Water and Environmental Research Institute of the Western Pacific
Annual Technical Report
FY 2006

Introduction

The Water & Environmental Research Institute of the Western Pacific or WERI is one of 54 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 32nd year of operation.

WERI's 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. The Institute provides its regional stakeholders with technical expertise in a diversity of water resources related fields including tropical climatology, surface water hydrology, rainfall catchment systems, groundwater modeling and management, water distribution systems, soil erosion and mitigation strategies and various aspects of water quality. Faculty members contribute significantly to both undergraduate and graduate teaching programs at the University of Guam (UOG) and conduct vigorous research 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 funds (via the US Geological Survey) under Section 104-B of the Water Resources Research Act. WERI has responsibility for the administration of three 104-B base grants: one for Guam, one for the Commonwealth of the Northern Mariana Islands (CNMI), and one for the Federated States of Micronesia (FSM). This report summarizes the Institute's regional activities under the USGS 104-B base grant program for the period March 1 2006 to February 28, 2007 (FY06).

Currently WERI has a fulltime director who is also a UOG faculty member, five (5) 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 seven (7) graduate research assistants who are completing their MS degree in the UOG Environmental Sciences program.

During FY06, WERI faculty were involved as principal investigators on nineteen (19) research and training projects. Funding sources for these projects, in addition to the US Geological Survey, included the US Weather Service, local agencies such as the Guam Department of Agriculture, Guam Bureau of Statistics and Plans, Guam Waterworks Authority, the Guam Environmental Protection Agency, and direct appropriations from the Guam legislature.

Over the same time frame, WERI faculty and staff taught nine (9) graduate courses and two (2) 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 eleven (11) refereed journal articles, eleven (11) conference proceedings and seven (7) technical reports. They also gave fifteen (15) professional presentations and participated in five (5) workshops. WERI faculty members served on sixteen (16) thesis committees of students in the Environmental Sciences and Biology MS programs and chaired seven (7) of them.

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 -U.S. Department of Commerce/NOAA Project -Pacific ENSO Applications Center with University of Hawaii: JIMAR Project

GUAM DEPARTMENT OF AGRICULTURE -PHASE II: Water Quality Monitoring in the Pago Bay Watershed

GUAM BUREAU OF STATISTICS AND PLANS -Geographic Information System Based Erosion Potential Model -To Develop a Digital Water Resources Atlas for all Water Sheds in Southern Guam

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 Waters 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 GEPA Engineers and Private Consultants in use of the MWHSOFT 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 and University of Guam research faculty.

WERI held RAC meetings in September though October 2006. Nineteen (19) people attended the Guam meeting and fifteen (15) people attended the CNMI and FSM meetings. The RAC groups examined the previous year's research, education and training priorities identified in past years and added or amended where appropriate. The meetings also provided a scientific forum for information exchange on new and recently completed projects within each regional entity.

In early November, a Request for Proposals (RFP) letter was sent out by e-mail to over three hundred (300) regional representatives in Guam, the CNMI and FSM. Recipients included all past and present RAC members; faculty members at the University of Guam, the Northern Marianas College in Saipan and the College of Micronesia in Pohnpei, and water resource professionals from several government agencies. Accompanying the RFP message were: a) a blank proposal form for submittal on the USGS Web Site, b) detailed instructions on how to fill out the form, and c) the critical water resource research, education and training needs identified for Guam, the CNMI and FSM.

Nine (9) research proposals, three (3) for Guam, three (3) for the CNMI and three (3) for FSM, and one (1) education and training proposal for FSM, were submitted for consideration in response to the RFP. Three RAC review panels, each composed of four highly regarded water resources professionals, were established to evaluate the research proposals. Their task was to evaluate and score the proposals relevant to their particular region in accordance with the long-standing criteria listed in the RFP. The appropriate proposals were e-mailed separately to the members of each review panel along with the critical needs list and a scoring form. They were advised to work independently and given two weeks to submit their numerical assessments to the WERI Director. Their scores were then tabulated and the projects ranked in descending order of average score. The seven (7) research proposals approved for funding were selected based on their regional ranking and availability of funds.

Watershed Land Cover Change Detection in Guam

Basic Information

Title:	Watershed Land Cover Change Detection in Guam
Project Number:	2006GU70B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Social Sciences
Focus Category:	Methods, Management and Planning, Conservation
Descriptors:	Land cover change detection, southern Guam
Principal Investigators:	Yuming Wen, Leroy F. Heitz, Shahram Khosrowpanah

Publication

PROJECT SYNOPSIS REPORT

Project Title: Watershed Land Cover Change Detection in Guam

Problem and Research Objectives

Much of land cover change (LCC) has been recorded qualitatively through the use of comparative photography and historical reports, however little quantitative information has been available at watershed scale. It is currently possible to detect LCC and determine the trends in ecological and hydrological condition at watershed scale using advanced geo-spatial technologies such as satellite remote sensing, GIS, and GPS. These technologies provide the basis for developing landscape composition and pattern indicators as sensitive measures of environmental change and thus, may provide an effective and economical method for evaluating watershed condition related to disturbance from human and natural stresses.

Landsat satellites can provide multi-date satellite imagery back to 1972 (Landsat 1), and Landsat 5 and Landsat 7 are still on orbit. Land cover has been derived from a multi-date satellite imagery database to detect changes on the Earth. Recent surveys indicate that land cover/use changes have a direct and enormous effect on water quality and environmental change. Watershed water quality and ecosystem are threatened constantly by both human impacts like forest fires and development and also natural phenomena like storms and droughts. In addition, the combined uses of GIS, remote sensing and GPS tools have been highlighted with respect to their advantages in watershed applications.

Spatial and temporal modeling of changes in wetlands and badlands in Southern Guam watersheds was identified as one of the highest priority research needs for Guam on the Guam Advisory Council meetings of November 15, 2004 and October 4, 2005. Multi-date Landsat satellite imagery were used to measure changes of watershed land cover from 1973 to 2001 for Guam. Topographic map of 1978 for Guam and recent IKONOS imagery was used as auxiliary information to improve land cover classification accuracy. The study area focused on all 14 watersheds in Southern Guam. The main objectives of this project aimed to extract land cover information from Landsat images and therefore to measure changes of land cover in the watersheds in the southern Guam.

Methodology

The principal investigators (PIs) searched available data, and preprocessed the data for land cover classification in ERDAS IMAGINE, a geospatial imaging processing software. GIS, remote sensing and GPS were the main geo-spatial technologies used to complete the project's objectives. GIS, remote sensing and GPS technologies were integrated to obtain land cover information, and measure the changes of land cover.

Principal Findings and Significance

The land cover information of 1973 and 2001 for all watersheds in the southern Guam has been obtained. Because of bad quality of Landsat Multi-Spectral Scanner (MSS) satellite image of 1973, digital line graph (DLG) data with data acquisition data as late as January 1, 1975 was used with Landsat MSS data of 1973 to extract land cover information. Land cover of 2001 was extracted from Landsat Thematic Mapper (TM) satellite image of March 15, 2001. By comparison of the land cover between 1973 and

2001, the following conclusions can be made. The watersheds in southern Guam were mainly covered by forest and grassland for both the years of 1973 and 2001. The area of forest increased by about 3% from 1973 to 2001, but the area of grassland decreased by over 17% between 1973 and 2001. The built-up/urban area increased by over 3 times from 1973 to 2001, and most of the increased urban areas occurred in forest and grassland. The area of water body decreased by about 50% in the past three decades. Most of decreased water areas was lost to urban areas. Land cover is an important factor for soil erosion and water quality evaluation. Information about changes of land cover over time will help government agencies in interest take proper measures to protect soil from erosion and improve water quality, and therefore may help them with decision making. The land cover information can also be applied for environmental modeling and assessment, and analysis of relationship between land cover change and climate change.

Polychlorinated Biphenyls (PCBs) and Organochlorine Insecticides in Biotic Components of Tanapag Lagoon, Saipan

Basic Information

Title:	Polychlorinated Biphenyls (PCBs) and Organochlorine Insecticides in Biotic Components of Tanapag Lagoon, Saipan
Project Number:	2006GU72B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Toxic Substances, Water Quality, Non Point Pollution
Descriptors:	PCB contamination of reef fish, risks to consumers, Tanapag Lagoon, Saipan
Principal Investigators:	Gary Denton, Michael Trianni, Harold Wood

Publication

PROJECT SYNOPSIS REPORT

Project Title: **Polychlorinated Biphenyls (PCBs) and Organochlorine Insecticides in Biotic Components of Tanapag Lagoon, Saipan**

Problem and Research Objectives

Tanapag Lagoon, on the western shore of central Saipan, harbors a rich diversity of marine life and supports a variety of commercial and recreational activities. Over the years, increased urban growth and commercial developments along the adjacent coastline have resulted in a loss of environmental quality, particularly in the southern half of the lagoon. Primary sources of anthropogenic disturbance in these waters include a power station and commercial port (Saipan Harbor), two small boat marinas, a sewer outfall, several garment factories, auto and boat repair shops, wood shops, government vehicle maintenance yards, a commercial laundry, and an acetylene gas producer. There are also a number of old military dumps and disposal sites in the area as well as a 50-year old municipal dump that served as the island's only solid waste disposal site until its closure a little over two years ago. Several streams and storm drains empty into the lagoon during the rainy season and provide a mode of transport into the ocean for any land-based contaminants. Overflows from sewer lines are also commonplace at this time of the year and the whole area is inundated by storm water runoff during periods of prolonged wet weather. The effects of these perturbations on the indigenous biota within the lagoon are largely unknown. Likewise, fundamental data describing the abundance and distribution of persistent and potentially toxic pollutants within the system is also lacking.

Mindful of these shortcomings, a contaminant assessment of surface sediments within Tanapag Lagoon was undertaken in 1999 (Denton *et al.* 2001, 2006a). The study revealed discrete areas of heavy metal enrichment within the lagoon and emphasized the need for an impact assessment of animal and plant communities within the area. To this end, a bioindicator survey was undertaken in 2003 and focused on dominant ecosystem representatives from nearshore waters within the lagoon (Denton *et al.* in prep). A survey of mercury and arsenic in resident fish followed shortly thereafter (Denton and Trianni. in prep.).

The current work focused on chlorinated hydrocarbons in dominant fish species from within the lagoon. Specimens chosen for analysis included those with restricted home ranges in order to delineated specific areas of potential enrichment, as well as species that were more roving in their feeding habits to provide information on the overall condition of the lagoon from a contamination standpoint. Representative species with different food preferences were selected from various trophic levels in order to evaluate the degrees of biological magnification that have taken place so far for each contaminant. The data thus far collected for PCBs is presented here.

Methodology

Fish were taken from seven sites between Muchot Point at the southern end of the lagoon and Pau-Pau Beach in the north. (Fig. 1). Sites 1-4 are impacted by land-based sources of contamination of one sort or another while sites 5-7 are not and serve as useful reference sites. Specimens were caught by local fishermen using hook and line, spear gun and Hawaiian sling. They were chilled immediately and transported to the laboratory in insulated containers. The fish examined during the study are identified in Table 2. The trophic level to which each belongs and their movements within the lagoon are also indicated.

