 meters of combined riverine floodplain and contiguous forested and savanna slopes sections were studied. Goals were to identify and describe wetlands resources, functions, and values within a time frame for field observations and measurements of about seven months. The investigating team consisted of a geologist, civil engineer, toxicologist, microbiologist, and two wild life biologists, assisted by graduate and undergraduate students and interested faculty form the University of Guam.

The biological survey confirmed earlier and more comprehensive efforts by Raulerson et al (1978) concerning the diversity and distribution of terrestrial and aquatic plants and animals. The ravine forest enclosing the river sections and the downstream ends of the wetlands are fairly homogeneous, relatively pristine, and contain several interesting and rare communities of plants. It is clear that the value of these wetlands is high in regard to wild life habitat.

Wetlands influence Ugum River stream flows and sedimentation in the dry season when sudden rains follow weeks of dry weather. Flow stages and stream and sediment discharges are modulated by the baffling effect of marsh grasses and tree hummocks and the absorbency of water in thick porous mats of decaying biomass. Wet season brings the wetlands biomass and soils to a more water-saturated condition and hydrodynamic and sedimentologic functions are not as well demonstrated during those months. There is a long unaddressed need to quantify the relationship between rainfall distribution, wetlands hydrology, downstream flows, and sediment discharge.

Many wetlands resources combine to control water chemistry through poorly understood biotic and abiotic reactions Levels of trace metals and nutrients, in turn, affect the chemistry of the river into which the wetlands empties. However, the immediate influence of a specific wetland is rapidly masked by dilution. One wetlands in this study has phosphate levels well in excess of ten times that of other wetlands, yet its contribution to dissolved phosphate levels in the Ugum River is not obvious after a few tens of meters downstream from their confluence. River flow characteristics also affect local water chemistry as reaches of high turbulence and aeration alternate with more laminar flows, and occasionally with oxygen-depleted conditions in slackwater pools. These changes in dissolved oxygen can be seen in nutrient data.

The valley of the Ugum-Bubulao Rivers is aesthetically of great value to the people of Guam. But it also presents a unique opportunity for conducting far reaching educational and research programs into tropical wetlands and rivers. While overview data in geology, biology, soils, hydrology etc. abound and need not be reinvented, fundamental information on water quality controls is sorely lacking: mechanisms, buffering and forcing functions, fluxes, kinetics, reaction rates, and the spatial and temporal variation in those parameters is simply unknown. The need for a sustainable source of good quality water is a justifiable rationale for undertaking a more focused research effort in these wetlands in the future.

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INTRODUCTION

Objectives and Scope:

This report describes a study of a small integrated non-tidal wetlands system lying wholly within the Ugum River Watershed in southern Guam (Figure 1). The objective of the project was to develop a sufficient understanding of the principal resources of the system so as to make a preliminary assessment of the functions and values associated with these wetlands. The study was in no way intended to be exhaustive; on the contrary the time frame for collecting observations and data was such that only an introductory analysis would be justified at this time. Several potentially important wetlands parameters could not be addressed at any level in the time frame and budget of this project, including groundwater hydrology, riverine sedimentation, micro-organisms in waters and soils, and archaeology.

Study Site Selection:

The wetlands system was chosen from many visited in southern Guam for the following reasons:

- ***Accessibility:*** Study sites can be accessed though the boonie road network immediately north of the former NASA Tracking Station in Dandan or from Talofofo Village by crossing the Talofofo and Bubulao Rivers on the unimproved farm road. The latter route can not be used in the rainy season.

- ***Complexity & Scale:*** Wetlands include perennial and intermittent riverine and palustrine types and ephemeral floodplain wetlands, ranging in size from nearly several tens to less than 001 hectares.

- ***Continuity:*** The wet and waters drain through a common point, the confluence of the Ugum and Bubulao Rivers. Thus hydrologic, chemical and biochemical resources and functions can be evaluated at one common end point, as well as at individual upstream stations.

- ***Geologic Uniformity:*** Previous studies indicate relatively uniform bedrock geology and upland soils in the area, reducing a potentially large source of variation in wetland characteristics.

- ***Economy & Synergism:*** The Ugum River watershed has been the focus of earlier and ongoing ecologic and hydrologic studies; thus a reconnaissance project in any part of this watershed would have related projects to drawn on for comparison and to help prevent repeated efforts.

- ***Pristine Conditions:*** Relative to the rest of south Guam, the Ugum-Bubulao confluence area is relatively untouched by human activity.

- ***Future Wetlands Modification:*** The wetlands in the study site would be submerged and new wetlands shifted upslope from their present positions should an often suggested water supply dam be constructed at the confluence of the Ugum and Bubulao Rivers.

Duration and Personnel:

Field work began in February 1995, and continued through the dry season and summer, ending in early September, 1995. The study involved the collaboration of many workers: Galt Siegrist, Jr. (Geologist, P.I.). Gary R. W. Denton (Chemist-Toxicologist, CO-PI), Leroy F. Heitz (Hydrologist, CO-PI), Earnest A. Matson (Bacteriologist, CO-PI), Special Consultants Agnes Rinehart (Botanist) and Barry D. Smith (Wild Life Biologist), and students R. Russell Lewis, and John M. U. Jocson of WERI/UOG and Frank A. Camacho, Trina Leberer, Ismael Perez, Mark Slattery, Brent Tibbets of the Marine Laboratory/UOG. Special field assistance and advice was generously given by Katherine Lofdahl, Pam Eastlick, and Lynn C. Raulerson of CAS/UOG and Mayor Vicente Taitague of Talofofo Village.

This project was undertaken for the Bureau of Planning, Government of Guam, Michael J. Cruz, Chief Planner. Original funding comes from the U.S. Department of Commerce through the Guam Coastal Management Program Grant #NA470ZO311.

Report Structure:

The first part of this report reviews relevant background information on the natural history of the study site, including its geography, geomorphology, bedrock, soils, and wetland vegetation and wild life. The second portion summarizes data collected specifically on this project and discusses them in terms of wetland functions and values.

Known Resources and Processes:

Wetland resources are the natural materials in the wetlands. They involve physical structure, extent, stability, chemical composition and variability and encompass the time frame between entrance and departure from a wetlands system. Resources may be conveniently grouped into lithospheric resources: minerals, rocks, saprolite, soils, and sediment; hydospheric resources: rainwater, flowing, ponded, and stagnant surface waters, loosely bound soil waters, phreatic pore waters, and shallow vadose groundwaters that flow from seeps and springs; and biospheric resources: living and dead wetland flora, microbial communities, animals residing in or using any component of the wetland. Resources are both reactants and products of the chemical, biological and physical transformations usually denoted as wetlands "functions".

General Geography and Geomorphology:

Location

The wetlands and interconnecting deepwater streams in this study lie entirely within the 18.4 km^2 (7.1 mi^2) Ugum River watershed and the U.S. Geological Survey 7.5' Talofofo Quadrangle (Figures 1 and 2). The area includes an approximate 800 meters of the Ugum

River and about 1000 meters of the Ugum's major tributary, the Bubulao River, above their confluence. It involves three small palustrine wetland systems and their drainage entering the Ugum River about 120, 600, and 750 meters upstream from the confluence with the Bubulao River. Countless ephemeral riverine-floodplain wetlands are also included in this system.

The area is generally located 1.2 kilometers north-northwest of the former NASA Tracking Station in Dandan, 0.6 kilometers southwest of the main Talofofo Falls on the Ugum River, and 4.51 kilometers southwest of Talofofo village. The wetlands-river study area is exactly bracketed by N. Lat. 13° 19' 16.8" and 13° 18' 50.8 " and E. Long. 144° 43' 15.7" and 144° 43' 47.6 "

Regional Terrain

The study area and enclosing uplands are set in highly dissected, rolling topography that is almost entirely in slope (mature topography). Most upper slopes are planar to gently convex upward (Plates 1, 2 & 10) ranging from several degrees to nearly vertical, with modal slopes of about 30-40 degrees. Deep dissection of divides and valley slopes along the main axis of the Ugum and Bubulao Rivers and the pronounced incision of main channels results from long continued island uplift, localized shallow faulting, and a certain amount of soil and slope mismanagement. Maximum regional relief is about 65 meters.

Where vegetation has not been removed, upper slopes support savanna, forest, and forested-ravine communities. Where vegetation has been stripped off., sheetwash, gullying, and mass wastage of highly weathered bedrock have transformed terrain into geomorphic badlands, redistributing significant quantities of loose sediment into gullies, then on to lower slopes and wetlands. The highly mobile, unconsolidated detritus makes a poor substrate for successful revegetation efforts.

Slopes draining into the Ugum and lower Bubulao valleys show numerous signs of instability, e.g. soil slips and creep, and meter-scale rotational slumps and translational mud and debris slides. Failed slopes are generally concave upward and are the proximal source of river sediment. They also provide the host deposits for many small wetlands constructed on the "toes" of slides and slumps.

Bubulao River uplands above a portion of study sites B1 & B2 (Figure 5, Plates 2, 4 and 5) have considerable agricultural activity that contributes sediment and chemicals to wetlands and the river, and subtracts small quantities of river water for irrigation. These effects were not quantified in this study.

Valley Modification and Lower Slopes

Lower valley slopes near the rivers are uniformly forested and appear stable. Valley profiles of the Ugum and Bubulao Rivers in the study area approach the classic "V" shapes of actively downcutting streams. Their confluence lies at an elevation of about +56 meters (185 ft). Both rivers are degrading their channels toward a base level elevation corresponding to the top lip of Talofofo Falls at an elevation of approximately about +36.5 meters (120 feet). The regional river gradient from the upstream end of the study site to the Falls averages about 1 to 3 centimeters drop per linear meter of river.

Valleys are well incised into volcanic bedrock of varying resistance to erosion and into weakly resistant saprolite. The main SW-NE axis of the Ugum River valley follows a suspected regional (Talofofo Bay-to Merizo) fracture zone mapped by Tracey et al (1964); several tributary drainage patterns within the greater Ugum watershed also appear to be fracture controlled, but that assertion remains to be tested.

In the channels of both the Ugum and lower Bubulao Rivers, short whitewater runs (<1-10 meters long) alternate with generally longer stretches of slackwater pools (5-40 meters long) (Plate 3). Whitewater features shallow, constricted channels (1 to 3 meters width, < 10 cm depth) funneling accelerated current flows over resistant ledges of volcanic bedrock. Obvious channel abrasion is occurring on the ledges and pot holing at the base of each falls. Intervening slackwater pools average about 30-40 centimeters depth (max 4.5 meters!) and about 4 meters width (max 8.7 meters).

Slackwater promotes localized and temporary deposition of bed load alluvium. Two large pools on the Ugum River, between Stations U11 and U12 and between Stations U4 and U7 (Figure 5) contain deposits of sand and gravel that are at least a meter thick and between 75 and 100 m^3 in volume. Fines from the suspended load are not major components of these deposits. Residence times for material in these deposits and threshold velocities for their export from these pool deposits are not known. Comparable slackwater stretches in the Bubulao show almost no coarse detritus in comparison with the Ugum River.

Sediment discharge and the ratios of suspended load to bed load relate to slope processes, land use activities, stream hydrology, and overall wetlands effectiveness as a sediment buffer. Magnitudes and differences between the Ugum and Bubulao Rivers in regard sediment load and discharge are important parameters to measure if consideration is still being given to constructing a dam at their confluence.

REGIONAL LOCATION MAP

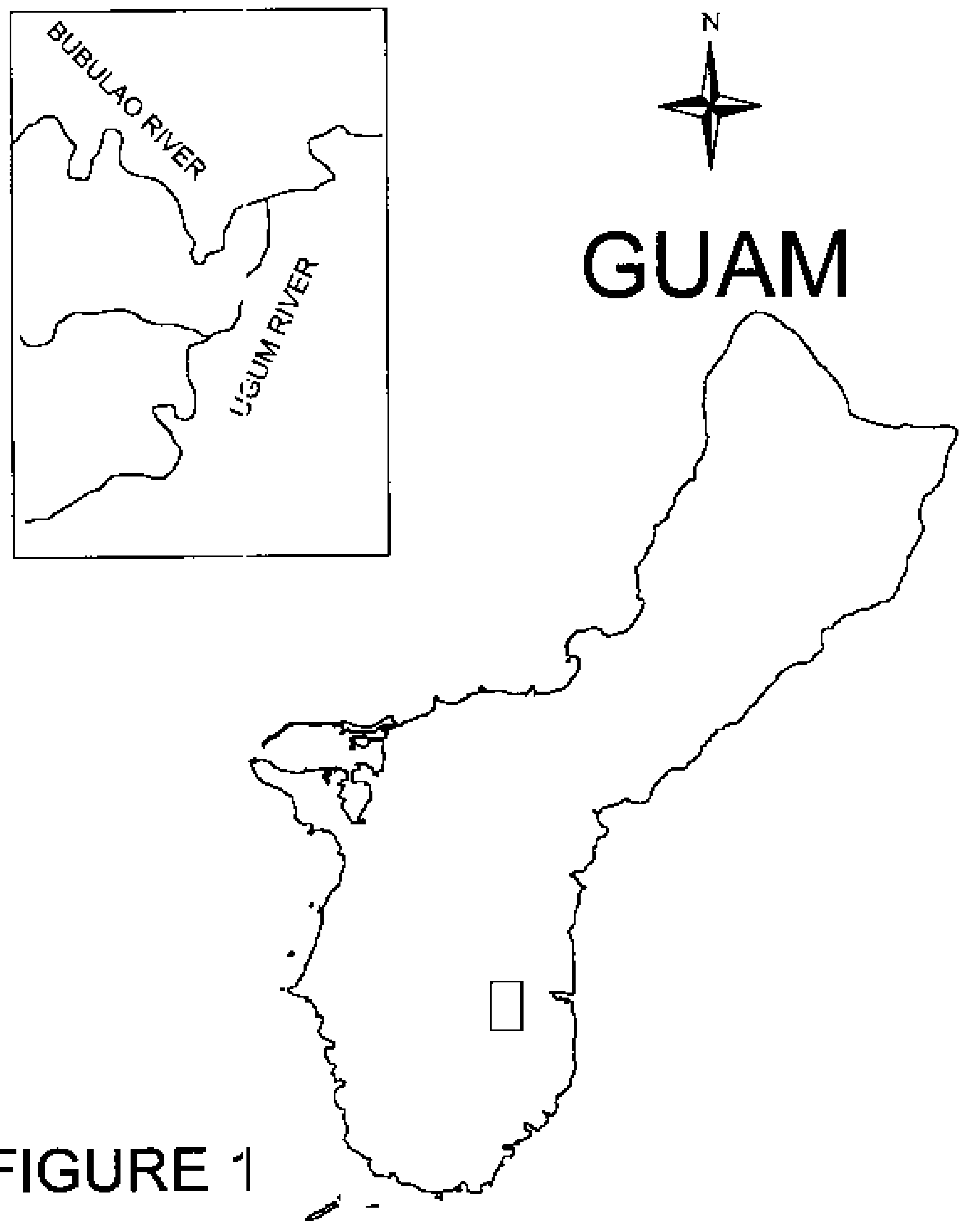


FIGURE 1

UGUM-BUBULAO R.

