Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2005

Introduction

The Water & Environmental Research Institute of the Western Pacific or WERI is one of 55 similar water research institutes set up by U.S. Congressional legislation at each Land Grant University in the United States and in several territories. The institute is now in its 31st year of operation.

WERIs mission is to seek solutions through research, teaching, and outreach programs, to issues and problems associated with the location, production, distribution, and management of freshwater resources. WERI provides technical expertise, and conducts vigorous research and both undergraduate and graduate teaching programs aimed at improving economic conditions and the quality of life for citizens of Guam and the regional island nations. WERI also operates a state of the technology water analytical laboratory and geographical information systems analysis and training facility.

WERI administers and carries out research, training, and other information transfer programs under a variety of federal and local funding sources, but the institute was created specifically to administer Department of Interior (US Geological Survey) funds under Section 104-B of the National Institute of Water Research (NIWR) 104-B Program. WERI has responsibility for 104-B funds on Guam, in the Commonwealth of the Northern Mariana Islands (CNMI) and in the Federated States of Micronesia (FSM). In the 2005-2006 period, WERI faculty was involved as principal investigators on nineteen research and training projects. Funding sources for these projects included US Geological Survey, US Weather Service, local agencies such as The Guam Department of Agriculture, Guam Bureau of Planning, Guam Water Works Authority and Guam Environmental Protection Agency, and direct appropriations from the Guam legislature.

Currently WERI has a fulltime director who is also a UOG faculty member, five regular research faculty, one adjunct research faculty, a water analysis laboratory manager and technician, a GIS and network administrator, two office staff, as well as eight graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program. During the 2005-2006 period, WERI faculty and staff taught nine graduate courses and two undergraduate courses in the Environmental Science MS program and the undergraduate pre-engineering curriculums respectively. At the same time WERI faculty were first or second authors on fourteen refereed journal articles or conference proceedings, nine technical reports, and eleven professional presentations and workshops. WERI faculty members serve as committee members on, or chair of twenty three MS research theses in the Environmental Sciences and Biology graduate programs.

Following is a list of non USGS Funded Projects carried out by the Institute during the period 2005-2006:

NATIONAL SCIENCE FOUNDATION

Collaborative Research: Testing and Constitutive Modeling of Fine Grained Tills Deposited by the Laurentide Ice Sheet

NATIONAL WEATHER SERVICE

Pacific ENSO Applications Center: With University of Hawaii

GUAM DEPARTMENT OF AGRICULTURE

PHASE I: Water Quality Monitoring in the Pago Bay Watershed

GUAM BUREAU OF STATISTICS AND PLANS

Geographic Information System Based Erosion Potential Model

DIRECT LOCAL FUNDING

Guam Hydrologic Survey

Northern Guam Aquifer Recharge

Heavy Metals Contamination in the Lonfit River Heavy Metals

South Guam Geologic Map Revision

Development of a Sutra Groundwater Flow Model for the North Guam Lens Aquifer

Using The Sutra Model To Predict Nitrate Contamination Flow Through The Northern Guam Aquifer

Background Fluorescence In In Waters In And Emanating From The Northern Guam Lens Aquifer Sytem

Water Resources Monitoring Program

In Cooperation with Hawaii District, USGS

GUAM WATERWORKS AUTHORITY (GWA) AND GUAM ENVIRONMENTALPROTECTION AGENCY (GEPA)

Training of GWA AND GEPA Engineers in use of the Haestadt Water Distribution System Modeling Program

Research Program

The Water and Environmental Research Institute (WERI) Advisory Council is the body, which determines research goals and priorities for WERI in general and the USGS 104B program in particular. The Research Advisory Council (RAC) for Guam consists of representatives from all Guam governmental agencies involved with water resources development or regulation, members of U.S. Federal agencies, military organizations on Guam that deal with water resources issues and members of the university research community. The RAC for the Federated States of Micronesia and the Commonwealth of the Northern Mariana Islands consist of representatives from various government departments that deal with water resources, representatives from local colleges, private sector engineers, environmentalists, and planners.

WERI held RAC meetings in September and October 2004. Nineteen (19) people attended the Guam meeting, fourteen (14) people attended the CNMI meeting and fourteen (16) people attended the FSM meeting. The RAC groups examined the previous years research priorities and discussed changes to keep the listings up to date.

In early November 2004, a Request for Proposals (RFP) was sent out by e- mail to the three regions: Guam, CNMI, and FSM. RFPs were sent to all regular members of the three RACs as well as to several agencies, institutions, and individuals that had expressed interest during the previous year. Each request for proposal included: a) 104-B proposal guidelines, b) an example of a well-written 104-B proposal, and c) the list of critical water resource needs for each of the regions.

Eleven (8) proposals, two (3) for Guam, four (4) for the FSM, and two (1) for the CNMI were submitted. Review panels were selected for each of the regions. These panels were made up of researchers not submitting proposals or from others highly regarded in the water resources area of each of the regions. The submitted proposals were e-mailed to the members of the appropriate review panels. Each panel member had the list of critical needs and a scoring procedure that had been agreed upon at earlier RAC meetings. They were advised to work independently. Following a three-week interval, reviews were returned to WERI and re-evaluated by the Director. The Director made no changes to the individual ratings by the review panel members. The proposals were all highly rated and there was sufficient funding in the 2005-2006 program to fund all eight of the proposals.

Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump

Basic Information

Title:	Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump
Project Number:	2005GU54B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Water Quality, Sediments, Toxic Substances
Descriptors:	Landfill Leachate, Heavy Metals, Biota, Sediments, Environmental Assessment
Principal Investigators:	Gary Denton, Harold Wood

Publication

1. Denton, Gary, R.W., Walter C. Kelly, H. Rick Wood and Yuming Wen. 2006. Impact of Metal Enriched leachate from Ordot Dump on the Heavy Metal Status of Biotic and Abiotic Components of Pago Bay. Water and Environmental Research Institute (WERI) Technical Report No. 113, University of Guam, Mangilao, Guam, 63 pp.

PROJECT SYNOPSIS REPORT

Project Title: Heavy Metals in Biotic and Abiotic Components of a Guam Reef Flat Impacted by Leachate from a Municipal Dump

Problem and Research Objectives

Pago Bay is a windward fringing reef flat on the eastern shore of central Guam. It is approximately 3 km long, 0.75 km at its widest point, and covers an area of around 1.5km^2. The bay harbors a relatively rich diversity of marine life and supports a variety of scientific, commercial and recreational activities. Additionally, local residents traditionally harvest many of its fisheries resources for food.

The bay receives continuous drainage from the Pago River system, a complex of three rivers that drains a catchment area of approximately 27 square kilometers inland. One of these rivers, the Lonfit River, receives leachate from the island's only municipal dump located just outside the village of Ordot, about two miles upstream of Pago Bay. The dump, which has been in continuous use for over 50 years, is unlined and does not have a leachate retention system in place. As a consequence, leachate emerging from it flows down gradient into the Lonfit River and out into Pago Bay. Over the years, local residents have voiced some considerable concern over the potential impact of contaminants in the leachate on the fisheries resources of the river, estuary and bay.

Chemical characterization of the leachate has identified heavy metals as the contaminants of primary concern, both from an ecological and human health perspective. Specific elements that exceed USEPA toxicity reference values included copper, chromium, iron, lead, manganese, mercury, nickel, and zinc (USEPA 2002, Denton *et al*. 2005). These metals tend to accumulate in sediments of the leachate streams under low stream flow conditions and are periodically swept downstream into Pago Bay during major storm events (Olsen and Denton in prep.). The biological effects of such episodic inputs into the bay are currently unknown. The study outlined here provides a necessary first step towards addressing these deficiencies by evaluating the degree of heavy metal enrichment in biotic and abiotic components of the bay.

Methodology

Surface sediments were collected from 44 sites in Pago Bay in January 2005. Sampling sites were located at ~100-m intervals along the beach and at ~100-m to 200-m intervals along five transect lines running perpendicular to the shore (Fig. 1). The precise location of each sampling station was recorded using GPS. Samples (~100 g) were gently scooped up in acid washed plastic containers so as not to disturb surface layers. Three separate samples were taken within a 3-m diameter circle at each site. In the laboratory, all samples for mercury analysis were dried at ~30^{o}C to minimize losses associated with volatilization. They were then sieved through a 1-mm Teflon screen in preparation for analysis. Samples analyzed for all other metals were dried at ~60^{o}C prior to sieving.

Biota samples were collected at low tide between June and September 2005 from 48 sites in the bay (Fig. 2). Emphasis was placed on collecting species with established or potential bioindicator capability as well as those traditionally harvested by local residents for food (e.g., algae, seacucumbers, bivalve mollusks). A complete list of the organisms taken for analysis, together with their respective collection sites, is shown in Table 2. It can be seen that not all species were available at all sites.

All specimens were handpicked from the reef flat and transported to the lab in clean polyethylene bags. Gross particulate material was rinsed from the algae beforehand by vigorously shaking the samples back and forth in clean seawater; the holdfasts and older, more encrusted portions of the plants were discarded. Blades of seagrass were carefully removed as close to the plant root as possible. The proximal 12 inches of each blade was found to be relatively free of epiphytic growth and was the only portion of the plant taken for analysis. Bivalves were scrubbed clean of adhering particulates and purged of their gut contents in clean seawater for 48 h prior to storage at -20^{o}C. Subsequently, the entire soft parts of thawed specimens were taken for analysis. In contrast, seacucumbers were dissected live to prevent tissue fluid cross-contamination that can occur during the thawing of frozen specimens. Dorsal sections of the body wall and the portions of the hemal system were separated out for analysis in these organisms.

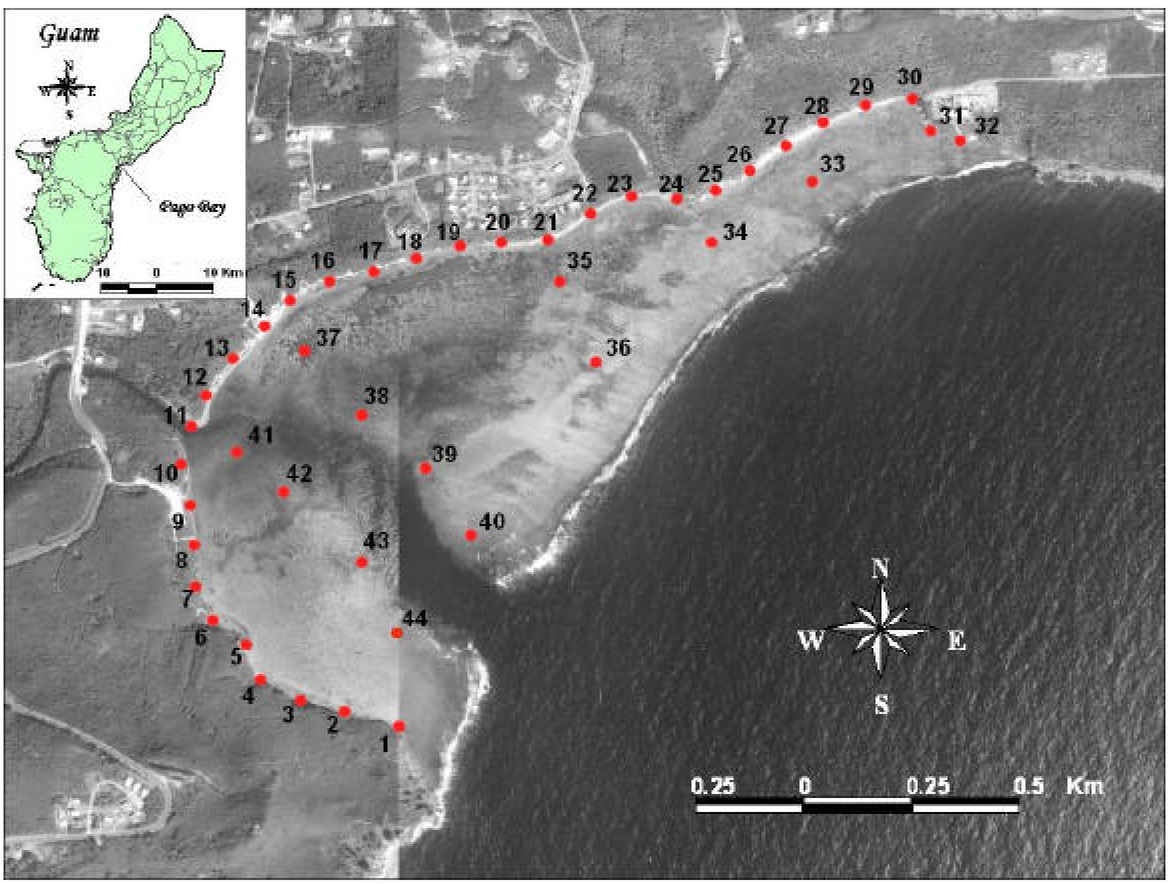

Figure 1: Sediment sampling sites within Pago Bay

All cleaned and separated samples were placed in acid-washed, polypropylene vials (80 ml). The analyses were performed on samples dried to constant weight at 60^{o}C for all metals except mercury. Owing to the relatively high volatility of this element the analysis was conducted on wet rather than dried tissues.

All samples were analyzed for heavy metals by atomic absorption spectroscopy (AAS) following conventional wet oxidation in hot mineral acids. This digestion procedure is essentially similar to EPA method 3050A, SW-846 (USEPA 1995) with minor modifications. Mercury was determined by flameless (cold vapor) AAS using the syringe method described by Stainton (1971). Arsenic determinations utilized the hydride generation technique.