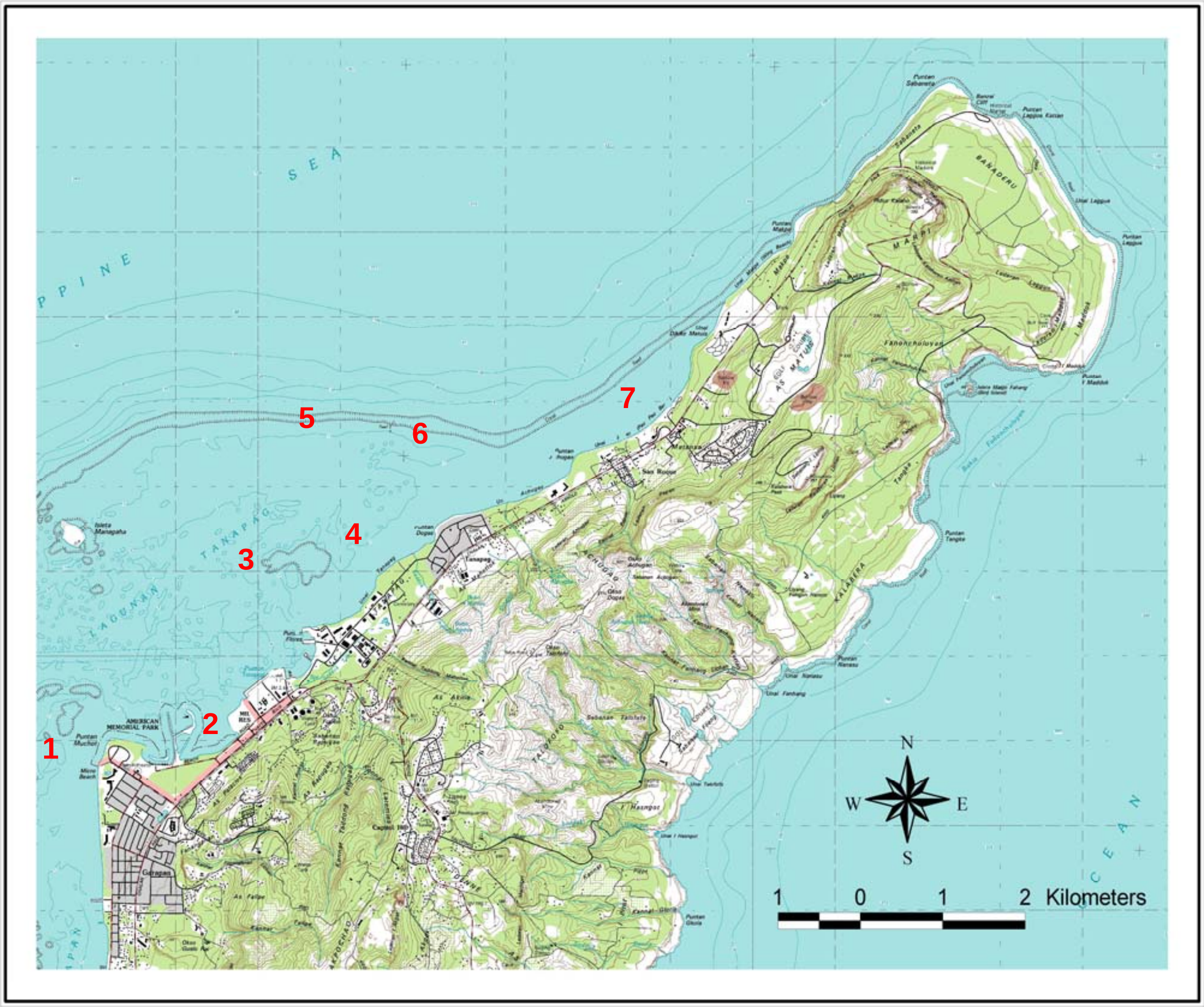

Figure 1: Map of northern Saipan showing fish sampling sites 1-7

In the laboratory, axial muscle was taken from directly under the dorsal fin on the right side of the fish analysis using high quality stainless steel instruments. Most fish were readily identified and processed within a few hours of capture. Those that weren't were deep-frozen as quickly as possible and processed within one month of returning to Guam. All tissue samples were homogenized and freeze dried prior to analysis. Approximately, 3 g of dried tissue was extracted with approximately 40 ml of hexane in an accelerated solvent extractor (Dionex 200 ASE). Following alumina cleanup, the extract was reduced to a final volume of 0.1 ml before gas chromatographic analysis. The surrogate and internal standard used to determine PCB recoveries were PCB 103 (100 pg/µl) and petachloronitrobenzene (250 pg/µl) respectively.

Table 2: Fish Sampled During the Present Survey

Species	Trophic Level*	Micro Beach/Reef	Puerto Rico Dump (seaward edge)	Seaplane Reef	Outer Lagoon Site 1	Outer Lagoon Site 2 (Dankulo Rock)	Tanapag Shoals	Pau-Pau Shoals
Acanthurus blochii	H,DI,R							
Acanthurus lineatus	H, DI, S	22		12		3		2
Acanthurus nigricans	H, DI, R	1					1	
Acanthurus nigricauda	H, DI, R		1				1	
Acanthurus nigrofuscus	H, DI, S		2		1			
Acanthurus olivaceous	O, DI, R					1		
Acanthurus triostegus	H/P, DI, R					1		1
Balistiodes viridescens	C, DI, S		1					
Calotomus carolinus	H, DI, R	2		1				
Caranx melampygus	C, DI, R			2				
Chaetodon ornatissimus	C, DI, S			1				
Cheilinus chlorous	C, DI, R					1		
Cheilinus trilobatus	C, DI, R			2	1		1	
Cheilo inermis	C, DI, R					I		
Chlorurus frontalis	H, DI, R					1		
Chlorurus sordidus	H, DI, R					4	3	
Coris aygula	C, DI, R			1				
Ctenochaetus striatus	H, DI, S	1				2	4	1
Epinephelus maculatus	C, DI, S					1		
Epinephelus howlandi	C, DI, S			2				
Epinephelus merra	C, DI, S			1		1		
Gnathodentex aurolineatus	C, NO, R	1				1	1	1
Halichoeres trimaculatus	C, DI, R					1		
Hemigymnus melapterus	C, DI, R				2			
Heteropriacanthus cruentatus	C, NO, S	1						
Kyphosus biggibus	H, DI, R					1		

Table 2: Fish Sampled During the Present Survey (cont.)

Species	Trophic Level*	Micro Beach/Reef	Puerto Rico Dump (seaward edge)	Seaplane Reef	Outer Lagoon Site 1	Outer Lagoon Site 2 (Dankulo Rock)	Tanapag Shoals	Pau-Pau Shoals
Lethrinus atkinsoni	C, NO, R	2				1		
Lethrinus erythracanthus	C, NO, R					1		
Lethrinus harak	C, NO, R	10	3	5			4	1
Lethrinus obsoletus	C, NO, R	1			1			
Lethrinus olivaceous	C, NO, R					2		
Lethrinus xanthochilus	C, NO, R	3				3		2
Lutjanus fulvus	C, NO, R	1				1		
Lutjanus kasmira	C, NO, R			1		1	2	
Lutjanus monostigmus	C, NO, R	1						
Myripristis amaena	P/C, NO, S	2				1		7
Myripristis berndti	P, NO, S	1	10	2		7	2	1
Myripristis kuntee	P/C, NO, S	1						
Myripristis murdjan	P/C, NO, S	1						
Myripristis pralina	P/C, NO, S	2					4	
Myripristis violacea	P/C, NO, S	7	4					8
Naso annulatus	H, DI, R					1		
Naso lituratus	H, DI, R	4	14	15		1	5	15
Naso unicornis	H, DI, R		1		1		1	1
Naso vlamingii	H, DI, S						1	
Neoniphon argenteus	C, NO, S					1		
Neoniphon opercularis	C, NO, S		1					
Neoniphon sammara	C, NO, S	3						3
Parupeneus barberinus	C, DI, R				1		1	2
Parupeneus multifasciatus	C, DI, R	1	2			1		
Plectropomis laevis	C, DI, R						1	
Pseudobalistes fuscus	C, DI, S					2		
Rhinecanthus aculeatus	O, DI, S						4	
Rhinecanthus rectangulus	O, DI, S			1				
Sargocentron spiniferum	C, NO, S		1	1		1		6
Scarus ghobban	H, DI, R	1		2	3			
Scarus globiceps	H, DI, R				2			
Scarus psittacus	H, DI, R			2		1		
Scarus sp.	H, DI, R			1				
Siganus spinus	H, DI, R		1				1	1
Sphyraena flavicauda	C, DI, R			2				
Sufflamen chrysoptera	O, DI, S					1		
Thalassoma trilobatum	C, DI, R					1		
Triaenodon obesus	C, NO, R			1				
Zanclus cornutus	O, DI, R			1				

* H = herbivore benthic; P = planktivore; C = carnivore; O = omnivore; R = roving/large home range; S = sedentary/small home range
NO = nocternal feeder; DI = diurnal feeder

PCB analysis was performed by gas chromatography (Varian 3400CX) using an electron capture detector and a 60 m x 0.25 mm i.d. fused silica MDN-5S, polymethyl-5% phenyl-siloxane (0.25µm film thickness) capillary column (Supelco). Gas flows (N_2), through the column and the detector, were 1 ml/min and 30 ml/min respectively. The initial column temperature was maintained at 50^{o}C for the first minute of each run. It was then ramped to 150^{o}C at 30^{o}C/min, then to 280^{o}C at 25^{o}C/min, where it was held for 20 min to give a total run time of 76 min. Injector and detector temperatures were held constant at 280^{o}C and 310^{o}C respectively.

PCB quantification was accomplished using a 20-congener calibration standard representing PCB homologues Cl_2 to Cl_{10} (NOAA 1993). These congeners are selected on the basis of their potential toxicity, bioaccumulation and/or frequency of occurrence in environmental samples (McFarland and Clarke 1989). Complete chromatographic separation of all congeners was achieved although several of them are known to co-elute with other PCB congeners present in commercial PCB mixtures.

The $\sum_{20}$PCB content of the sample was calculated from the sum of the individual congener data. Undetectable congeners were set to zero during this process. PCB congener recoveries from a certified standard reference material (marine mussel: SRM 1974) were within acceptable limits. Method detection limits for individual chlorobiphenyls in the standard mix ranged from 0.02-0.15 ng/g.

Principal Findings and Significance

Over 300 fish representing 65 different species were sampled for analysis during the course of this work. The data thus far collected are summarized in Table 3. Congener prevalence and abundance were in line with that reported earlier for reef fish from Guam (Denton *et al.* 2006b). ΣPCB_{20} in the samples ranged from 1.17-116 ng/g dry wt. The data was converted to ng/g wet weight using a wet to dry weight ratio of 5 (Denton *et al.* 1999). 'Total' PCB concentrations were estimated by doubling the sum of all detectable chlorobiphenyls in the calibration standard (O'Connor 1998).

Muscle tissue of marine fish from relatively uncontaminated waters usually contains total PCBs in the low ng/g range on a wet weight basis while specimens from contaminated environments may contain levels two to three orders of magnitude higher. The data presented here range from ~0.47-46.4 ng/g when converted to total PCBs on a wet weight basis with close to 80% of all fish analyzed so far having levels of <10 ng/g (Fig. 2).

The current FDA food standard for PCBs in fish is 2.0 µg/g wet weight/, well below the maximum concentration encountered during the present work. Unfortunately, this blanket standard does not address variations in consumption rates and so may not adequately protect people living in predominantly fish eating communities like those of the Pacific Islands. The more conservative USEPA risk-based consumption guidelines for PCBs in fish are therefore more appropriate here (USEPA 2000). These guidelines are based on an interim reference dose (RfD) of 20 ng PCB/kg body weight/day for a person weighing 70 kg. They take into account the PCB levels in the fish consumed and indicate the maximum number of 8 oz fish meals that may be consumed each month. Unrestricted consumption (i.e., more than sixteen 8-oz fish meals per month) is recommended only for fish with PCB levels of 5.9 ng/g wet weight or less.

Table 3: PCB Levels in Axial Muscle of Dominant Food Fish from Tanapag Lagoon, Saipan