TOPOGRAPHIC MAP

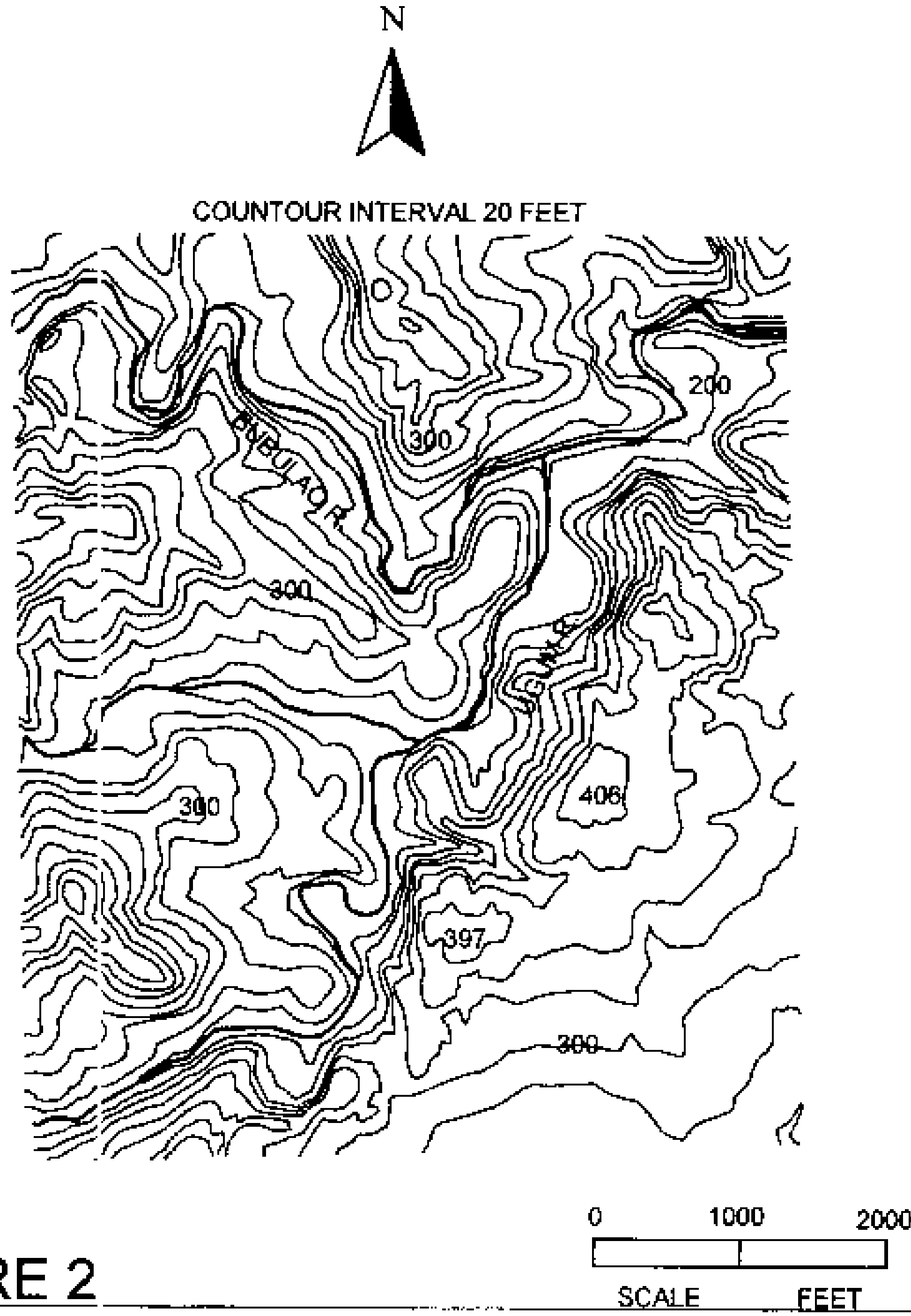


FIGURE 2

Bedrock Geology:

Wetlands and surrounding terrain lie entirely within two Lower Miocene volcanic units that were defined, and mapped and field described by Tracey et al (1964) and mineralogically and chemically analyzed by Stark and Tracey (1963). The units are the Bolanos Pyroclastic member (BPM) and the Dandan Flow member (DFM), both components of the larger mapping unit, the Umatac Formation.

Bolanos Pyroclastic Member

The BPM is comprised of several hundred meters of dark gray to light tan, tuffaceous mudstones, sandstones, conglomerates and breccias. A typical outcrop can be seen at the main ford on the Bubulao (Plates 4 and 5). In the badlands areas east of the Ugum, the BPM weathers rapidly to saprolite of variegated red and yellow ochre and pastel colors, often with sets of well-oriented fractures and partings infilled with manganese oxides (Plate 6). Sand-sized grains of the black iron ore, magnetite, some showing perfectly developed octahedral crystal forms are ubiquitous in mineral placers in gullies, tire tracks, and alluvial fans throughout the badlands. In other areas on Guam, the BPM contains abundant coralline limestone clasts and may carry assorted planktonic fossils.

In white water channel outcrops in Ugum and Bubulao Rivers immediately upstream from their juncture (Plate 7), the BPM occurs as a massive debris flow conglomerate composed of subrounded basalt pebbles and cobbles averaging about 7 centimeters in diameter, but with occasional boulder clasts exceeding 50 cm in diameter. Clasts in these outcrops are uniformly hard and well cemented with a calcareous tuffaceous matrix providing very erosion-resistant ledges, similar in structure and function to concrete. Further upstream on the ford across the Bubulao River, a flight of rapids appears to have developed in a cherty (high silica) unit within the tuffaceous sandstone beds in the BPM (Plate 5).

Dandan Flow Member

The DFM appears as an accumulation of individual spheroidally weathered basalt boulders (Plate 8 & 11), similar in composition to the individual clasts in the BPM. There is no obvious reason to suppose, as did Tracey et al (1964) that this unit was once a continuous lava flow unit. It more closely resembles residuum from the chemical weathering of a poorly cemented debris explosion, but it take a major study to determine the origin of the DFM and its relationship in time of origin with the BPM. Boulders from the DFM litter the eastern valley slopes above the Ugum River and many have found their way into the river itself where they cannot be distinguished from clasts eroded out of the BPM.

Bedrock Weathering:

Volcanic bedrock silicate minerals decompose rapidly in humid tropical climates: Magnesium, sodium, silica, and to some extent potassium, among major elements are generally mobilized into the aqueous environment; aluminum, iron and also potassium are incorporated into clay minerals (hydrated aluminosilicates), and aluminum, iron, and manganese into oxyhydroxides. The latter are highly insoluble and constitute the major portion of the familiar red residuum in badlands areas.

Clays are potentially the most important inorganic solid part of the ecosystem. They are characteristically small platelet-shaped crystals, with high surface areas/weight, and are chemically reactive. Their upper size is 4μ (micrometers), but they may extend down to colloidal size. They evolve progressively from complex multi-layered structures with many common cations bound up between these layers to very simple 2-layer structures with no cations bound in the interlayer. The transition from the complex group called smectites to the simpler structures called kaolinite and halloysite is a natural progression in humid tropical weathering of volcanic rocks.

Not only do smectites have cations bound up in their inter layer, they are able to exchange these ions with other common ions in the aqueous environment. They also can exchange their interlayer cations with trace metals, organic molecules, fertilizers, and other environmentally important substances. Also their highly reactive surface easily adsorbs chemicals from the aqueous environment. Thus smectites, the principal derivative mineral from volcanic rocks eroding off slopes are capable of carrying natural and exchanged contaminants into wetlands. Three paths are thus available to contaminants: a) They may erode directly into the wetland, structurally bound in smectite crystals; b) they may arrive as hydrated ions or complexes liberated into the aqueous environment from decomposing smectites in transit and/or c) they may piggyback as lightly bonded impurities on surfaces and edges of smectite platelets.

The ability of smectites to exchange impurities between the environment and its inter-layer sites (Option "a" above) is called its Cation Exchange Capacity or CEC. It is conditional on the alkalinity of pore waters. At the acid pH's of many wetland soils, CEC is relatively inoperative as exchangeable sites are tightly blocked with hydrogen and aluminum hydroxyl ions. Furthermore, organic colloids in soil, an even greater contributor to CEC, also varies positively with alkalinity.

Soils Units:

Soil units in the research area fall into two general types, with several variants to each depending upon slope. No wetland variant has been published for the study site. Underlying the boulders of the DFM and coarse breccias of the BPM are well-drained, red to red-brown silty-to-sandy-clay soils grading down into clays and at about 1 half meter depth, to variegated red-white colored saprolites. This highly variable soil unit was mapped as the Akina Silty Clay and as Akina-Badlands Complex (Young, 1988). Published analyses of a typical pedon from The Akina taken further south near Inarajan (Soil Conservation Service, 1983) indicate a pH at 10 cm depth of about 4.5 and 5.5 at 30 cm depth and a consistent color of 2.5Y/R. During torrential rains, these soils are mobilized through sheetwash and down gullies into ephemeral badlands marshes and playas or into the Ugum and Bubulao River drainage system. The coarser and physically denser residua e.g. magnetite grains lag behind the flux of fine clays and silts and placer out onto upland slopes as an veneer that inhibits further erosion except during the severest rainfall.

The Agfayan Clay (Young, 1988) forms on the BPM, but is restricted to slopes and uplands underlain by the light colored, friable tuffaceous sandstones, and well-bedded carbonate cemented facies. The most accessible example of this soil can be observed in the outcrops along the upper limit of the Bubulao River study area, in the ford and upland along the main farm road to the south. The Agfayan typically is more alkaline (pH = about 6) than the Akina and less oxidized, with blackish yellow colors common (10YR 2/1 to 4/2) (Soil Conservation Service, 1983). The mineralogical difference between the Akina and Agfayan units, as published, is that the dominant clay mineral is smectite in the Agfayan and kaolinite in the Akina unit.

Hydrology:

Water Budget

Annual rainfall in the Ugum River watershed varies between about 230 mm (90 in.) in the lower reaches and 280 mm (110 in.) in the upland watershed area, with a weighted average of about 257 mm (101 in.) (Reference). The area weighted average precipitation for the entire watershed varies markedly over the wet and dry seasons (Figure 3), where "dry season" generally means January through May, and "wet season" generally means July through November. No reliable rain gauging station exists within the geographical limits of this study.

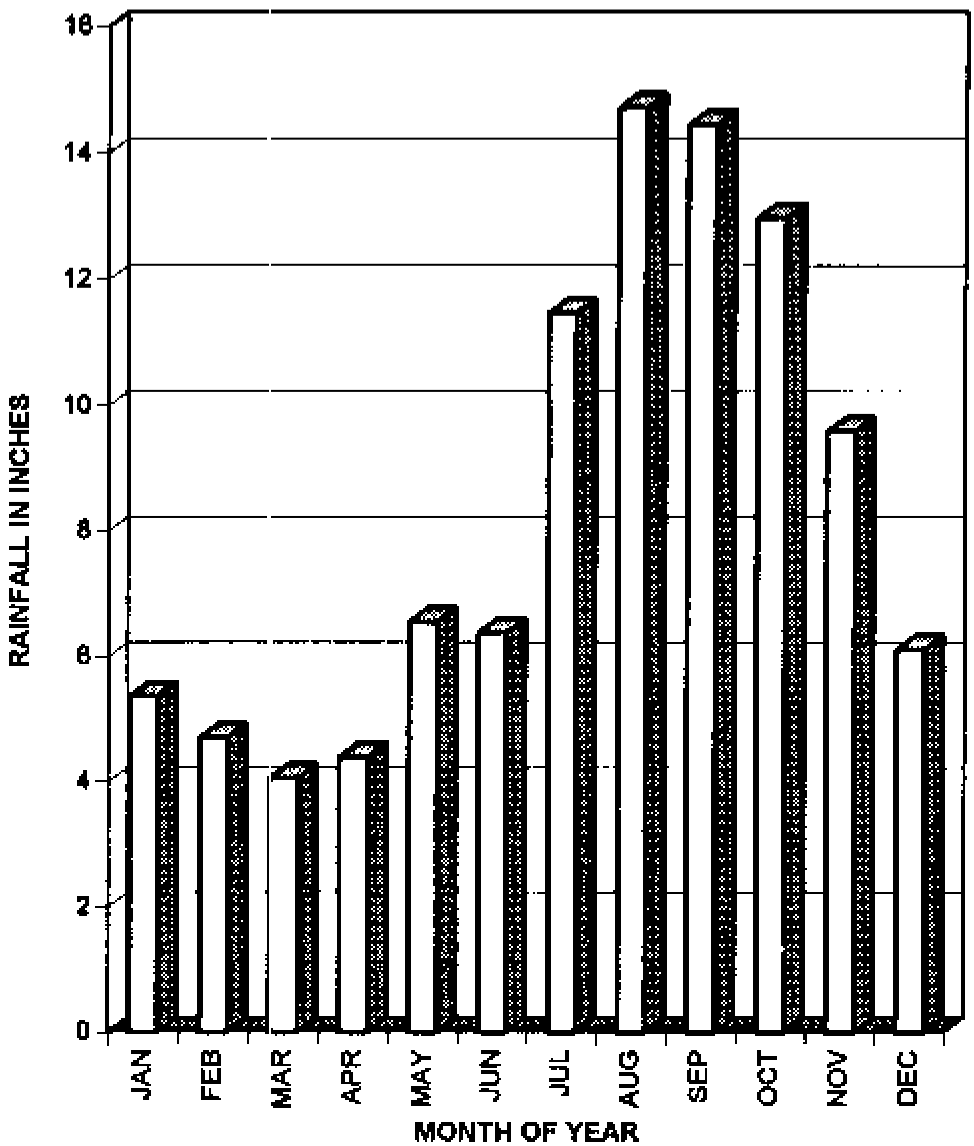


Figure 3: Monthly Rainfall Distribution at Guam WMSO Rain Gage (4229). Period of record is 1957-1993.