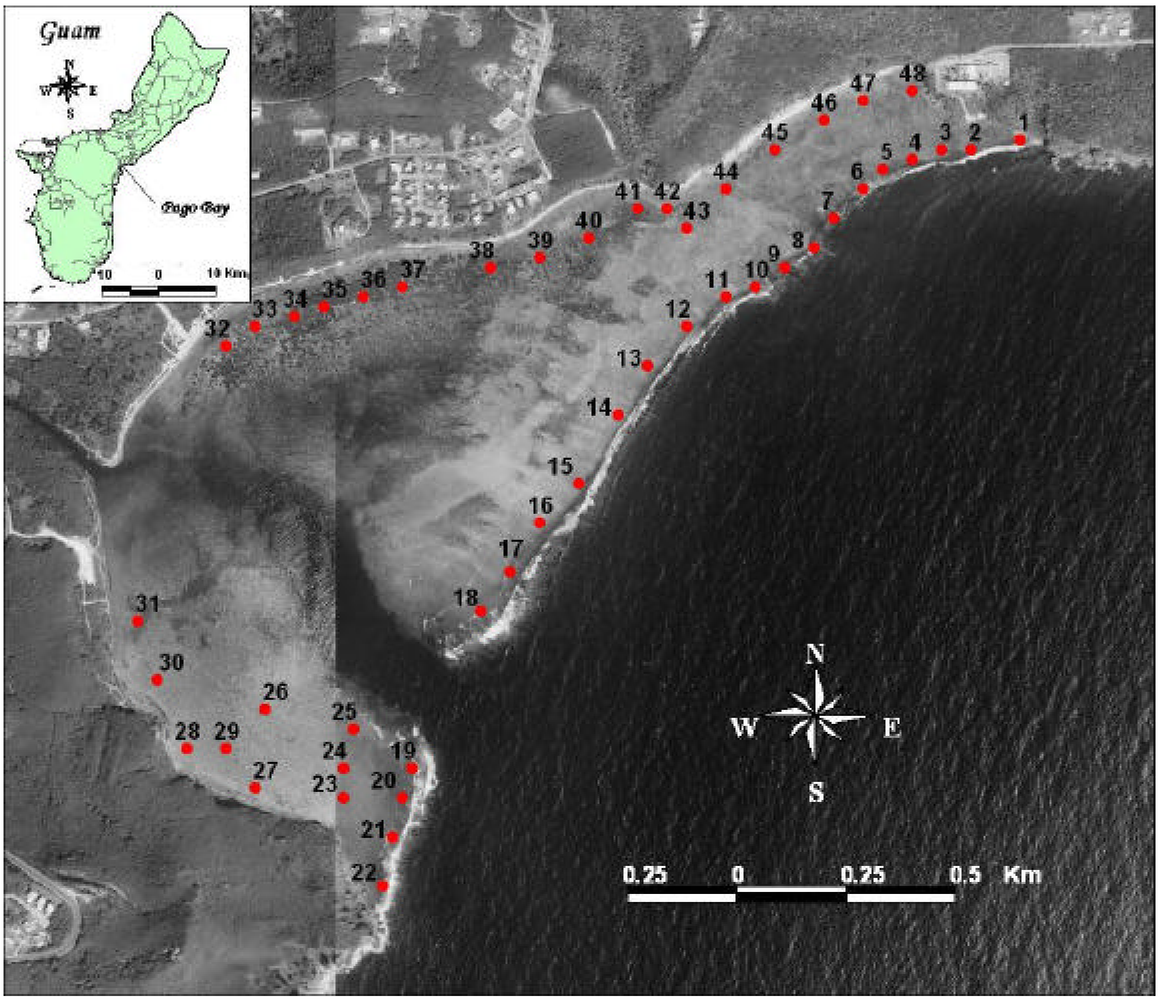

Figure 2: Biota sampling sites within Pago Bay

Appropriate quality control and quality assurance procedures, including full procedural blanks, matrix spikes and certified reference materials, were built into the analytical protocols. All reagents used were analytical grade and all glassware was acid-washed and deionized water rinsed prior to use. Standard stock solutions were purchased from a commercial supplier. Heavy metal recoveries from a biotic standard reference material were within acceptable limits for all elements examined.

Table 1: Flora & Fauna Sampled in Pago Bay During the Present Study

Species	Biota Sites
Algae:	
Acanthophora spicifera	39, 41, 42, 46, 47
Gracilaria salicornia	42, 48
Caulerpa racemosa	10
Caulerpa serrulata	44
Caulerpa sertularioides	48
Chlorodesmis fastigiata	21
Padina boryana	27, 28, 42, 44, 45, 47
Turbinaria ornata	26, 40, 41, 43, 45, 47
Sargassum cristafolium	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22
Sargassum polycystum	23, 24, 25, 37, 39, 40, 41, 42
Seagrass:	
Enhalus acoroides	29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 41
Seacucumber:	
Holothuria atra	4, 6, 12, 13, 16, 17, 19, 20, 22,
Bivalves:	
Asaphia violascens	48
Ctena bella	31, 34, 36, 37
Gafrarium pectinatum	34
Quidnipagus palatum	29, 31, 36, 48,
Scutarcopajia scobinata	36

Principal Findings and Significance

Sediment characteristics varied appreciably from one end of Pago Bay to the other and largely controlled the elemental composition of sediments at each site. At the northern end of the bay, surface sediments were composed largely of bioclastic carbonates (e.g., foraminifera, coral, shells, *Halimeda* debris and calcareous red algae), while volcanic detrital material predominated at the southern end, adjacent to the river mouth (Randall and Holloman 1974). A mixture of the two sediment types occurred to varying degrees in between.

Bioclastic sediments are typically lower in most heavy metals compared with their volcaniclastic counterparts. As a consequence, metal levels determined in sediments from Pago Bay during the current investigation were generally higher in the alluvial deposits around the river mouth and southern shoreline. Certain elements (e.g., arsenic, chromium, copper, iron, manganese) were also marginally elevated at sites impacted by groundwater intrusion. A highly localized zone of mild mercury, lead and zinc enrichment was identified at the northern end of the bay, near the University of Guam Marine Laboratory and WERI. This was thought to reflect the wastewater disposal systems (septic tanks) currently in place there.

The sedimentary data is summarized in Table 2, together with background heavy metal levels normally encountered in coral reef deposits and sediments from the Lonfit River.

The vast majority of data gathered during this investigation fell within the combined natural ranges for these two sediment types. Heavy metal levels found in the biota examined are summarized in Table 3. The data were compared with levels encountered in similar and related species from clean and polluted environments elsewhere (Table 4). It was concluded that metal concentrations in biotic and abiotic components of Pago Bay are generally low by world standards and largely reflect natural contributions associated with alluvial discharges and groundwater intrusion. A more detailed evaluation of the data along is available in Denton *et al*. (2006)

The study clearly demonstrates that Pago Bay is not a permanent sink for sediment bound metal contaminants mobilized downstream from the Ordot Dump. We therefore conclude that any contaminated sediments deposited in and around the river mouth, the reef channel and the southern half of the bay during a normal wet season, are re-suspended and flushed from the system by major storms (typhoons) that approach the eastern side of the island. Under such conditions, the reef channel serves as a conduit for their transportation and dispersion into offshore waters beyond the reef margin. Thus, the climatic and topographic characteristics of the area combine to provide an effective means of periodically flushing out pockets of contaminated sediments from the entire watershed into the ocean. Past concerns of heavy metal accumulation in fisheries recourses in this region are therefore unwarranted.

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Table 2: Baseline Heavy Levels (µg/g dry wt.) in Lonfit River & Coral Reef Sediments Compared with Sediments from Pago Bay

Metal	Lonfit River[a] (lithogenic: volcanics)	Coral Reef[b] (biogenic: carbonates)	Pago Bay[c] (lithogenic/biogenic mix)	Degree of Enrichment in Pago Bay: Location
Ag	<0.1	<0.1	<0.2	None
As	<0.1	0.5-3	<0.2-1.6	None
Cd	<0.2	<0.1	<0.2	None
Cr	50-80	1-5	2-21	None
Cu	50-70	<0.1-3	<0.1-20	None
Fe	50,000-60,000	50-500	203-41,743	None
Hg[d]	20-30	2-10	1-15	V. Mild: N. end
Mn	1,000-1,500	10-50	11-453	None
Ni	60-120	<0.2-3	<0.2-25	None
Pb	<1-2	<1	<0.3-14	Mild: S. end; N. end
Zn	50-70	<1-5	<1-90	Mild: river mouth; N. end

[a] Olsen and Denton in prep; [b] Denton *et al.* 1997, 2001; [c] This study; [d] Mercury concentrations as ng/g dry weight

Table 2: Heavy Metals Levels in Dominant Biotic Representatives from Pago Bay, Guam

Species	Statistic	Metal (µg/g dry wt.)									
		Ag	As	Cd	Cu	Cr	Fe	Hg[a]	Mn	Ni	Pb
ALGAE:											
Acanthophora spicifera	Mean[b]	nc	0.56	0.2	2.13	0.56	470	1.7	11.3	3.75	nc
	Range	all <0.15	0.20-1.72	<0.07-0.47	1.22-3.15	<0.11-1.98	192-877	1.09-2.83	6.38-21.6	3.05-5.20	<0.30-1.36
Gracilaria salicornia	Mean	nc	1.55	nc	0.78	0.54	66.9	2.48	11.3	0.3	nc
	Range	all <0.26	1.43-1.67	all <0.26	0.47-1.17	0.26-1.15	35.2-145	1.74-3.48	7.6-17.5	<0.16-1.07	all <0.58
Caulerpa rasemosa	Mean	nc	1.19	nc	0.98	0.44	436	1.18	10.3	1.4	nc
	Range	all <0.15	1.04-1.53	all <0.15	0.77-1.19	0.39-0.60	345-527	1.17-1.20	8.89-11.7	0.39-0.60	all <0.46
Caulerpa serrulata	Mean	nc	1.82	nc	0.83	nc	470	3.14	12.1	1.92	nc
	Range	all <0.22	1.63-2.22	all <0.22	0.67-0.90	all <0.31	448-517	2.83-3.66	11.2-13.1	1.65-2.16	all <0.48
Caulerpa sertalarioides	Mean	nc	2.88	nc	1.41	0.5	65.5	3.94	14.5	1.58	nc
	Range	all <0.21	2.19-3.48	all <0.21	1.31-1.49	0.30-1.09	62.0-69.5	3.50-4.19	13.6-15.4	1.51-1.65	all <0.46
Chlorodesmis fastigiata	Mean	nc	9.55	nc	2.34	2.14	696	6.63	23.9	1.06	nc
	Range	all <0.15	9.24-9.90	all <0.15	2.29-2.40	1.91-2.40	617-784	6.52-6.81	21.3-26.7	0.95-1.17	all <0.34
Padina boryana	Mean	nc	3.54	nc	1.58	0.48	672	1.73	45.1	2.29	nc
	Range	all <0.18	1.96-11.0	<0.14-0.32	0.74-4.65	<0.21-2.14	262-1828	0.59-2.97	19.0-108	1.56-3.36	<0.27-13.8
Turbinaria ornata	Mean	nc	20.4	nc	0.7	nc	238	3.25	6.4	1.15	nc
	Range	all <0.26	8.58-36.9	<0.14-0.30	0.30-1.95	<0.16-1.83	48.7-1207	1.75-5.20	2.88-18.2	0.49-3.22	<0.30-1.62
Sargassum cristafolium	Mean	nc	85.4	nc	0.88	nc	96.4	2.21	8.45	2.82	nc
	Range	all <0.19	70.9-97.3	<0.14-0.31	0.46-1.63	<0.14-1.20	17.3-653	1.12-3.40	2.61-40.7	0.68-8.00	<0.18-5.22
Sargassum polycystum	Mean	nc	15.8	nc	1.82	1.39	911	2.29	61	3.15	nc
	Range	all <0.26	9.61-22.4	<0.14-0.29	0.92-2.79	0.60-2.66	236-1820	1.72-3.61	29.4-101	1.48-5.01	<0.3-1.51
SEAGRASS:											
Enhalus acoroides	Mean	nc	0.28	nc	1.95	nc	107	1.73	11.2	2.2	nc
	Range	all <0.19	0.10-1.2	all <0.19	0.74-5.7	<0.15-0.60	59.1-273	1.13-3.6	4.61-36.4	1.26-4.30	<0.29-1.10
SEACUCUMBERS:											
Holothuria atra (body wall)	Mean	nc	3.36	nc	1.21	0.19	23.5	2.02	0.51	0.17	nc
	Range	all <0.14	1.77-5.83	all <0.14	0.89-1.62	<0.09-0.32	17.5-39.5	1.13-4.48	0.28-0.82	<0.09-0.37	all <0.28
Holothuria atra (Hemal tissue)	Mean	nc	4.93	nc	5.11	2.85	92.2	16.2	2.06	0.6	0.91
	Range	all <0.8	1.29-11.2	all <0.8	3.75-6.37	0.67-13.6	54.4-292	1.75-52.3	1.00-3.92	0.34-1.16	0.38-<1.10
BIVALVES:											
Asaphia violascens	Mean	0.11	-	0.11	0.16	7.61	971	-	15.2	5.87	0.81
	Range	-	-	-	-	-	-	-	-	-	-
Ctena bella	Mean	nc	5.13	1.2	8.1	nc	66.9	10.7	2.25	12.3	0.55
	Range	all <0.18	4.59-6.89	0.66-2.51	5.79-20.9	all <0.27	55.1-74.3	5.63-17.4	1.63-3.30	7.83-21.2	0.22-1.35
Gafrarium pectinatum	Mean	0.14	-	1.14	0.21	17.0	386	-	22.9	16.4	0.27
	Range	-	-	-	-	-	-	-	-	-	-
Quidnipagus palatum	Mean	nc	16.8	nc	17.5	nc	846	36.9	6.81	nc	0.43
	Range	all <0.13	9.71-27.2	all <0.13	4.26-68.5	<0.12-0.46	601-1292	21.9-62.4	2.92-23.1	<0.12-0.46	<0.20-0.89
Scutarcopajia scobinata	Mean	0.34	-	0.34	1.01	6.07	2178	-	6.07	9.09	0.64
	Range	-	-	-	-	-	-	-	-	-	-

[a] mercury concentrations expressed as ng/g wet weight; [b] mean = geometric mean; nc = not calculable; dashes indicate no data

Table 4: Heavy Metals in Similar and Related Species of Marine Organisms from Guam and Elsewhere