Species	PCB Congeners (ng/g dry wt.)																				Σ_{20}PCB	Total PCB
	8	18	28	44	52	66	77	101	105	118	126	128	138	153	170	180	187	195	206	209		(wet wt.)
Micro Reef and Beach Area (site 1)																						
Acanthurus lineatus	nd	0.81	nd	nd	0.42	nd	nd	1.40	nd	0.52	nd	0.43	nd	nd	nd	0.08	0.26	nd	nd	nd	3.92	1.57
Acanthurus nigricans	4.47	4.11	nd	nd	0.31	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.17	nd	nd	0.52	9.58	3.83
Acanthurus lineatus	nd	0.22	nd	nd	1.29	nd	nd	3.36	0.82	2.78	nd	0.74	1.77	1.71	0.26	0.71	0.17	nd	nd	nd	13.8	5.52
Acanthurus lineatus	nd	nd	nd	nd	1.29	nd	nd	2.27	0.37	1.30	nd	0.34	0.93	0.96	nd	0.13	nd	nd	nd	nd	7.59	3.04
Acanthurus lineatus	nd	nd	nd	nd	0.81	1.64	nd	nd	nd	0.15	nd	nd	nd	nd	nd	0.07	nd	nd	nd	nd	2.67	1.07
Acanthurus lineatus	27.5	0.34	nd	nd	1.11	nd	nd	2.66	nd	0.20	nd	nd	nd	0.14	nd	nd	0.15	nd	nd	nd	32.1	12.8
Acanthurus lineatus	nd	nd	nd	nd	1.10	nd	nd	nd	0.07	0.33	nd	0.13	0.30	0.15	nd	nd	0.12	nd	nd	nd	2.21	0.88
Acanthurus lineatus	nd	0.84	nd	nd	2.02	nd	0.17	nd	nd	nd	nd	0.10	nd	nd	nd	0.05	nd	nd	nd	nd	3.17	1.27
Acanthurus lineatus	nd	nd	nd	nd	nd	1.17	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.17	0.47
Acanthurus lineatus	nd	nd	nd	nd	nd	nd	0.96	nd	1.50	2.61	nd	0.73	2.19	0.85	nd	0.58	0.24	nd	nd	4.79	14.4	5.78
Calotomus carolinas	nd	nd	nd	0.78	2.29	nd	nd	3.59	0.16	0.96	nd	0.22	0.55	0.60	nd	0.08	nd	nd	nd	nd	9.22	3.69
Calotomus carolinas	0.50	0.35	nd	nd	0.39	1.32	nd	nd	nd	nd	nd	nd	nd	1.41	nd	nd	nd	nd	nd	nd	3.96	1.58
Ctenochaetus striatus	nd	0.95	1.06	nd	0.73	nd	nd	3.72	1.02	3.06	nd	0.70	1.19	0.81	0.16	0.33	0.18	nd	nd	nd	13.9	5.57
Gnathodentex anrolineatus	2.37	1.88	4.18	2.57	3.52	nd	1.53	12.3	5.99	12.8	1.16	5.10	8.39	7.08	3.27	3.64	2.45	1.85	2.09	2.56	84.7	33.9
Heteropricanthus cruentatus	0.69	0.98	2.09	nd	0.54	nd	nd	1.60	nd	0.80	nd	0.20	0.36	nd	nd	0.18	0.49	nd	nd	0.55	8.49	3.40
Lutjanus fulvus	0.66	0.48	nd	nd	0.92	nd	nd	2.54	nd	1.10	nd	nd	0.58	nd	nd	0.70	0.48	nd	nd	nd	7.45	2.98
Naso lituratus	0.28	0.24	nd	1.78	2.26	nd	0.72	12.0	4.28	10.0	nd	2.53	nd	5.04	0.90	1.37	0.49	nd	0.12	nd	42.1	16.8
Naso lituratus	2.46	4.77	nd	nd	0.71	nd	nd	nd	0.07	0.62	nd	0.13	nd	nd	0.15	nd	0.87	0.11	0.11	nd	9.99	4.00
Naso lituratus	5.10	6.91	nd	nd	1.74	nd	0.23	8.94	2.87	7.04	nd	nd	nd	2.93	1.97	1.42	1.43	nd	nd	nd	40.6	16.2
Neoniphon sammara	nd	nd	nd	nd	0.58	nd	nd	3.16	0.13	1.19	nd	0.39	0.67	nd	nd	0.42	0.39	nd	0.48	nd	7.42	2.97
Neoniphon sammara	1.32	nd	nd	nd	1.11	nd	nd	nd	nd	0.37	nd	nd	0.56	1.18	0.23	1.25	0.39	nd	nd	nd	6.40	2.56
Parupeneus multifasciatus	0.85	1.47	1.63	nd	1.55	nd	nd	1.53	nd	1.94	nd	0.67	1.36	0.91	nd	0.97	0.83	nd	nd	nd	13.7	5.49
Myripristis amaena	nd	0.40	nd	0.68	0.91	nd	0.32	3.27	0.10	1.18	nd	0.30	0.42	0.10	0.12	0.23	0.21	0.06	nd	0.60	8.90	3.56
Myripristis pralina	nd	1.10	3.32	0.96	1.30	nd	nd	4.52	0.29	2.46	nd	0.69	0.12	0.40	0.29	0.54	0.25	nd	nd	1.32	17.6	7.02
Myripristis murdjan	1.29	1.15	4.44	0.85	1.00	nd	0.20	3.51	nd	1.19	nd	0.35	0.42	nd	nd	0.24	0.81	0.05	0.07	0.61	16.2	6.47
Neoniphon sammara	1.42	1.11	4.00	nd	1.12	nd	nd	4.12	0.51	3.56	nd	1.07	2.10	1.10	0.36	0.73	0.41	nd	0.48	0.79	22.9	9.15
Myripristis kuntee	0.67	0.46	nd	nd	0.75	nd	nd	3.60	nd	1.62	nd	0.39	0.80	0.30	0.09	0.64	0.26	nd	0.24	0.46	10.3	4.12
Myripristis berndti	2.21	1.72	6.55	nd	2.25	nd	nd	3.86	nd	1.46	nd	0.51	0.46	nd	nd	0.59	0.34	nd	nd	1.94	21.9	8.75
Myriprisits pralina	nd	nd	nd	0.68	0.41	2.08	nd	1.71	nd	0.31	nd	0.09	nd	0.36	nd	0.17	nd	nd	nd	nd	5.79	2.32
Myripristis violacea	nd	nd	nd	nd	0.41	3.31	nd	nd	nd	0.78	nd	nd	0.10	0.51	nd	0.30	nd	nd	nd	nd	5.41	2.16
Myripristis violacea	nd	nd	nd	0.94	1.01	nd	nd	4.16	0.71	2.40	nd	0.56	1.30	1.47	0.13	1.36	0.40	nd	nd	nd	14.4	5.77
Myripristis amaena	nd	nd	nd	1.25	0.36	1.92	nd	nd	nd	0.46	nd	0.10	0.09	0.21	nd	0.69	nd	nd	nd	nd	5.07	2.03
Myripristis violacea	nd	nd	nd	1.58	1.37	4.60	nd	3.53	0.16	1.18	nd	0.19	nd	0.39	nd	2.22	nd	nd	nd	nd	15.2	6.09
Myripristis violacea	nd	nd	nd	2.12	0.75	nd	nd	nd	nd	0.76	nd	0.15	nd	0.77	nd	0.54	nd	nd	nd	nd	5.09	2.04
Myripristis violacea	nd	nd	nd	1.71	1.85	2.67	nd	nd	nd	0.42	nd	0.21	nd	0.39	nd	0.37	nd	nd	nd	0.31	7.92	3.17
Myripristis violacea	nd	nd	nd	nd	0.63	2.32	nd	nd	0.26	0.77	nd	0.28	0.47	0.60	0.08	0.19	0.34	nd	nd	nd	5.93	2.37
Myripristis violacea	nd	nd	nd	nd	nd	2.31	nd	nd	nd	0.15	nd	0.09	nd	0.15	nd	0.53	nd	nd	nd	nd	3.24	1.29
Scarus ghobban	nd	nd	1.05	0.57	0.80	nd	nd	3.63	0.76	3.28	nd	0.83	2.02	0.84	0.30	0.46	0.25	nd	nd	nd	14.8	5.91

Table 3 (cont.): PCB Levels in Axial Muscle of Dominant Food Fish from Tanapag Lagoon, Saipan

Species	PCB Congeners (ng/g dry wt.)																				Σ_{20}PCB	Total PCB (wet wt.)
	8	18	28	44	52	66	77	101	105	118	126	128	138	153	170	180	187	195	206	209		
Puerto Rico Dump (site 2)																						
Balistoides viridescens	2.04	0.62	nd	1.22	0.41	nd	nd	5.40	0.09	0.89	nd	nd	nd	1.05	nd	0.49	nd	nd	nd	nd	12.2	4.89
Lethrinus harak	2.54	1.77	4.99	2.04	0.69	nd	nd	5.76	nd	1.56	nd	0.22	nd	3.02	nd	1.90	1.21	nd	nd	nd	25.7	10.3
Lethrinus harak	3.71	1.36	nd	1.29	0.60	nd	nd	6.21	1.08	2.92	nd	0.89	1.45	4.10	0.61	1.49	1.15	0.12	nd	nd	27.0	10.8
Naso lituratus	2.33	1.67	3.70	nd	nd	nd	nd	2.89	nd	1.01	nd	0.18	nd	1.68	nd	0.07	nd	nd	nd	nd	13.5	5.41
Naso lituratus	2.63	1.28	nd	nd	1.20	nd	0.89	5.47	nd	1.01	nd	0.18	nd	nd	nd	0.51	0.34	nd	nd	nd	13.5	5.41
Naso lituratus	3.08	1.03	nd	nd	0.28	nd	nd	4.28	0.20	1.18	nd	0.18	nd	1.81	nd	0.41	0.16	nd	nd	nd	12.6	5.04
Naso lituratus	2.96	1.47	0.26	nd	0.74	nd	nd	7.41	1.43	4.05	0.58	0.82	0.72	2.37	nd	0.51	nd	nd	nd	nd	23.3	9.32
Naso lituratus	3.51	2.38	6.30	1.66	2.39	nd	nd	19.3	6.11	13.1	0.16	3.07	4.65	6.92	nd	1.15	0.47	nd	nd	nd	71.1	28.4
Naso lituratus	2.67	1.94	0.35	nd	nd	nd	nd	5.40	0.25	1.15	0.87	nd	nd	0.15	nd	nd	nd	nd	nd	nd	12.8	5.11
Naso lituratus	2.04	2.51	nd	nd	nd	nd	nd	8.42	2.57	5.58	nd	1.34	1.60	4.83	nd	0.75	0.41	nd	nd	nd	30.1	12.0
Naso lituratus	2.13	1.57	3.48	nd	nd	nd	nd	3.36	0.11	1.33	0.15	0.16	nd	nd	nd	0.33	nd	nd	nd	nd	12.6	5.05
Naso lituratus	1.27	0.70	0.83	nd	0.32	nd	nd	2.08	nd	0.35	nd	0.20	nd	nd	nd	0.14	nd	nd	nd	nd	5.88	2.35
Naso lituratus	0.93	0.57	2.17	0.50	2.27	nd	nd	11.0	3.45	8.28	nd	2.02	3.96	6.22	0.85	1.48	0.65	nd	0.17	nd	44.5	17.8
Naso lituratus	2.61	0.90	nd	nd	0.26	5.84	nd	nd	nd	0.17	nd	0.12	nd	nd	0.06	0.09	nd	nd	nd	nd	10.1	4.02
Naso lituratus	nd	nd	0.16	3.53	2.68	nd	nd	27.8	10.2	24.3	4.41	5.94	13.3	14.3	2.41	3.71	1.23	nd	0.72	1.14	116	46.4
Naso lituratus	0.48	1.04	2.92	nd	0.43	nd	nd	nd	nd	0.27	nd	0.08	nd	nd	nd	0.26	0.29	0.37	nd	0.68	6.81	2.73
Naso lituratus	nd	0.87	nd	nd	1.10	nd	nd	5.17	1.63	3.76	nd	1.09	2.08	1.53	0.29	0.81	0.59	nd	nd	0.34	19.2	7.70
Parupeneus multifasciatus	10.5	6.68	0.83	nd	2.67	nd	nd	12.3	3.20	7.81	nd	2.54	3.82	16.14	2.02	6.95	4.43	nd	nd	nd	79.9	32.0
Parupeneus multifasciatus	2.53	2.35	nd	nd	1.02	nd	nd	10.6	0.50	3.01	nd	0.42	0.56	4.25	0.57	2.67	nd	nd	0.88	nd	29.4	
Outer Lagoon (sites 5 and 6)																						
Acanthurus nigrofuscus	2.72	0.80	nd	2.19	1.66	nd	0.81	14.7	2.73	7.72	nd	1.42	2.58	3.73	0.23	0.48	nd	nd	nd	nd	41.8	16.7
Cheilinus tribolatus	nd	0.56	nd	2.00	0.99	nd	nd	8.08	1.73	5.45	nd	0.89	1.71	2.48	0.16	0.33	nd	nd	nd	nd	24.4	9.76
Hemigymnus melapterus	2.51	0.91	2.62	0.29	0.56	nd	nd	3.11	nd	0.69	0.13	0.08	0.59	3.26	0.26	0.66	1.11	nd	nd	nd	16.8	6.71
Hemigymnus melapterus	3.00	0.91	nd	3.40	1.80	nd	nd	8.66	0.42	1.96	nd	nd	0.28	1.17	0.13	0.22	nd	nd	nd	nd	22.0	8.78
Lethrinus obsoletus	nd	0.67	nd	nd	0.312	nd	nd	2.98	nd	0.73	nd	nd	nd	0.46	nd	nd	nd	nd	nd	nd	5.15	2.06
Naso unicornis	3.00	5.24	nd	2.85	2.20	nd	nd	14.4	3.97	11.0	0.23	2.48	4.51	4.83	0.67	1.07	0.54	nd	nd	nd	57.0	22.8
Parupeneus barberinus	1.78	1.20	2.21	nd	0.44	nd	nd	2.09	nd	0.61	nd	nd	nd	0.43	nd	nd	nd	nd	nd	nd	8.8	3.50
Scarus ghobban	2.17	0.93	2.24	1.28	1.23	nd	0.70	6.45	1.15	3.25	nd	0.68	0.81	1.68	nd	0.53	0.36	nd	nd	nd	23.5	9.39
Scarus ghobban	1.63	0.86	0.13	1.26	1.00	nd	nd	3.98	0.09	0.91	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	9.85	3.94
Scarus globiceps	2.20	1.38	nd	1.10	0.64	nd	nd	4.21	nd	0.71	nd	0.07	nd	0.82	nd	0.07	nd	nd	nd	nd	11.2	4.48

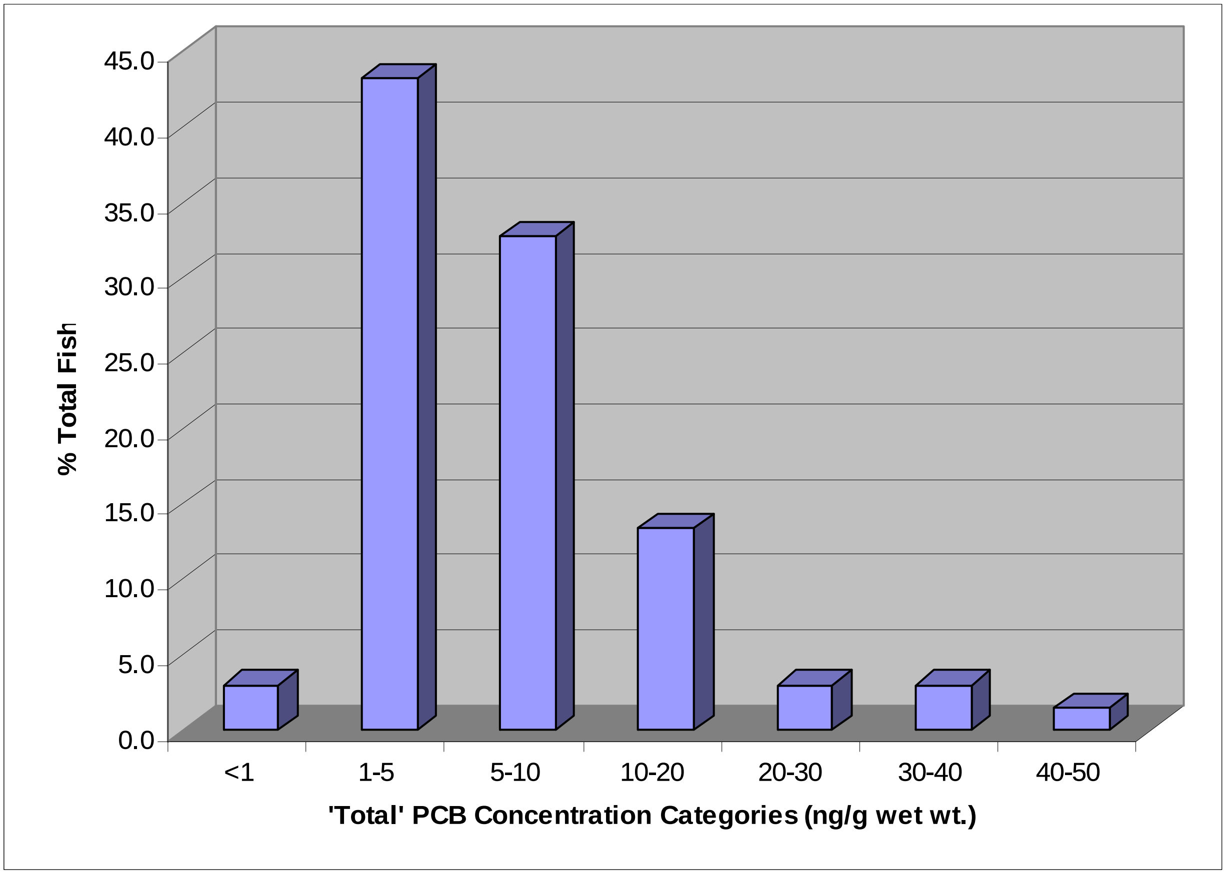

Figure 2: Frequency distribution histogram of 'total' PCB levels in fish examined to date