Two long-term stream gaging records exist for the Ugum River watershed (U.S. Geological Survey, 1993). None covers exactly the stretch of Ugum or Bubulao Rivers studied in this project, but the stations are near enough on the Ugum to have relevance. The records derive from U.S.G.S. gaging stations (Figure 4). Station 168550 below the Ugum River Water Treatment intake pumps has a continuous record from 1952 to 1970 and covers the flow of the entire watershed. Station 168545 at the top of Talofofo Waterfalls covers an area of approximately 14.9 km^2 (5.76 mi^2), and has been in operations since 1977. Flows at the latter site range from an all time low in June-July, 1978 of 0.96 m^3 sec^1 (cms) or 3.4 ft^3 sec^{-1} (cfs) to an estimated high of 166.8 cms (5890 cfs) in February 1980.

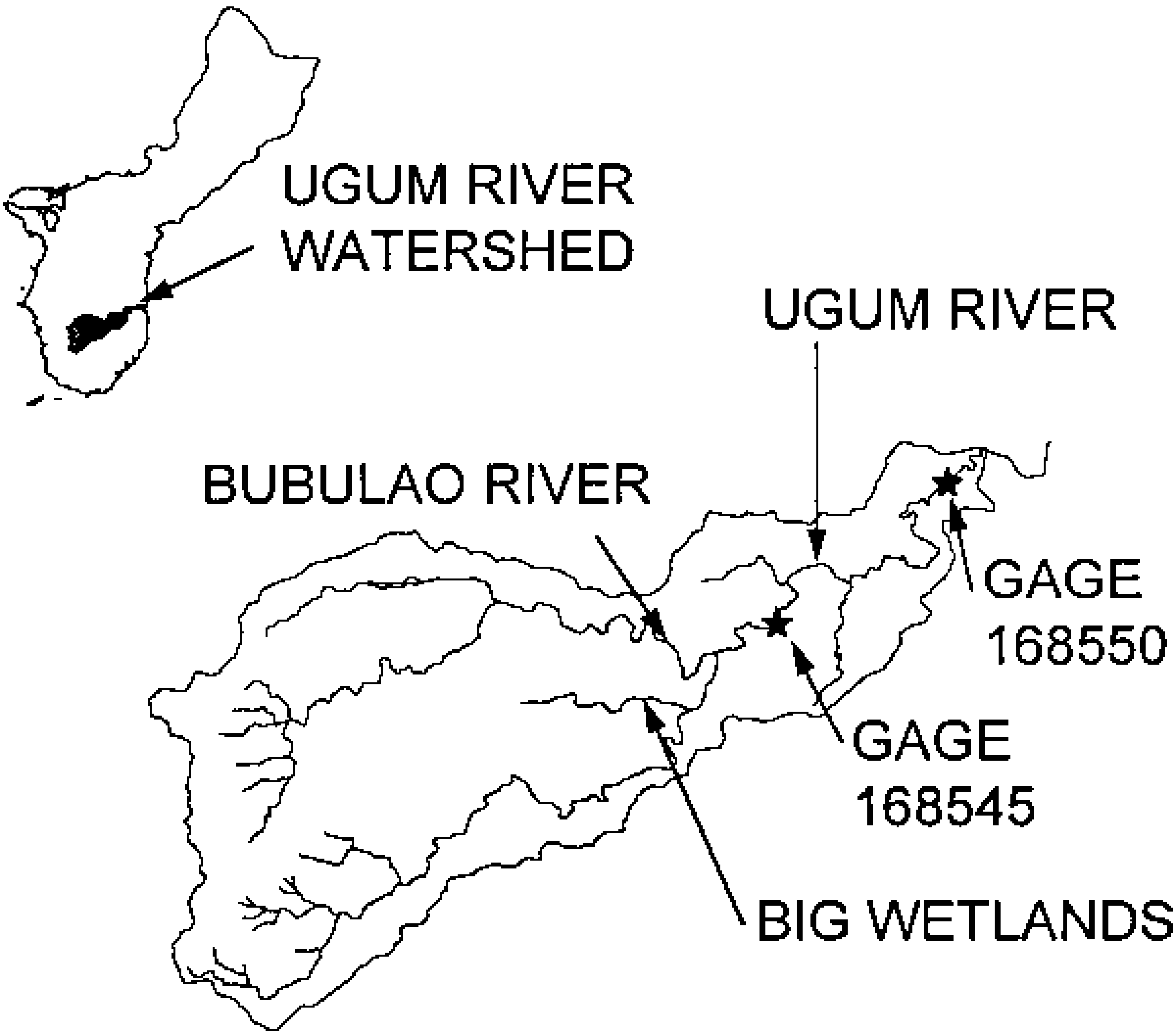


Figure 4: Locations of U.S. Geological Survey Stream Gaging Stations (Star) in Ugum Watershed.

Water Supply
A two million per day water diversion/treatment system is currently in operation on the Ugum River about 2 kilometers downstream from the study site. Intake water quality is considered excellent. Several comprehensive studies over the past fifteen years have considered the confluence of the Ugum and Bubulao Rivers to be an appropriate site for a water supply dam (U.S. Army Corps of Engineers, 1980; Barrett Associates, 1994). Preliminary dam designs indicate that the entire wetland system and the much of the lower forested slopes in this study will be drowned by the projected reservoir.

Plate 1. Regional Geomorphology
Overview of mature topography in study site. Photo looks west from top of Dandan-Bubulao foot trail. Wetlands BW (marsh section) lies in valley in right-central mid-background as light green hues. August 29, 1995.

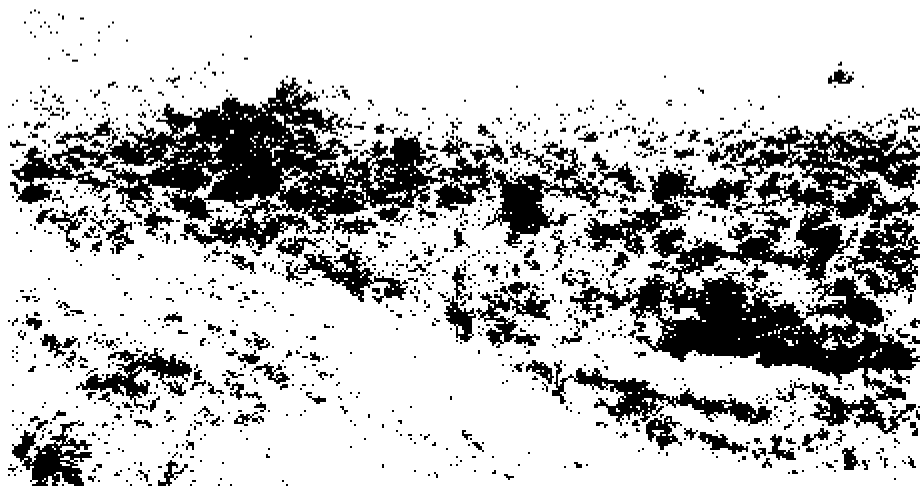


Plate 2. Regional Geomorphology
Overview of mature topography in study site, looking west. Photo overlaps Figure 1. Forested Ugum River Valley runs NE-SW in middle foreground. Bubulao River Valley flowing west to east in right background. August 29, 1995.

Plate 3 Pool Below Shallow Rapids.
Ugum River Station U14 near confluence with Bubulao River. Water flow measurements underway. May 18, 1995.

Plate 4. Tuffaceous Sandstone Outcrop. Outcrop of horizontally stratified Bolanos Pyroclastic Member on Bubulao River at main ford Station B1. May 18, 1995.

Plate 5. Step Falls on Bubulao River. Flight of rapids cascade down Bolanos Pyroclastic strata at Station B1. May 18, 1955.

Plate 6. Manganese-filled fractures: Black Mn oxide minerals are ubiquitous throughout Dandan and Bolanos members of Umatac Formation. High Mn levels in wetlands are related to bedrock chemistry and in situ chemical processes.

Plate 7. Bubulao Caprock Waterfalls
Falls on Lower Bubulao River at Station B3. Caprock is well-cemented flow breccia from the Bolanos Pyroclastic Member. Falls are about 2.8 meters high. Water sampling shown in foreground. May 18, 1995.

Plate 8. Weathering in Badlands.
Chemical decay of Dandan Flow member typically produces spheroidally weathered boulders strewn on surface. Badlands are east of Ugum River valley March 27, 1995.

Plate 9. Water Sampling.
Waters flowing from Phosphate Wetlands (Station PW2) being sampled on May 18, 1995.

Plate 10. Downstream Wetlands:
Overview from Dandan foot trail of forested wetlands DW, middle foreground and Ugum River Valley (left to right) beyond. Large savanna area in far background. June 3, 1995.

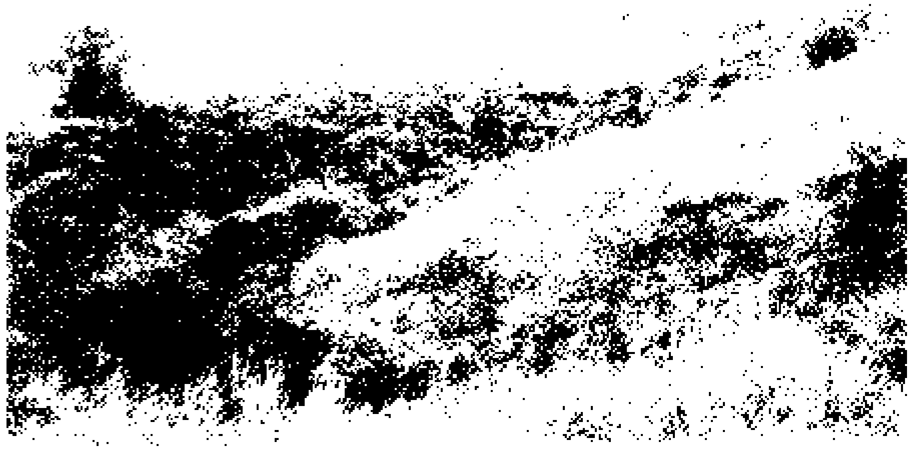


Plate 11. Sampled Rock:
Sphroidally weathered boulder of Dandan Flow member sampled at Station D2. Compositional inhomogeneity from concentric weathering is extreme.

Plate 12. Soil Sampling:
Bucket augering on ephemeral floodplain wetlands (EFW) below Bubulao Falls (background) at Station B3. May 18, 1995.

Biology
Raulerson et al (1978) in a comprehensive baseline study of the Ugum River watershed enumerated and discussed terrestrial plants growing in a large are encompassing our study sites, listed aquatic animal and plant species, and reported on the quality of river waters. Their work was preliminary to the possible development of a water supply dam on the Ugum. The authors identified and described two distinct terrestrial plant ecosystems, ravine forest and savanna, as well as two marshes that they considered to be specialized communities.

The study emphasized the pristine nature of the climax ravine forest and its inherent homegeneity within the area studied. The authors stressed that the ravine forests and rivers were populated in large part by indigenous plant and animals species respectively. They noted that the two marshes (in this report swamps, DW and PW) were dominated by *Phragmites karka* and *Acrosticum aureum*, as well as *Barringtonia samoensis, Hibiscus tiliaceus* and other "edge" species. They reported no water analysis from these marshes.

Wetlands:
Wetlands were first defined for this project on a practical reconnaissance level as transitional areas lying between deepwater aquatic (open streams) and terrestrial (upland) ecosystems. By accepted definition however, they must be areas that " are inundated or saturated by surface or groundwater at a frequency or duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (U.S. Army, Corps of Engineers, 1987, p 13). Wetlands are characterized by diagnostic hydrophytic vegetation, hydric soils, and hydrologic conditions. Definitions and delineation criteria of wetlands, and adjacent deepwater aquatic habitats, and nonwetlands are well described by the U.S. Army, Corps of Engineers (1987).

Deepwater aquatic areas (streams) were studied in this project because they collect, dilute, and redistribute wetland discharge waters that are utilized downstream for fishing, river recreation, agricultural irrigation, potable water, and aquaculture, before entering lower estuarine and marine strand recreational and reef environments. Uplands were also examined because of the contribution they may make to the neighboring wetlands of chemical and particulate pollutants, brought in by sheetwash and sediment. Functions and values of a given wetland can only discussed in an abstract sense if its adjacent habitats are ignored.

Three perennial wetlands areas with a single, definable discharge sites were examined in some detail, while others noted in this study. In general, the larger the wetland, the more significant and the more tangible are its functions and values.

Big Wetlands
The largest wetland in the Ugum-Bubulao site is centered at N. Lat 13° 18' 51.6" and E. Long. 144° 43' 40.5" and contains a drainage basin of approximately 50 hectares (Figures 2 and 5). We termed this area Big Wetlands (BW) for this study and report. Its lower 4.5 hectares is a forested swamp, drained by a single stream entering the west bank of the

Ugum River at Station U1 (Table 1, Figure 5), about 200 meters upstream from the main overland foot trail from the Dandan plateau to the western Bubulao River watershed (Figure 5). The remainder up-gradient portion of BW is a marsh wetlands.

The small stream draining BW averages about 0.75 meters in width, and 0.3 meters depth during August, 1995, the wettest month when such measurements were made. About five hundred meters up this small stream from its discharge point on the Ugum River, the wetland evolves from a forested swamp wetland into a *Phragmites* marshland. The marsh wetlands terminate about twelve hundred meters further west where what are now a series of unorganized anastomosing water courses seep from underneath forested and grassy slopes. Additionally, several seep- and sheetwash-fed ephemeral streams move through the forested and savanna slopes of the watershed in the west and southwest, but there the exact drainage pattern remains a mystery.

BW occupies a typical humid tropic alluvial fan (Plate 1) that originally developed from stream sediment transport off the prominent western divide. Fan development may have been preceded by a series of low-angle slumps or landslides. Unlike arid climate fans, those in the tropics have more mud promoting rapid dispersal of sediment away from steeper slopes and flatter gradients.