Species	Location	Metal (µg/g dry wt.)											Reference
		Ag	As	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn	
ALGAE:													
Acanthophora spicifera	Pago Bay, Guam	all <0.27	0.20-1.55	<0.16-0.47	<0.21-1.88	1.22-3.03	192-877	1.09-2.83	6.38-21.6	3.05-5.20	0.31-1.36	3.36-8.04	This study
Acanthophora spicifera	Tanapag Lagoon, Saipan	<0.08-0.51	0.53-1.13	<0.13-0.70	<0.26-1.54	2.88-30.5	-	1.86-10.2	-	1.78-2.52	0.49-8.14	17.6-130	Denton *et al.*, in prep.
Gracilaria salicornia	Pago Bay, Guam	all <0.26	1.43-1.67	all <0.26	<0..25-1.15	0.98-1.17	35.2-145	1.74-3.48	7.60-17.5	<0.16-1.07	all <0.58	2.92-8.71	This study
Gracilaria salicornis	Tanapag Lagoon, Saipan	all <0.11	2.19-2.82	<0.07-0.20	<0.23-0.93	1.22-2.90	-	2.42-4.38	-	<0.19-0.52	<0.23-1.17	11.6-24.8	Denton *et al.*, in prep.
Gracilaria sp.	N. Queensland coastal wateres, Australia	all <0.2	-	<0.2-0.8	1.7-4.0	2.3-3.9	1250-2030	-	51.1-94.7	0.3-1.4	all <0.4	11.2-15.6	Burdon-Jones *et al.*, 1975
Caulerpa racemosa	Pago Bay, Guam	all <0.15	1.04-1.53	all <0.15	0.41-0.60	0.77-1.19	345-527	1.17-1.20	8.89-11.7	1.19-1.55	<0.34-1.05	1.86-2.39	This study
Caulerpa racemosa	Gt. Barrier Reef, Australia	-	-	0.17-0.48	-	1.4-2.6	-	22-246	-	0.82-1.6	<0.67-2.4	0.27-10.0	Denton & Burdon-Jones, 1986
Caulerpa serrulata	Pago Bay, Guam	all <0.22	1.66-2.22	all <0.22	all <0.31	0.67-0.90	448-517	3.01-3.66	11.2-13.1	1.65-2.16	all <0.48	1.73-2.12	This study
Caulerpa serrulata	Gt. Barrier Reef, Australia	-	-	0.20-0.49	-	1.0-2.4	-		-	0.78-2.4	all <0.93	1.7-5.2	Denton & Burdon-Jones, 1986
Chlorodesmis fastigiata	Pago Bay, Guam	all <0.15	9.24-9.90	all <0.15	1.91-2.40	2.29-2.40	617-784	6.52-6.81	21.3-26.7	0.95-1.1	all <0.34	4.51-4.72	This study
Chlorodesmis fastigiata	Gt. Barrier Reef, Australia	-	-	0.10-0.50	-	1.4-2.4	-	38-130	-	0.41-1.7	<0.57-2.1	1.3-12.1	Denton & Burdon-Jones, 1986
Padina australis	Gt. Barrier Reef, Australia	-	-	0.4-0.6	-	2.0-3.0	-	1-4	-	1.0-1.4	<0.9-5.0	3.8-9.5	Denton & Burdon-Jones, 1986
Padina boyana	Pago Bay, Guam	all <0.18	1.96-11.0	<0.15-0.32	<0.23-2.14	0.74-4.65	262-1516	0.59-2.97	19.0-108	1.56-3.36	0.27-13.9	2.75-8.27	This study
Padina commersonni	Singapore coastal waters	-	-	0.4-0.6	2.9-6.5	3.8-7.3	112-202	<10[b]	40.8-82.6	4.0-6.5	4.3-7.9	20.7-50.1	Bok & Keong, 1976
Padina gymnospora	Puerto Rico	-	-	-	-	nd	520-5700	-	80.0-150	23.0-32.0	-	-	Stevenson & Ufret, 1966
Padina tenuis	Penang Island, Malaysia	-	-	7.1	25.6	5.7	3328	1025[b]	2844	-	17.1	45.5	Sivalingam, 1978; 1980
Padina tenuis	Townsville coastal waters, Australia	<0.1-0.4	-	0.2-1.4	1.4-10.0	1.4-5.1	355-4037	-	37.8-496	0.7-8.4	<0.3-6.2	3.7-30	Burdon-Jones *et al.*, 1982
Padina tetrostromatica	Goa coastal waters, India	-	-	nd	-	3.2-7.9	389-1005	-	205-531	8.0-18.3	3.0-28.3	4.5-11.7	Agadi *et al.*, 1978
Padina tetrostromatica	Goa coastal waters, India	-	4.8-12.6	nd	-	8.7-20.1	-	-	233-456	nd	nd	20.2-31.5	Zingde *et al.*, 1976
Padina tetrostromatica	Townsville coastal waters, Australia	<0.1-0.4	-	0.2-1.2	1.6-9.9	2.0-11.1	606-8055	-	61.8-554	0.9-4.0	1.1-4.9	5.5-25.7	Burdon-Jones *et al.*, 1982
Padina tetrostromatica	Townsville Harbor (upper reaches)	<0.1	-	<0.4	31.5	58.9	6429	-	818	13.1	108	440	Burdon-Jones *et al.*, 1975
Padina tetrostromatica	Townsville Harbor (lower reaches)	<0.1-0.4	-	0.2-0.6	2.1-9.9	4.4-11.1	-	-	-	0.7-5.6	2.0-10.2	67.2-166	Burdon-Jones *et al.*, 1982
Padina sp.	Lizard Island, Great Barrier Reef	-	-	0.2	-	2.2	-	2	-	1.1	<0.74	5.9	Denton & Burdon-Jones, 1986
Padina sp.	Agana Boat Basin, Guam	0.89	32.2	0.3	0.68	1.53	-	<2	-	1.18	0.46	11	Denton *et al.*, 1999
Padina sp.	Apra Harbor, Guam	all <0.10	5.8-38.1	0.2-0.5	1.3-3.0	2.6-36.6	-	7-26	-	1.1-3.2	2.6-6.5	45.1-192	Denton *et al.*, 1999
Padina sp.	Agat Marina, Guam	<0.10	20.5	<0.1	2.7	4.1	-	<2	-	2.9	<0.25	18.7	Denton *et al.*, 1999
Padina sp.	Merizo Pier, Guam	<0.10	17.4	<0.1	14.1	27.2	-	3.00	-	2.28	8.07	78.3	Denton *et al.*, 1999
Padina sp.	Tanapag Lagoon, Saipan	<0.10-0.29	3.56-12.3	<0.11-1.72	<0.30-1.43	1.30-25.3	-	1.74-6.33	-	0.88-1.65	<0.27-14.7	5.3-107	Denton *et al.*, in prep.
Sargassum conusum	Korean waters	-	-	1.6	-	7	-	-	-	-	5.8	14	Pak *et al.*, 1977
Sargassum cristafolium	Pago Bay, Guam	all <0.16	2.39-117	<0.15-0.31	<0.20-1.20	0.46-1.63	17.3-653	1.12-4.06	2.61-40.7	0.68-5.13	<0.19-2.99	0.76-4.83	This study
Sargassum fulvellum	Korean waters	-	-	2.4-3.0	-	8-19	-	-	-	-	4.2-6.2	11-23	Pak *et al.*, 1977
Sargassum cgrevillei	Penang, Malaysia	-	-	6.4	-	5.2	-	-	-	-	5.2	15.5	Sivalingam, 1978
Sargassum horneri	Korean waters	-	-	1.7-2.7	-	9-25	-	-	-	-	6.7-8.9	28-61	Pak *et al.*, 1977
Sargassum pallidum	Vostok Bay, Sea of Japan	-	-	-	-	4.3	-	-	-	-	-	2.7	Saenko *et al.*, 1976
Sargassum pallidum	Pacific coastal waters	-	-	1.3-5.1	-	1.6-4.3	-	-	-	-	5.5-25.2	2.7-95.9	Khristoforova *et al.*, 1983
Sargassum polycystum	Pago Bay, Guam	all <0.16	9.61-22.4	<0.15-0.29	0.60-2.66	0.92-2.79	236-1765	1.72-3.61	52.6-101	1.48-5.01	<0.31-1.51	2.56-7.01	This study
Sargassum polycystum	Tanapag Lagoon, Saipan	all <0.16	15.6-22.9	0.28-0.40	<0.31-0.57	1.27-1.47	-	0.45-0.88	-	0.81-1.08	0.45-0.51	12.6-15.9	Denton *et al.*, in prep.
Sargassum sp.	N. Queensland coastal wateres, Australia	all <0.2	-	all <0.2	<0.4-3.1	2.2-3.1	1186-1398	-	29.7-48.8	<0.3-1.1	all <0.4	7.0-10.0	Burdon-Jones *et al.*, 1975

[a] mercury concentrations as ng/g wet weight; [b] mercury concentrations as ng/g dry weight; dashes indicate no data

Table 4 (cont.): Heavy Metals in Similar and Related Species of Marine Organisms from Guam and Elsewhere

Species	Location	Metal (µg/g dry wt.)											Reference
		Ag	As	Cd	Cr	Cu	Fe	Hg[a]	Mn	Ni	Pb	Zn	
SEAGRASSES:													
Enhalus acoroides	Pago Bay, Guam	all <0.16	0.10-1.22	all <0.16	<0.15-0.64	0.74-5.73	59.1-273	1.13-3.56	4.61-36.4	1.26-4.26	<0.30-1.07	4.96-16.6	This study
Enhalus acoroides	Tanapag Lagoon, Saipan	all <0.20	0.03-0.19	0.15-0.60	<0.30-0.40	2.15-48.0	-	0.60-2.34	-	0.60-2.34	<0.22-2.05	20.0-33.0	Denton *et al.*, in prep.
Halodule uninervis	Tanapag Lagoon, Saipan	all <0.20	-	0.29-0.66	<0.32-1.09	2.45-6.46	-	0.70-1.25	-	0.70-1.25	<0.32-1.09	21.1-35.8	Denton *et al.*, in prep.
Halodule uninervis	Cleveland Bay, Townsville, Australia	<0.3	-	0.5	1.6	2.7	1995	-	96.0	0.7	7	11.0	Denton *et al.*, 1980
Halodule pinifolia	Lockhardt River, Cape York, Australia	0.1	-	1.1	2.3	7.7	2010	-	46.0	4.9	3.6	26.0	Denton *et al.*, 1980
Halophila ovalis	Lockhardt River, Cape York, Australia	<0.2	-	0.5	1.0	9.0	4418	-	68.0	1.7	1	67.0	Denton *et al.*, 1980
Zostera capricornia	Upstart Bay, N Queensland, Australia	<0.2	-	0.2	0.9	3.0	5250	-	70.0	0.6	0.4	18.0	Denton *et al.*, 1980
Zostera capricornia	Shoalwater Bay, N. Queensland, Australia	<0.2	-	0.2	1.9	2.8	3500	-	44.0	1.8	0.4	14.0	Denton *et al.*, 1980
SEACUCUMBERS:													
Bohadschia argus (muscle)	Apra Harbor, Guam	all <0.13	7.8-17.7	0.1-0.1	<0.2-0.4	0.6-2.3	-	5-5	-	1.0-1.4	<0.3-0.6	13.8-18.0	Denton *et al.*, 1999
Bohadschia argus (muscle)	Small boat marinas, Guam	all <0.10	all <0.01	0.10-0.10	<0.10-0.10	0.6-0.9	-	1-7	-	0.3-1.1	all <0.4	8.3-16.6	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Apra Harbor, Guam	all <0.14	16.6-32.6	0.32-0.39	7.28-31.9	2.84-39.0	-	221-459	-	0.43-1.21	<0.33-0.88	41.4-374	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Small boat marinas, Guam	all <0.14	<0.10-0.20	0.18-0.28	6.27-12.6	2.25-3.47	-	6-96	-	0.39-0.90	all <0.37	40.6-96.8	Denton *et al.*, 1999
Bohadschia argus (muscle)	Tanapag Lagoon, Saipan	<0.09	7.45	<0.09	<0.37	0.86	-	3.42	-	0.30	<0.14	15.9	Denton *et al.*, 1999
Bohadschia argus (hemal system)	Tanapag Lagoon, Saipan	<0.11	0.59	0.32	4.27	2.48	-	36.3	-	0.44	<0.36	44.2	Denton *et al.*, 1999
Bohadschia mormorata (muscle)	Tanapag Lagoon, Saipan	all <0.12	1.03-10.1	<0.3-0.74	<0.30-0.71	0.45-2.01	-	0.54-3.04	-	0.65-1.11	<0.12-0.88	9.92-41.5	Denton *et al.*, in prep.
Bohadschia mormorata (hemal system)	Tanapag Lagoon, Saipan	all <0.09	0.60-12.1	<0.11-3.72	3.14-29.7	2.34-5.63	-	39.0-321	-	0.47-3.39	<0.30-10.3	93.4-503	Denton *et al.*, in prep.
Holothuria atra (muscle)	Pago Bay, Guam	all <0.14	1.77-5.83	all <0.14	<0.09-0.30	0.89-1.62	17.5-39.5	1.13-4.48	0.28-0.82	<0.09-0.27	all <0.28	12.8-17.8	This study
Holothuria atra (hemal system)	Pago Bay, Guam	all <0.78	1.29-11.2	all <0.78	0.67-13.6	3.75-6.37	54.4-144	3.16-52.3	1.07-3.19	<0.49-1.16	all <1.57	56.9-301	This study
Holothuria atra (muscle)	Apra Harbor, Guam	all <0.12	13.6-23.2	<0.1-0.1	<0.1-0.3	0.7-1.2	-	7-8	-	<0.2	all <0.3	15.5-17.9	Denton *et al.*, 1999
Holothuria atra (hemal system)	Apra Harbor, Guam	<0.35-4.90	7.24-28.3	0.25-0.26	2.21-8.58	4.70-5.19	-	49-88	-	all <0.50	all <0.92	120-180	Denton *et al.*, 1999
Holothuria atra (muscle)	Small boat marinas, Guam	<0.01-0.24	all <0.01	<0.1-0.1	all <0.20	1.3-2.5	-	8-22	-	all <0.20	all <0.60	12.6-21.2	Denton *et al.*, 1999
Holothuria atra (hemal system)	Small boat marinas, Guam	<0.11-0.72	<0.01-0.18	0.09-0.12	0.08-3.14	3.69-6.37	-	16-91	-	all <0.43	all <0.72	117-253	Denton *et al.*, 1999
Holothuria atra (muscle)	Tanapag Lagoon, Saipan	all <0.13	0.61-15.4	all <0.13	<0.28-0.69	0.96-3.10	-	<0.48-4.55	-	<0.12-0.45	<0.15-2.09	13.1-24.1	Denton *et al.*, in prep.
Holothuria atra (hemal system)	Tanapag Lagoon, Saipan	<0.07-0.25	0.12-2.04	<0.08-0.25	<0.26-4.99	3.11-11.2	-	5.53-63.2	-	<0.12-0.77	<0.11-6.33	29.8-287	Denton *et al.*, in prep.
Holothuria sp. (whole)	Townsville coastal waters, Australia	all <0.2	nd	<0.2	<0.3-6.3	<0.3-3.5	-	-	-	all <0.5	<0.4-3.8	13.9-39.4	Denton, unpublished data
Molpadia intermedia (muscle)	Georgia Strait, Vancouver (dump site)	-	-	1.7	2.2	26	-	-	-	1.7	1.4	171	Thompson & Paton, 1978
Stichopus variagatus (muscle)	Gt. Barrier Reef, Australia	-	-	all <0.1	-	1.5-2.1	-	<1-3	-	all <0.5	all <0.90	1.9-13.9	Burdon-Jones & Denton, 1984
BIVALVES:													
Asaphia violascens	Pago Bay, Guam	0.11	-	0.11	0.16	7.61	971	-	15.2	5.87	0.81	72.9	This study
Asaphia violascens	Tanapag Lagoon, Saipan	0.99-1.32	-	0.62-0.70	11.9-12.2	26.5-73.3	-	-	-	5.07-7.35	68.1-102	220-332	Denton *et al.*, in prep.
Ctena bella	Pago Bay, Guam	0.09-0.12	4.59-6.89	0.11-2.51	0.14-0.18	5.79-20.9	55.1-74.3	5.63-17.4	1.63-3.03	7.83-21.2	<0.20-1.35	112-289	This study
Ctena bella	Tanapag Lagoon, Saipan	0.33-0.81	0.92	1.16-2.71	0.82-0.92	5.31-14.1	-	22.0	-	4.40-5.57	5.94-6.38	384-430	Denton *et al.*, in prep.
Gafrarium pectinatum	Pago Bay, Guam	0.14	-	1.14	0.21	17	386	-	22.9	16.4	0.27	59.6	This study
Gafrarium pectinatum	Tanapag Lagoon, Saipan	<0.14-0.62	2.64-4.42	0.78-1.79	0.58-1.31	6.69-35.3	-	9.91-23.3	-	10.6-14.1	7.97-46.9	42.3-62.6	Denton *et al.*, in prep.
Gafrarium tumidum	Magnetic Island, N. Queensland, Australia	5.7	-	0.3	1.6	7.1	1066	11.9	64.5	3.1	68.8	-	Burdon-Jones *et al.*, 1975
Gafrarium tumidum	Red Rock Bay, Townsville, Australia	5.3	-	0.3	0.6	7.7	787	14.5	145	5.1	26.3	-	Burdon-Jones *et al.*, 1975
Quidnipagus palatum	Pago Bay, Guam	<0.08-0.13	9.71-27.2	<0.08-0.10	<0.13-0.46	4.26-68.5	601-1292	21.9-62.4	2.92-23.1	10.4-24.7	0.20-0.89	93.6-341	This study
Quidnipagus palatum	Tanapag Lagoon, Saipan	0.32-24.1	1.67-3.24	0.16-1.40	4.46-10.6	14.7-1876	-	33.6-111	-	7.30-13.1	9.01-184	305-1027	Denton *et al.*, in prep.