63% of the total number of fish analyzed to date fell into the unrestricted consumption category, and a further 22% contained levels that permit consumption of up to sixteen 8 oz fish meals per month (i.e. 6-12 ng PCB/g dry wt.). It should be noted that these guidelines are based on noncancer health endpoints and are four times higher (less sensitive) than the equivalent USEPA fish meal consumption rate guidelines derived using cancer health endpoints (based on an acceptable cancer risk of 1 in 100,000 over a 70 year lifetime). That said, it would seem that PCB levels in fish from Tanapag Lagoon are comparable with those found in specimens from relatively clean environments and do not represent a particularly significant health risk to consumers enjoying moderate consumption of these resources.

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Development of an optimum Operational Management for the Saipan Water Distribution System

Basic Information

Title:	Development of an optimum Operational Management for the Saipan Water Distribution System
Project Number:	2006GU75B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Engineering
Focus Category:	Models, Water Supply, Management and Planning
Descriptors:	Water System Modeling, Consumer Demands, GIS Applications
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz

Publication

PROJECT SYNOPSIS REPORT

Project Title: Development of an Optimum Operational Management Scheme for the Saipan Water Distribution System

Problem and Research Objectives

The goal of the Commonwealth of the Northern Marianas Islands (CNMI) Government is to provide 24-hour water service to all residents served by the Commonwealth Utility Corporation (CUC) water system. A special task force, which has been created by the CNMI government, has been carrying out various projects to accomplish the goal of providing 24-hours water service to all CUC customers. Large sums of Federal funds have been expended on system metering, drilling new wells, and adding new water storage capabilities. In spite of these attempts, CUC has not been able to completely accomplish the 24-hours water goal. The basic reason for this problem is that the Saipan water system is a very complicated system and the CUC operators find it difficult to understand the complex system hydraulics which controls how water flows through the system. In addition, inadequate inflow to the system, system leakage, and lack of ways to examine various system operation scenarios have made the goal of 24-hours water service difficult to obtain.

The Saipan water distribution system, as shown in Figure 1, is operated as 14 interconnected sub-regions. Each sub-region, a sample of which is shown in Figure 1, is expected to operate somewhat independently. WERI researchers have initiated the development of a skeletonized computer model of each of the fourteen sub-regions of the CUC water system using the Haestad WaterCAD water distribution system modeling program. These skeletonized models do not include all pipes in the system, but are limited to all pipes greater than 4 inch in diameter, and all the major water sources, tanks and transmission components of each sub-region. The skeleton models represent the major components that control the hydraulic movement of water through the system.

The goals of this project were: 1) to complete the skeleton model of the Saipan water distribution system that will includes all major pipes, wells, reservoirs, and springs and, 2) develop sub-region based demands to apply to the water system model, and 3) operate the entire system as a whole to assist in developing optimum ways to transfer water through the system.

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 understanding of the most efficient means to move water from water supply rich regions to those that have supply shortages. The overall goal is to provide delivery of water on a 24 hour basis to all areas served by the system.

Methodology

The first major component of the project was the completion of the 14 sub-regional skeleton models. The skeleton model that was developed includes all the pipes greater that 4 inch diameter. Several trips were made to Saipan to field verify various aspects of each of the sub-region models and to discuss the complex connections in the system with CUC water division and field staff. We gathered available data on the physical and hydraulic description of all of the pumps, wells and spring sources including the hydraulic characteristics of all well and booster pumps used to move water through the system. This was necessary to be absolutely sure the model was a valid representation of the existing field condition in the water system.

In order to accurately predict the pressure at the junction nodes, it was necessary to assign the proper elevation for each pipe junction. This was done by exporting the junction nodes for each sub-region from the Haestad water system model to the ArcGIS shape file format (Figure 2). The exported shape file contained an empty field for the junction elevation variable. This point shape file of junction location was next added to the ArcGIS map. Next a digital elevation model raster file was added to the map. Elevations were assigned to each junction using the "Extract Values To Points" ArcGIS tool. This function extracts the elevation value for the junction from the grid cell in which the junction node resides and assigns that value to the junction node. The junction node shape files with updated elevations were then imported back to the Haestad format. The model was then ready to run with updated elevations resulting in proper pressure computations at each junction node.

A second very important modeling consideration for a water distribution system model is the customer water demands in the system. Demands are input to the water system model at junction nodes. A detailed analysis was carried out in order to assign realistic junction node demands. First a listing of customers in each sub-regional area was obtained from Saipan water master plan of 1996. Figure 3 shows the location of each of the sub-regions. Table 1 shows the listing of number of customers for each of the sub-regions that was obtained from CUC. CUC personnel also provided information on the estimated number of people being served at each customer location. They felt that 6 people per customer location was a good estimate to use for our study's purposes. The next step was to multiply the number of customers per region by 6 people per customer to get the total number of people being served in each sub-region. The number of people in each region was multiplied by varying values of typical US national usage rates of 80, 100, and 150 (gallons/person/day) to get the total volume of water required in each region per day. These numbers were then adjusted to the gallons per minute (gpm) flow rates that the water system model requires. The total gpm for each region was divided by the total number of junctions in the region to obtain a flow demand for each junction. The junction demands were then assigned to the junctions using the global editing option of the Haestad model. For our first model runs we used the 100 gallons/per capita/per day values for our initial model runs. Values for other use rates could be easily entered for the junctions.

Each sub-model was run and meticulously checked in steady state mode to be sure all computed flow and pressure values were reasonable and agreed with measured system values provided by CUC.

Principal Findings and Significance

The main product of this project was the development of a skeleton model that contains updated descriptions of the main transmission and distribution lines, the sources, storage tanks and pumps in Saipan's water distribution system. The model has been verified by the CUC water division staff and the water demand rates used are those that represent the best estimates based on Saipan's water master plan of 1996. Each sub-region model is operational and ready for use for making improvements in water system operation. These improvements should help CUC to meet the Government's goal of providing 24-hours water to all customers.

Future studies should be made to update the estimates of water system demands that were used in this study. New census data has been made available since the last master plan effort was made. If these new census values are applied using GIS techniques more realistic demands for each junction location can be found. Also major demand customers should also be identified. These include commercial laundries, laundromats, and barracks areas for guest workers. These locations induce large demands at point locations in the system and need to be adequately accounted for if the model is to be a true representation of the real system.

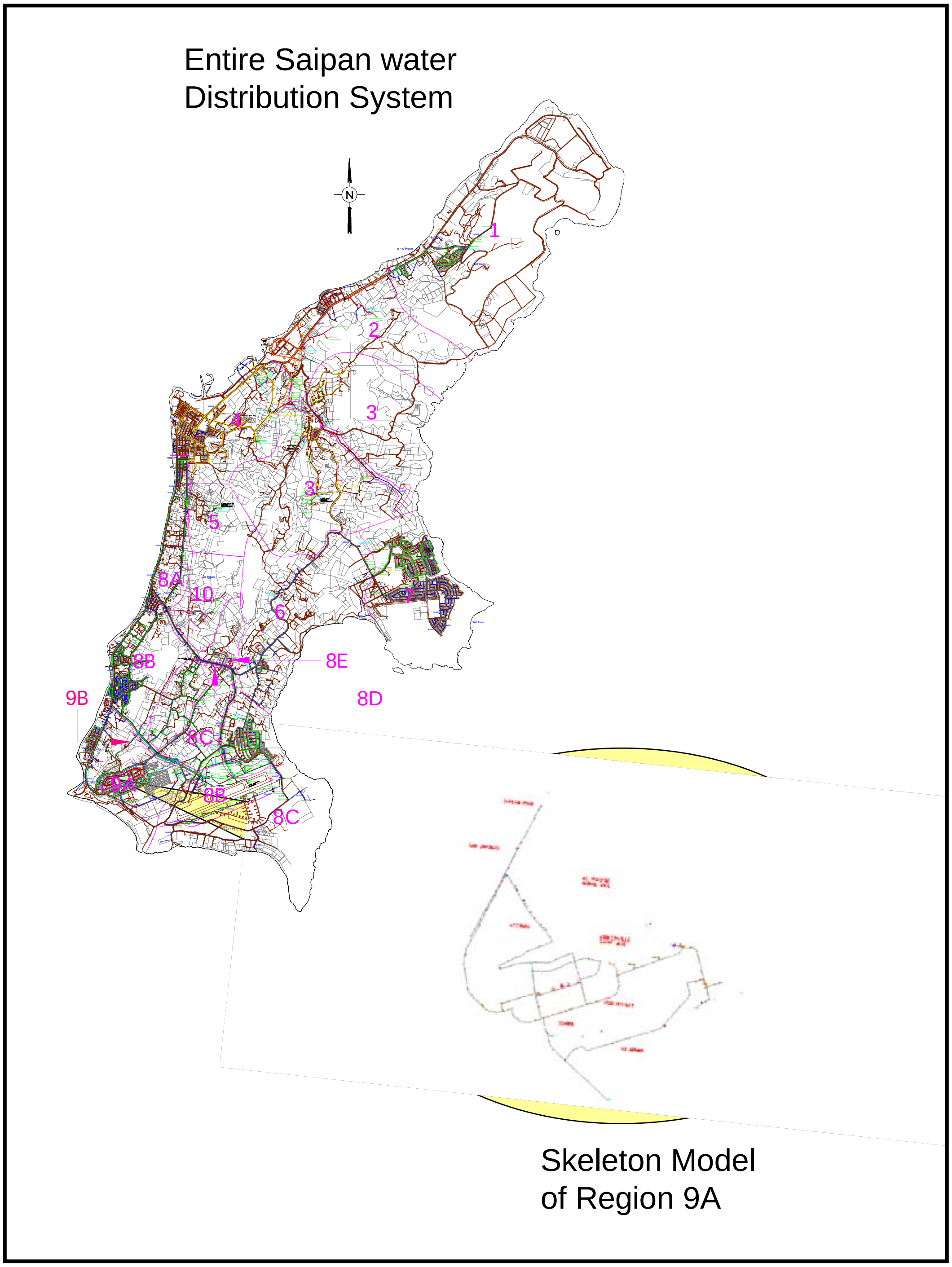

Figure 1. Saipan water distribution system and skeleton model of sub-region 9a.