Phosphate Wetlands

A second wetlands discharges through the east bank of the Ugum River approximately 150 meters downstream from the BW discharge point and immediately downstream from a significant set of step falls or rapids at Station U4. This wetland (Plate 9) will be referred to as Phosphate Wetlands (PW) from the high dissolved phosphate loading in its discharge waters. PW is about 1 hectare in area and drains a bowl-shaped catchment of about 7.7 hectares. The area and characterized by an ill-defined anastomosing drainage system of 5-20 centimeter wide, 5 centimeter deep rivulets winding though black water-logged soil. Dominant vegetation consists of *Phragmites* downstream and *Barringtonia racemosa* upstream.

PW has almost certainly began its existence as the toe of a major slump block. The eastern divide of the Ugum River above PW features the familiar scalloped-out amphitheater form (in plan view) that is associated with rotational slumps. Other slumps off this divide can be seen in the process of developing. Their downslope expression is a jumbled mess of waterlogged saprolite, soil and some bedrock, a prime location for swamp or marsh vegetation to gain a foothold.

Downstream Wetlands

Approximately 120 meters upstream from the confluence of the Ugum and Bubulao Rivers, on the east side of the Ugum River valley is the discharge point of the third wetlands (Plate 10). This area is about 0.6 hectares, and drains another bowl-shaped catchment of about 11 hectares through several steep gradient spring-fed streams that coalesce into a singe discharge stream. This wetlands, called Downstream Wetlands or DW was analyzed as a control to PW when the latter's unusual chemistry was revealed.

As in the case of PW, DW originated from rotational slumping off the eastern divide of the Ugum River watershed.

Riverine Wetlands
In addition to the three well-defined perennial wetlands, ephemeral floodplain wetlands (EFW) were noted. They are generally associated with small areas of *Phragmites* and bamboo and many if not all were partially submerged (up to 15 centimeters) during much of August and early September, and were water logged even in June. Soil profiles indicate that they were constructed from successive overbank flooding and sedimentation events, latter modified though weathering and erosion. They usually drain into nearby river channels through several ill-defined channels and diffuse seepage. Water quality was not measured on EFW. On the combined Bubulao and Ugum Rivers within the study site, a total of about 0.25 hectares can be called EFW.

METHODS

Field Methods:

Introduction

Field parties of several investigators each made reconnaissance examinations of the entire accessible Ugum and Bubulao River watersheds prior to selecting the study site in February, 1995. Subsequently, the principal investigator spent one field day with each individual co-investigator and each consultant conducting a first-order reconnaissance of the entire site and evaluating future field transect lines and measurement/observation/ sampling stations. Team members addressed their respective tasks over the period between late February and September inclusive. Each measured, observed, photographed, sampled, etc. as needed using specific and separate field protocols outlined below. All ran one major transect paralleling and several perpendicular to main rivers and wetlands. Each investigator used his or her own site and sample labeling scheme which the principal investigator integrated into one in this report. Figure 5 and Table 1 indicate sampling and measuring sites. The botanical survey which is fully included in this report as an Appendix used its own numbering system. The confusion should be eliminated by Table 1 which gives our report numbers, but cross-checks them with the UG and MD numbers from the Appendix as well.

Rock and Soil Sampling

Rock samples were collected by hammer and chisel from representative outcrops. Perhaps a dozen outcrops are located directly in or are immediately adjacent to wetlands. Six rock samples were collected for analysis ("R" in Table 1). The inhomogeneity of weathered rocks, especially the concentrically structured boulders of the DFM (Plate 11) make representative sampling impossible without collecting a prohibitively large number of specimens.

Soils were collected at nine sites as indicated by "S" in Table 1, using bucket auger (Plate 12) and were instantly double bagged in two quart Ziploc plastic bags to inhibit further oxidation. Soils samples were taken at intervals throughout each augered hole, down to 60 centimeters, but mineralogical and chemical analyses were only carried out on materials taken at a standard depth of 30 centimeters. Except for two upland samples, soils were collected from wetland sites near where water quality and water flow measurements were also taken.

Hydrologic Measurements

Water flow measurements were taken along both rivers and in BW and PW ("F" in Table 1). A Marsh-McBirney, Inc. *FLO-MATE 2000* was set up at stations where channel width and depths were well defined to permit reproducible transect lines at different stream stages. (Plate 12) The *FLO MATE 2000* is a portable, open-channel electromagnetic flow meter. Individual meter readings were taken every 0.5 ft across the stream, normal to the stream bank. The flow measurement for the entire stream was then calculated from a weighted average of all individual measurements. Flow measurements on BW and PW were made with a notched weir. They constitute minimum flow values because of leakage under and around the weir plate. Flow measurements on DW were computed by averaging four timed fillings of a two gallon plastic jug that captured probably 90-95 percent of the water flowing over a small falls twenty meters upstream from the mouth.

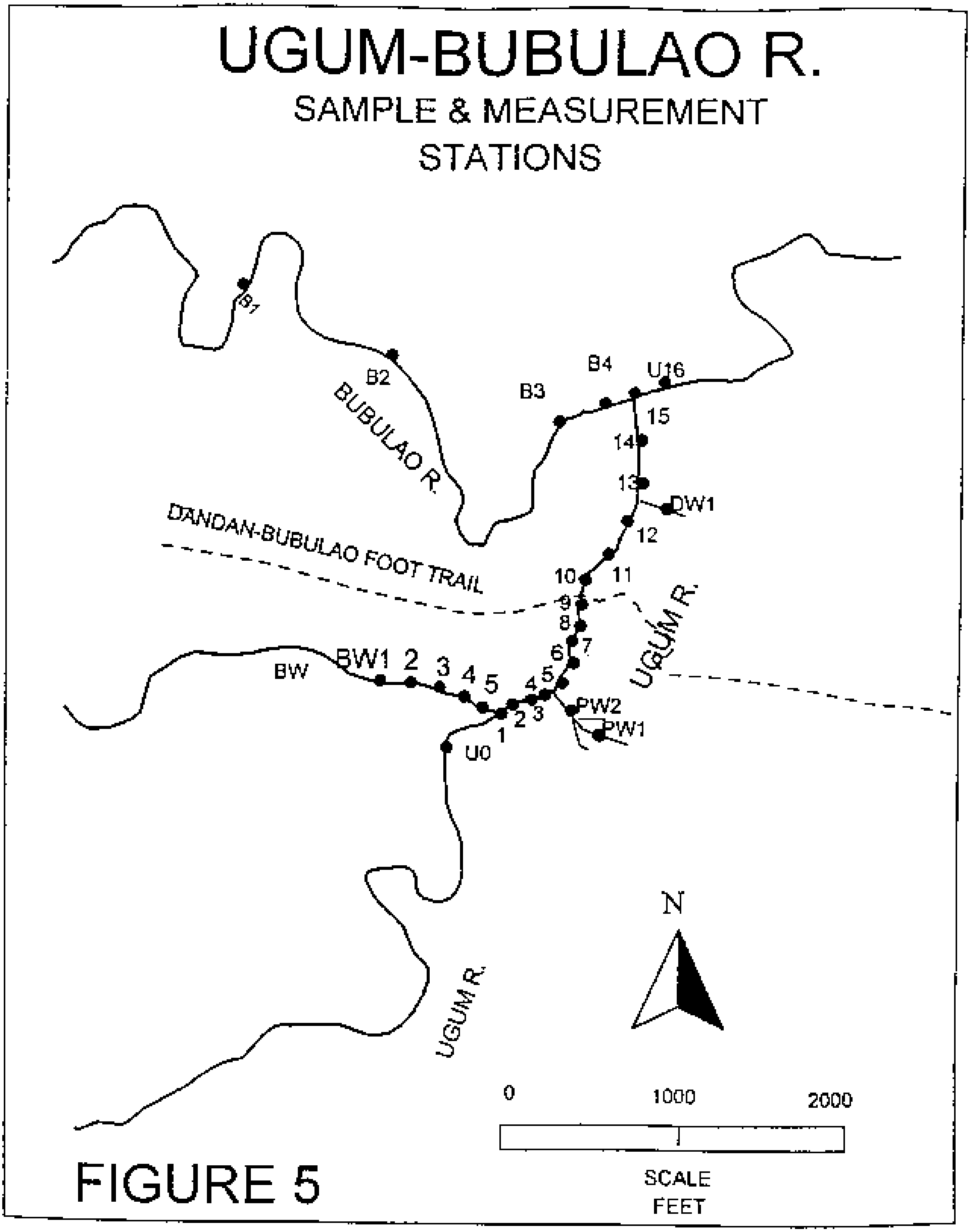
Water Quality Sampling

Water quality sampling was conducted at stations marked with a "W" in Table 1. Nutrients: Samples were collected in 50 cc polyethylene bottles rinsed thoroughly in waters flowing immediately downstream from the collection spot. All samples were stored in the shade until return to the UOG later that day. Waters of the Ugum and Bubulao Rivers as well as wetlands BW and PW were sampled in mid March, mid May, at the end of August and early September. Wetland DW was sampled only once in early September.

Table 1: Field Sampling and Measuring Stations

W = Water Sampling; F = Water Flow Measurements; R = Rock Sampling; S = Soil Sampling; B = Botanical Observations (UG & MD also used, see Appendix); A = Wild Life Observation Station

Site	Activity	Site Location and Description
B1	W,F,R,S	Farm road ford; rock from stream cut; soil above cut
B2	F	300m d/s from B1 at working melon and bean field
B3	R,W	Base of 4m high falls, 150m u/s from confluence with Ugum River
B4	F,S	Midway between falls and confluence; small floodplain wetland soil, N side, 2m from bank
U0	B	20-40m u/s from study area (= UG #10-12)
U1	W	Immediately u/s from major swamp draining from west
U2	W	20m d/s from U1, opposite mouth of swamp drain
U3	W,B	10m d/s from U2, in slackwater; (= UG #9)
U4	W,B	50m d/s from U3, at rapids above confluence with wetland on east bank (= UG #8)
U5	W,S	5m d/s from mouth of BW, 1m out from east bank
U6	W	15m d/s from U5, in middle of 8m wide slackwater
U7	W	10m d/s from U6 at lower end of slackwater at U6
U8	B,S,R	At survey marker on right floodplain (= UG#7)
U9	F,B	35m d/s from U8 (= UG#6)
U10	W,B	At boonie trail intersection (= UG#5)
U11	R,W,B	35m d/s from trail, 15m u/s from deep and large slackwater "lake";(= UG#4)
U11a	W	Same as U11, in small slackwater pool behind 2m diam. rock in stream
U12	W,B	20m d/s from lower end of large slackwater pool.
U13	F,B	40m u/s from confluence with Bubulao River (= UG #2)
U14	R,S,W	25m u/s. from confluence, in rapids, rock sampled from rapids, soil on .5m high right bank.
U15	B	Confluence of Bubulao and Ugum Rivers (= UG#1)
U16	W	25m d/s from confluence, right bank
BW0	S	125m from BW5 at confluence with Ugum River.
BW1	B	25m u/s from BW2
BW2	B,S	25m u/s from BW3
BW3	B	25m u/s from BW4
BW4	W,F	25m u/s from BW5
BW5	W,B	3m u/s from mouth at confluence with Ugum River (= MD#1)
PW1	W,F	10m u/s from mouth, in *Barringtonia* swamp.
PW2	W	Mouth of PW
DW1	W	10m u/s from mouth of DW
D1	R,S	Dandan-Bubulao Trail, east side of valley, beginning of badlands, tuff breccia
D2	R,S	Dandan Badlands at UACOE survey marker, Dandan Flow member boulder


UGUM-BUBULAO R.
SAMPLE & MEASUREMENT
STATIONS
B1
B2
BUBULAO R.
B3
B4
U16
15
14
13
DW1
12
DANDAN-BUBULAO FOOT TRAIL
10
11
9
8
7
6
UGUM R.
BW
BW1
2
3
4
5
4
5
3
2
1
PW2
PW1
U0
UGUM R.
N
0
1000
2000
SCALE
FEET
FIGURE 5

Metals: Water samples from each site were collected for metal analysis on one occasion (May 18, 1995). Each sample was analyzed for total and dissolved metal levels. Collections were facilitated using a 10 ml polypropylene syringe the tip of which was held just below the surface of the water. (Plates 5 and 9). The sub-sample required for total metal analysis was expelled directly into 25 ml polypropylene bottle containing 50 μl of concentrated nitric acid as a preservative. The sub-sample required for filterable metal analysis was passed through an in-line, Swinnex filter assembly (13 mm diam.) prior to the final collection and acidification process. The appropriate field blanks (Milli-Q water) were treated similarly. All items involved in the collection and filtration of water samples were acid washed beforehand to remove extraneous sources of metal contamination.

Botanical Survey (See Appendix)

A relevé method of analysis modified by Braun-Blanquet (1932, in Brower & Zar, 1984) was used. Stations were located approximately every 50 meters along the Ugum River from its confluence upstream to the end of the study area and into the adjacent wetland swamps. The strip along the Ugum was 4m wide plus the river width as measured at bank full stage. The depth of the study included parts of the plants overhanging the station. The weakness of this method is that stations are not uniform in size because of variation in river width. Additionally, results are semi-quantitative. The strength of the method is it characterizes each site, is time-effective, and leads to estimate of the regional spatial floristic variation. Percentage of cover is estimated in layers.

Herb Layer	Plants or parts of plants (tree roots etc.) 0-1 meter in height.
Shrub Layer	Plants or parts of plants 1-3 meters high.
Tree Layer	Plants or parts of plants 3-10 meters in height.
Canopy layer	Plants or parts of plants in excess of 10 meters in height.

Collected plants were pressed and dried, and have been curated at the Herbarium in the Science Building at the University of Guam.

Aquatic Wild Life Survey

Aquatic wild life was observed and noted in the moving water and floodplain during transects walked parallel to the main course of the Ugum River, from the Dandan-Bubulao trail to BW, and along BW and PW for about 50 meters.

Laboratory Methods:

Rock and Soil Analysis

Rocks were cut at WERI and thin sectioned off island. Thin sections are 30μ slices of rock epoxied to glass slides that allow examination and estimation of the mineral composition of the rock in transmitted light with petrographic microscope. A Nikon Single POL polarizing microscope with photomicroscopic capability was used at the WERI laboratory. Slides were examined and compositional counts made at 80x magnification in white light.