[a] mercury concentrations as ng/g wet weight; dashes indicate no data

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Anthropogenic Impact on nitrogen cycle in Tumon Bay using 15N, and 14 N isotopic ratio method.

Basic Information

Title:	Anthropogenic Impact on nitrogen cycle in Tumon Bay using 15N, and 14 N isotopic ratio method.
Project Number:	2005GU55B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Toxic Substances, None
Descriptors:	Nitrogen 15 isotope, algal bloom
Principal Investigators:	Maika Vuki, Gary Denton

Publication

1. Author (Vuki, Maika; Denton, Gary, Wood, Rick, Emmanuel, Jacqueline; Limtiaco, John; 2006, Anthropogenic impact on Nitrogen cycle in Tumon Bay using the Nitrogen 15 isotope studies. WERI, University of Guam, Mangilao, Guam, USA (in preparation)

PROJECT SYNOPSIS REPORT

Project Title: Anthropogenic Impact on nitrogen cycle in Tumon Bay using ^{15}N and ^{14}N stable isotope method.

Problem and Research Objectives

Tumon Bay, on the western shore of northern Guam, is the major tourist hub on Guam. Approximately one million tourists visit Guam every year and most of them spend their time at Tumon Bay. More than 25 hotels are located in this area together with a vast array of shopping outlets, restaurants, and recreational facilities. Maintaining the natural beauty of Tumon Bay is, therefore, tantamount to maintaining a healthy economy and has become a top priority in recent years. In the middle of 2004 a major road works was completed on the Southern end of the main road and a new shopping mall will soon be built along the cliff edge beside John F Kennedy High School. These new developments will contribute to the already heavy impact of nutrients and other less desirable elements in the estuarine along the bay. The presence of stands of green alga along the shoreline of Tumon Bay is already obvious and is a major concern. The alga, *Enteromorpha clathrata,* is not a recent invader. It occurs naturally on Guam although it's increased presence and abundance in Tumon Bay appears to have paralleled the commercial developments that have occurred in the area over the last 30 years.

Another possible contributing factor to nutrient enrichment is the discharge of ground water from the northern lens aquifer through springs and seeps along the northern part of the island. There are more than ten major springs and numerous small seeps that flow into Tumon Bay. These groundwater springs are naturally enriched with nitrate – the nutrient traditionally believed to be responsible for the algal problem in Tumon Bay (Fitzgerald 1976). However, there is no clear evidence due to the increasing population of *E. clathrata* in the recent years. The alternative explanation based on phosphorus as the nutrient of primary concern also requires more data due to the increasing use of fertilizer in this area. Under natural conditions phosphorus levels in Guam's groundwater are probably low enough to limit algal growth in the Bay for much of the year. However, with the advent of bayside hotels and concomitant increases in landscaping activities, phosphorus enrichment associated with excessive fertilizer applications is suspected to have occurred in this area.

A study conducted by Denton in 2000 on Tumon bay show significant levels of nitrates in the spring water, enough to sustain algal growth. However, phosphorus levels were very low that could have significant limiting effect on the estuarine. The study also showed the rapid decline in the phosphorus level levels towards the open sea, which was reported to be due biological and chemical processes. However, there is no clear evidence from the data on the contributing factor to the increasing algal growth.

A major limitation on previous nutrient studies on Tumon bay (and in Guam waters, in general) is the ability to establish the source of pollution. For example, the source of nitrogen that contributes to the increased growth *E. clathrata* is speculated to be due to increased development along the bay but there is still limited evidence. Knowing the source of the nitrogen or nitrates would provide a better understanding of addressing the problem. One approach of establishing the source of nitrogen will be to conduct an isotopic ratio ($^{15}N/^{14}N$). Nitrogen has two stable isotopes in the environment, ^{14}N and ^{15}N. The dynamics of the nitrogen cycle in the environment gives a very stable ratio between the two isotopes. Anthropogenic sources of nitrogen have a very distinctive ^{15}N delta values. Previous studies have shown that the isotopic ratio of nitrogen could provide a clear distinction between nitrogen sources from human and animal waste compared to inorganic sources such as fertilizer. By analyzing the isotopic ratio and the different form of nitrogen in the various components in the environment (water, plants, fish) could provide a signature for the movement of nitrogen in the nutrient cycle. Such measurement could be made in an area like Tumon bay to establish the links to possible sources and the mechanism of nitrogen transfer in the ecosystem

The aims of this study are

1. To determine the different forms of nitrogen compounds in the water system on Tumon Bay. This will involve determining the levels of nitrates, nitrites and ammonia in all the possible inputs including those that has been studied
2. To determine the isotopic ratio of stable nitrogen isotopes, ^{15}N and ^{14}N at the different components of the nitrogen cycle (water, plants, fish, invertebrates) in order to discriminate the contribution of human or animal waste nitrogen from fertilizer and industrial nitrogen
3. To determine the mechanism of nitrogen uptake through the different levels of the nitrogen cycle based on the data collected.
4. To compare the findings with previous data on the levels of nitrogen containing nutrients

Methodology

Samples were collected from the Tumon Bay and treated for chemical analysis. There were 10 sites selected. Water samples for nutrient studies were filtered and analysed using an FIA the nutrient analyser at the WERI laboratory. This was carried out to determine the levels of nitrates, nitrites, phosphate, and ammonia in the water samples. Another set of water samples were collected and treated with sulfuric acid and stored at cool temperature before shipment for stable isotope analysis. In addition to the water samples, some plants, alga, and sediment were also collected and dried for stable isotope analysis. All the stable isotope analyses were carried out at the Coastal Science Laboratory at Austin Texas.

Principal Findings and Significance

Results from this study will provide stakeholders such as major hotels, tourist tour operators and tourists on the actual sources of nitrogen in the environment. At least the contribution from human and animal waste as opposed to fertilizer could be differentiated. This will allow hotel operators and municipal authority to know the impact

of specific activities along the bay area, e.g. fertilizer application, sewage discharge, etc. It could help minimize the algal growth that is a growing concern along the bay.
The study will enhance the analytical capability of the WERI laboratory. This method has a great potential to compliment some of the existing data that lack conclusive evidence of nitrogen source or sources. It would also provide excellent training for undergraduate and graduates students at the University of Guam on analytical and environmental studies.
Preliminary analysis of data appears to show that the nitrogen from the spring waters and estuarine waters have similar delta ^{15}N values. The higher delta ^{15}N values could also imply that the major nitrogen sources could be organic.
Two undergraduate students were also trained in chemical analysis and research methodology during this project. One of them has been accepted to pursue his PhD at graduate school in the US.

Developing Digital Watershed Atlas for Guam

Basic Information

Title:	Developing Digital Watershed Atlas for Guam
Project Number:	2005GU56B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Engineering
Focus Category:	Models, Management and Planning, Surface Water
Descriptors:	Watershed management, Drainage, Water Resources Development, Resource Planning
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz, Yuming Wen

Publication

1. Khosrowpanah, shahram; Yuming Wen, 2005, Digital Atlas: A Useful Tool for Examining Southern Guam Streams, College of Liberal Arts and Social Sciences 27th Annual CLASS Conference, 6pp.

PROJECT SYNOPSIS REPORT

Project Title: Developing A Digital Watershed Atlas for Guam

Problem and Research Objectives

Protecting streams from pollution, soil from erosion, and the coastal environment from degradation requires an effective management plan. An effective management plan requires accurate baseline information. This information should be stored and formatted in such a way that it could be easily available for any water resources study such as; watershed planning and management, estimating upland erosion, and impacts of mans activities on the quality and quantity of the streams and lake. In addition, the information should be stored in such a way that it could be easily updated and will be available to all interested agencies and researchers. During the 1990s, geographical information systems (GIS), with their ability to pull spatial data from different sources into an integrated environment, emerged as significant tools for hydrologic modeling. Particularly, GIS provided a consistent method for watershed delineation using digital elevation models (DEMs). A GIS can be visualized as a series of transparent overlays placed over a map of an area being investigated. Each overlay contains data describing a particular parameter of interest, e.g. one overlay for rainfall amount, a second for ground slope, etc., etc. The relationship and interactions between parameters can be easily modeled and explored. However, in order that GIS user's can take the best advantage of the layers that have been inputted into the GIS data base, it requires that all the layers be projected in a common agreed upon projection. The overall objective of this project was to create a digital atlas of Southern Guam's watershed by using GIS technology that includes the watershed boundary with its physical and environmental components. To accomplish the goal several steps were taken such as: a) identify the map projection and a digital elevation model (DEM) that should be used for developing atlas, b) develop watershed boundaries for all major basin in South Guam, c) develop physical characteristics of each watershed such as vegetation, soil types, river miles, badlands, roads, and location of stream gages.

Methodology

To accomplish the goal of the project several steps were taken. The first step was to form a core user group for atlas development. At the startup of the project, the researchers put together a committee with representatives from Government of Guam and other related agencies. The role of this committee was to determine: a) the best available source of digital elevation data, b) the map projection to be used for the development of the atlas, c) what are the smallest sub-watersheds that should be considered, d) what data layers should be included in the atlas and, e) how will the data be made available to the users and the general public. The core group met several times during the project period. The second step was developing physical characteristics of the southern Guam's watersheds. During this phase the layers that describe the physical characteristics of the southern Guam watersheds were put together. This included developing**;** a) standard Digital Elevation Model (DEM) set for the island, b) watershed boundaries for all major basins in South Guam, c) stream maps for all the major streams, e) layers showing river mile locations for all major streams, f) stream profiles (graphs of elevation vs. river mile) for all major rivers, and g) slope and slope aspect maps for all of South Guam. All the data in phase II was collected from the previous studies and field works that have been done on Guam. The last step was to projecting all the layers into one common projection system that was determined by the core group.

Principal Findings and Significance

A core user group was established, and three user group meetings were organized to determine an existing digital elevation model (DEM) data with the best spatial resolution we could get. The DEM data obtained from US Geological Survey (USGS) with a horizontal spatial resolution of 10 meters has been used to delineate the watershed boundaries in the Southern Guam. According to the agreement made among the core user group members, the projection used for the watershed atlas is UTM, and the datum is North American Datum 1983 (NAD83). Arc Hydro data model and hydrology functions in Spatial Analyst extension for ArcGIS 9x were used for watershed delineation. The watersheds' hydro edges were determined by using the digital elevation model, and referenced to the previously determined Flood and Emergency Management Agency's (FEMA) watershed boundaries. Some minor errors were corrected by referencing contour lines. The watershed delineation resulted in 14 watersheds in the southern Guam (Figure 1). Available GIS datasets such as DEM (Figure 2), rivers (Figure 3), soils (Figure 4), stream gage stations (Figure 5), vegetation (Figure 6), roads and satellite images were input to the digital watershed atlas for each watershed. Slope and aspect information was created from the DEM data. The completed watershed atlas will be available to the public, and a primary source for watershed management and planning, soil erosion simulation, assessment of contamination in rivers or watersheds, government's decision-making support systems, etc.