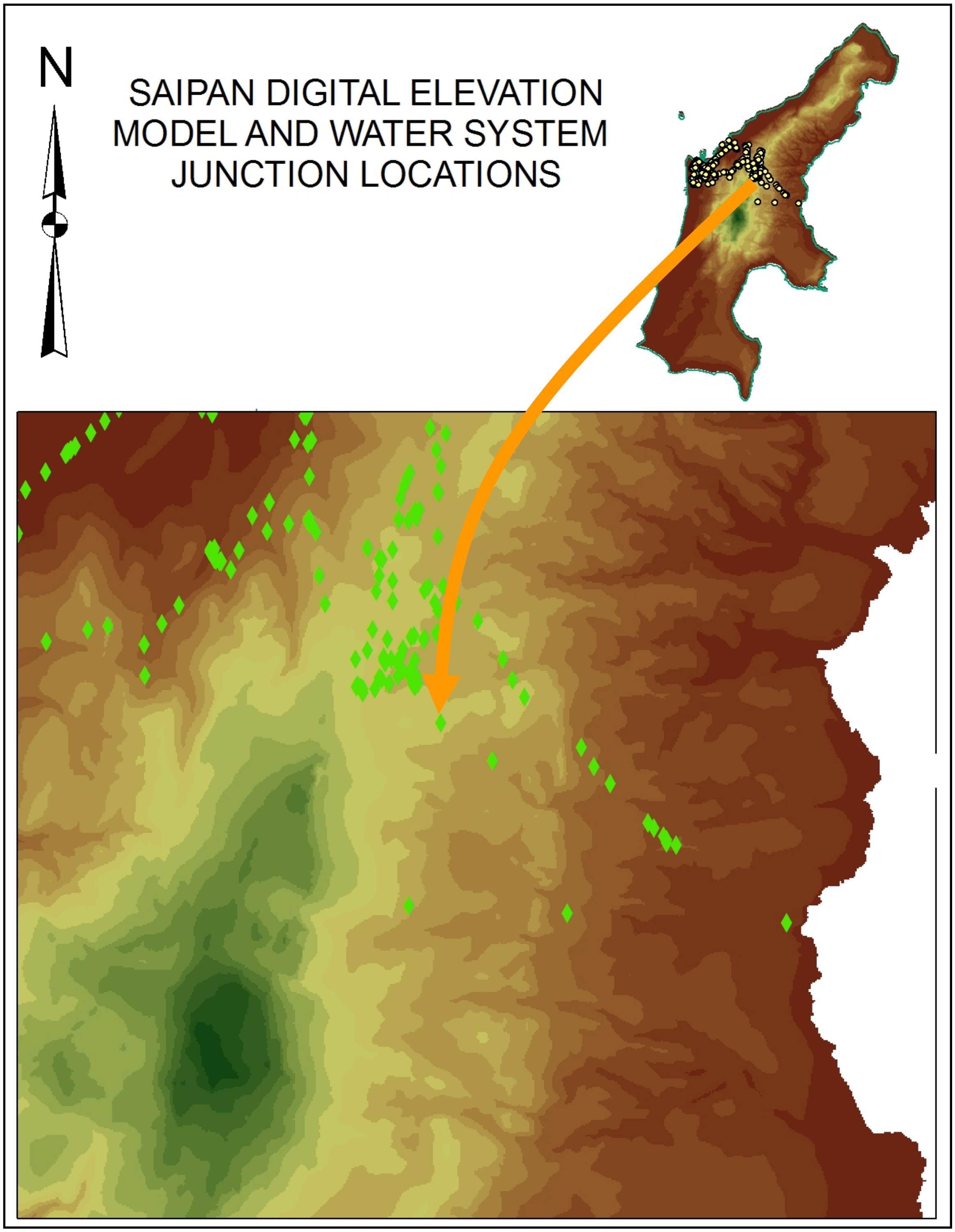

Figure 2. Saipan digital elevation model (DEM) with water system junction nodes used for assigning junction node elevations.

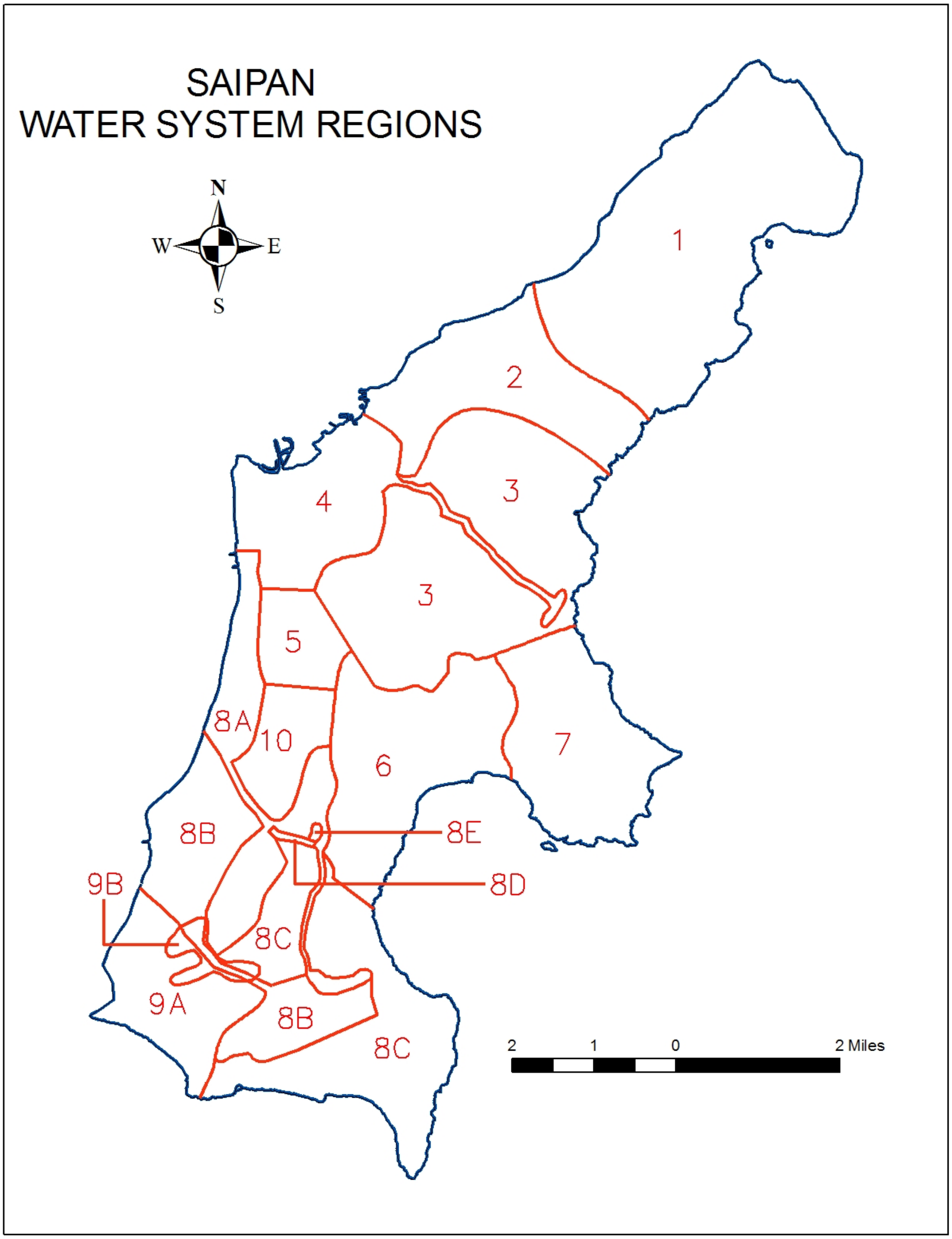

Figure 3 Saipan water system sub-regions

	WATER USE DEMAND CALCULATION							
		FOR						
	SAIPAN WATER DISTRIBUTION SYSTEM							
	Using CUC Routing System							
Region	**# Customers**	**# People**	**Water Use GPD/P**	**Water Use GPD/P**	**Water Use GPD/P**	**Water Use (gpm)**	**Water Use (gpm)**	**Water Use (gpm)**
		6/customer	**80**	**100**	**150**	**80**	**100**	**150**
1	443	2658	212640	265800	398700	148	185	277
2	582	3492	279360	349200	523800	194	243	364
3	908	5448	435840	544800	817200	303	378	568
4	3163	18978	1518240	1897800	2846700	1054	1318	1977
5	249	1494	119520	149400	224100	83	104	156
6	1180	7080	566400	708000	1062000	393	492	738
7	1113	6678	534240	667800	1001700	371	464	696
8A	2078	12468	997440	1246800	1870200	693	866	1299
8B	1361	8166	653280	816600	1224900	454	567	851
8C	1211	7266	581280	726600	1089900	404	505	757
8D	180	1080	86400	108000	162000	60	75	113
8E	50	300	24000	30000	45000	17	21	31
9A	1545	9270	741600	927000	1390500	515	644	966
9B	164	984	78720	98400	147600	55	68	103
10	384	2304	184320	230400	345600	128	160	240
TOTAL	**14,611**	**87,666**	**7,013,280**	**8,766,600**	**13,149,900**	**4,870**	**6,088**	**9,132**

Table 1 Water system customers and demands by sub-region

Response of Well Heads of the Northern Guam Lens Aquifer to Rainfall and Sea Level Fluctuations at Daily Resolution

Basic Information

Title:	Response of Well Heads of the Northern Guam Lens Aquifer to Rainfall and Sea Level Fluctuations at Daily Resolution
Project Number:	2006GU76B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Climatological Processes, Water Quantity
Descriptors:	Rainfall, sea level, groundwater, recharge, typhoons, extreme events, prediction
Principal Investigators:	Mark Lander

Publication

PROJECT SYNOPSIS REPORT

Project Title: Response of Well Heads of the Northern Guam Lens Aquifer to Rainfall and Sea Level Fluctuations at Daily Resolution

Problem and Research Objectives

This project was an intensive one-year study of newly acquired daily values of well head, rainfall, and sea level. Data has been obtained for other wells that were not available in previous research efforts (Lander et al. 2001). Substantial preparatory work was done to properly format all data in a side-by-side daily order, for ready analysis and comparison. The immediate objective was a set of statistical model predictions of the daily value of the head at each well using the values of the daily rainfall and daily sea level. The parameters (e.g., coefficients for the rainfall response curve, coefficients for the sea level response, the constraints applied to the outflow, and the numerical value of the floors on the predicted head) that optimize these predictions will give insight into the hydraulic and geological properties of Guam's northern lens aquifer. Of particular interest will be to document the well responses to pulses of heavy rainfall, and the nearly step-function drops of sea level that occur after the close passage of typhoons. There are several pulse occurrences of substantial rainfall, and rapid rises and falls of sea level in response to typhoons and to El Niño. The response of the wells to these extreme events will be benchmark tests of any numerical model simulation of the NGLA. This study provides baseline information for identifying the physical properties of the aquifer, and their implications for numerical simulation of the NGLA and for Guam's water management plan. Recent acquisition of rainfall, sea level, and wellhead data at *daily* resolution — plus the acquisition of data for several more wells than were used in the previous study (Lander et al. 2001) — has allowed a more in-depth analysis of the well hydrograph responses to variations in the rainfall and sea level. For example: a highly accurate prediction of the daily hydrograph of Well A20 in Ordot was made using only the daily rainfall data obtained at the Guam International Airport. Correlations between the predicted well head and the observed well head exceeded +.90 (Fig. 1).

Moving to the wells of the northern Guam Lens Aquifer, very different response characteristics to rainfall are found than at the Ordot Well (A20). Whereas Well A20 is in argillaceous limestone, has an elevated wellhead (15 meters above sea level), and shows no response to changes in sea level; the wells in the north are in limestone of higher permeability, they have a head that is near sea level, and the head responds to variations in sea level. The response of the northern wells to rainfall pulses is much faster than at A20. Using the same well-as-reservoir approach for the response of the northern wells to the time series of daily rainfall yields less skillful predictions (Fig. 2).

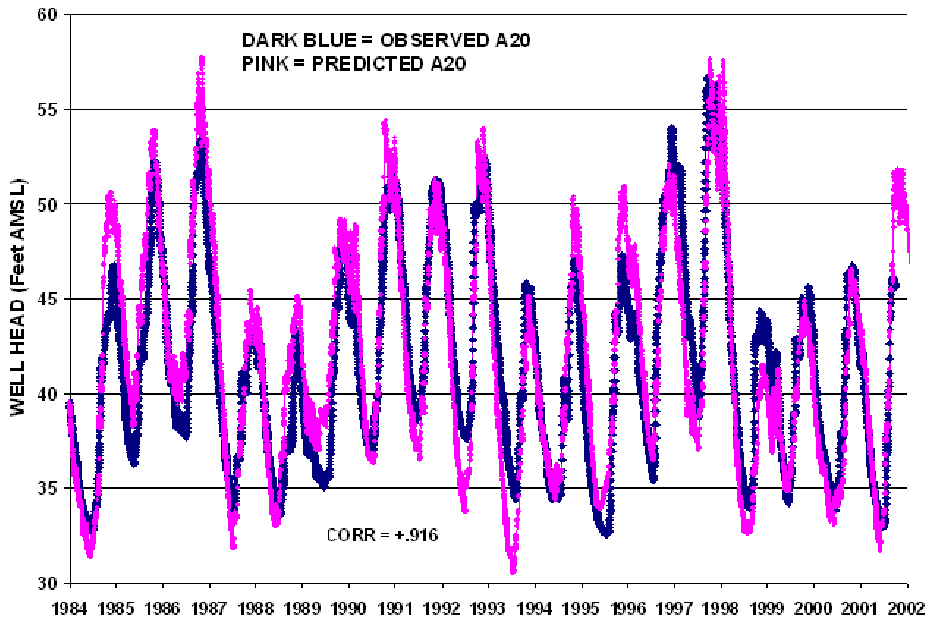

Figure 1. A comparison of the observed A20 well hydrograph versus the predicted hydrograph.

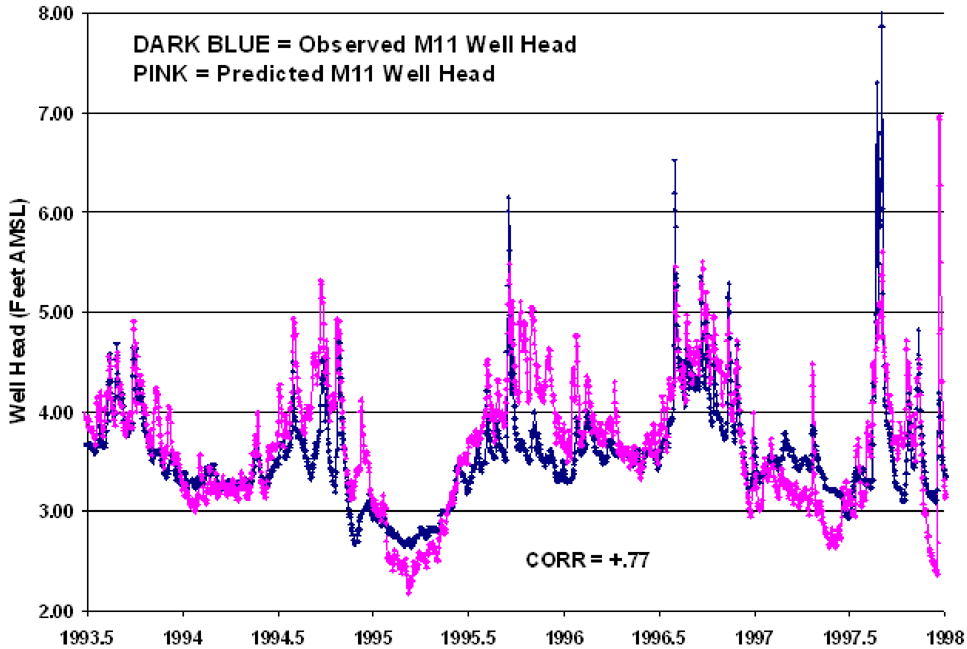

Figure 2. Predicted (pink time series) and observed heads (dark blue time series) for Well M11. The predicted time series was based on daily rainfall and sea level data.