Soils from 30-cm depths were analyzed at the Agronomy Department of the University of Maryland. Samples were analyzed for pH, then air-dried and 5 subsamples of 100 grams each were classified by sieve and averaged, with fines resuspended dispersed and centrifuged. Clay-sized particles were glycolated and analyzed by X-ray diffraction for clay mineral composition; coarser silts and sands by petrographic microscope. Chemical analyses of size fractions were run on a KEVEX X-Ray fluorescence. Organic carbon was estimated by low-temperature ashing of subsamples from each size class.

The selection of 30 centimeters eliminated a source of variation (variation with depth) but in so doing, introduced a bias that in future studies should be eliminated with a suite of vertical samples from each site. All soils have a basic inhomogeneity with depth as well as laterally.

Water Quality Analysis

Physical Properties & Nutrients: Conductivity (µS at 20 °C, Orion model 140 SCT meter) and pH and Eh (Corning model 350) were measured by immersing probes directly into the bottles after subsamples for nutrients had been removed. Reactive P and Si (Parsons *et al.* 1984) and Nitrate plus nitrite (*i.e.*, NOx, Jones 1984) were measured colorimetrically on a Beckman DU-64 spectrophotometer using 1 or 5 cm quartz cells as appropriate. All reagents and standards were made up in 18 M Milli-Q+® water using accepted procedures (APHA *et al.* 1989).

Trace Metals: Metals analysis was undertaken at the WERI laboratory using Atomic Absorption Spectroscopy (AAS) adopting the most sensitive settings of the instrument. Mercury and arsenic levels were determined by flameless AAS following either reduction to the base metal (Hg) or generation of the metal hydride (As). The remaining metals were analyzed by flame or furnace AAS depending upon concentrations present. In this instance, samples were aspirated (flame) or injected (furnace) directly into the AAS without further adjustment or use of matrix modifiers. Simultaneous corrections for non-atomic absorption were made using a deuterium lamp. All sample absorbances were calibrated against serial dilutions of the appropriate standards after adjustments for the blank.

RESULTS

Rocks and Soils:

Table 2 lists mineralogy and selected trace element chemistry of bedrock samples ("R" from Table 1) and Table 3, lists mechanical analyses and composition of 6 selected wetlands soils and two non-wetlands soils from the upper valley slopes. ("S" from Table 1). Neither rock nor soil mineralogy and chemistry contained surprises when compared to earlier published analyses (Tracey & Stark, 1963, Reagan & Meijer, 1983, Barnard, 1986; Soil Conservation Service, 1983).

Mafic volcanic rocks such as BPM and DFM contain appreciable heavy metals bound up in silicates, oxides, and sulfides, but still considerably less than the metal concentration of other volcanic formations on Guam (Stark & Tracey; Reagan & Meijer, 1983; Barnard, 1986). Volcanic minerals are liberated from host rocks and usually transformed into more stable hydrated phases during chemical weathering. This can take place in the phreatic zone below the water table, in the vadose zone above the water table, and/or on the earth's surface. The common reactions were discussed later under the section on chemistry. Metals are imported into rivers and wetlands as a) chemically bonded components of unweathered volcanic rocks or in weathered particles (e.g. clay mineral crystals), b) hydrated ions, via overland or groundwater flow and c) complexed and stabilized organic molecules.

Wetlands biochemical processes are capable of concentrating metals, specially in micro-environments in the soil and pore waters (See Below). However, neither the BPM nor the DFM appear to carry sufficient contaminant metals to pose a direct threat to biological communities, irrigation applications, nor to downstream drinking water supplies.

Table 2. Bedrock Mineralogy and Selected Element Chemistry

Site	Unit	Major Minerals	Minor Minerals	Fe %	Mn %	Cu ppm	Ni ppm	Cr ppm	As ppm	Zn ppm	Pb ppm
B1	BPM tuffac. Sstone	Plagio. Augite Magnetite	Calcite Glass Chert	4.5	0.04	60	35	90	1	5	<1
B3	BPM Clast	Plagio. Augite	Magnetite Hypersth.	9.2	0.19	220	185		<1	5	1
B3	BPM Matrix	Plagio. Augite Magnetite Glass	Zeolite? Calcite Serpentine	5.4	0.08	80	110	210	1	20	<1
U8	BPM Clast	Plagio. Augite	Olivine Glass Iddingsite Magnetite Hornblende	11.3	0.15	165	70	195	<1	12	<1
U11	BPM Matrix	Plagio Augite Magnetite	Calcite Glass	7.9	0.11	115	100	145	2	35	1

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Continuation of Table 2

Site	Unit	Major Minerals	Minor Minerals	Fe %	Mn %	Cu ppm	Ni ppm	Cr ppm	As ppm	Zn ppm	Pb ppm
U14	BPM Clast	Augite Plagio. Hyperth. Glass	Magnetite Zeolite Olivine Pyrite	12.3	0.16	180	135	300	1-2	15	2
D1	DFM Un-weath.	Augite Hypersth.	Magnetite Hematite	8.96	0.18	210	80	15	<1	11	<1
D2	DFM Weath-ered	Smectite Goethite	Pyrolusite Kaolinite Hematite	14.9	0.34	230	130	5	<1	9	<1

Soil analyses in Table 3 indicate that heavy metals are predictably concentrated in the clays size fractions and in decayed plant remains. Wetlands soil forming processes act to scavenge and accumulate metals until heavy rains flush them into rivers.

Table 3. Soil Analysis

(soil depth = 30 cm; mechanical analyses by dry sieving; clay identification by X-Ray diffraction; chemical data by X-Ray fluorescence., organics = dry weight plant remains) nd = no data

	SIZE %	Fe %	Mn %	Cu ppm	Ni ppm	Cr ppm	As ppm	Zn ppm	Pb ppm
SITE B1 Unit EFW									
% Clay	30.3 smectite	12.5	1.23	140	60	95	2	15	3
% Silt	35.8	10.9	0.81	35	10	<5	<1	4	1
% Sand	17.5	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	4.5	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	11.2	1.5	.08	260	430	290	<1	<1	3
pH 5.02									
SITE B4 Unit EFW									
% Clay	18.9 smectite	9.8	0.87	170	65	125	2	6	23
% Silt	47.9	7.9	0.14	55	40	8	<1	2	6
% Sand	12.8	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	9.6	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	10.3	5.6	0.55	310	255	85	2	1	13
pH 3.55									
SITE U5 UNIT EFW									
% Clay	24.7	6.7	0.39	210	280	35	3	2	30
% Silt	29.5	6.9	0.29	45	80	10	<1	<1	7
% Sand	14.6	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	18.9	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	13.4	3.4	0.37	290	380	65	2	1	35
pH 5.15									

Continuation on next page

Continuation of Table 3

	SIZE %	Fe %	Mn %	Cu ppm	Ni ppm	Cr ppm	As ppm	Zn ppm	Pb ppm
SITE U8 UNIT EFW									
% Clay	19.9 smectite> kaolinite.	8.8	0.77	190	170	85	3	2	40
% Silt	30.6	6.9	0.09	35	55	10	<1	1	9
% Sand	19.1	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	5.0	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	24.8	3.4	0.32	50	90	45	2	<1	35
pH 5.02									
SITE BW0 Unit BW									
% Clay	29.2 kaolinite >smectite	6.78	0.33	105	220	100	2	1	15
% Silt	34.9	6.81	0.41	50	135	40	<1	<1	6
% Sand	9.0	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	none	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	26.4	13.5	1.25	200	185	130	1	<1	25
pH 2.45									
SITE BW2 Unit BW									
% Clay	33.1	8.94	0.47	475	140	290	2	1	45
% Silt	27.9	7.98	0.26	205	110	85	<1	<1	15
% Sand	6.7	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	none								
% Organics	32.3	11.0	1.05	610	200	245	1	1	30
pH 3.02									
SITE D1 Unit Akina-Badlands									
% Clay	37.6 kaolinite	13.5	0.35	200	165	30	<1	<1	4
% Silt	23.4	7.8	0.16	35	60	5	<1	<1	<1
% Sand	22.2	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	17.9	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	nd	nd	nd	nd	nd	nd	nd	nd	nd
pH 6.09									
SITE D2 Unit Saprolite									
% Clay	35.0 kaolinite	24.8	0.96	135	20	20	<1	<1	2
% Silt	30.2	10.3	0.25	55	20	15	<1	<1	<1
% Sand	28.9	nd	nd	nd	nd	nd	nd	nd	nd
% > Sand	6.2	nd	nd	nd	nd	nd	nd	nd	nd
% Organics	nd	nd	nd	nd	nd	nd	nd	nd	nd

Hydrology

Field measurements of streamflow made at various wet land study sites in the Ugum drainage and are shown in Table 4. Location of these sites is shown in Table 1 and Figure 5.

Flow measurements taken in March (2.29-3.18 cfs) and May (1.69-2.05) of the dry season indicate a range of percent excedence from 75 to 87, or that we should expect long term flow averages to exceed those values between 75 and 87% of the time. As anticipated late dry seasonal percentage values were higher than those computed earlier in March. Wet season flow values (6.62 cfs) values measured in August brought those excedence values down to 47% on the Ugum River.

Observations made at the mouths of perennial wetlands BW, PW, and DW indicate continual but diminished flows throughout the dry season. August flow values of 0.4 for BW, 0.06 for PW, and 0.08 for DW, all draining into the Ugum River appear small in comparison to ambient river values, but their sum of about 0.54 cfs is in excess of 9 % of Ugum River flow. A flow duration curve describing flow variability at Site 168545 is shown as Figure 6, which also includes an estimated flow duration curve for the Bubulao River at its mouth and the Ugum River above its confluence with the Bubulao River. The latter two curves were derived from Site 168545 data scaled for the areas of drainage involved.

Flow duration curves plot anticipated flows as a function of historic data. The X or horizontal axis indicates the percentage of all flow measurements, taken continuously over time, that a particular flow measurement on the vertical Y axis would exceed. Thus a flow of 6 cfs measured at Talofofo Falls would be exceeded over a long time span by about 85 percent of all measurements made at that station.

A flow duration curve describing flow variability at Site 168545 is shown as Figure 6, which also includes an estimated flow duration curve for the Bubulao River at its mouth and the Ugum River above its confluence with the Bubulao River. The latter two curves were derived from Site 168545 data scaled for the areas of drainage involved.

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Table 4: Flow Measurements in Rivers & Wetlands

STATION	LOCATION	DATE	FLOW (CFS)
B1	Bubulao R. , just u/s of ford	10 March 95 13:52	3.17
B2	Bubulao R. About 1/2 way between ford and confluence	10 March 95 10:38	3.34
B4	Bubulao R. half way from falls to confluence	10 March 95 12:27	3.18
U13	Ugum R. u/s of confluence with Bubulao	10 March 95 13:03	2.29
B1	Bubulao R. just u/s of ford	18 May 95 08:50	3.41
B2	Bubulao R. About 1/2 way between ford and confluence	18 May 95 09:30	3.04
B4	Bubulao R. half way from falls to confluence	18 May 95 10:09	2.05
U13	Ugum R. u/s of confluence with Bubulao R.	18 May 95 10:10	1.69
U9	Ugum, 75 meters d/s of Phosphate Wetland	18 Aug 95 10:50	6.62
BW4	Big Wetland, 30 meters u/s from mouth	18 Aug 95 11:20	0.40
PW1	Phosphate Wetland, 10 meters u/s from mouth	18 Aug 95 10:10	0.06 (v-notch weir)
DW1	Downstream Tributary Wetland, 20 meters u/s from mouth	20 May, 95 Noon	0.02
DW1	Downstream Tributary Wetland, 20 meters u/s from mouth	8 Sept. 95 10:15	0.09

A flow duration curve describing flow variability at Site 168545 is shown as Figure 6, which also includes an estimated flow duration curve for the Bubulao River at its mouth and the Ugum River above its confluence with the Bubulao River. The latter two curves were derived from Site 168545 data scaled for the areas of drainage involved.

Flow duration curves plot anticipated flows as a function of historic data. The X or horizontal axis indicates the percentage of all flow measurements, taken continuously over time, that a particular flow measurement on the vertical Y axis would exceed. Thus a flow of 6 cfs measured at Talofofo Falls would be exceeded over a long time span by about 85 percent of all measurements made at that station.

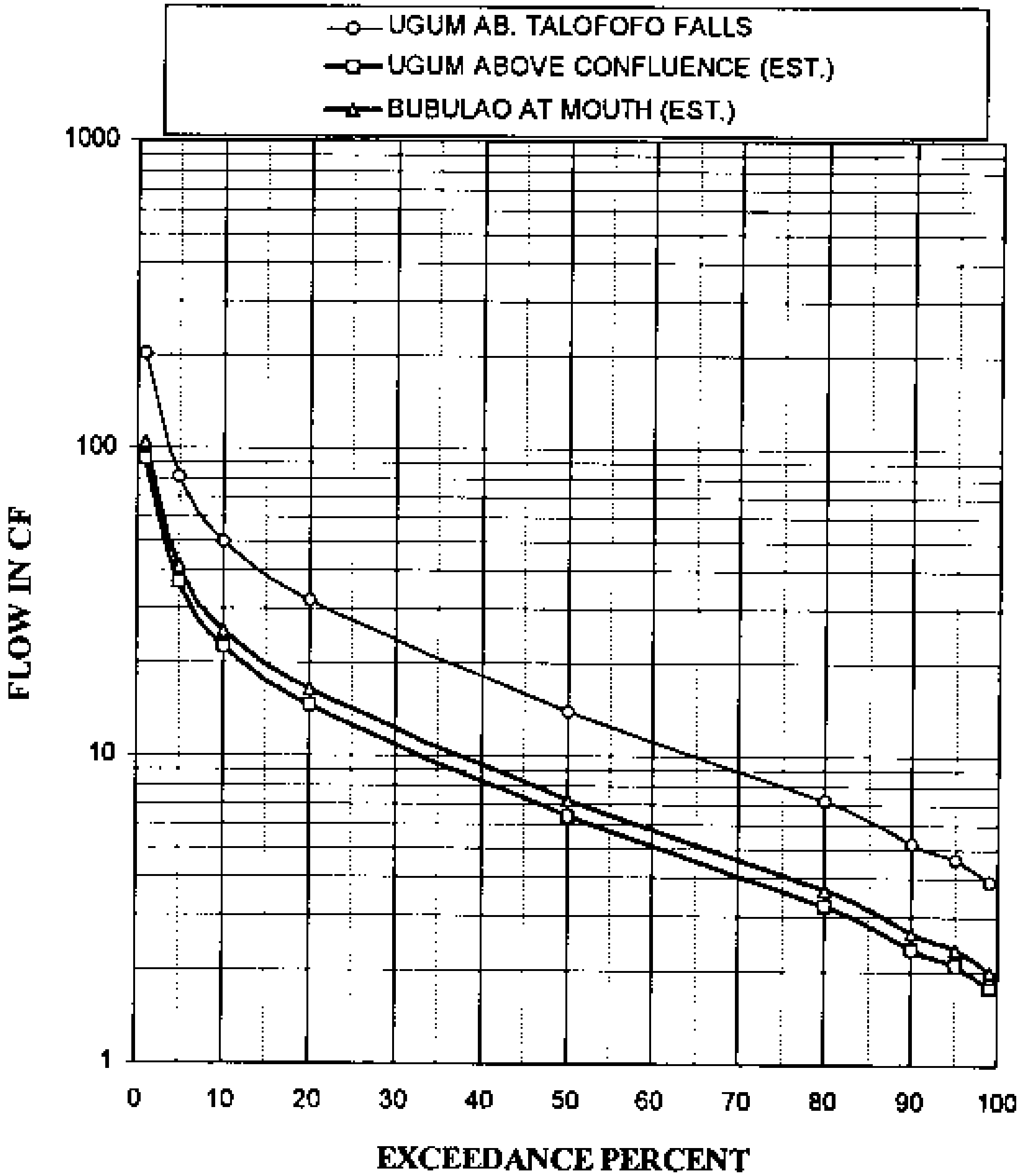

Figure 6: Flow Duration Curves
Ugum River above Talofofo Falls, Gage (168545) and Bubulao River at mouth (estimated).