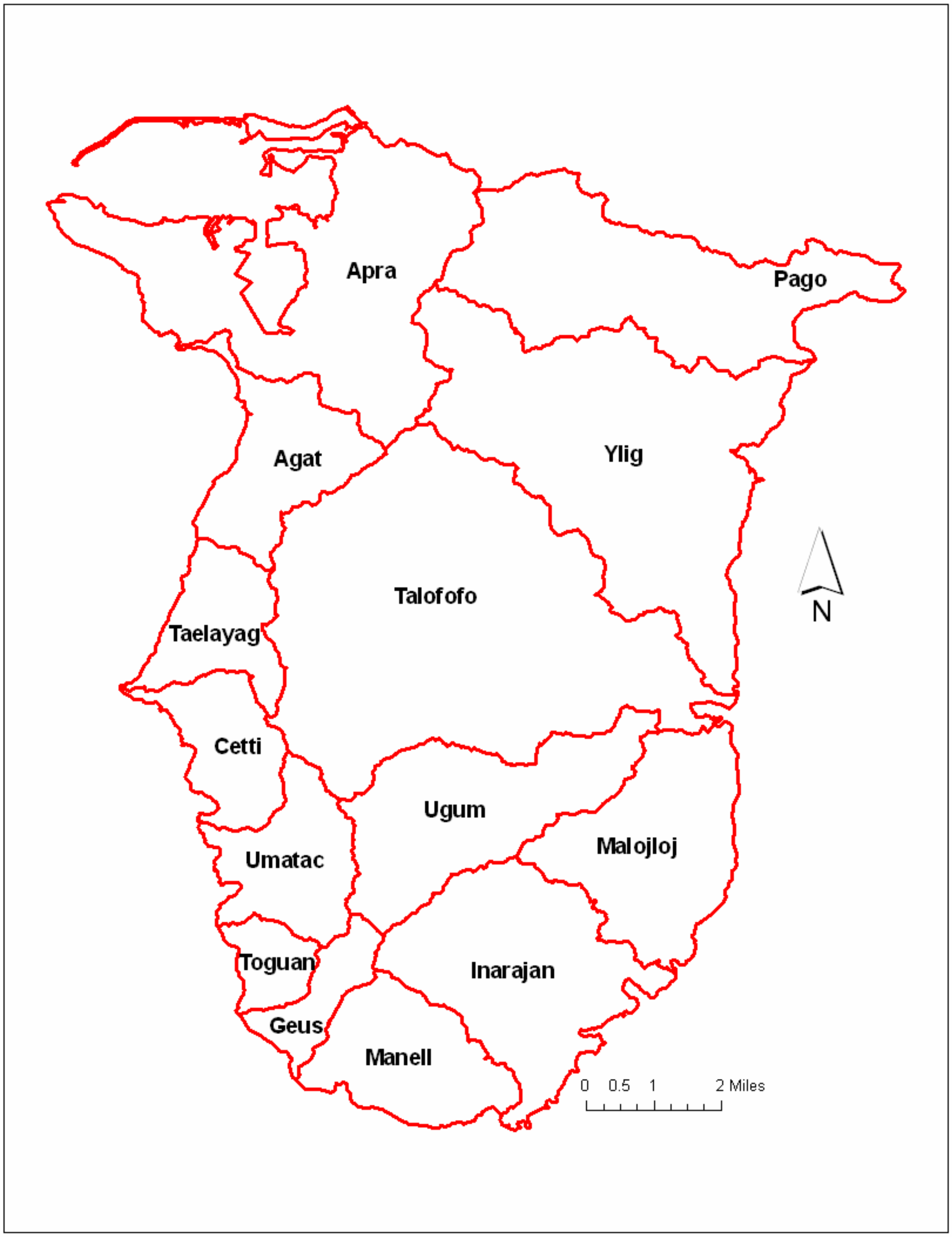

Figure 1. Delineated Watersheds in Southern Guam.

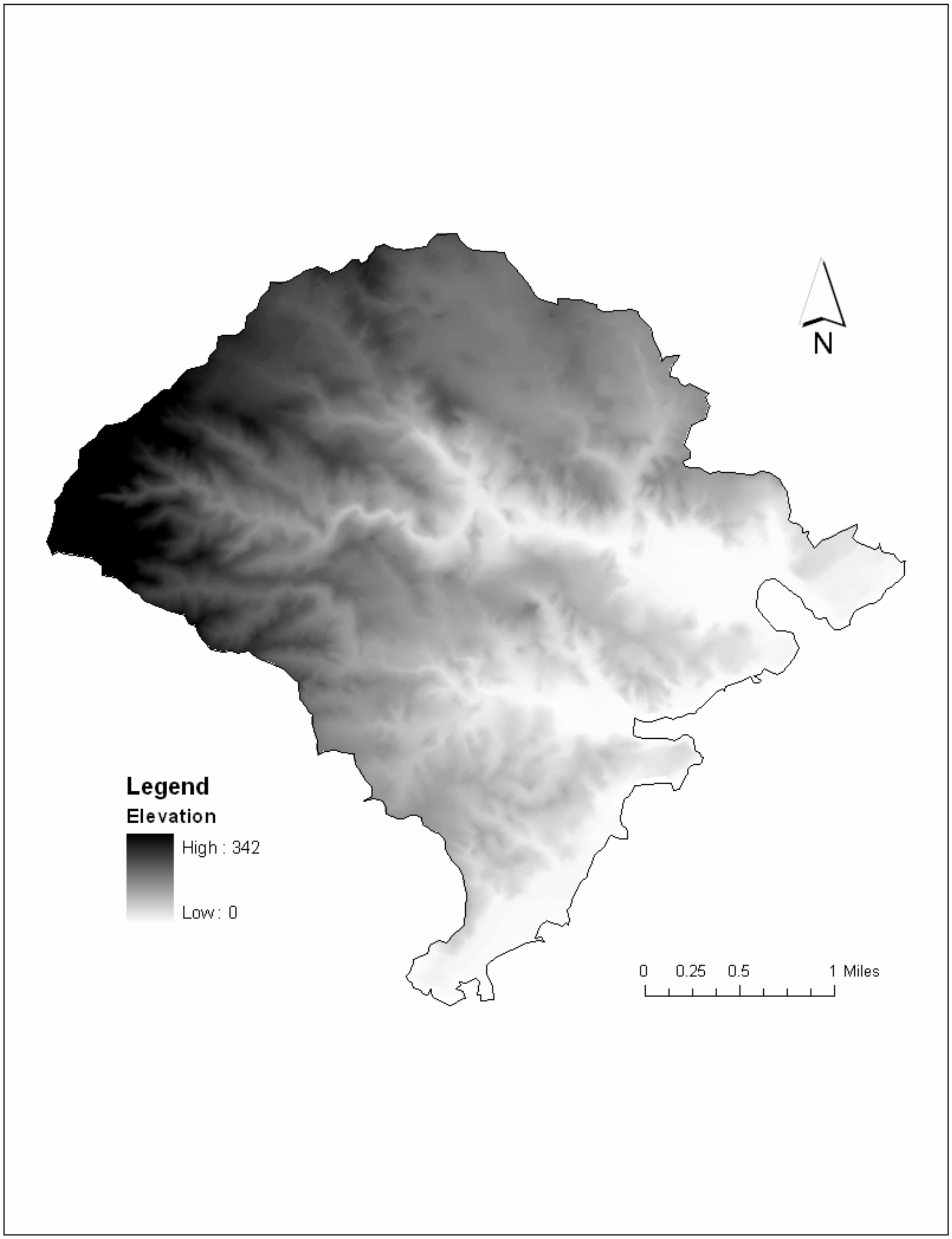

Figure 2. Digital Elevation Model (DEM) date for Inarajan Watershed.

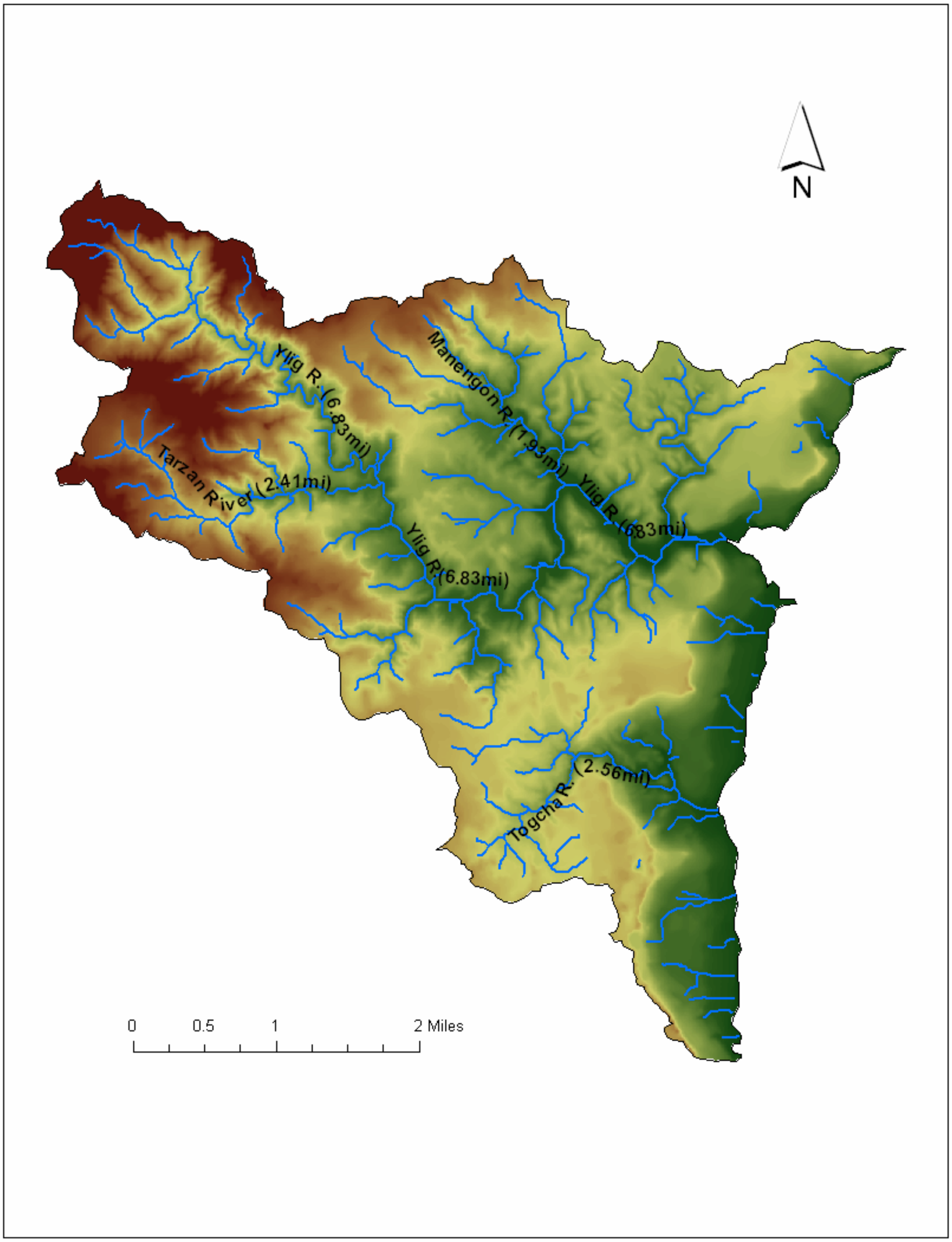

Figure 3. Rivers with River Miles in Ylig Watershed.