Methodology

Instead of using correlation analysis to determine the relationships among wellhead rainfall and sea level (as in Lander et al. 2001), a conceptual model of the well-as-reservoir was used. The wellhead was assumed to respond to the rainfall in the same manner as a reservoir, with the changes in the storage (i.e., gage height, S) in the model reservoir given by:

$$\Delta S = \text{Inflow} - \text{Outflow} \qquad (1)$$

The outflow was assumed to be proportional to the Storage or gage height, S:

$$\text{Outflow} = k\,(S - \text{Floor}) \qquad (2)$$

Where k is a constant, and “Floor” is the base level below which no outflow occurs.

The observed daily rainfall at the Tiyan WSO was used as the inflow to the reservoir. With suitably chosen constants, and a floor beneath which no outflow was allowed to take place, the predicted water level in the model reservoir matched the well head of A20 very closely.

The finite difference integration of the following equation yielded the predicted A20 well head in Fig. 1:

$$(\text{Well head})\ D = (\text{Well head})\ D\text{-}1 + K1\ (\text{Rain}) - K2\ ((\text{Well head})\ D\text{-}1 - \text{Floor}) \qquad (3)$$

Where D = Day; and K1, K2, and “Floor” are constants.

A further refinement of Equation (3) to include a delayed response to the rain at time lags of up to one month yielded even better predictions (not shown).

An additional constraint on the values of the coefficients was for them to accurately replicate the short-term response to extreme daily rainfall events (Fig. 4). The problem thus becomes one of optimizing the performance of the predictions in a multidimensional phase space that includes: (1) the correlation coefficient between the predicted wellhead and the observed wellhead for the entire time series, (2) the match of the predicted wellhead versus the observed wellhead response for selected extreme daily events, and (3) the mean absolute error between the predicted wellhead time series and the observed wellhead time series. The mathematics of analyzing this phase space for local and global minima was beyond the scope of this project, but values were chosen manually that gave satisfactory results on the graphical presentations of the time series. Cross correlation values between the predicted wellhead time series (12 years) and the observed time series exceeded +.90 for well A20, and +.75 for the M series wells, while retaining fidelity to the observed wellhead responses to extreme daily rainfall events.

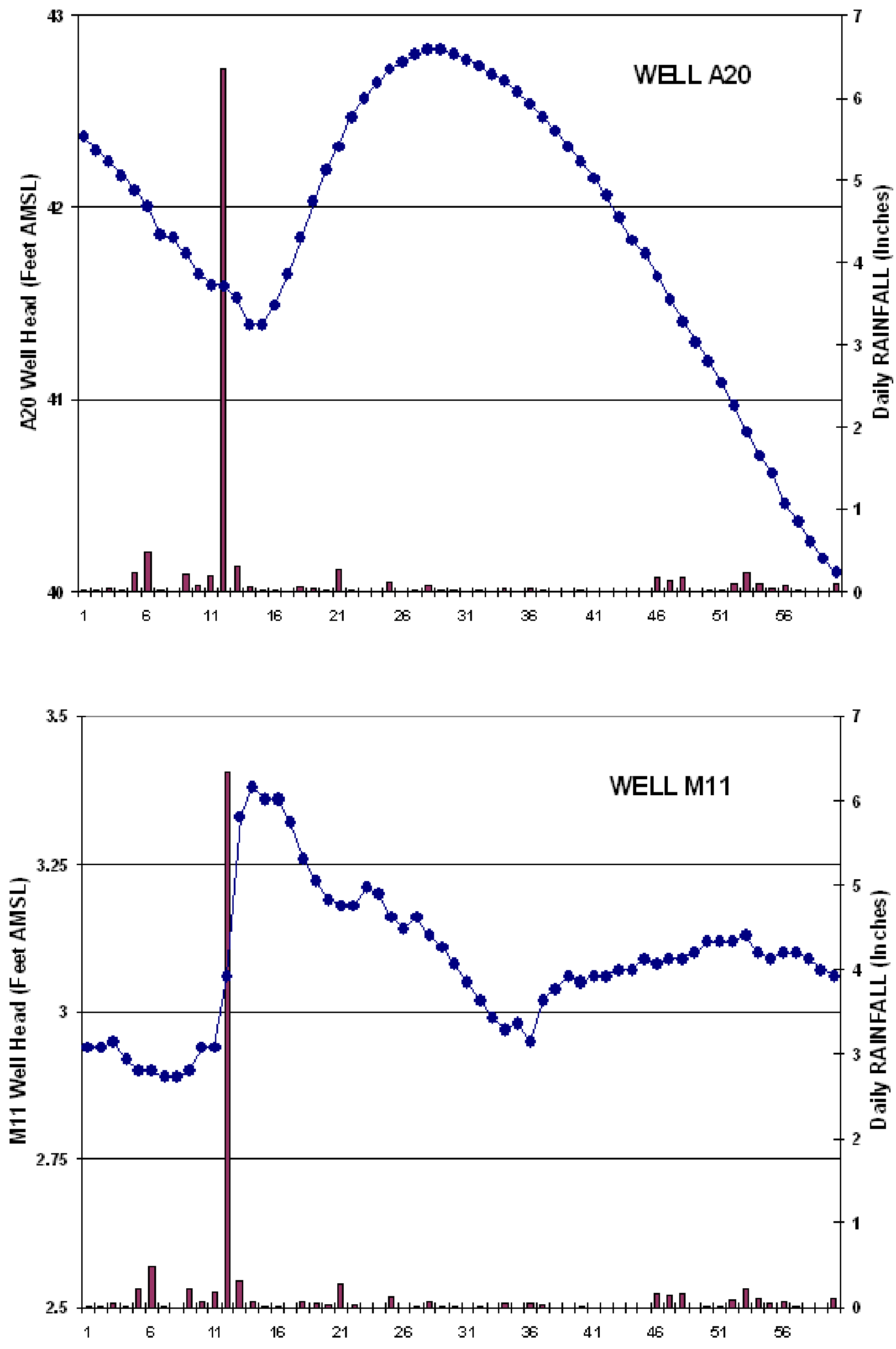

Figure 3. The response of Well A20 (top panel) and Well M11 (bottom panel) to a pulse of heavy rain (6 inches) that occurred on January 12, 1988.

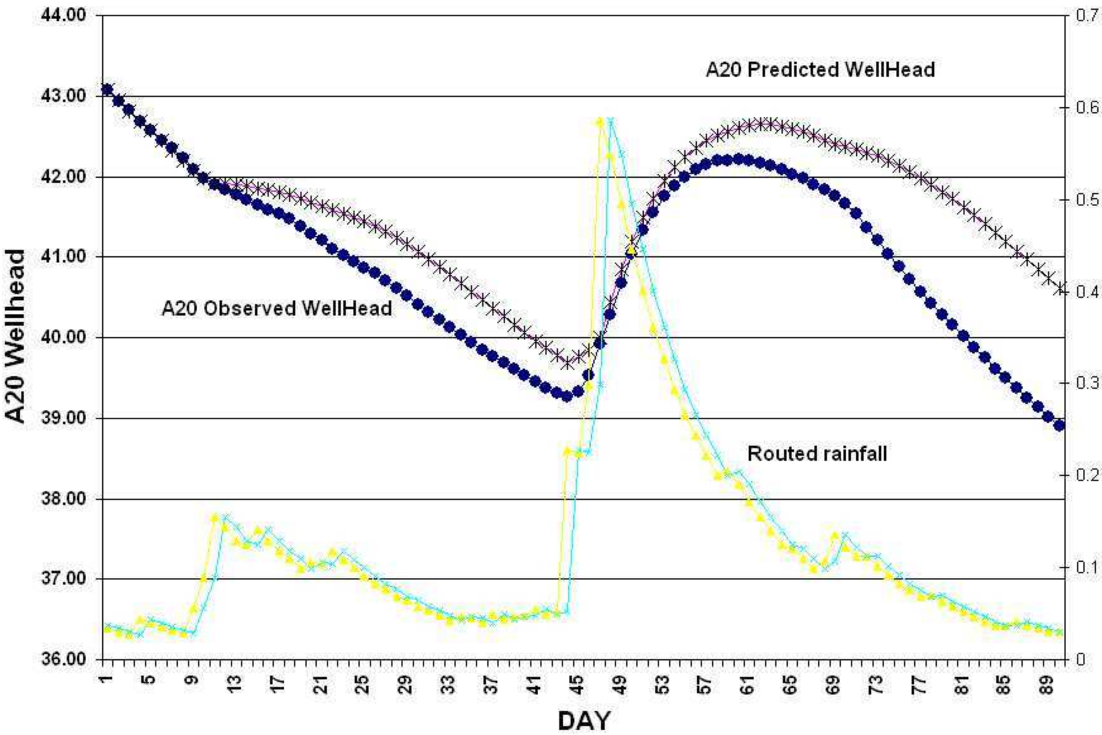

Figure 4. Observed (solid circles) and predicted (cross hatches) A20 wellhead response to an extreme daily rainfall event that occurred on 15 February 1999. Day 1 = January 1, 1999. The rainfall is fed into the well with a delayed response given as the outflow from a hypothetical intervening reservoir.

Principal Findings and Significance

Very accurate predictions of wellhead in the northern Guam lens aquifer can be made from known values of daily rainfall and sea level. Cross correlation values exceeding +.90 can be achieved for the argillaceous A series wells, and exceeding +.75 for the M series wells in the north. All of the predictions were made in hind cast. The high accuracy of these predictions, however, implies that were substantial rainfall and/or sea level anomalies to be known in advance, say through accurate predictions of El Niño, then useful predictions of wellhead could be made.

While in the course of this project, some important findings emerged that have potential value for future research: (1) an abrupt rise of the sea level was noted on Guam beginning during 1998 and continuing through the following decade, and (2) an extreme 24-hour rainfall amount occurred in late June of 2004 while Guam was in an outer *rainband* of Typhoon Tingting.

During 1998, a rapid sea level rise was noted in Guam tide gage readings. Since that year, the sea level on Guam has remained well above its historical stand. This sea level rise also appears in the time series of Guam's wellheads. Substantial erosion occurred along much of Guam's coastline over the past decade, and its cause is debated. There were an unusual number of typhoons during the 1990s, and the sea level rose abruptly after the 1997 El Niño. It is not known what effects a rising sea will have on the flow characteristics of the NGLA. The location of dissolution-widened channels within the limestone is affected by the long-term sea level. A sustained rise in Guam's sea level could have an impact on the properties of Guam's aquifer.

The daily rainfall during the passage of Typhoon Tingting near Guam on 28 June 2004 was over 20 inches for most of the island. This occurred while Guam was in an outer rain band of the typhoon. The center of the typhoon passed well north of Guam. This was the first time that a 20-inch daily rainfall event occurred in anything other than the direct passage of a typhoon eye wall over Guam (e.g., both Chataan and Pongsona yielded 24-hour rainfall in excess of 20 inches across much of Guam). Whereas Tingting produced its extreme 24-hour rainfall through the net accumulation of several hours with rain rates on the order of 2 inches per hour, the same extreme daily rainfall values in Chataan and Pongsona occurred with extraordinary hourly rain rates of 6 or 7 inches per hour within the typhoon eye wall. This is an avenue for further research.

Hydrological modeling of atoll islands in the Federated States of Micronesia

Basic Information

Title:	Hydrological modeling of atoll islands in the Federated States of Micronesia
Project Number:	2006GU79B
Start Date:	3/1/2006
End Date:	2/1/2007
Funding Source:	104B
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	Atoll islands, groundwater modeling, salt-water intrusion
Principal Investigators:	john jenson, Donald Rubinstein, Yuming Wen

Publication

PROJECT SYNOPSIS REPORT

Project Title: Hydrologic Modeling of Atoll Islands

Problem and Research Objectives

Water shortages pose a serious concern to the inhabitants of atoll islands. The small size, low elevation, unique geology, and isolation of atoll islands combine to create a system that can threaten the well-being of entire populations during times of prolonged drought or recovery from heavy tropical storms. Under normal conditions the fresh water demand is met by rooftop rain catchment supplies, but once these supplies are exhausted the inhabitants turn to ground water. However, the location, quality and quantity of ground water are not readily identifiable for many of the atoll islands. Without such knowledge long-term water resources planning is made difficult, if not impossible. As atoll islands are becoming more and more developed the need for accurate ground water assessment is increasing.