Figure 6 also includes an estimated flow duration curves for the Bubulao at its mouth (Drainage Area = 2.96 sq. mi.) and the Ugum River above its confluence with the Bubulao (drainage area = 2.62 sq. mi.). These last two curves were computed using the duration curve for the gaged record of the Ugum River above Talofofo Falls with scaling based on drainage area.

Water Quality:

Physical Parameters

Redox Potential: The redox potential provides an indication of the intensity of oxidation or reduction reactions occurring in a liquid. These reactions are important because they determine the chemical form of many inorganic substances in wetland soils and water (notably, nitrogen, iron, manganese and sulfur) which in turn influences the solubility, mobility and availability of these substances to biological systems.

An oxidation-reduction reactions occur when electrons are transferred from a donor (which becomes oxidized) to an acceptor (which becomes reduced). The reduction processes are largely biologically mediated, the source of electrons (and energy) being derived from the decomposition of organic matter by nonphotosynthetic microorganisms (Salomons and Förstner 1984).

The redox potential range extends from +700 mv (highly oxidized environment) to -300 mv (highly reducing environment). Reduction occurs sequentially in a manner that is paralleled by an ecological sequence of microorganisms - aerobic heterotrophs, denitrifiers, fermentors, sulfate reducers and methane bacteria (Stumm and Morgan 1981). Oxygen is the first component in the medium to be reduced by aerobic bacteria. A redox potential reading of around +350 mv is indicative that oxygen depletion is beginning to occur. When oxygen has dropped sufficiently, nitrate becomes the primary electron acceptor that facilitates the continued decomposition of organic matter. A redox potential of +220 mv reflects the start of nitrate reduction. The reduction of manganese closely parallels nitrate reduction, beginning at around +200 mv, and is followed in decreasing order by the reduction of iron (+120 mv), sulfur (-150 mv) and than carbon (-250 mv). Thus, the overall productivity of wetlands and adjacent riverine ecosystems is enhanced by greater nutrient availability as a result of these anaerobic processes that recycle nutrients into soluble forms.

In the current study, the redox potential values of water samples collected ranged from +365 to +132 mv and were thus indicative of a system that fluctuated between oxidizing and moderately reducing (Table 3). The predominant oxidation states of nitrogen would therefore have shifted from the soluble nitrate ion (NO_3^-) at the higher redox potential to nitrite (NO_2^-), nitrogen gas (N_2) and ammonium (NH_4^+) at the lower values recorded. Likewise the solubility of manganese would increase in accordance with the valence change (Mn^{4+} to Mn^{2+}) that normally accompany a declining redox potential. Inorganic iron and sulfur, on the other hand, would not be influenced by the magnitude of change observed and would predominantly occur in the water column as insoluble ferric (Fe^{3+}) oxyhydroxides and the soluble sulfate ion (SO_4^{2-}) respectively. It should be noted however, that because many redox systems involve both electron and proton transfer, it is necessary to take into account the pH of the medium in order to describe the various species of a chemicals present in the system.

pH: The pH of water is a measure of its hydrogen ion (proton) activity and is measured on a scale which runs from 0 (very acidic) through 7 (neutral) to 14 (very alkaline). The pH of waters draining wetlands waters are influenced in part by the nature of the wetland soil, the residence time of the water in the wetland itself. The general effect of submergence tends to increase the pH of acid soils and depress the pH of alkali soils to the extent that they converge around neutrality (Ponnamperuma 1972). This is reflected in the pH of the overlying water. Organic matter may also influence the pH of wetland soil and water through the production of reduction products, carbon dioxide and organic acids (Motomura 1962; Ruttner 1963).

Natural waters can have a pH ranging from 4-9 although the majority fall between 5.5-8.6 (AWWA 1990). In the current study the pH of surface waters leaving the swamp and in the adjacent rivers ranged from 6.9-8.1 and were within acceptable limits for the preservation of aquatic life (USEPA 1976). Also, in consideration of the near neutral pH and redox potential measured in our samples, the dominant chemical forms of inorganic nitrogen, manganese, iron and sulfur are likely to be as previously described above.

Specific Conductance: Specific conductance is a measure of the waters ability to conduct and electrical current (expressed as micromhos/centimeter at 25 C) and is a convenient way of measuring gross mineral contamination in aquatic systems. Raw waters normally register specific conductances of 50-500 mmhos depending on such factors as hardness (AWWA 1990). In the present study, specific conductances determined in samples collected from the Bubulao and Ugum rivers showed little variation and fell towards the lower end of this range (89-170 mmhos)

The specific conductance of water draining wetlands often has a higher specific conductance than water entering the system due to the mobilization of dominant cations from the water-logged soil into the surrounding water. In this regard, Ca^{2+} and Mg^{2+} are the main contributors to conductivity increases in wetlands containing neutral and alkaline soils where as in acid soils, like that present at our test site, conductivity increases would be expected to occur as a result of increases in Fe^{2+} and Mn^{2+} in addition to the displacement of Ca^{2+} and Mg^{2+} by cation-exchange reactions (Ponnamperuma 1965).

Chemical Parameters: Nutrients

Nitrates: Nitrates are derived from a variety of natural sources including mineral deposits, the decomposition of organic matter, and bacterial fixation of atmospheric nitrogen. They are also derived from agricultural runoff (fertilizers and animal waste), septic systems and waste water discharges. Surface waters generally have nitrate nitrogen levels of less than 2 mg/l (AWWA 1990). Detectable levels found in the samples collected during the present study were low and ranged from 1.1-16.8 µg/l. Interestingly, levels recorded at sites on the Ugum River were highest in tributary waters leaving wetlands BW and PW, and decreased with increasing distance downstream (see May 18 samples, Tables 7 and 8) Nitrogen's role as one of the most important elements in aquatic ecosystems is undisputed. It occurs in several forms, and participates in a large number of biological processes. Together with phosphorous, it is the most production stimulating nutrient and acts as a catalyst for the decomposition of organic material in sediment (Jansson *et al.* 1994).

Under the reducing conditions which prevail in wetland soils, nitrogen occurs mainly as organic nitrogen and ammonium nitrogen. Nitrate is very unstable under these conditions and undergoes denitrification to nitrogen gas and is lost to the atmosphere. Ammonium ions, produced from the bacterial decomposition of organic matter, are held in both the fixed and exchangeable form. The amount of exchangeable ammonium present will depend on the abundance and type of clay mineral present (Hall *et al.* 1970). Growing plants assimilate both nitrate and ammonium ions and convert them into protein. Organic nitrogen in wetland soil consists of a vast array of simple and complex substances that are not available to plants unless converted to the inorganic form.

In anaerobic wetland soils, the mineralization of organic nitrogen stops at the ammonia stage because of the lack of oxygen for nitrification to nitrate (Ponnamperuma 1972). Ammonia therefore accumulates under these conditions unless it is taken up by plants. Ammonia released into the water column during the decomposition if organic matter may also be lost by volatilization although if sufficient oxygen is present, oxidation results in nitrification, mainly by microorganisms, and produces nitrate which is non-volatile (Brezonik 1972). No doubt this accounts for the relatively high nitrate levels observed in surface waters draining the wetland site. Moreover the marked decline in nitrate levels at downstream sites likely reflects the rapid assimilation of this essential nutrient by the resident plant biomass.

Table 5: Physical Properties and Nutrient data from Ugum, Bubulao Rivers and Wetland Tributaries.

nd = no data

Date	Site	Conductance µS	pH	Eh millivolts	Phosphate µg/L	Nitrate µg/L	Silica g/L
March 23	UO	166	7.3	344	36.7	3.0	2.3
	U4	163	7.6	343	46.9	3.0	2.3
	U13	163	7.7	347	50.9	4.4	2.3
	B1	149	7.2	347	30.8	1.2	2.4
	B3	149	7.7	347	23.5	1.6	2.4
	BW5	160	7.3	348	40.3	5.9	2.2
	PW2	132	7.5	344	503.1	5.4	2.4
May 18	U13	170	7.3	319	5.8	3.3	19.3
	U16	165	7.6	315	4.0	2.3	17.4
	B1	159	7.2	355	4.0	7.0	16.7
	B3	162	8.1	298	2.2	2.3	16.1
	BW5	160	7.0	365	6.2	6.1	19.4
	BW2	148	6.9	325	5.5	7.0	17.4
	PW2	148	7.2	318	123.6	4.2	12.7
Aug. 18	U4	130	nd	nd	79.2		2.4
	U4	126	nd	nd	69.6	1.1	2.4
	PW2	120	nd	nd	871.4	5.4	5.7
	PW1	89	nd	nd	93.7	10.9	2.0

Continuation on next page

Continuation of Table 5

Date	Site	Conductance µS	pH	Eh millivolts	Phosphate µg/L	Nitrate µg/L	Silica g/L
Aug. 29	U5	158	8.4	132	74.3	5.4	14.6
	U6	139	7.6	185	31.3	2.2	14.8
	U7	136	7.7	177	63.4	3.3	15.4
	U4	154	8.1	180	37.1	9.8	14.0
	U3	157	8.0	184	32.0	16.8	14.0
	U2	111	7.5	208	56.9	13.0	11.8
	U1	105	7.3	223	51.4	3.3	11.5
	U1	113	7.3	228	45.6	7.6	11.8
	U0	141	7.6	23.2	42.2	6.5	13.7
	PW1	137	8.1	22.1	501.1	8.7	35.0
	PW2	156	8.1	223	448.6	14.0	32.8
Sept. 7	DW1	116	7.0	328	111	1.8	29.3
	DW1	118	7.0	327	110	1.8	289
	U11	107	7.4	315	46.5	6.6	126
	U11a	111	7.4	31.5	46.5	7.9	124
	U12	130	7.4	316	48.2	5.7	12.9

Phosphates: Phosphates in nonpolluted surface waters are primarily of mineral origin and are usually present at concentrations of less than 30 µg/l. Anthropogenic sources of phosphates include fertilizers, detergents, and animal wastes. Phosphates, like nitrates, are plant nutrients and can lead to excessive or nuisance growths of algae and other aquatic plants when levels in surface waters exceed 25 mg/l (AWWA 1990).

In the present study, levels determined in surface waters ranged from 2.2-63.4 µg/l with the exception of PW. Levels here were considerably higher and ranged from 124-503 µg/l. The source of this very localized, yet significant, point source of phosphate enrichment was determined to be an occasionally used military field latrine, covering some 300 sq. meters and located approximately 250 meters from the point of sample collection.

Although phosphate is not directly involved in the reduction-oxidation reactions that occur in flooded wetland soils, its solubility, mobility and availability is related largely to the oxidation state of iron present in the system. For example, phosphate is released along with the reduction of ferric iron to the more soluble ferrous form, largely because phosphate can occur as the insoluble ferric compound and also because it is occluded with iron oxide on silt and clay particles under oxidizing conditions,. The reduction of iron therefore strips away the precipitated layer of hydrated iron that has phosphate occluded or co-precipitated with it (Mahaptra 1966). For this reason, phosphate is generally more available to plants under reducing conditions.

Organic phosphorous can serve as a plant nutrient only after its mineralization into the inorganic orthophosphate form. The solubility and availability of soil phosphorous also tends to be increased in waterlogged soils as a result of chelation with dissolve organics

Shapiro 1958). Organic matter may also cause a reduction in the amount of inorganic phosphorous due to the process of assimilation by bacteria decomposing the organic matter.

Site & Time Relationships of Nutrients: From Table 5, we note that each sampling date and site has distinct chemical signatures, for a specific time of day, such that the contribution from each wetlands tributary may be identified at that time. For example, on March 23, in the Bubulao River downstream at B3, the conductivity, phosphate, and nitrate are lower than in the Ugum River at U13 at the same time of day. Also, on that date and time, we note elevated levels of phosphate in PW that are reflected at downstream stations on the Ugum River.

On August 29, a downstream transect was conducted in the Ugum River from U1 to U7 (Figures 7 and 8). Both the conductivity and pH, as well as the nitrate, decrease going downstream. This is probably is the result of groundwater intrusion during this dry period or to net bicarbonate and nitrate removal due to photosynthesis in the stream bed. At sites U3 and U4, which are downstream of BW and upstream of PW, there is a distinct change in chemistry owing to the occurrence of a slow moving pool of water in the Ugum River in which active photosynthesis occurs, and/or to input from BW. Further downstream at U5-U7, the phosphate increase results from input from PW. This input of phosphate may have stimulated in-stream photosynthesis, because nitrate (also enriched by PW) simultaneously decreased in the Ugum River. This suggestion that photosynthesis was stimulated is also supported by the significant and sudden increase in conductance and pH at U5.

On September 7, samples were taken from Ugum River at contiguous sites U11 and U11a, on tributary wetlands DW, and at a site (U12) directly below DW on the Ugum River show no compelling evidence of a chemical influence from DW in conductivity, pH, Eh, or nutrient data, suggesting that this tributary does not affect Ugum chemistry during high flow in the rainy season. However, the chemistry at downstream site U12 is changed to a minor extent in comparison with sites U11 and U11a that lie above a major slackwater "lake" upstream. There may indeed be a minor contribution from wetland DW, but its magnitude may only be detectable during the dry season.