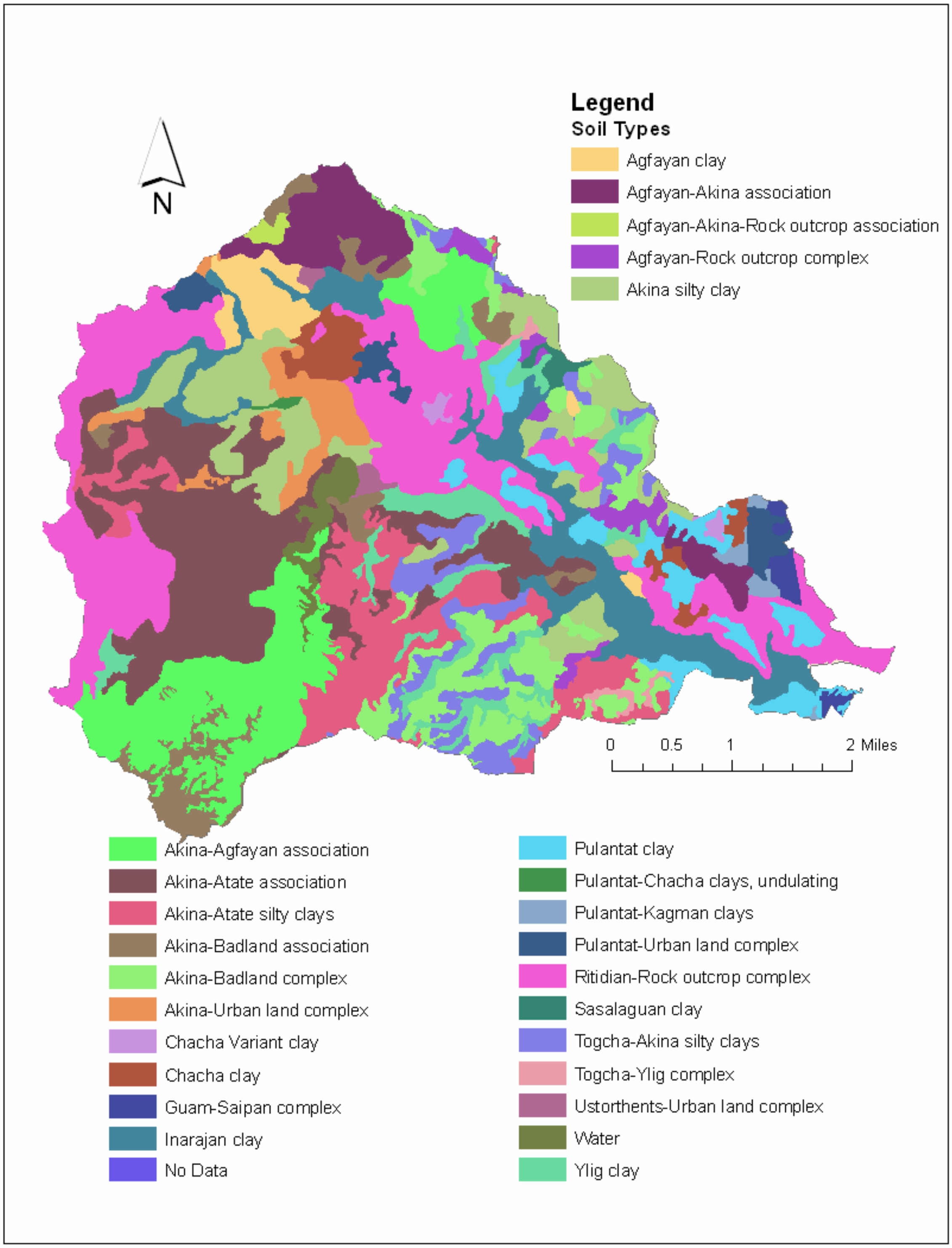

Figure 4. Soils in Talofofo Watershed

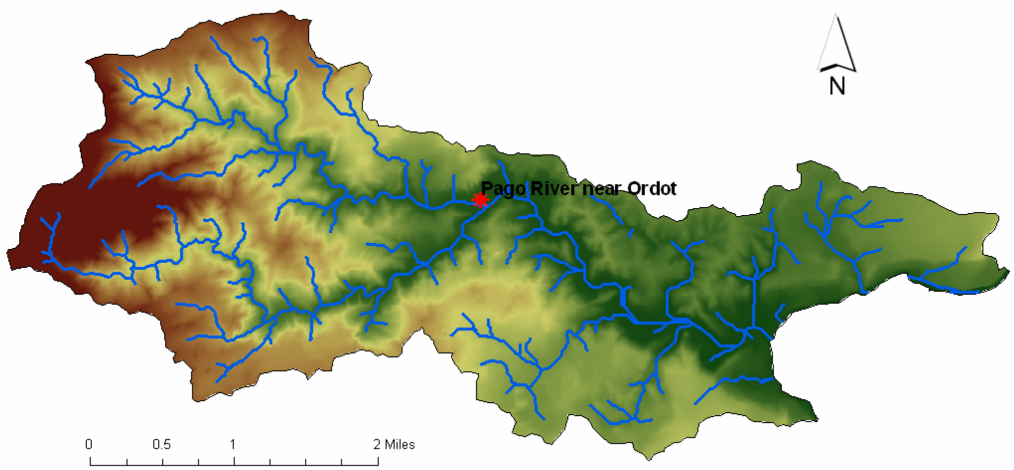

Figure 5. Stream Gage Station in Pago Watershed

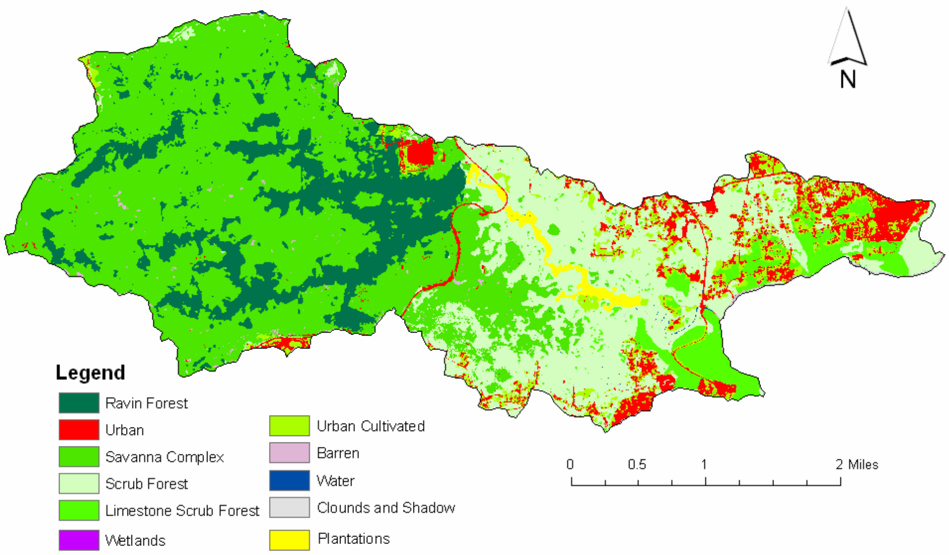

Figure 6. Vegetation in Pago Watershed

Watershed Management for Enipein Watershed, Pohnpei Island, the Federated States of Micronesia

Basic Information

Title:	Watershed Management for Enipein Watershed, Pohnpei Island, the Federated States of Micronesia
Project Number:	2005GU58B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Sediments, Management and Planning
Descriptors:	Watershed Management, Land Use, Sedimentation, Rivers
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz, Mark Lander

Publication

1. Khosrowpanah, Shahram; Mark, Lander; Leroy, Heitz, 2005, Pohnpei The Wettest Island on Earth? Tools for Managing Watershed, Institutions for Sustainable Watershed Management: Reconciling Physical and Management Ecology in the Asia Pacific, AWRA Summer Specialty Conference, Honolulu, Hawaii, 1-7pp.
2. Lander, Mark; Shahram, Khosrowpanah, 2005, Is there a Pot of Gold at the end of Pohnpeis Rainbow, College of Liberal Arts and Social Sciences 26th Annual Research Conference, 4pp.

PROJECT SYNOPSIS REPORT

Project Title: Watershed Management for Enipein Watershed, Pohnpei Island, the Federated States of Micronesia

Problem and Research Objectives

The Enipein Watershed Basin (shown in the figure 1 and 2), situated in the Kitti Municipality in the South of Pohnpei Island, is home to around 1,000 people. This area of approximately 10 square miles boasts one of Pohnpei's most remarkable watersheds, which includes unique native forests, a spectacular web of rivers, steams and fresh water swamps, and extensive mangrove forests, sea grass beds and coral reefs. According to the Conservation Society of Pohnpei (CSP) many of Pohnpei's 110 endemic plants and 13 endemic bird species along with thousands of other terrestrial and marine creatures are found in this area. The Enipein Watershed is also unique in that the area actually encompasses part of the Pohnpei Watershed Forest Reserve, and the whole of the Enipein Mangrove and Marine Sanctuary/Park and the Nahtik Marine Protected Area.

With Pohnpei's growing population and the resident's ever-increasing need for cash, the Enipein watershed's fragile habitats and invaluable resources are becoming highly threatened. In recent years large areas of native forests and ecologically sensitive areas are being cleared for housing and road development projects and unmanaged agricultural activities (e.g., sakau/kava plantations). These new development activities are now negatively impacting the biodiversity health of the area, the freshwater resources, as well as the mangrove forests and coral reefs. But more importantly to the people of Enipein are the serious health risks and economic costs caused by these unregulated development activities. The Cholera outbreak of 2000, which was born in the Enipein Community due to unsanitary water sources, ultimately took over the entire island and resulted in numerous cases and several deaths and substantial financial losses to the government. There are also a growing number of landslides in the area which are contributing to increased soil erosion, poor water quality and adding probable danger to the lives of the people of Enipein. Sediment eroded from the watershed accumulates on reefs offshore, which could have a negative impact on mangrove swamps, fisheries, and corals.

To implement any watershed management scheme to protect the Enipein fragile environment requires having a better understanding of the physical and environmental components of the watershed. The objectives of this project were to: 1) install stream flow, sediment, and rain gages for selected sites within the Enipein Watershed; 2) monitor the gages and develop stage discharge rating curves for selected sites; 3) develop a correlation between stream flow, sediment load and rainfall; and 4) develop a hydrologic database for future use. The baseline information will be used for future comparison between Enipein watershed and other watersheds that have less human activity such as the some of the watershed in Madolenihmw. The results will reveal the impact of the various activities such as land clearing, land slide/slope failures, and population growth on the quality of the watershed.

Methodology

The methodology that was used for completing the project was: site selection, instrument installation, training CSP personnel for data collection, data collection and analysis, and finally development of a database for future use. Within the Enipein watershed there are two streams that join together in a mangrove swamp before draining onto the reef as shown in Figure 1 and 2. We selected two sites for installing the instruments. The criteria for site selection were: easy accessibility, natural or man-made protection from flooding; close proximity of stream-flow and rain gages; and locations in the streams where the cross sectional area could be easily measured.

The cross section description of each of the selected sites was surveyed using standard level and stadia surveying methods. The distance between the two sites was measured and recorded and cross sectional data and plots were developed for each of the sites. Two level loggers were installed at each of the selected cross sections. The location and elevation of each level logger was surveyed and recorded. The function of the level logger is to measure the changes of the river depth versus time. The level logger stores the data internally on site for downloading at a later date. We found that the loggers could easily hold two months of data between downloads. To make necessary adjustment for barometric pressure changes, a barometric logger was installed at a site close to the stream-monitoring site. All Level data was taken at 15 minute intervals. Two personnel from CSP were trained in downloading the data from the level loggers. They were also trained in stream flow measuring techniques. The hand streamflow measurements were used in the development of a rating curve of flow vs. level for the sites where the loggers were installed. Direct streamflow measurements were made on a monthly basis and the level and baro-loggers were downloaded every other month.

Two recording tipping bucket rain gages were installed in the basin (see Figure 2) and the data from the gages were used to develop a correlation between the water level and flow changes in the stream and rainfall. The rainfall data, which had 1-second time resolution, was downloaded from the gages as frequently as every two months. The level of turbidity of each stream was measured using a field turbidimeter.

Principal Findings and Significance

The first goal was to develop a stage discharge rating curve for flow at the selected site. Having a rating curve and the level of water (using level logger data) will enable us to estimate the flow rate at the selected site. To do this, we first determined the elevation differences between the two selected sites from the level loggers. Using a roughness calculation (Chow, 1959) we estimated the Manning's roughness coefficient between the two selected sites (n=0.06). We ran a standard step backwater calculation between the two sections and we determined the value for flow rate by trial and error between the two sections. This process needs to be continued for a longer time in order to have a better relationship between flow and the depth of water. To improve the accuracy of the calculated rating we measured the flow rate at the selected site using a portable flow meter on a monthly basis. The measured values were compared to those determined using the backwater calculation techniques. The data collection and analysis will be continued until a reliable rating curve has been developed.

The relationship between streamflow and rainfall was also examined. As shown in Figure 3, there is a close relationship between rainfall and changes in streamflow at the recording site. Figure 3 shows that the response of the watershed to rainfall is very rapid. This flashy response characteristic could cause rapid flooding in the stream and also elevated soil erosion. Since the watershed response is very fast, any of man's activities such as clearing the land will have a huge impact on the stream's water quality as well as the mangrove forests and coral reefs that they streams drain into. At the present time we are collecting stream turbidity data and a relationship between rainfall, stream flow and level of turbidity for the stream will be develop as more data is collected.

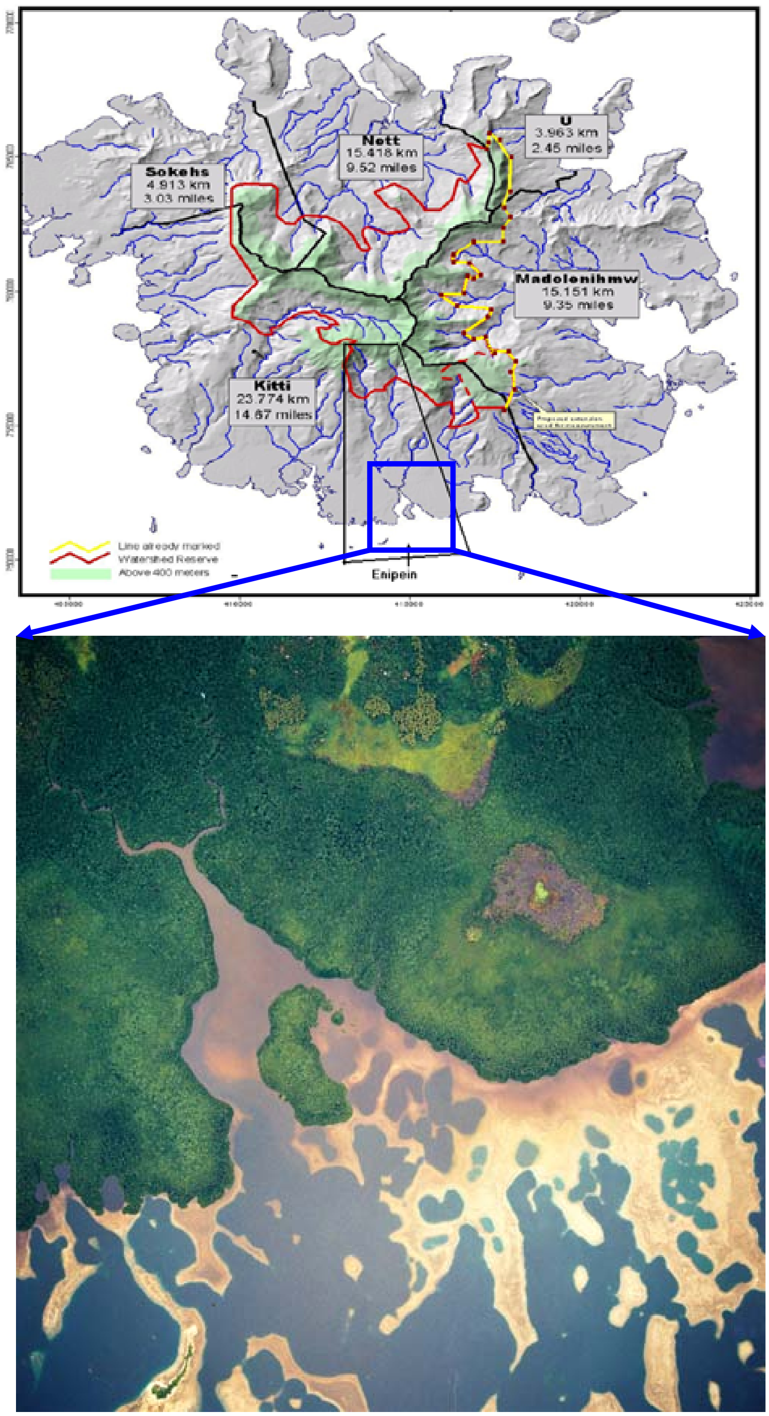

Figure 1. Enipein Watershed, Kitti Municipality, Pohnpei Island.

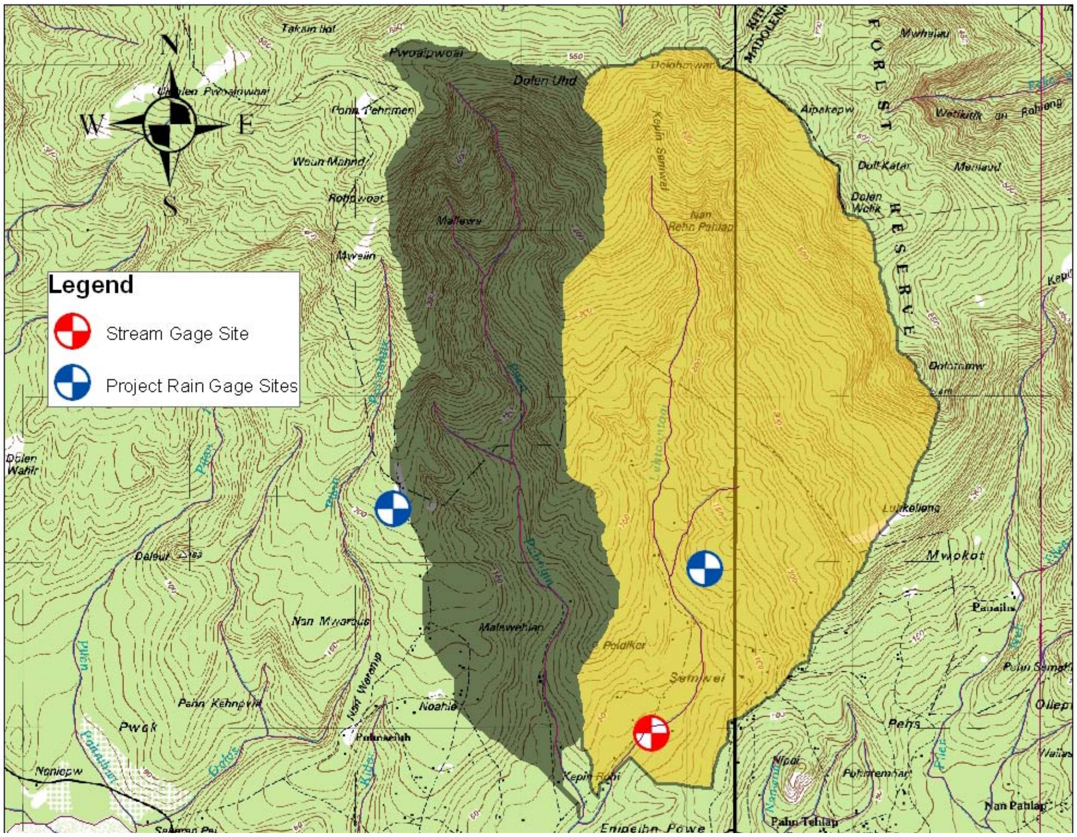

Figure 2. Enipein watershed boundary and gage locations.