The full objective of this thesis project is to develop numerical and analytical groundwater models that will enable islands water resources planners to confidently establish long-term water resources plans for the islands under their stewardship.

Methodology

The methodology includes five main parts: theory, observation, experimentation, analysis, and application.

The theoretical portion of the project includes analyzing all published papers about atoll island geology, hydrology, hydrogeology, and numerical modeling. This process began one year ago, and is still continuing today. Numerous studies have been performed, each one dealing with a specific island or group of islands, which range geographically from the Caribbean, to the Indian Ocean, and the entire Pacific Ocean Basin. From these studies have come published values for the geology of atoll islands, the rainfall rates for each area of study, the customs of the inhabitants of atoll islands, and the parameters and steps used in creating numerical models.

The Observation phase of the project is mostly complete. Three expeditions were taken to Ulithi Atoll, Yap State, FSM, the first in January 2006, the second in August 2006, and the third in January 2007. A fourth visit is planned for Pingelap, Pohnpei State, FSM, in July 2007. These two atolls have been studied previously and have published values of geology and hydrology. The trips to Ulithi consisted of hydrology, water uses, geology, and vegetation surveys. The wells on the four inhabited islands were each analyzed for depth-to-water, temperature, and salinity. The islands were circumnavigated in order to analyze the surface geology at each location around the atoll island, and especially to compare the windward side with the leeward side.

The Experiment phase consists of constructing groundwater models which accurately depict the observations found during previous atoll island studies. The observations included subsurface geology, hydraulic conductivity of geologic zones, depth to water table, thickness of freshwater lens and transition zone, rainfall rates, tidal range and efficiency, and vegetation. Using these parameters, including published water and soil properties, an atoll island groundwater model has been constructed, and is currently being calibrated to match the conditions observed in the field. Both steady-state and transient models are being run. Steady-state models are used to study the average freshwater lens behavior to be expected, and transient models are used to study short-term behavior of the freshwater lens due to pumping, drought, typhoons, and sea-level rise.

Work performed during the analysis phase will result in pinpointing any trends seen from the modeling simulations. The patterns seen from the steady-state simulations will enable water resource managers to predict the average conditions of the freshwater lens on atoll islands across Micronesia. The results of the transient simulations, i.e. the water table elevation, the thickness and volume of the freshwater lens, will be graphed over time to show the reaction of the lens to various extreme climatic events. The modeling results will allow adequate preparation to be made for these events.

Principal Findings and Significance

The steady-state simulations are currently being run. The results are being compared to the field observations, and models adjusted accordingly to match these observations. It is clear from the published studies that the geology of all atoll islands cannot be accurately represented in one global conceptual model. The overall geology is similar on all atolls, but the details vary considerably, which greatly influence the hydrology, particularly the freshwater lens. Using one general conceptual model for all computer simulations and water resources plans will lead to erroneous results. It thus seems fitting to have several conceptual models, each one representing a variation of the general conceptual model, and using these conceptual models to construct separate groundwater models.

Management of the Nanpil River Watershed, Pohnpei Island, the Federated States of Micronesia

Basic Information

Title:	Management of the Nanpil River Watershed, Pohnpei Island, the Federated States of Micronesia
Project Number:	2006GU81B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Sediments
Descriptors:	watershed modeling, rainfall runoff relationships, automated turbidity and streamflow monitoring
Principal Investigators:	Shahram Khosrowpanah, Leroy F. Heitz, Mark Lander

Publication

PROJECT SYNOPSIS REPORT

Project Title: Management of the Nanpil River Watershed, Pohnpei Island, the Federated States of Micronesia

Problem and Research Objectives

Studies being carried out by WERI researchers have shown that the mean annual rainfall for Pohnpei varies from 325 to 200 inches as one move from the mountainous interior to the coastal areas of the island. The negative impacts of these huge amounts of rainfall are soil erosion, land slides, and poor water quality. Sediment lost due to erosion pollutes rivers and as it accumulates offshore, could have a negative impact on mangrove swamps, fisheries, and coral reef communities.

The Nanpil River, which serves as a major source of the domestic water supply for the Island of Pohnpei, is located in the Nanpil Watershed in the North West part of the island. As shown in Figure 1, it stretches between Nett and Sokehs municipalities. The watershed has an area of approximately 3 square miles (US Army Corps, 1988). A 12-ft high dam, completed in 1977, diverts part of the water flow from the Nanpil River for domestic use. The water that is diverted from the dam flows to the water treatment plant located in Nonponmahl. This water is a major source of domestic supply for the island. According to Pohnpei Public Utilities Corporation (PUC), after heavy rains the water treatment plant cannot produce quality water because of high turbidity. During these high turbidity times, the filters require frequent back-washing at intervals as small as 12 hours.

There is a general perception among the many residents of Pohnpei that the day-to-day flow (excluding floods during extreme rain events) in many of Pohnpei's streams has been reduced from what it was a decade ago. There are several possible reasons for reduced stream flow in Pohnpei, such as: land use practices, climate change, construction of municipal roads and population growth. It is the purpose of this project to begin acquiring baseline measurements of all the relevant physical characteristics of the watersheds. Analysis of these characteristics can lead to recommendations that will assist the local government in implementing informed watershed management/protection plans. In the future it may be necessary to study two or more watersheds that have differing degrees of alterations by human activities to better characterize the affects of man's activities.

The objectives of this project were to: 1) install stream level, sediment, and rain gages at selected sites within the Nanpil Watershed; 2) monitor the gages and develop rating curves for stream level versus flow at the selected site; 3) develop a relationship between stream flow, sediment load and rainfall; and 4) develop a watershed characteristic database for future use. This project has generated baseline information and correlations among the dynamic components of the Nanpil watershed environment.

The baseline information will be used for future comparison between the Nanpil watershed and the ongoing study of the Enipein Watershed. The findings will reveal the impact of the various activities such as land clearing, land slides/slope failures, and population growth on the water quality of the streams in the watershed. This information will help various parties such as the Conservation Society of Pohnpei (CSP), Land Management, Pohnpei EPA, and local mayors to implement plans for protecting the watersheds in Pohnpei. Pohnpei's Public Utilities Commission (PUC) will be able to operate the water treatment plant more efficiently by knowing the relationship between the level of the stream's turbidity and the available water at the stream. Also the information obtained in this project may be used by Pohnpei's Weather Service to enable them to provide flash flood warnings for the Nanpil River.

Methodology

To complete the project three tasks were undertaken: site selection, instrument installation, data collection and analysis and development of a baseline data base. The former US Geological Survey (USGS) gaging station lies one-half mile above the PUC's water supply intake structures (Figure 2). This site was selected for installation of a level logger for measuring the stream level. The reasons this site was selected include: easy accessibility, natural or man-made protection from flooding; and availability of places in the streams where manual stream flow measurements could be easily made. Another favorable asset of this site is that past USGS stream flow and stream level data could be used to assist in re-establishing the rating curve between stream stage and stream discharge.

With the help of CSP, the old USGS gage station was cleared of debris and sediments that had accumulated for the last 10 years. One level logger, as shown in Figure 3, was installed in the old USGS gage house structure. The location and elevation of site was surveyed and recorded. The function of the level logger is to measure the changes of the river depth (stage) versus time. The level logger stores the data internally on site for downloading at a later date. We found that the logger could easily hold two months of data (recorded at 5 minute intervals) between downloads. To make necessary adjustment for barometric pressure changes, a barometric logger was installed at the old USGS gage station. All Level and barometric data was taken at 5 minute intervals. Two personnel from CSP were trained in stream flow measuring techniques. The manual streamflow measurements were used to supplement the old USGS stream level and streamflow data in the development of a rating curve of flow vs. level for the site as shown in Figure 4. Direct streamflow measurements were made on a monthly basis and the level and baro-loggers were downloaded every other month.

One Turbidimeter Measurement Device (TMD) was installed at the dam site as shown in Figure 5. The TDM has been measuring the turbidity (NTU) at fifteen (15) minute intervals. The turbidity and flow data will be used to develop a relationship between streamflow and turbidity.

Two recording tipping bucket rain gages were installed in the basin (see Figure 1) and the data from the gages will be used to develop rainfall vs. runoff modeling characteristics for the watershed. The rainfall data, which had 1-second time resolution, was downloaded from the gages every two months.

Principal Findings and Significance

The water level (stage) changes have been recorder by the level logger at the old USGS site. The flow rate at the selected site using a portable flow meter has been measured. These data with the flow vs. depth that is available from past measurements by the US Geological Survey helped us to develop a preliminary rating curve (stage versus flow) for the Nanpil River. This will enable us to estimate the flow rate in the Nanpil River at the stream gage site. The data collection and analysis will be continued until a reliable rating curve has been developed.

The level of turbidity at the Nanpil dam has been collected for the last five months. The relationships between streamflow, rainfall, and turbidity were also examined. As shown in Figure 6, there is a close association between rainfall, streamflow and changes in turbidity in the stream. The flashy response characteristic of the stream indicates rapid flooding in the stream and also elevated soil erosion. The time to stream flow peak for a given rainfall event is in the order of 1 hour. In examining the data there seems to be a direct correlation between stream flow and turbidity. As more streamflow and turbidity data is gathered we will be carrying out a correlation analysis of the streamflow vs. turbidity data to further define this relationship. We will also be modeling the basin using the US Army Corps of Engineers Hydrologic Modeling System (HMS). After the modeling parameters have been developed from calibration studies using measured data, we will be able to examine the impacts of storms such as typhoons that bring huge amounts of rain at very high rainfall intensity rates to Pohnpei.

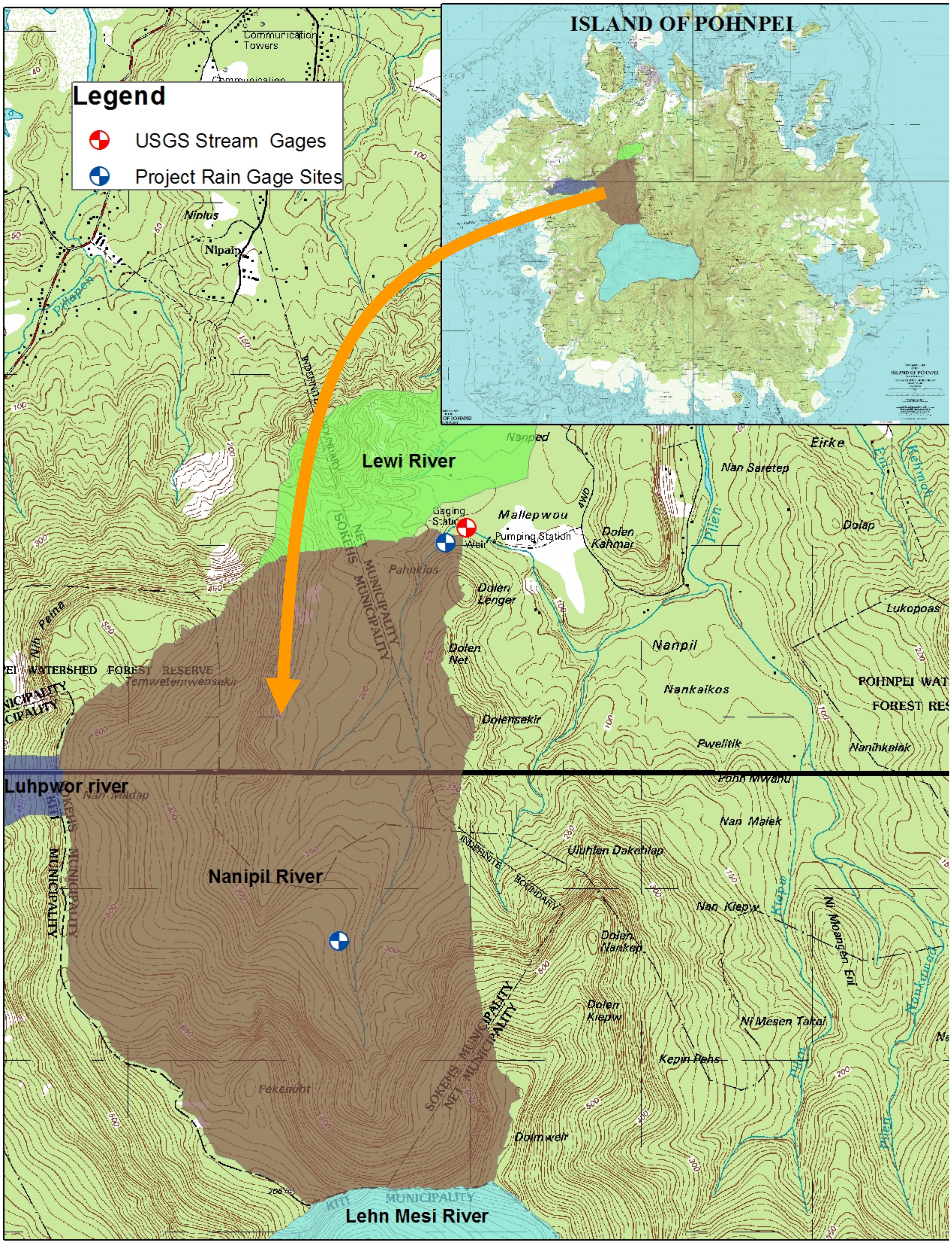

Figure 1. Nanpil Watershed, Sokehs and Nett Municipalities, Pohnpei Island.