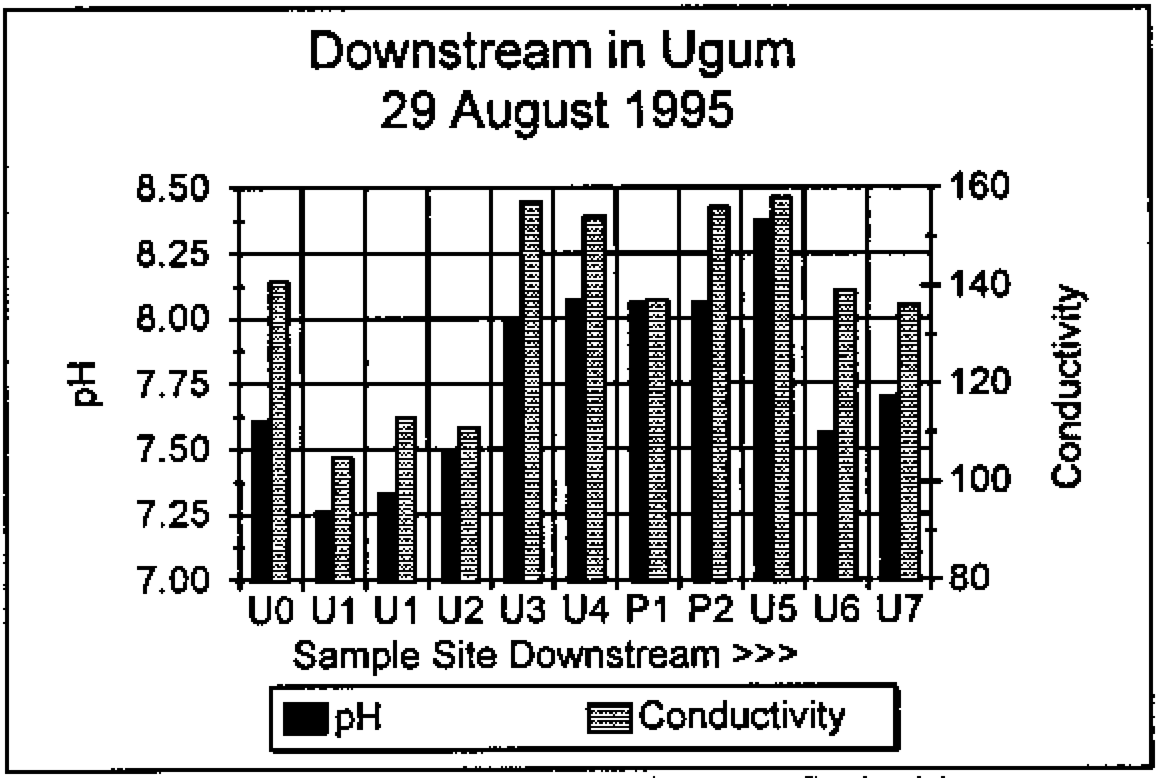

Figure 7. Downstream Variation in pH and Conductivity
Sites in the Ugum River from about 50 meters above confluence with Big Wetlands (U1), going past Phosphate Wetlands (PW1 and PW2). Variation measured over a 1 hour period on August 29, 1995.

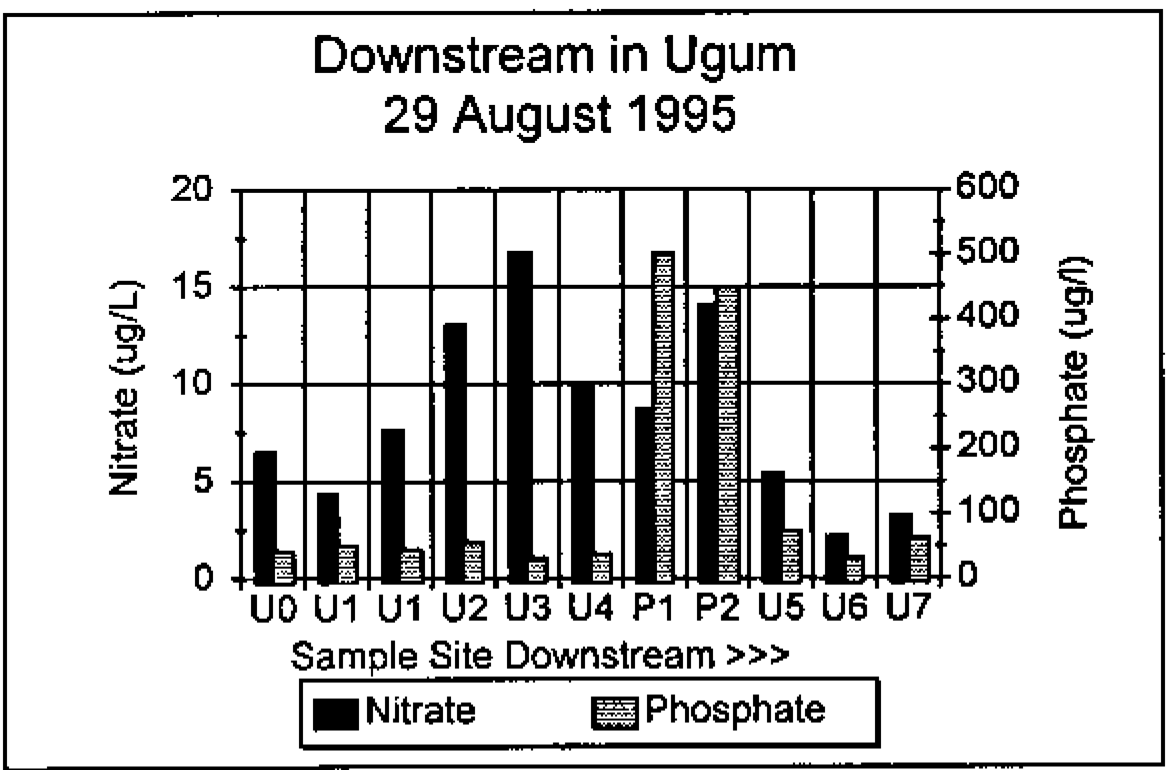

Figure 8. Downstream Variation in Nitrate and Phosphate (as in Figure 7).

Essential Metals

Iron: Iron is the fourth most abundant element in the earth's crust. It is common in many rocks and is an essential trace element required by both plants and animals. Concentrations in surface waters may vary considerably depending upon such factors as local geology, pH, redox potential, sources of contamination, and other chemical components in the water. On Guam for example, iron levels in the river and streams in the southern part of the island range from less than 10 µg/l to 10 mg/l or more (Siegrist and Denton, unpublished data).

In the present study, dissolved levels ranged from 120-342 µg/l with the highest values consistently occurring in waters draining the wetland study site. This is to be expected in view of the acid nature of the wetland soil, its high iron and organic matter content and the reducing conditions that normally prevail in this system.

In well oxygenated waters, at near neutral pH, much of the inorganic iron is present as particulate and colloidal ferric oxide and hydroxide. Thus, dissolved iron levels are usually low compared with that in suspension as indicated during the present study (see Table 6). However, relatively high concentrations of dissolved iron can exist in such environments as a result of the elements interaction with organic matter (Beck *et al.* 1974). The reducing conditions found in wetland soils are tantamount to facilitating this reaction and play a key role in mobilizing iron out of the system into the aerobic environment.

As noted above, one of the most important chemical changes that takes place when a soil is submerged is the reduction of iron and the accompanying increase in its solubility. In the latter context, large release in ferrous (soluble) iron have been observed when the redox potential of the soil fell below +200 mv (Patrick 1964). In this form, iron is readily complexed by dissolved organics residing in soil pore waters and transported into the overlying water by diffusion processes. Thus, appreciable quantities of dissolved iron can be maintained in the presence or absence of oxygen due to complexation with organic matter (Theis and Singer 1974). Interestingly, iron in this complexed form is relatively inactive chemically and physiologically, and therefore has little effect on aquatic life forms

Much of the dissolved organic matter in natural waters consists of complex, heterogeneous, brown or yellow acidic polymers formed, at least in part, during the decomposition of lignin and simpler organic molecules collectively referred to as humic matter (Christman and Ghassemi 1966; Jackson 1975)

Manganese: Manganese is a vital micro-nutrient for both plants and animals. Manganese oxide deposits commonly are associated with iron oxides and silicate in discrete but adjacent areas or layers (Lind *et al.* 1988). Levels of dissolved manganese generally range between 1-100 µg/l (Wilson 1980) but may be appreciably higher in waters draining manganese enriched areas. Dissolved levels in the present study ranged from 6.2-22.3 µg/l in the main rivers studied and 252-374 µg/l in waters draining the wetland study site.

Manganese, like iron, forms insoluble oxides in well oxygenated waters at normal pH. Thus, dissolved concentrations of manganese in surface waters are often low compared with levels found in suspended form as seen in the present study (Table 6).

Manganese is reduced to the soluble form more readily and at a higher redox potential than iron. The redox process is also much more sensitive to pH changes. For example, a redox potential of +220 mv signifies the beginning of manganese reduction at neutral pH. However, at pH 5 the effect of acidity in bringing manganese into solution is so marked that changes in redox potential have little effect on the solubility. Thus, in acidic, waterlogged wetland soils the conversion of easily reducible manganese to the exchangeable and water soluble form can begin at a redox potential of around +400 mv (Turner and Patrick 1968).

Although many of the factors that affect iron reduction in freshwater systems also influence manganese, both metals behave independently of one another and differ markedly in their affinity for organic matter. As mentioned above, the importance of organic matter in facilitating the recycling of iron is well established. However the association of manganese with natural humic substances is generally thought to be of limited importance in this regard (Moore *et al.* 1979, Carpenter 1983).

Calcium: Calcium can be leached from practically all rocks but is much more prevalent in waters from regions with deposits of limestone, dolomite, and gypsum. Regions in which volcanic soils predominate, like those of southern Guam, have very low concentrations in the water (<10 mg/l). Concentrations in waters from limestone areas range from 30-100 mg/l (Lind 1979). Calcium is important to the biological productivity of waters and is considered as a micronutrient for most algae. Waters with concentrations of 10 mg/l or less, like those of the Ugum and Bubulao rivers (see Table 6), are usually considered to be oligotrophic, whereas waters with 25 mg/l or more, are usually distinctly oligotrophic.

Magnesium: Magnesium in natural waters comes mainly from the leaching of igneous and carbonate rocks. In areas where these sources are common, magnesium concentrations in water often range from 5-50 mg/l. In the present study, dissolved manganese levels ranged from 2.6-5.4 mg/l. which is within the range required to satisfy normal plant growth and development (Lind 1979).

Arsenic: Compounds of arsenic are ubiquitous in nature and relatively insoluble in water. Levels in surface waters rarely exceed 1-2 µg/l under natural conditions. During the present study, levels of this element were consistently below an analytical detection limit that approached the lower end of this range.

Arsenic exists in the trivalent and pentavalent states and its compounds may be either organic or inorganic. Arsenic speciation in saturated wetland soils are undoubtedly influenced by the redox conditions that prevail although little is known regarding the cycling of arsenic as a function of redox conditions in lacustrine sediments.

Copper: Copper occurs as various mineral forms and is essential for life. It also has a diversity of uses in industry and is a common contaminant of industrial and municipal waste streams. Levels found in freshwaters range from 0.5-50 µg/l depending on local geology and sources of contamination (Wilson 1980). In non polluted environments levels range from around 1-5 µg/l (Boyle 1979). Levels determined during the present study ranged from <0.9-1.2 µg/l and were therefore reflective of low background levels from all possible sources.

Zinc: Zinc usually is found in nature as the sulfide and often coexists with other metals especially iron, copper, lead and cadmium. It has a multiplicity of industrial and commercial uses and, consequently, is one of the most abundant and widespread environmental contaminants. Zinc concentrations in surface waters near population growth centers generally range from 2-200 µg/l (Wilson 1980) although levels in excess of 1000 µg/l have been found in grossly polluted situations (Kopp and Kroner 1967). Pristine freshwater environments generally contain dissolved zinc levels in the order of 0.1-1.0 µg/l (Kennedy and Sebetich 1976; Martin *et al.* 1980). It is noteworthy that the zinc concentrations found during the present study are reflective of an environment that fits into the latter category (Table 6).

Table 6. Elemental Analysis of Surface Waters from the Bubulao & Ugum Rivers (18 May 1995)

Site	Concentration (µg/l)										
	Fe	Mn	Ca*	Mg*	Ag	As	Cd	Cu	Hg	Pb	Zn
					UNFILTERED						
U13	258	38.2	7.0	5.3	<0.2	<1.2	<0.1	1.3	<0.4	<0.5	0.3
U16	418	48.8	6.3	10.4	<0.2	<1.2	<0.1	1.9	<0.4	<0.5	1.2
BI	314	35.5	6.6	5.2	<0.2	<1.2	<0.1	1.7	<0.4	<0.5	0.5
B3	462	24.3	6.1	5.2	<0.2	<1.2	<0.1	1.4	<0.4	<0.5	1.6
BW5	4835	321	6.6	4.4	<0.2	<1.2	<0.1	1.2	<0.4	<0.5	0.3
BW2	5161	402	6.6	4.4	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.3
PW1	645	64.3	7.7	2.7	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.4
					FILTERED						
U13	159	22.3	7.0	5.2	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.2
U16	146	15.1	6.2	5.4	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.5
BI	137	17.8	5.9	5.2	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.4
B3	120	6.2	6.1	5.2	<0.2	<1.2	<0.1	1.2	<0.4	<0.5	0.3
SW5	342	252	6.1	4.4	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.2
SW2	338	374	5.8	4.1	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.3
PW1	118	16.9	7.1	2.6	<0.2	<1.2	<0.1	<0.9	<0.4	<0.5	0.2

* Ca and Mg expressed as mg/l

Nonessential Metals

Cadmium, Lead, Mercury and Silver: These elements occur naturally but have no known biological function. They are accumulative poisons and impair biological processes at relatively low concentrations. Based on their toxicity and high pollution potential they rank among the most serious heavy metal contaminants in the world today. They normally occur in fresh waters in the low to sub-parts-per billion range but may be significantly higher in waters receiving industrial effluents, urban runoff and domestic wastewaters. In the present study, levels of each metal were consistently below the limits of analytical detection (Table 5) which, in keeping with our previous findings, implies a contamination free environment.