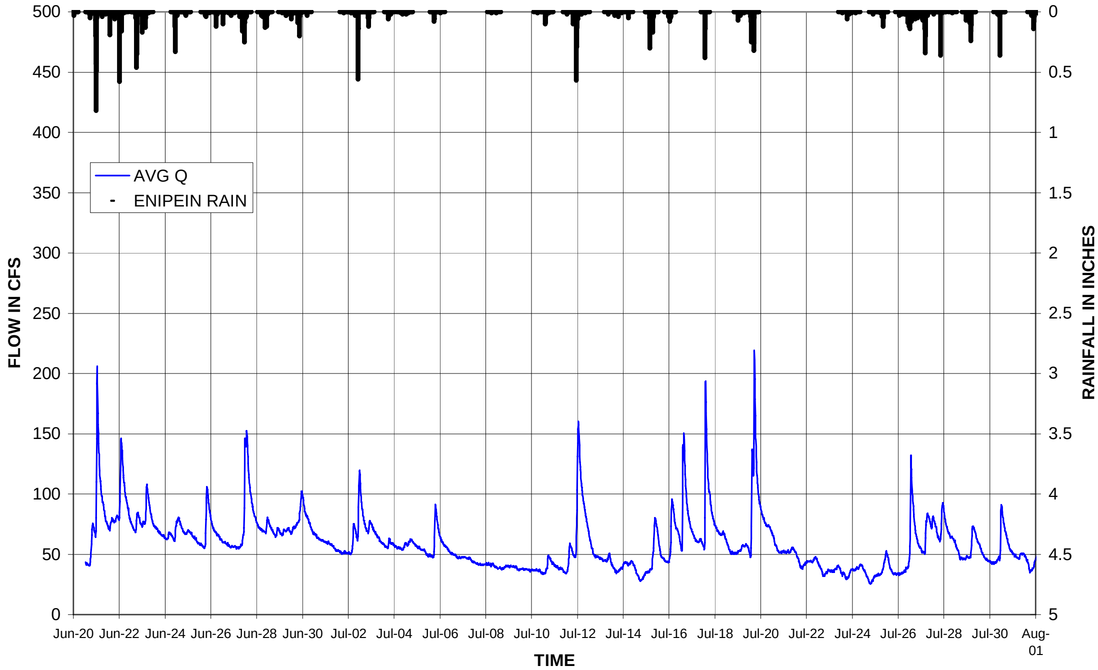

Figure 3 Calculated streamflow vs. measured rainfall in Enipein Watershed for June and July 2005.

Geologic Study, Map Development, and Water Resources Analysis of Fais Island, Yap State, FSM

Basic Information

Title:	Geologic Study, Map Development, and Water Resources Analysis of Fais Island, Yap State, FSM
Project Number:	2005GU60B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Social Sciences
Focus Category:	Groundwater, Hydrology, Climatological Processes
Descriptors:	Groundwater, Island Karst, Carbonate Island Aquifers, Water Supply, Water Resources
Principal Investigators:	john jenson, Donald Rubinstein

Publication

1. MacCracken, R.S. 2006. Water Resources Analysis of Fais Island, Yap State, FSM: MS Dissertation. University of Guam. 67 p.

PROJECT SYNOPSIS REPORT

Project Title: Geologic Study, Map Development, and Water Resources Analysis of Fais Island, Yap State, FSM

Problem and Research Objectives

Fais Island is a very small (2.6 km^2) uplifted carbonate island, with about 320 people who rely almost exclusively on coconuts and rainwater catchments for potable water. On average, about once in ten years the coconut crop and rain catchments are destroyed by a typhoon. El Nino-related droughts, which often follow the typhoons in the western Pacific, render rain even the surviving rain catchments ineffective as well, and either eliminate or prevent the recovery of the coconuts. Although the island possesses a couple of dug wells that can be made serviceable in emergencies, neither is convenient to the three villages, and water must be drawn and carried by hand. A previous attempt to installed drilled wells in the mid-1990s was only marginally successful. Residents reported that most of the wells installed drew only brackish water. Moreover, since the island has no electrical power, pumping required maintenance of a portable solar panel power supply for each one. Today, only two wells remain serviceable, from which water must also be carried by hand to the villages.

On small, remote islands such as Fais, successful development of emergency water supply requires making optimal use of all the potential sources of water. Since there is no way to preserve the coconut crop through storms and droughts, emergency needs must be met by ensuring some combination of sufficient rain catchment and storage capacity and groundwater production capacity. Technical recommendations for development and protection of water resources must also be compatible with the island's social traditions, cultural values, and indigenous authority.

The central objective of this study was therefore to make a comprehensive survey of the island's rain catchment system and groundwater resource potential, from which appropriate recommendations could be made to prepare residents for worst-case emergencies, such a prolonged drought following a major storm. The project thus had three components: (1) assessment of the current and needed capacities for rain catchment and storage, (2) identification of the cultural and social practices relevant to water production, storage, and emergency provision, and (3) assessment of the potential for future groundwater development.

Methodology

Fieldwork in August 2004 focused on the first and second objectives. Specific activities included measuring the rainwater catchment and storage capacity of each household and conducting a comprehensive water use survey through personal visits and interviews with over one-third of the island's households. A preliminary survey of wells and water quality was also made. Follow-on work in May and June 2005 focused on the third objective, along with completion of the work begun on the first two. Specific activities during the second field season included mapping the groundwater-related features, specifically, coastal caves, springs and seeps, and the serviceable wells. Specific objectives of the socio-economic portion of the project included describing the existing patterns of water usage, distribution, and water resource sharing, and quantifying current water production versus estimated demand for different uses of water.

The data gathered on rainwater catchment, storage, and household usage patterns were applied to a model that also accounts for local average monthly rainfall to predict the capability of alternative solutions to meet water requirements for the residents of Fais under normal as well as emergency conditions. Field survey and mapping of the caves, coastal discharge, and wells provided the basis for recommendations for development of existing wells, and identification of geologic factors to consider for successful future well installation.

Principal Findings and Significance

Results from this project include specific recommendations for upgrades of household and communal catchment and storage capacity, secure provision and maintenance of emergency equipment, tools, and supplies to ensure that minimum water needs can be met even under worst-case conditions. Specific recommendations are also made for development of pumping and transmission of water from the two serviceable drilled wells to existing nearby storage facilities, as well as for cadastral survey and testing of existing wells, requisite to installation and design of future wells. The hydrogeologic survey produced maps of caves and coastal discharge features, which provide a basis for determining most likely sites from which good quality might be obtained from future wells.

FSM atoll groundwater resource inventory

Basic Information

Title:	FSM atoll groundwater resource inventory
Project Number:	2005GU61B
Start Date:	5/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Models, Drought
Descriptors:	Atoll island aquifers
Principal Investigators:	john jenson, Yuming Wen

Publication

PROJECT SYNOPSIS REPORT

Project Title: FSM atoll groundwater resource inventory

Problem and Research Objectives

Atoll islands are uniquely vulnerable to drought. During the severe droughts that accompany ENSO events, the western Pacific region can go for months without rain. At such times, water production from rooftop rain catchments, which supply the routine needs of island residents when rainfall is normal or abundant, ceases completely. Groundwater, which is the resource of last resort at such times, can become too saline for human consumption, or even disappear entirely as the shallow, thin groundwater lenses of the atoll islands become depleted. This is the first phase of a two-year project. The purpose of this phase is to collect and organize the information necessary to prepare to a state-of-the-art hydrological model to serve as a tool for planning, preparing, and responding effectively to recurring droughts. Specifically, such a model will provide reliable estimates of the amount of water that can likely be extracted under drought conditions before the potable groundwater supply is depleted, and the rate at which the freshwater lens can be expected to recover as precipitation returns to normal. Such knowledge will not only provide a basis for more effective management of emergency water supplies during droughts, but will also for sustainable management practices when rainfall is normal or abundant.

Methodology

This phase of the project included an initial search of the primary earth science bibliographical databases, construction of a comprehensive GIS data base on the atoll islands of the FSM, construction of a spreadsheet implementation of a simple analytical model of atoll hydrology, and a field reconnaissance visit to a representative atoll. Technical recommendations for development and protection of water resources must also be compatible with the island's social traditions, cultural values, and indigenous authority. The next phase of this project will therefore also include a survey of water usage habits and social and economic factors that govern or influence the use of groundwater, particularly during emergency conditions, on atoll islands in the FSM.

Principal Findings and Significance

The principal products of this phase of the project include a comprehensive bibliography of atoll island hydrology, a GIS database containing the basic areal, topographic, and all other available geographic, demographic, and hydrologic data for each atoll island in the FSM. In addition, we have constructed a spreadsheet model for making preliminary estimates of freshwater lens thickness based on estimated vertical and horizontal hydraulic conductivity and known or estimated rainfall. This model will provide the starting point for a more sophisticated numerical model of atoll island hydrology incorporating models for infiltration, evapotranspiration (ET), and recharge, and more realistic geology. Work is underway to refine the conceptual model based on the latest work and current understanding of atoll geology and the latest meteorological and hydrological data on atolls in the FSM. During an initial field visit to Ulithi Atoll, Yap State, in January 2006, the research team visited all four inhabited islands and four additional uninhabited islands, some of which are used as “garden islands” to grow crops, and which accordingly have existing dug wells that can be brought into service when needed. The field team established working relationships with island leaders, including the managers and technicians of the water utilities and school teachers who have agreed to assist in collecting data on water production and consumption, as well as setting up a field station from which to collect data on evapotranspiration and well response to tidal forcing. Plans for the next phase include development of a SUTRA-based numerical model incorporating a model for infiltration based on soil moisture and ET conditions, and utilizing field data that will be collected by the team’s partners on Ulithi as well as during subsequent field visits during the coming year.

Development of a Source, Transmission and Storage model of the Saipan Water System

Basic Information

Title:	Development of a Source, Transmission and Storage model of the Saipan Water System
Project Number:	2005GU62B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Model Studies, Distribution Systems, Water Demand, Water Use Data
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publication

PROJECT SYNOPSIS REPORT

Project Title: Development of a Source, Transmission and Storage Model of the Saipan Water System

Problem and Research Objectives

In Saipan, Commonwealth of the Northern Marianas Islands (CNMI), large investments have been made in water distribution system improvements, but delivery problems still exist. The major problem is that many areas of the island that are being served by the public water system do not have 24-hour water service. A stated goal of the CNMI government is to provide 24-hour water to all residents served by the Commonwealth Utility Corporation (CUC) water system. This goal will be unattainable until the CUC has a complete knowledge of their water delivery capabilities and operational limitations.

Over the years the CUC water distribution system has grown and new wells have been added to the system. This physical expansion has been well documented but improvements in the hydraulic characteristics and delivery capabilities of the entire system have never been fully examined.

The Saipan water distribution system has been divided into 10 operational sub-regions. Each region is expected to operate somewhat independently. However, due to inadequate inflow to the system, system leakage, and lack of knowledge of the system behavior as a whole, the system is unable to provide complete 24-hour water service. In the past WERI researchers have developed computerized models of each of the ten sub-regions of the CUC water system using the Haestad WaterCad water system modeling program. The models included a physical system description, details of water usage, and parameters describing system operation. This previous project involved the examination of the entire system behavior when each of the sub-systems was operated independently.

The goal of this latest project was to develop a skelatonized model of the entire water delivery system. Skelatonization means to remove all but the major water sources, tanks and transmission components of each sub-region and then joining these sub-regions together at the regional boundary points. The benefits expected from the project include a better understanding of: the adequacy of the existing pumps and well systems, the adequacy of the existing storage facilities to provide for daily fluctuating demands, the ability of the well and storage system to provide sufficient flows, and a more in depth comprehension of the most efficient means to move water from water supply rich regions to those that have supply shortages in order to maintain delivery of 24 hour water to all areas in the system.

Methodology

The steps that were taken to complete the goals of this project were to: develop a skeletonization of each water sub-region which reflects the transmission and major distribution lines, join all the sub-region, and operate the model for water system management. As mentioned earlier, the project investigators previously developed separate models of each of the 10 sub-regions. These models included a complete description of the physical components of the pipes, tanks, pumps, and the wells in the system.

The first step of this project was to remove pipes except the main transmission lines from the existing 10-region water system models. This process is called system skeletonization. Then we joined the regions together at the boundary points. During this stage we were working closely with CUC Engineering Staff, to gather any missing data on the physical and hydraulic description of all major transmission lines transmitting water from the well and spring sources to the storage facilities. We also updated the new model to include any new data on the physical and hydraulic description of all the major transmission lines available to transmit water to the population centers.

Principal Findings and Significance

The most important outcome of this project was the development of a complete water distribution model that describes the physical components of the Saipan water delivery system. The model has been verified through field visitation. As the result of this project, Saipan is the only island in the western Pacific that has a complete working model of their entire water system. Figure 1 shows one of the pumping stations in region 7. The skeleton model that has been developed will enable the CUC to explore various operational schemes for moving water from pumps such as shown in Figure 1 to system storage sites. This will help the agency provide water to the customers for a longer time period than a few hours a day. Figures 2 and 3 provide an illustration of the skeletonization process as applied to Region 7 of the water distribution system. Figure 2 shows all the existing pipes within the Region 7 and Figure 3 shows the skeletonized system of the same system. The skeleton systems for each of the water systems sub-regions have been inputted into Haestad Water Distribution System model. The CUC has purchased the Haestad model. Researchers working on this project provided detailed training in the use and operation of the model and engineers in the Water Division of CUC are presently operating the model.