Figure 2. The US Geological gaging station on Nanpil River, Pohnpei Island

Figure 3. Hobo Water Level Logger

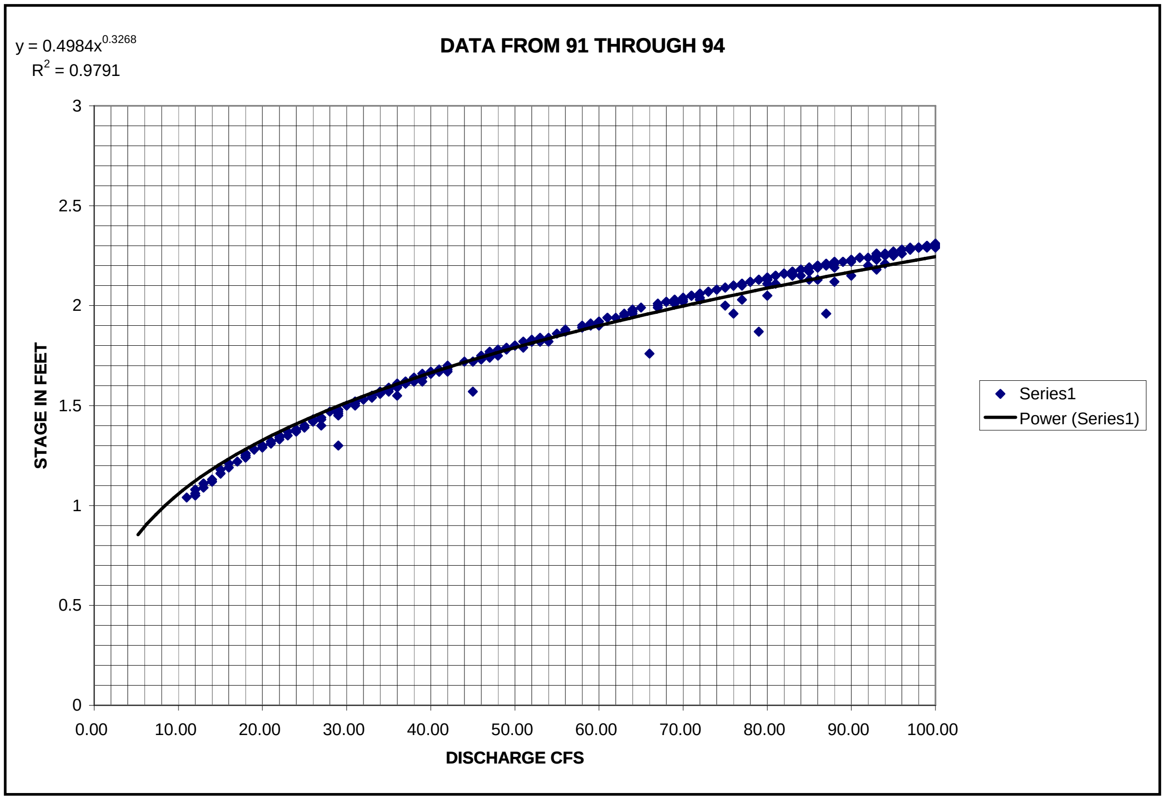

Figure 4 Rating curve for Nanpil stream gage above the PUC diversion dam.

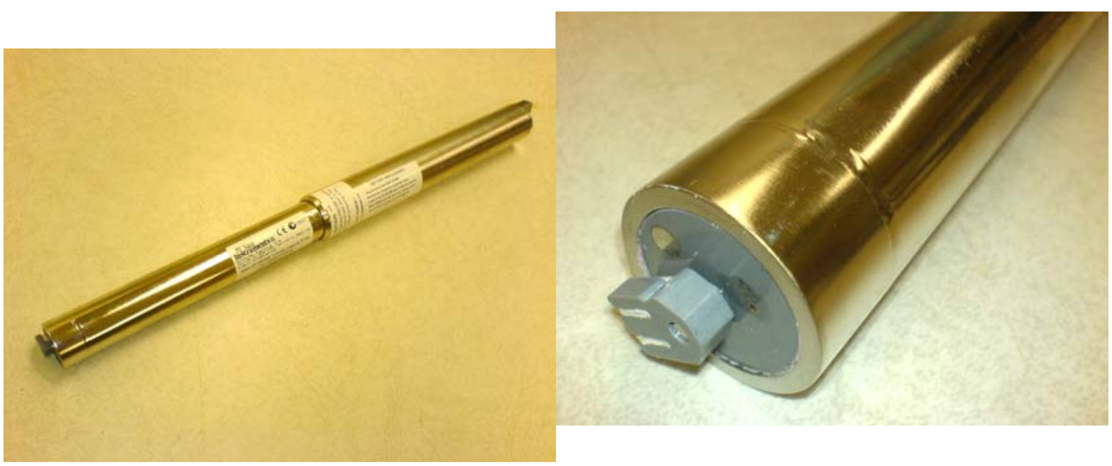

Figure 5. Turbidemeter.

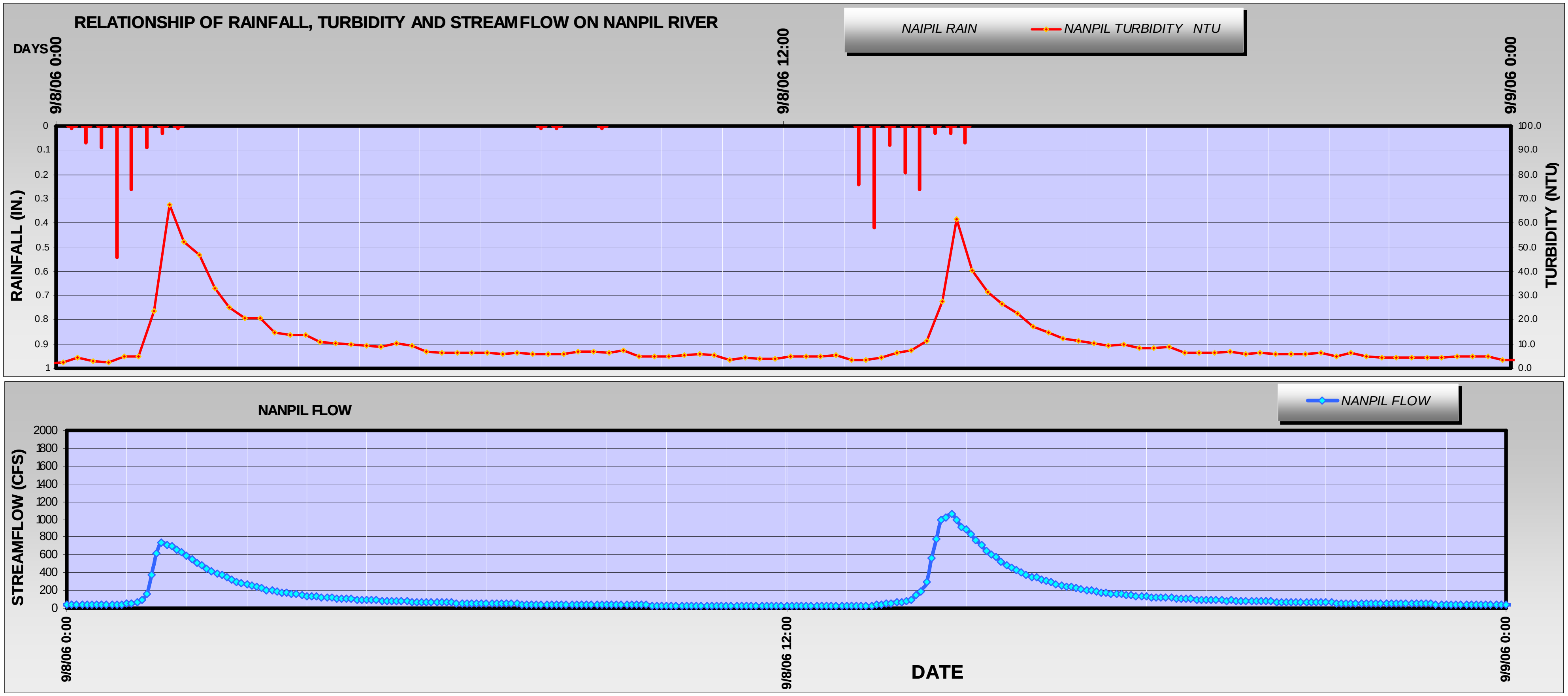

Figure 6. Rainfall vs Streamflow and Turbidity on Nanpil River September 9, 2006.

Information Transfer Program

Integrating Environmental Education into Pohnpei's Primary School Curriculum

Basic Information

Title:	Integrating Environmental Education into Pohnpei's Primary School Curriculum
Project Number:	2006GU80B
Start Date:	8/27/2006
End Date:	6/15/2007
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Education, None, None
Descriptors:	Environmental Workbook, Primary School Children, Teaching Guide, Pohnpei State
Principal Investigators:	Carla Schuk, Carla Schuk

Publication

Project Synopsis Report

Project Title: Integrating Environmental Education into Pohnpei's Primary School Curriculum

Problem and Research Objectives

While environmental education has been designated as a component of Pohnpei's curriculum, it has never been made an instructional priority in the classroom. Because of this, Pohnpei's citizens have only minimal knowledge about their environment and the impacts of their actions on it. Pohnpei is faced with a number of environmental issues from the upland forest down to the coral reef. Deforestation and sedimentation effects on Pohnpei's drinking water are significant. Coastal water pollution, dredging, and over-fishing are other problems that Pohnpei is currently facing. The Conservation Society of Pohnpei (CSP) saw the need to provide primary school teachers with tools to integrate environmental education into the current curriculum in order to educate students about local environmental problems and their possible solutions.

CSP has developed an Environmental Resource and Activity Book (ERAB) for grades 1 through 8. The ERAB contains a resource guide for teachers, as well as activities that integrate information about Pohnpei's environment into curriculum subject areas. ERAB activities incorporate language arts, math, reading comprehension, visual arts, and science to enable teachers to cover environmental subject matter without creating increased curriculum requirements. About 30 percent of the activities deal with water and waste management. Through discussions with teachers and the Department of Education, it has been deemed impractical to try to teach environmental education as a new subject area. With this in mind, CSP designed the ERAB with environmental lessons and activities that will compliment various subject areas in the existing school curriculum. The objectives of the ERAB project are:

1. To provide resources to teachers that will complement their curricula with messages of environmental awareness without creating new burdens and work demands.
2. To develop an awareness and understanding in students of the environment and ecology of Pohnpei, fostering a sense of stewardship towards environmental protection.
3. To collect local teachers' input for the ERAB and to produce a final draft for printing.
4. To train teachers in the use of the ERAB within the classroom in order to integrate environmental education into their current curricula.

The work reported here describes the final stages of integrating ERAB into Pohnpei State education curriculum.

Methodology

In the spring of 2006, CSP formed a task force of education professionals from the Department of Education and local teaching staff, to edit and produce a final draft of the ERAB. Participating teachers introduced some of the activities into their classrooms at a level that matched the abilities of the students. This process was followed by a series of teacher trainings in the summer of 2006 to introduce the ERAB to teachers and provide them with the opportunity to practice using the activities. The teachers participated in role-playing and practiced using the activities and lessons. The three training sessions were divided by grade levels: (1) for teachers of grades 1-3; (2) for teachers of grades 4-6; and (3) for teachers of grades 7-8.

Principle Findings and Significance

The final draft of the Environmental Resource and Activity Book (ERAB) is now complete and ready for critique and editing by the task force team. Instead of developing one book for all grades as first thought, the ERAB was divided into books for grades 1-3, grades 4-6, and grades 7-8. Each book has a teacher's resource book that includes environmental information for teachers and students that is currently being evaluated by the task force team. CSP has also introduced the idea of the ERAB to fifth and sixth grade teachers involved in our other educational programs, e.g., the *Green Road Show* and *Youth to Youth in Environmental Awareness*. They have received positive feedback from many teachers about the concept and tentative commitment to pilot these activities in their classrooms.

The task force team met three times to review the book, make comments and suggest changes to the project where appropriate. The team will convene one last time in June 2007 after piloting some of the activities within their classrooms and to make any minor last minute revisions before printing in July.

We anticipate holding the teachers training in August during the Department of Education's training program. The Environmental Educators will assist the teachers who take part in the training to pass on their knowledge to their coworkers. This should enable all teachers to utilize the books within their classrooms. The ERABs will be distributed at this time for the 2007-2008 school year. All teachers will be provided with an evaluation survey of the ERAB that will be collected in January 2008. CSP Environmental Educators will continue to assist teachers in ERAB use and provide further trainings as requested. It is our hope that every teacher will use at least one activity per subject area within their classrooms within the first year.

Information Mangement

Basic Information

Title:	Information Mangement
Project Number:	2006GU84B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	NA
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Hydrology, Management and Planning
Descriptors:	Climatological and hydrological databases
Principal Investigators:	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.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2006GU86B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	NA
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, None
Descriptors:	Data dissemination, public eductation
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 (5) 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	2	0	0	0	2
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Publications from Prior Projects

1. 2002GU4B ("Impact of Ordot Dump on Water Quality of Lonfit River Basin in Central Guam") - Articles in Refereed Scientific Journals - Golabi, M.H., Gary, R.W. Denton, H. Rick Wood, Yuming Wen and Clancy Iyekar, 2007, Impact of Ordot Dump on Water Quality of the Lonfit River Basin in Central Guam. 1. Soil Characterization of Nutrient Retention. Micronesica, 39 (1): 41-54.
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