Botany:

The entire botanical study is included as an Appendix to this report as it contains voluminous tables of plant species information. The floristic composition of the riverine banks and wetlands banks is similar to comparable geomorphic areas of southern Guam, but contains several unusual species as well. Notable are *Hernandia labryinthica* and *Barringtonia racemosa*. Fosberg (1960) described the *Barringtonia* swamps of the lower Talofofo River where this species grows in conspicuous hummocks with intervening muddy channels. He stated that on Guam, the species is only known from the Talofofo River. Its occurrence several kilometers from the lower Talofofo in the easily accessed PW is important from both a research and educational biogeographical and ecological standpoint. Generally, the flora in the Ugum River wetlands and surrounding watershed are no different in coverage, diversity and distribution than recorded in the earlier survey by Raulerson et al (1978).

Wild Life:

Aquatic wildlife is neither prolific nor unusual in the wetlands and rivers; neither is terrestrial wild life obvious on surrounding slopes, with the exceptions of Insecta and Arachnida. Aquatic animals reported are not exceptional for similar riverine environments in south Guam. The remaining wild life observed is as previously reported in Raulerson et al (1978) with the exception of the now absent feral caribao.

Wetlands

Water flow in BW is constrained by dense mats of roots extending from vegetation growing between rivulets. It is therefore impossible to subdivide channels into habitat categories such as riffle and runs habitats. Mats also hinder direct observation of benthic stream fauna. Murky waters from fine suspended particles also contribute to the difficulties in observing organisms. A program of systematic electro-shocking will be required to make a rigorous assessment of aquatic fauna in BW. The most conspicuous aquatic animals occurring in the waters through BW were water striders, probably *Limnogonus* sp. One juvenile prawn, *Macrobrachium lar* was observed among roots at the bank edge, and one very young toad, *Bufo marinus* was noted on the immediate floodplain of BW. Signs of feral pigs are everywhere in BW. No fauna were recorded from PW.

Rivers
The Ugum channel downstream from BW consists of broad shallow pools (slackwater), runs (laminar flow) and riffles (shallow turbulent flowing whitewater). Each zone is inhabited by a diversity of fishes and benthic invertebrates. The most conspicuous fish species was *Awaous guamensis*; specimens that were quite large for this species (>100 mm in length) were observed foraging in lotic waters of runs. Smaller stream gobies, *Stiphodon elegans*, were numerous over hard substrates of runs and rifles.

The most commonly observed invertebrates were the freshwater prawn *Macrobrachium lar*. Although no large males were seen, intermediate-sized males frequented pools, often displaying antagonistic territorial behavior. Lack of large males possibly is attributable to trapping, as one trap was noted. Small atyid shrimps, *Atyopsis pilipes* were associated with emergent vegetation along banks of pools and another, as yet to be identified crustacean species was noted in whitewater.

Large individuals of the freshwater nerite *Neritina pulligera* were observed on areas of stream bed that were relatively free of sediment. Most of these snails were very large (>50 mm in anterior-posterior length) and old, as indicated by the highly eroded nature of their shell spires. Sediment-free substrate was flecked with egg cases of *N. pulligera*. A large *Thiara scabra* was the only other stream gastropod noted.

DISCUSSION & CONCLUSIONS

Functions and Values:

The discussion of functions and values should be predicated on the assertion that no single definition of either has been accepted in a wetlands context. The concepts discussed here are those of several authors and the scientists who worked on this project.

Wetland functions include the collective physical, biological, and chemical interactions occurring between wetland resources. Functions involve processes of in the state or condition of a wetland resource, and include transformations in the composition, structure and form, and diversity. For example, rocks are a resource; weathering is then a wetland function as it transforms rocks into various soils through combinations of reactions involving hydrolysis, dissolution, redox, hydration and microbial activity. Soil then is also a resource, derived from rocks, but itself providing additional functions (habitats, chemical transformations, water storage, etc.)

Values are sociological parameters, anthropogenic properties by which wetlands are deemed to be useful or "good". The value of a given wetland has traditionally been associated with some undefined index related to its functions. A list of wetland functions appropriate to consider for the Ugum-Bubulao study site and an evaluation of the importance of the three wetlands together with the linkage streams are listed in Table 7.

Table 7. Potential Functions and Values Appropriate for Ugum River Watershed

Hydrologic Functions	Related Values
Conveyance of waters	Flood Control, Water Supply
Storage of waters	Flood Control, Water Supply
Sediment collection	Sedimentation control, Fishing
Groundwater recharge	Water supply
Chemical Functions	
Redox transformations	Water quality. ecosystem survival
Acid-Base transformations	Water quality, ecosystem survival
Buffering functions	Water quality, ecosystem survival
Contaminant/ nutrient transfer	Water quality, ecosystem survival
Biologic Functions	
Habitat formation & modification	Survival, reproduction and/or replication
Biomass production	Agriculture, timbering, flood control, fishing & hunting
Geologic Functions	
Weathering, Mass Wasting & Erosion	Soil Formation, wetland creation
Morphometric Functions	
Open Space	Recreation, aesthetics, education
Pristine State	Education, research, aesthetics, historic, archaeologic

Hydrologic

Big Wetlands, sitting within a relatively large drainage basin obviously exerts a locally significant control on soil erosion and sediment discharge off the western divide regions of the Ugum River watershed. It also exerts an important brake on potential flood water stage, velocity, and Ugum River discharge during heavy rainfalls when the marsh and forested wetlands are not saturated with water. However, during prolonged wet periods it appears that BW will not act to retard flows.

PW and DW each drain small basins and individually play insignificant roles in flood water control, although the total of several score of similar wetlands in both the Ugum and Bubulao drainage basins affect stage and discharge. This is implied by the fact that the sum discharge from BW, PW, and DW is almost 9 percent of the total flow on the Ugum River immediately above its confluence with the Bubulao River.

Chemical

All the functions listed above are operating together in the wetlands and river systems. The point source of phosphate pollution from PW wetlands and of Mn and Fe from BW, and the variation pattern in phosphate and nitrate downstream from wetland effluents underscore the generally held notion that wetlands chemical activity can exert a major influence on immediate river waters.

The phosphate point source is probably unique, but the Mn and Fe pattern shown at BW exists in other large wetlands on Guam (Siegrist & Denton, 1993). The mobility of these elements in solution stems from their stabilization on organic molecules or as adsorbates on clay particles, processes that take place in the wetlands. They then proceed downstream, in any season, and in the case of the Ugum River enter the water treatment plant or reach the higher pH, higher Eh waters of the estuary where Mn and Fe oxidize and precipitate onto available substrate.

Wetland water chemistry appears to be less predictable. Obviously there are sources of seasonal and diurnal variation that relate to soil chemistry, microbe activity, photosynthesis, chemical kinetics of reactions, water volumes and residence times, and many other factors. These sources of variation could not be addressed in this short study, nor should they have been, but a full understanding of wetland functions will never be complete without addressing the causes of the spatial and temporal variability in water chemistry.

The chemical composition of the Ugum and Bubulao Rivers are generally within the normal ranges of those reported earlier for other rivers on Guam (Zolan & Ellis-Neill, 1986; Matson, 1989; Denton & Wood) and summarized in Barrett & Associates (1994). The relative uniformity of water quality arises from the fact that wetlands and rivers lie on bedrock and soil of similar chemistries throughout southern Guam. What local variation does arise is quickly overwhelmed by dilution.

Biologic

Wetland PW supports an unusual *Barringtonia racemosa* swamp forest containing *Lindsaea repens* var. *lingulata*, a fern that is rare on Guam. Other biologic values of the Ugum wetlands appears to be linked with the enormous biomass being generated. Wide open trials cut blazed in the dry season had vanished completely by late August. Grasses in the upstream marsh portion of BW had grown an estimated 1.0-1.5 meters in four months, feeding back into its value as a baffle of slope sediment and a retarding force to flood water surge. River reaches act variously as shelter, breeding, feeding, and dispersal habitats for prawn, shrimp, snails, and fish and a source of waters for amphibians and insects.

Geologic
Rocks are a primary resource insofar as their chemical weathering produces the sediment, especially clay minerals, soils, and many nutrients that support a viable wetland system. Rocks also are involved in the aesthetics of the area from at least two contrasting standpoints. Their natural structure and colors add charm to the landscape as viewed from upper slopes and divides. Secondly, the well-cemented breccia layers of BPM and flows in the DFM cropping out along stream valleys throughout all of southern Guam provide the resistant caprocks that inhibit vertical cutting of river channels. They thus promote and maintain the height and beauty of rapids and waterfalls. All waterfalls throughout the extent of the research area, indeed throughout the entire length of the Ugum and Bubulao Rivers have developed on resistant layers in the BPM and DFM.

Natural slope failures such as slumps and slides have lowered the relief, modified slope profiles, and transported massive volumes of sediment to valley bottoms. Wetlands develop from such activities because the natural surface drainage and the shallow groundwater plumbing system is instantly deranged; seeps and springs form and their effluent soaks into the accumulated sediment at the toe of the new slope and wetlands begin. Newly created drainage through the new wetland will redistribute the unstablized sediment and further along regional local gradient and an alluvial fan with a covering wetland marsh of forest will develop.

Natural gravity-driven geomorphic processes control the formation and many aspects of the evolution of downslope wetlands, but human impacts are certainly not negligible: Slope instability, and sheetwash and gully erosion, and stabilizing vegetation losses are exacerbated by off-road vehicles and set fires.

Morphometric
The pristine nature of the Ugum Study sites obviously translates to a major educational and research resource for the people of Guam and tropical scientists in general. The area is ideal for conducting reconnaissance field trips and class projects for schools, colleges, and environmental groups. It contains a diversity of resources and functions that should satisfy any series science teacher. The Ugum River sites moreover, contain the framework for conducting far reaching research in tropical wetland science: the complex ecosystem encompasses countless subsections: forestry, marsh ecology, aqueous geochemistry, wetland chemistry, hydrology, and chemical and physical sedimentation just to name a few.

These is little question that the view of the Ugum and Bubulao confluence area from high on the divides includes impressive vistas of savanna land, thickly forested knobs and ravines, streams and waterfalls, and abundant wetlands. The function and value, especially relative of this resource, can be argued, but the area is superficially at least as devoid of human impact as any on Guam, except for the eastern half of the lower Tarague terraces. Except for the obvious exacerbation of badlands erosion from off road vehicles, human impact on topography and drainage seems benign.

Water Quality
Studies of seasonal changes in the nutrient chemistry of streams and rivers provides valuable information about biological productivity in and erosion from the watershed, the export of materials from it, and the function of different types of landforms within a watershed. Some landforms in a watershed, such as swamps and marshes, increase the retention of particles and dampen export to downstream reaches. They also may increase in the export of solutes that have been produced during mineralization of particulate material . These "wetlands" also serve to provide the time and habitat necessary to transform materials from the particulate to the dissolved phase, and vice versa, depending upon the element in question. Other landforms, such as rapids and falls, help to flush particulate materials from accumulation zones, especially after periods of high runoff. Together, all parts of the watershed system serve to deliver terrestrial materials downstream and , ultimately , to the coastal zone. Erosion is a one-way street.

Disturbances to a watershed may either increase or decrease the export of materials. Dams and other similar devices may significantly decrease the export of nutrients, sediment and water to alluvial plains and estuaries and ultimately help destroy existing upstream and downstream habitats. A reduction in water and sediment yield from a watershed may promote erosion in downstream estuaries and a migration of salt water further upstream which, in turn, will induce a change in vegetation and decrease bankside stability. Channelization, on the other hand, also promotes erosion by increasing the discharge rate from a watershed. Prior to any proposed change in land use, studies should be conducted of the solute and particulate load of a watershed such that predictions might be made of the effects of such a change.

Based on these preliminary data, the entire watershed contains several different types of landforms that affect major river chemistry differently. There are site-specific sources of nitrate, silica and phosphate within each tributary. Further, biological activity within the rivers is important and induces major changes in chemistry when water flows through ripples, over rapids and falls, and within lentic areas (Stumm and Morgan, 1981).

SUMMARY AND RECOMMENDATIONS

The current study, though preliminary in nature and scope, has examined the major resources within several wetlands and riverine environments in the Ugum-Bubulao River watersheds. The results, for the most part, suggest a clean, relatively undisturbed environment reflective of local geomorphic and geologic characteristics, the indigenous biota, seasonal change, and anaerobic processes occurring in adjacent wetland soils. Wetlands in the Ugum-Bubulao River study site form from ongoing geologic and slope processes and their continued viability is vital for providing plentiful wild life habitats, constraining aquatic ecosystems, providing an ideal venue for education and research, and for mediating extremes in stream and sediment discharges. Above all, they are absolutely critical in controlling water quality by regulating and recycling nutrients and trace metals within the ecosystem, a fact that only recently has been recognized by the scientific community. This greater awareness has been facilitated by a general thrust in research effort focused on understanding the complexities of biotic and abiotic interactions that occur in wetlands. It is noteworthy, however, that much of this research has centered upon temperate continental wetlands with comparatively little attention being directed toward their tropical counterparts, and almost none to small tropical islands with the high ratios of coastal to terrestrial environments.

The writers are persuaded that if further work is to be undertaken on wetlands resources, function, and values, it should target directly at an understanding of the chemical and biological transformations that determine water quality. We suggest making wetlands BW into a long term research laboratory where scientists and engineers can develop those understandings and apply them to the rest of the wetlands in southern Guam. Of special importance are the following lines of wetlands research that will immediately impact our island's water quality.

- An energy and organic materials budget for BW.
- A determination of the flux of organic carbon, nutrients, and essential elements in and out of BW.
- A vertical delineation of the nature and extent of anaerobic activities in BW.
- Identification of the physical and chemical forms of iron and manganese in BW's waters, soils, and soil waters.
- A clearer understanding and quantification of seasonal hydrodynamic controls
- An analytical measure of the resilience of wetlands to anthropogenic perturbations
- Continued baseline monitoring of water quality data in all biotic and abiotic components within BW.

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APPENDIX A:

A Reconnaissance Botanical Survey of the Ugum Riverine Forest

By

Agnes F. Rinehart
September 1995

*****Not included with Technical Report.*****
Available upon request at the University of Guam Water and Energy Research Institute (WERI).