Figure 1. Saipan’s pumping station, Kagman area.

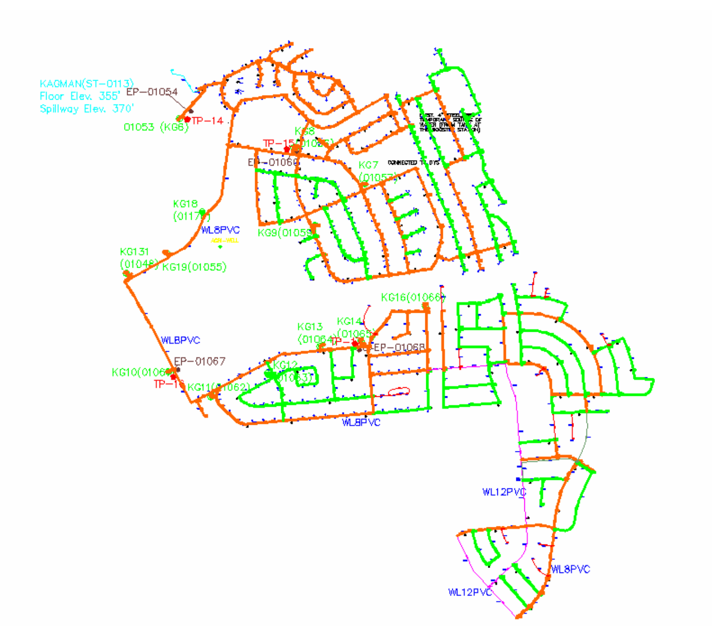

Figure 2. Region 7, Kagman, all pipes.

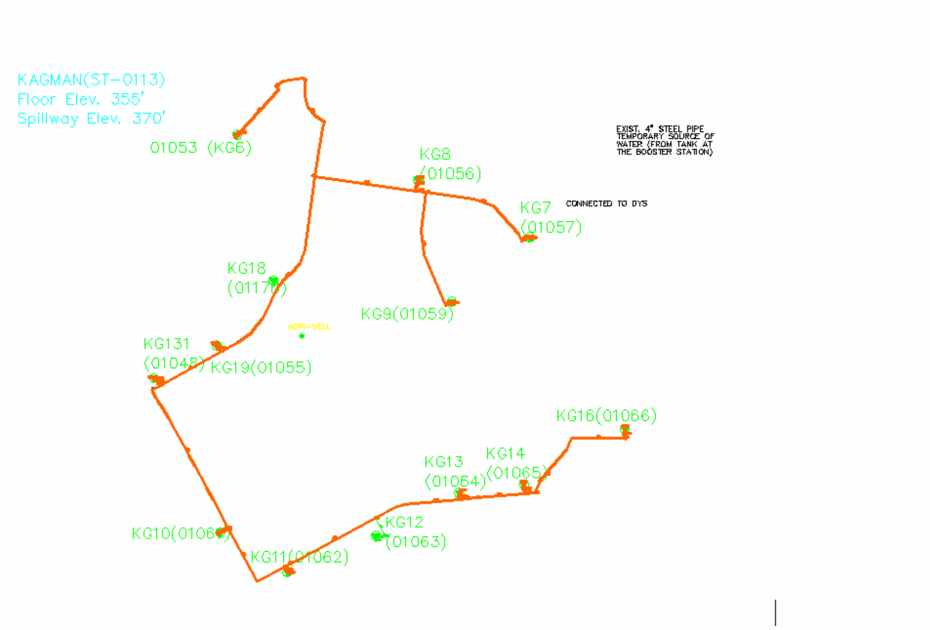

Figure 3. Region 7, Kagman, system skeleton.

Information Transfer Program

Information Management

Basic Information

Title:	Information Management
Project Number:	2004GU45B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Hydrology, Management and Planning
Descriptors:	None
Principal Investigators:	Leroy F. Heitz, Leroy F. Heitz

Publication

INFORMATION MANAGEMENT

WERI's mission involves maintaining and providing water resources related data to researchers, water resources managers, educators and the general population of the islands of the Western Pacific. This project was used to provide funding to maintain subscriptions to a wide variety of data sources dealing with meteorology, climatology and hydrologic data. These resources are maintained at WERI and made available to researchers, water managers, educators and the general public throughout the region. Communication and information exchange between experts in the area of water resources is vital to the improvements in the wise use of this resource.

Water System Operation and Maintenance Training for Pohnpei State FSM

Basic Information

Title:	Water System Operation and Maintenance Training for Pohnpei State FSM
Project Number:	2005GU59B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Education, Water Supply, Management and Planning
Descriptors:	
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publication

Project Title
Water System Operation and Maintenance Training for Pohnpei State FSM

Problem and Research Objectives
The need for effective information transfer and training on all aspects of water resources is an immediate need in the Federated States of Micronesia (FSM). Micronesia is an area where formal reports and professional publications are simply not effective information transfer vehicles. In this part of the world, the most effective means of information transfer is one-on-one or small group discussions and workshops. In response to these unique circumstances, a special training program was designed for FSM. The training concentrated on the water system operation and maintenance problems experienced in Pohnpei State, FSM. The specific objective of this training was to increase the technical understanding of operation and maintenance of pumps and automatic valves in the water supply and wastewater collection systems operated by the Pohnpei Utility Corporation (PUC). Since other utilities in FSM experience similar problems, the training was made available to utility personnel from Chuuk, Yap and Kosrae State. The need for water resources related training continues to be given a high priority by the FSM advisory council. This specific training was requested by the PUC as part of the WERI advisory council meeting held in November 2004.

Methodology
The training project consisted of a one week long workshop that covered various water supply operations and maintenance topics. As can be seen from the schedule below, the training provided a mix of classroom, laboratory and field site instruction and hands-on activities. Pohnpei Utility Corporation provided the required classroom and shop space required to carry out the training.

The instructor who led the classroom, shop and field site sessions was Mr. Mack McPherson from Hawaii Engineering Services. This Hawaii based company specializes in pumping and water distribution and waste water system sales, repair, and maintenance. They have had a long term association with the various utilities in Micronesia.

Upon completion of the workshop the attendees had a much better understanding of key operation and maintenance activities required to sustain functioning water distribution and wastewater collection systems with special emphasis on pumps and automatic regulating valves.

Table 1. Training Topics for Water and Waste Water System Repair and Maintenance Training

SESSION	TOPICS
Day 1 Morning	Site inspection of water supply and waste water disposal facilities
Day 1 Afternoon	Pump station equipment design, operation, and maintenance
Day 2 Morning	On site hands on training covering inspection, testing, and preventative maintenance
Day 2 Afternoon	Shop hands on training at PUC Shop covering preventative and overhaul maintenance of existing pumps and controls (Session 1)
Day 3 Morning	Shop hands on training at PUC Shop covering preventative and overhaul maintenance of existing pumps and controls (Session 2)
Day 3 Afternoon	Pressure regulating (PRV) and altitude valves: purpose and theory of operation
Day 4 Morning	On site hands on training covering inspection, testing, and preventative maintenance of PRVs and altitude valves
Day 5 Afternoon	Shop hands on training at PUC Shop covering preventative and overhaul maintenance of existing PRVs and altitude Valves

Principal Findings and Significance

Twenty people working at Pohnpei Utility Corporation (PUC) and the other utilities in the Federated States of Micronesia participated in the training. The training covered pump and automatic valve repair and maintenance. The sessions covered general topics on pump repair for well pumps, booster pumps and pumps used in the wastewater collection system and automatic valves within the distribution systems. Repair training was carried out on the specific pumps and valves in the Pohnpei system. Since the water systems in the other states are similar to the Pohnpei system the training was meaningful to trainees from the other states.

The net results of this training will be better management of one of Pohnpei island's most valuable resources, its water. Specific results will be a more reliable water supply and wastewater disposal system. With better pump maintenance practices the reliability of the pumping components will be much greater. With better operation of the automatic valves in the systems the tanks will be operated more efficiently and pressure will be maintained at levels that assure good operation of the system.

As always, the goal of the training was to help provide the local government with on-island capabilities to maintain water supplies that that can provide safe drinking water for the entire island on a 24-hour basis.

Figure 1 Students performing field maintenance on pressure regulating valve

Figure 2 Students performing shop repair procedures on water system valve

Informaton Transfer

Basic Information

Title:	Informaton Transfer
Project Number:	2005GU91B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Hydrology, Management and Planning
Descriptors:	
Principal Investigators:	Leroy F. Heitz

Publication

WERI's mission involves a large information transfer-dissemination component. Key elements include written forms such as brochures and pamphlets, a web site, technical reports, journal articles, newspaper columns, and book chapters. The audience for the results of USGS sponsored research is widely varied geographically and by education level. It is important that WERI make this information available in a very widely distributed form.

This project funded the design, layout and printing of five technical completion reports resulting from USGS funded research projects. One hundred (100) hard copies of each report were printed and the reports were prepared for publication on WERI's Web page and entered into WERI's on-line searchable Technical Reports Data Base.

WERI's Web page, shown below, is located at http://weriguam.org/home/index.htm, and is the Institute's focus for Information Transfer/ Dissemination.

WERI Web Page

It is very important that WERI's Web page be updated and optimized on a regular basis. To provide this a professional web maintenance firm was contracted to provide maintenance to the WERI Web page on a regular basis. This year the firm continued refining the web-site and added all newly completed WERI technical completion report into the database search engine for accessing the reports on line.

Because of Guam's remote location it is difficult and quite costly for researchers to present their findings at technical conferences and symposiums. This project funded a portion of off-Island travel expenses for PI's and graduate students presenting refereed professional papers summarizing all or a portion of current or past 104-B research projects.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	8	0	0	0	8
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	11	0	0	0	11

Notable Awards and Achievements

Publications from Prior Projects

1. 1999GU01 ("Island karst hydrology of Guam and its incorporation into a general carbonate island karst model") - Articles in Refereed Scientific Journals - Taboroi, D., Jenson, J. W., and Mylroie, J. E., 2005, Karst features of Guam, Mariana Islands: Micronesica, v. 38, no. 1, p. 17-46.
2. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Articles in Refereed Scientific Journals - Stafford, K., Mylroie, J., Taboroi, D., and Jenson, J., 2004, Eogenetic karst development on a small, tectonically active, carbonate island: Aguijan, Mariana Islands: Cave and Karst Science, Transactions of the British Cave Research Association, v. 31, No. 3, p. 101-108.
3. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Book Chapters - Jenson, J. W., Keel, T. M., Mylroie, J. R., Mylroie, J. E., Stafford, K. W., Taborosi, D., and Wexel, C., 2006, Karst of the Mariana Islands: The interaction of tectonics, glacioeustasy and fresh-water/sea-water mixing in island carbonates: Geological Society of America Special Paper 404, p. 129-138.
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5. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Dissertations - Toepke, K.M. 2006. GIS Inventory of the Caves and Karst of the Mariana Islands. MS Dissertation. Mississippi State University, Mississippi.
6. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Water Resources Research Institute Reports - Keel, T.M., J.E. Mylroie and J.W. Jenson. The caves and karst of Rota Island, Commonwealth of

the Northern Mariana Islands: Technical Report No. 107. Water and Environmental Institute of the Western Pacific, University of Guam Mangilao, Guam. 184 p.

7. 1999GU01 ("Island karst hydrology of Guam and its incorporation into a general carbonate island karst model, ") - Conference Proceedings - Taboroi, D., Jenson, J. W., Mylroie, J. E., 2006, Karst Environments of Guam, Mariana Islands. in Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas, p. 220-227.
8. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Conference Proceedings - Stafford, K. W., Mylroie, J., E., Jenson, J. W., Mylroie, J. R., and Taborosi, D., 2006, Dissolution Controls Related to the Carbonate Island Karst Model on Tectonically Active, Carbonate Islands: Tinian and Aguijan, CNMI. in Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, p. 205-219.
9. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Conference Proceedings - Keel, T. M., Jenson, J. W., Mylroie, J. E., Mylroie, J. R., Stafford, K. W., Camacho, R., 2006, The Caves of Rota, Commonwealth of the Northern Mariana Islands. in Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas, p. 76-87.
10. 1999GU01 ("Island karst hydrology of Guam and its incorporation into a general carbonate island karst model") - Conference Proceedings - Reece, M. A., Mylroie, J. E., and Jenson, J. W., 2006, Notches in Carbonate Cliffs and Hillslopes: Origin and Implications. in Davis, R. L., and Gamble, D. W., eds., Proceedings of the 12th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador, Bahamas, p. 143-152.
11. 2002GU5B ("Inventory of Karst Features Relating to Past and Present Groundwater Flow on Tinian, CNMI, in Terms of the Carbonate Island Karst Model") - Conference Proceedings - Toepke, K.M., J.E. Mylroie, and J.W. Jenson. 2006. GIS Inventory of the Caves and Karst of the Mariana Islands. Abstracts and Programs, 13th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador Island, Bahamas. Conference program and abstracts, p. 25.
12. 2002GU2121 ("Inventory of karst features relating to past and present groundwater flow on Saipan, CNMI, in terms of the Carbonate Island Karst Model, , Mar 2001-Feb 2002") - Conference Proceedings - Wexel, C., J.W. Jenson, and J.E. Mylroie. 2006. Karst Features of Saipan in Terms of the Carbonate Island Karst Model. Abstracts and Programs, 13th Symposium on the Geology of the Bahamas and Other Carbonate Regions, Gerace Research Center, San Salvador Island, Bahamas. Conference program and abstracts, p. 26.
13. 2002GU4B ("Impact of Ordot Dump on Water Quality of Lonfit River Basin in Central Guam") - Water Resources Research Institute Reports - Denton, Gary, R.W., Mohammad H. Golabi, Clancy, Iyekar, H. Rick Wood and Yuming Wen. 2005. Mobilization of Aqueous Contaminants Leached from Ordot Landfill in Surface and Subsurface Flows. Water and Environmental Research Institute (WERI) Technical Report No. 108, University of Guam, Mangilao, Guam, 83 pp.
14. 2000GU2B (": Nutrient Status of Tumon Bay: Contributions from Hotel Landscaping Activities. ") - Water Resources Research Institute Reports - Denton, Gary, R.W., Carmen M. Sian-Denton, Lucrina P. Concepcion and H. Rick Wood. 2005. Nutrient Status of Tumon Bay in Relation to Intertidal Blooms of the Filamentous Green Alga, Enteromorpha clathrata. Water and Environmental Research Institute (WERI) Technical Report No. 110, University of Guam, Mangilao, Guam, 53 pp.